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

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

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INSTITUT DE L'ELEVAGE idele

ADEME
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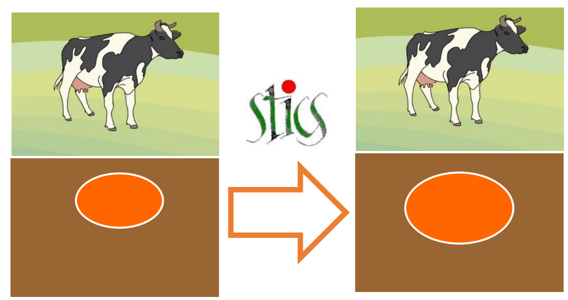
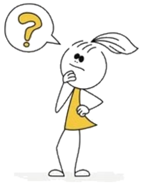
Background

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

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

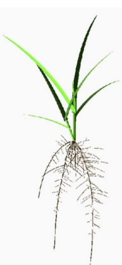
Used a research version derived from STICS Oct 2023

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

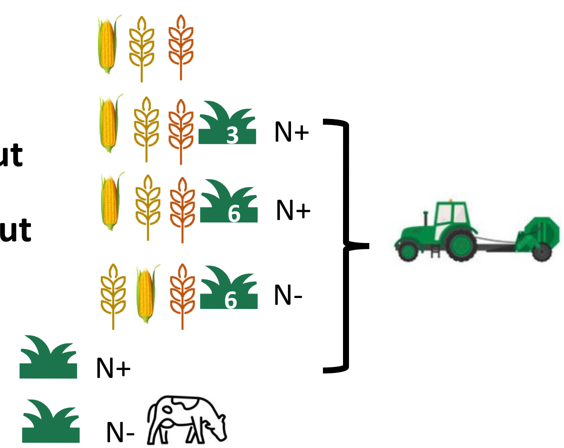
Kerbernez
Oceanic climate
3 Rotations: 1 with 3-year TG, **1 PG**
SOM: 4.7%; COS: 81 t C/ha (0-25cm); WHC:190 mm
27 years (1978-2004)
7 obs. of SOC&SON + yield, %N (grassland, corn)

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**
    - **T3**: T1 + **6 yrs.** of grassland , **highly fertilized** and **cut**
    - **T4**: T1 + **6 yrs.** of grassland , **low fertilized** and **cut**
    - **T5**: **permanent** grassland, **fertilized** and **cut**
    - **T7**: **permanent** grassland, **fertilized** and **grazed**



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)

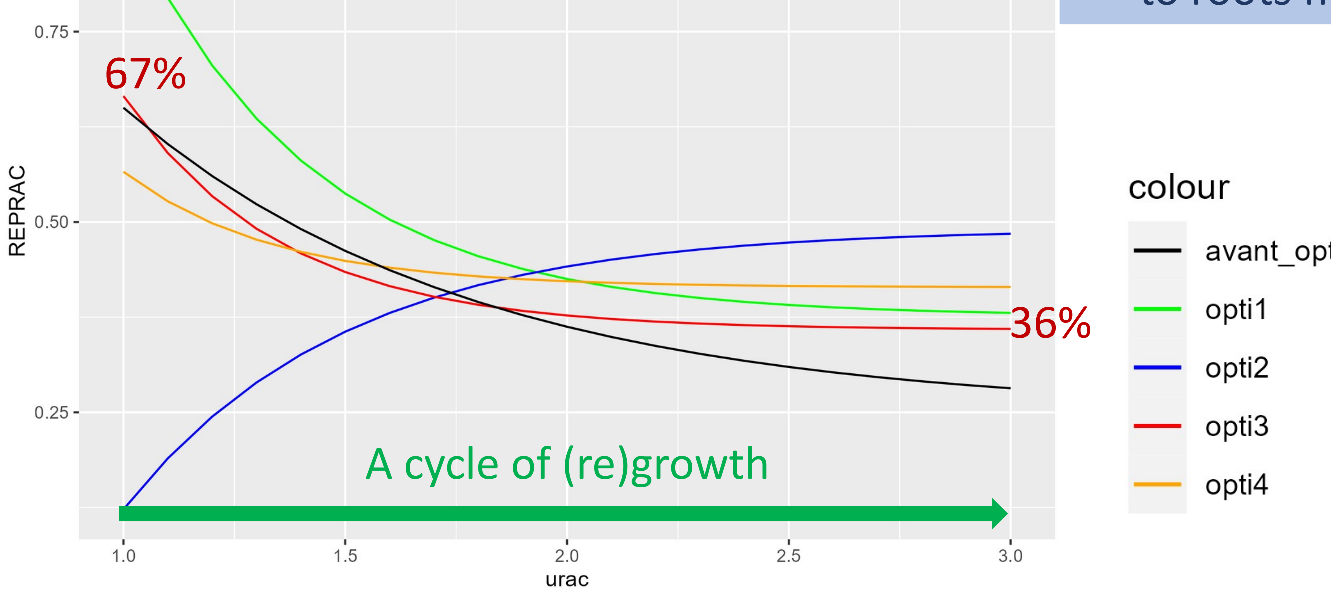
X	SOC (kg C ha^{-1})	Cutting yield (t DM ha^{-1})	Grass N content (% or 10gN kg^{-1})	Root C (kg C ha^{-1})	Root N (kg C ha^{-1})
initial	1912	1.37	1.07	NA	NA
before opti	1886	1.02	0.76	2628	81
after opti1	1731	1.02	0.85	2828	93
after opti2	1959	1.07	0.64	3127	93
after opti3	2048	1.01	0.75	1110	36
after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

Root parameter optimisation

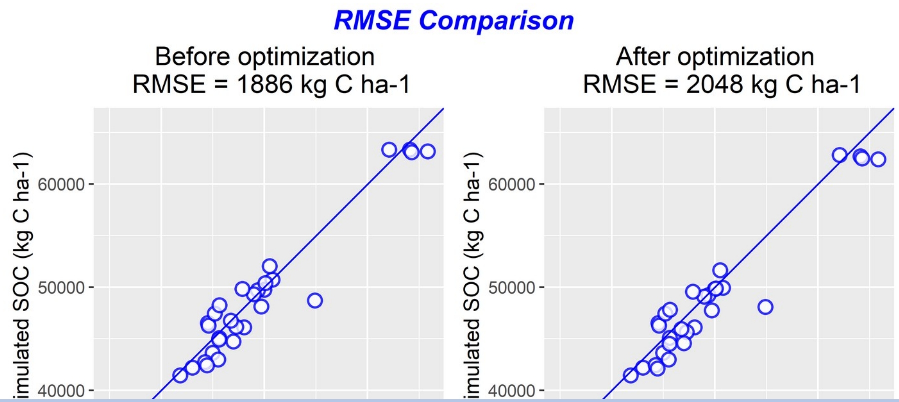
Parameter	Before optimisation	opti1	opti2	opti3	opti4
krepracperm	1.27	2.38	2.00	2.80	2.95
debsenrac	1200	358	247	3594	2987
parazorac	NA	56.3	20.7	22.6	21.3
repracpermin	0.25	0.38	0.49	0.36	0.41
repracpermax	0.65	0.91	0.12	0.67	0.57

- ↗ 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

Fraction of assimilates allocated each day to the roots, out of the total



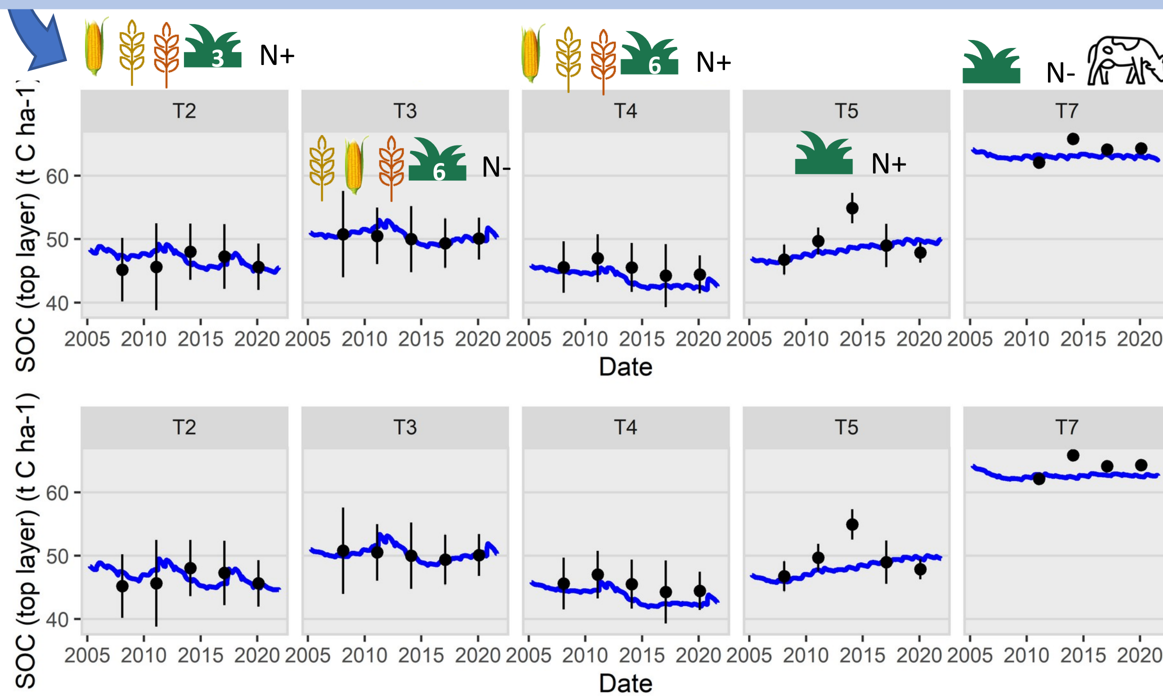
Comparison of SOC (opti. N°3)



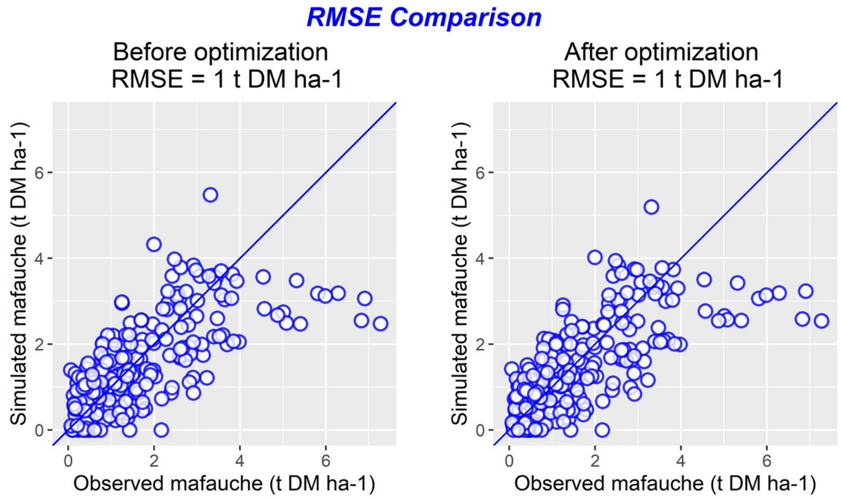
- SOC of all rotations and permanent grasslands within the range of observations
- Slight increase in RMSE after optimization

Before optimization

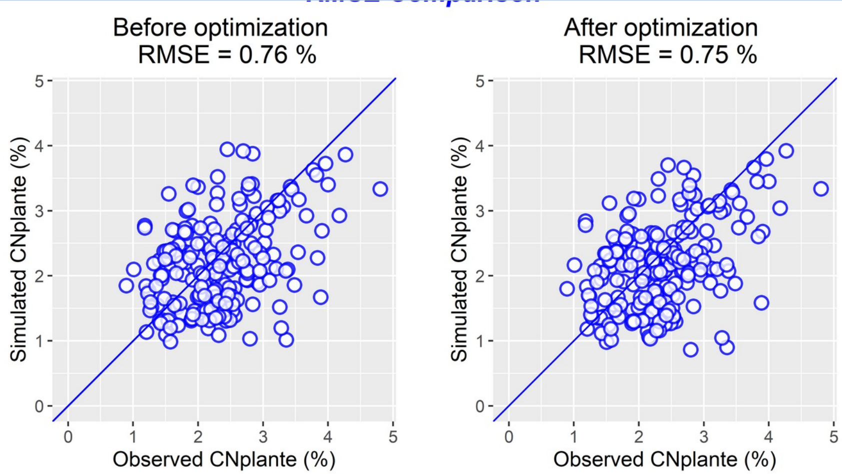
After optimization



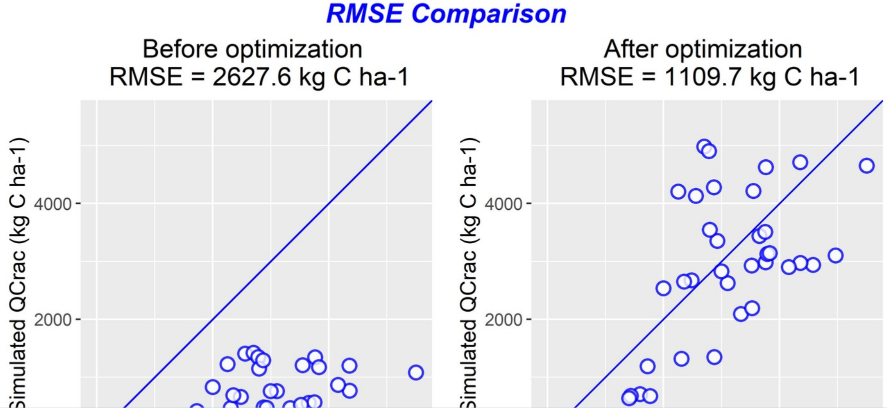
Comparison of grassland yields and grass N contents (opti. N°3)



No change in simulated cutting yield and grass nitrogen content

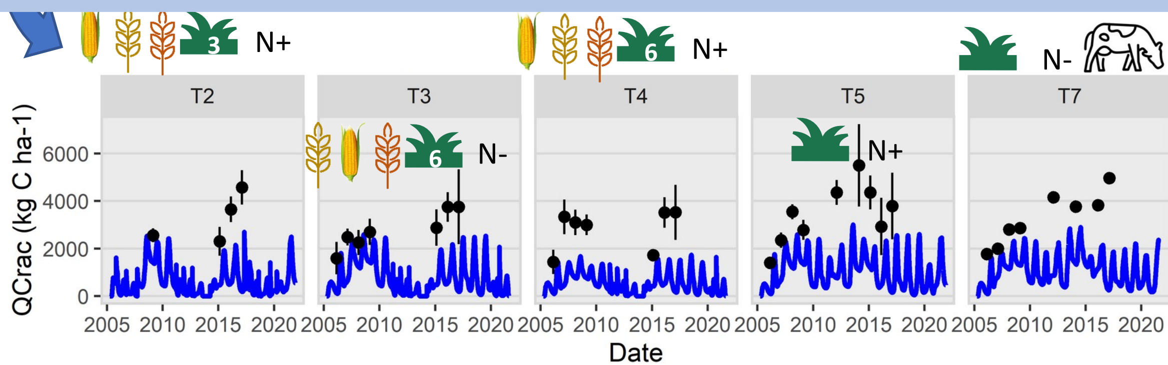


Comparison of root C (opti N°3)

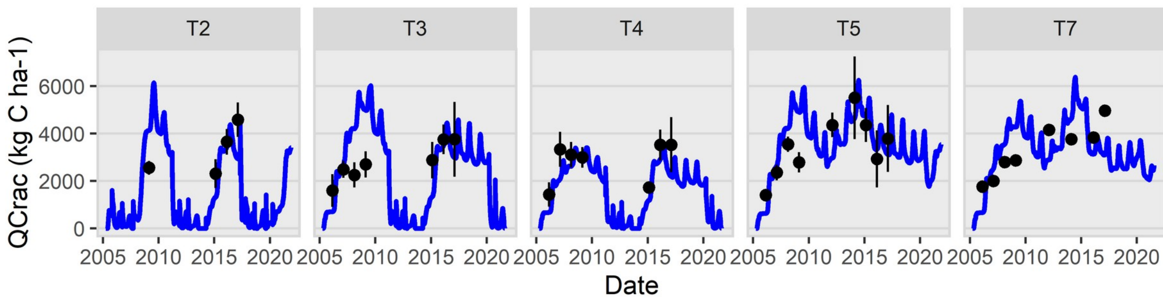


- Root C dynamics clearly better simulated after optimization (RMSE divided by 2.3)
- Same for root N

Before optimization

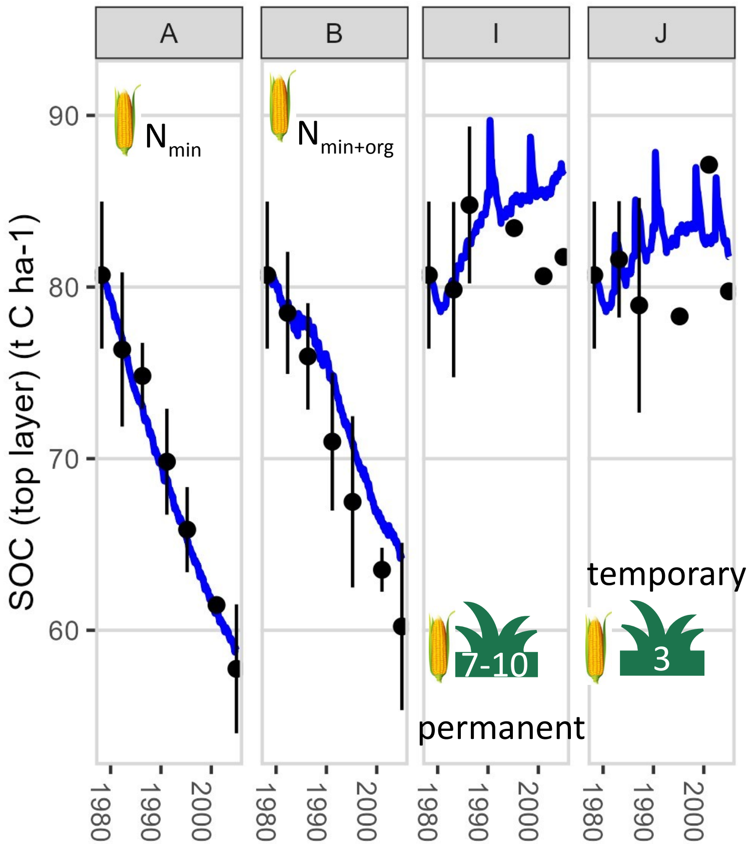


After optimization



Model assessment - Kerbernez site simulation

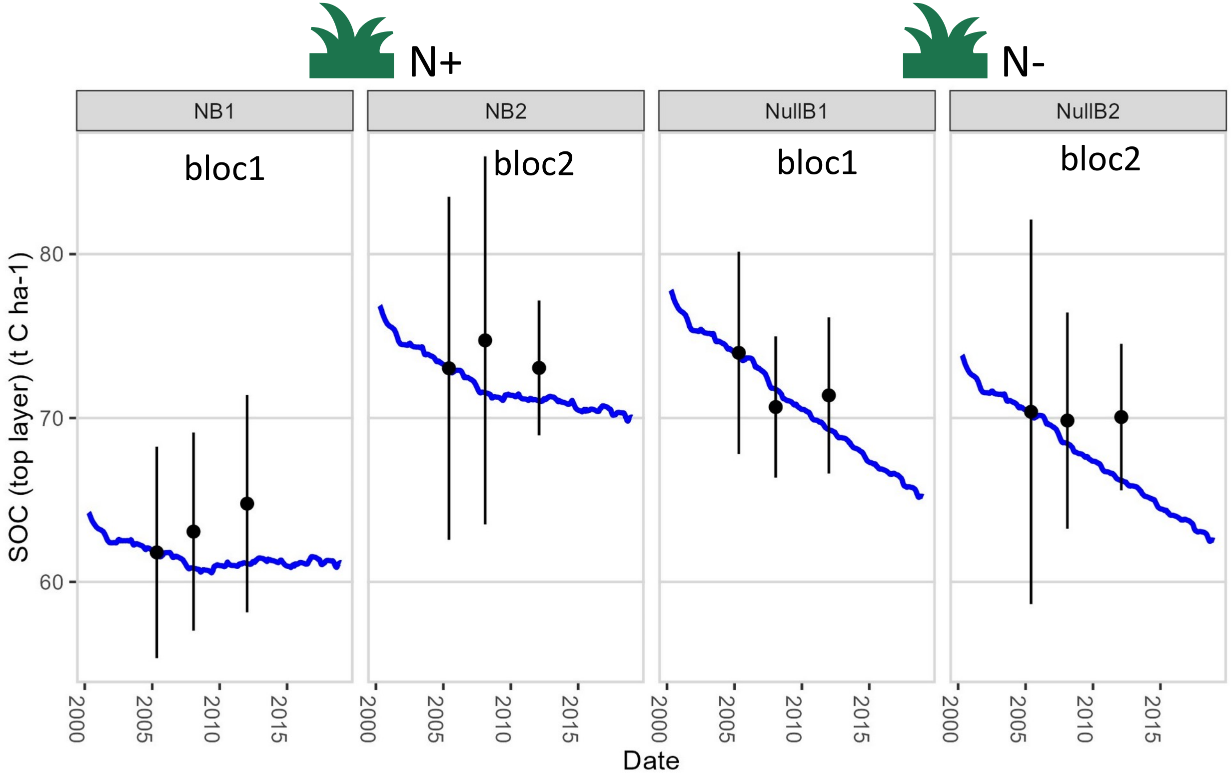
- 2 silage maize monocultures: A with only ammonitrate, B with both ammonitrate and cattle or pig manure
- 2 grasslands alternating with corn, cut 5 times/year, with ≈ 250 kg N/ha/year



- 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

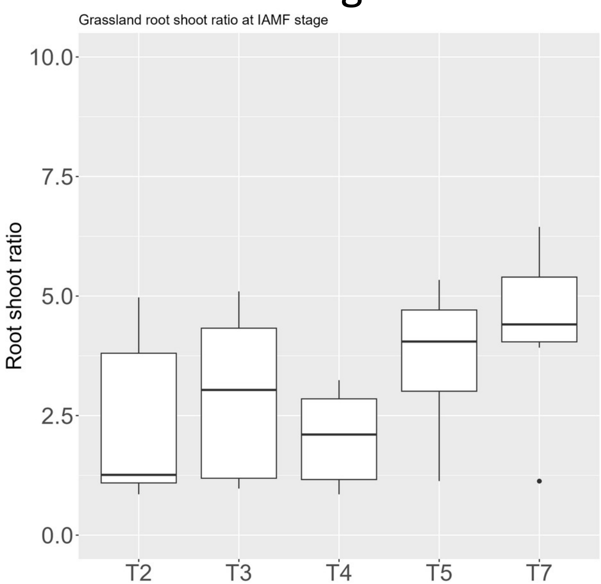


- A few observations with very high variability, 2016 samples not yet analyzed
- SOC dynamics quite well represented (N+: maintained SOC; N-: ↘ SOC, perhaps too large in relation to the trend observed)

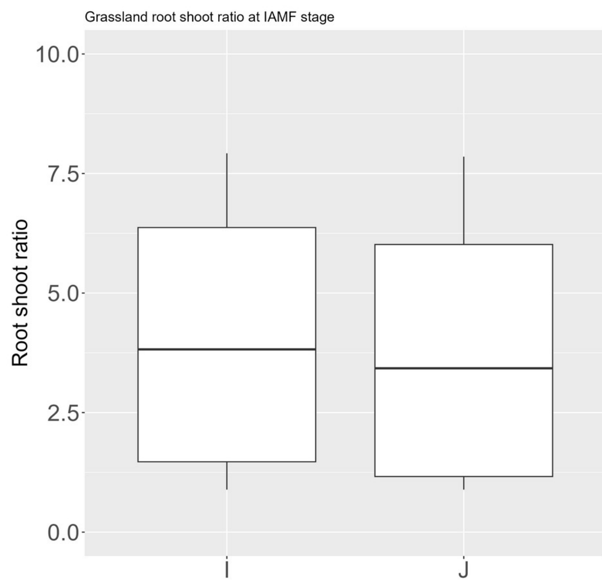
Model assessment - orders of magnitude

- 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)

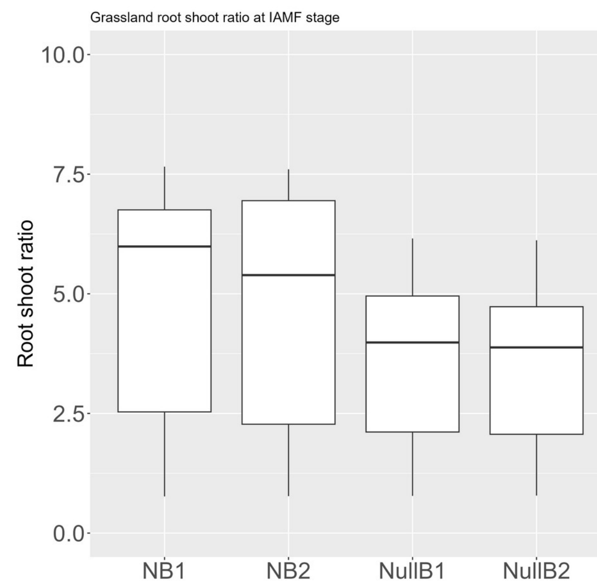
Lusignan



Kerbernez

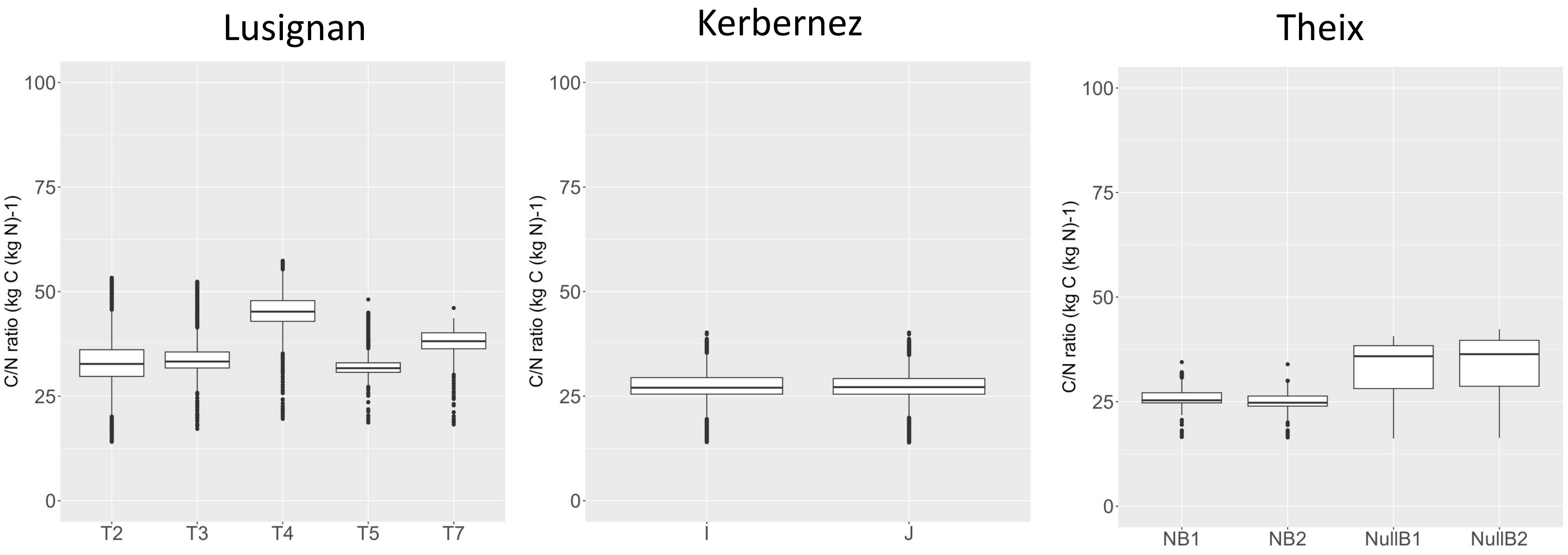


Theix



Model assessment - orders of magnitude

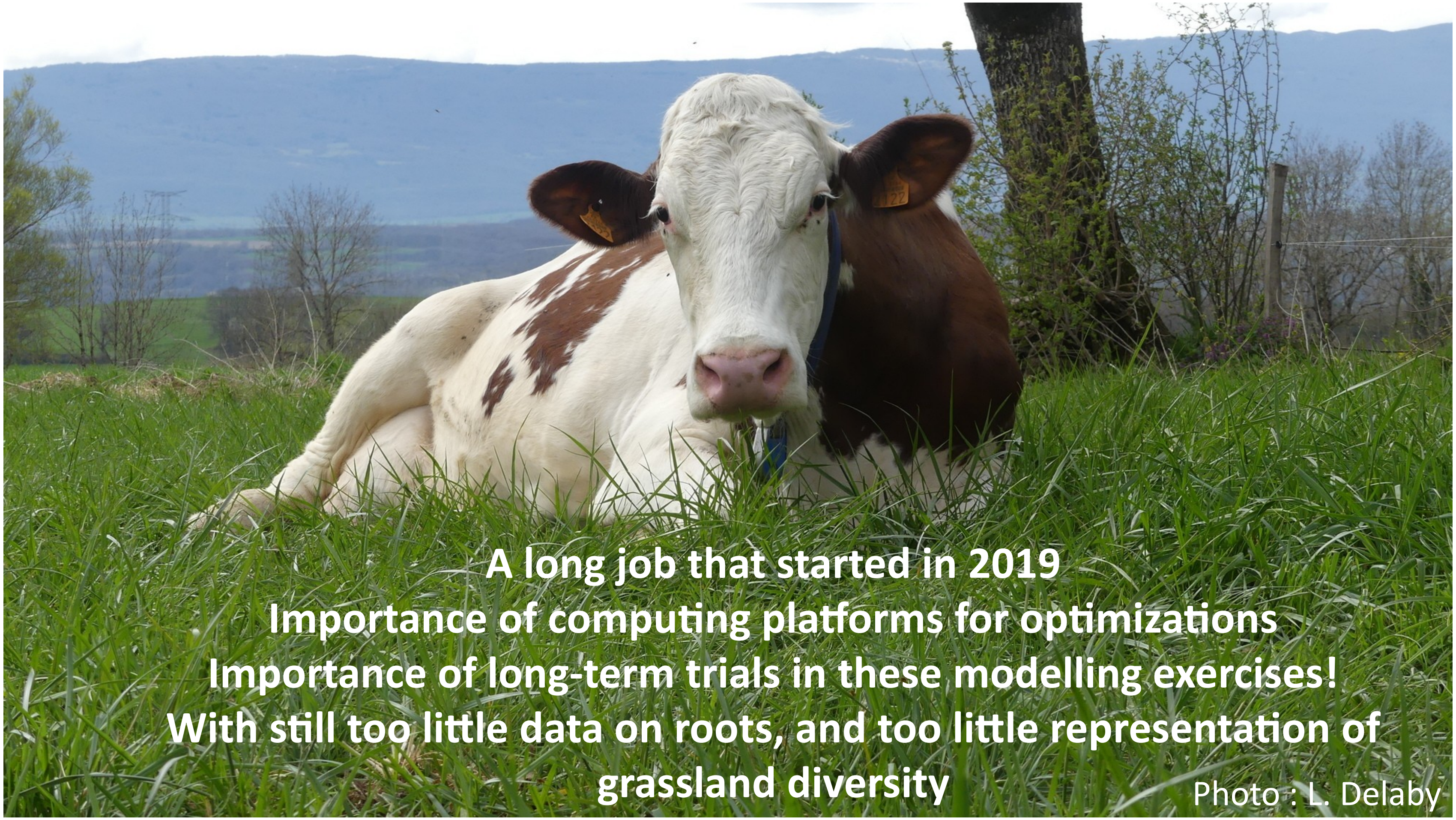
- Simulated grass root C/N ratio
  - Simulated values **within the expected range from 36 to 118 kg C (kg N)$^{-1}$** (Legay et al., 2016)
  - **Higher** C/N ratio **in unfertilized** or **lightly fertilized** treatments



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



STICS SOM simulation

Mechanistic

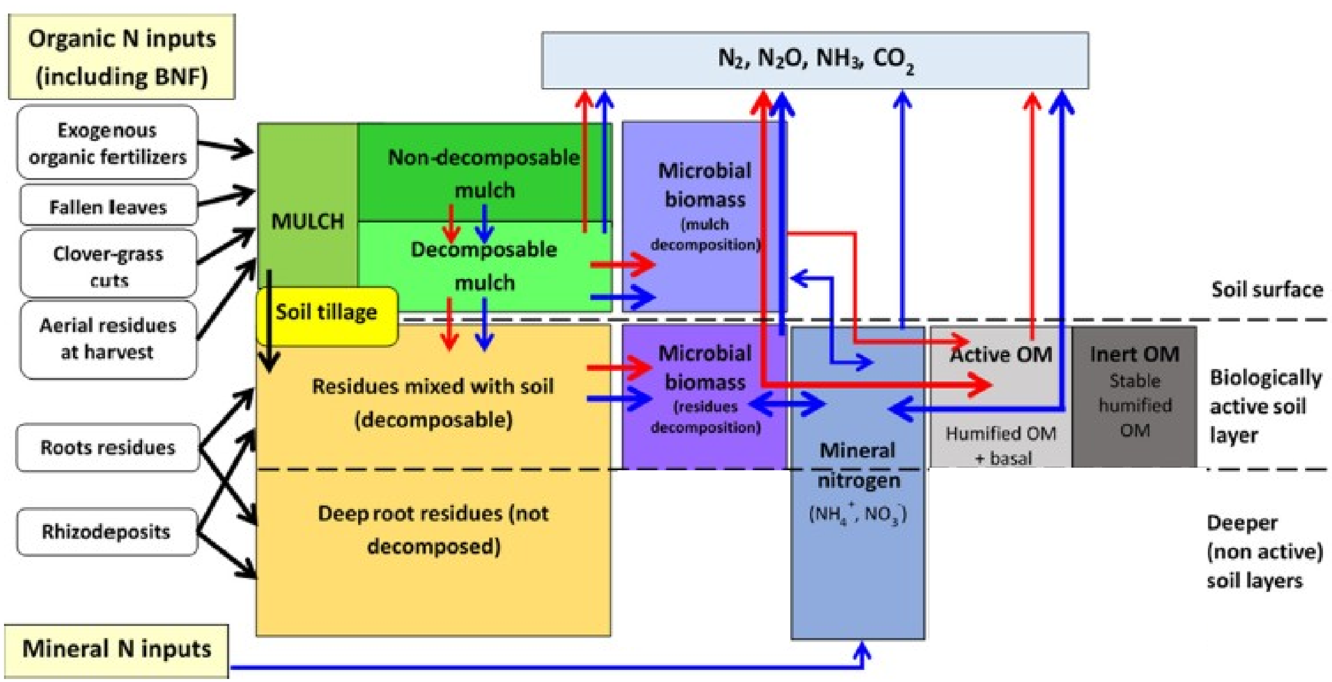
- C & N fluxes in the soil-plant system
- Limited to **topsoil layer**
  - (Formerly) worked horizon
  - Below: C inputs from dead roots

⇒ Evaluation focused on this soil layer

Compartmentalized

3 "pools" with ≠ average C&N residence time

- **Fresh OM** (on the surface, buried by tillage)
- **Microbial biomass**
- **Humified OM** (active / inert)



STICS SOM simulation … depends on

Soil initialization :

- Initial SOC and its distribution between active and inert fractions
- Cropping history => inert fraction between 0.4 (permanent grasslands) and 0.65 (Crop rotations)

Soil/climate conditions with SOC mineralisation favored by :

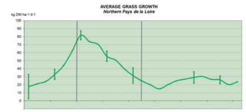
- Acid soils, soils poor in clay and limestone
- Hot, humid conditions, high mineral N availability

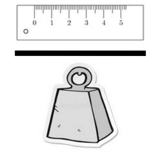
Soil C inputs associated with :

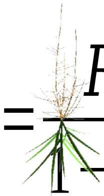
- Simulated management (organic inputs, crop residues)
- Plant simulation: biomass quantity, aerial/root partitioning, senescence

Root simulation

- Daily growth in length (RLJ)

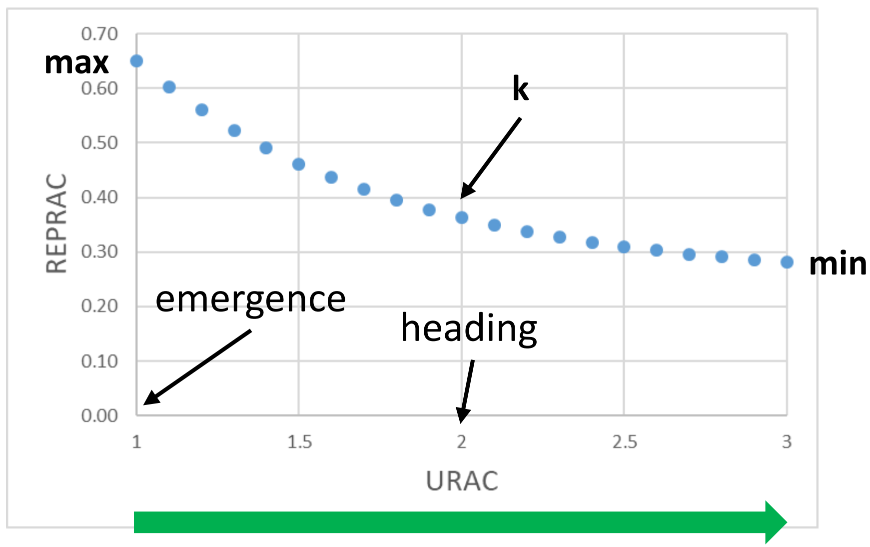






$$RLJ(I) = \frac{REPRAC(I)}{1 - REPRAC(I)} \times DLTAMS(I) \times longsperac_p \times 10^{-2}$$

- Dynamic distribution of assimilates between shoot and root parts
  - REPRAC = fraction allocated each day to the roots out of the total; function of a root development unit and 3 (**optimized**) parameters



A cycle of (re)growth

INRAE
Anne-Isabelle Graux
14 November 2023

Root simulation

- Length of living roots RL
  - Calculated from integration of RLJ
- Daily senescence of RL and production of dead roots => fresh MO
  - function of a sum of degree-days = root lifespan (**optimized**)
- Conversion of total root length (living+dead) into root biomass
- Fixed C content (380 g C/kg DM) but variable N content
  - N uptake = minimum between soil N availability and canopy N demand (sum of N demands of different organs); priority to roots
- Root N demand
  - function of RLJ, cover NNI and parameter = root C/N ratio for NNI = 1 (**optimized**)

Parameterization details

Revision of grassland parameters based on previous works

parameter	value	source
adilmax	7.8	Graux et al., 2020
extin	0.6	Graux et al., 2020
masecNmax	3	Graux et al., 2020
pgrainmaxi	0.0022	
parazofmorte	22.5	Legay et al., 2016
ratiodurviel	1	Graux et al., 2020
ratiosen	0.3	Graux et al., 2020
sensrsec	0.9	Launay et al., 2020
tcmax	26.5	Graux et al., 2020
tcmin	5	Graux et al., 2020
temax	26.5	Graux et al., 2020
temin	5	Graux et al., 2020
teopt	12	Graux et al., 2020
teoptbis	20.5	Graux et al., 2020

Parameterization details

Grassland parameters involved in newly activated options

parameter	all groups	source
draclong	400	
lvfront	0.05	
alloperirac	0.23	
kdisrac	0.00110	

Revision of the value of **6 shoot + 1 root parameters** to better represent the productive **grassland functional groups** (A, B) present in the experimental trials

parameter	A	B	source
durvieF	120	150	Cruz et al., 2010 (transformed into Q10 time)
efcroijuv	2	1.88	Duru et al., 2009 et 2010
efcroiveg	2.97	2.56	Duru et al., 2009 et 2010
efcroirepro	2.65	2.38	Duru et al., 2009 et 2010
longsperac	21333	21333	Fort et al., 2013
slamax	287	287	Cruz et al., 2010
slamin	177	177	Cruz et al., 2010

3 long-term French trials : contrasting conditions

Kerbernez

Oceanic climate, 36 m a.s.l

Treatment = rotation (1 to 3 rep.); 1 unit: 144 m²

4 **Rotations**: 1 with 3-year TG, 1 PG

SOM: 4.7%; COS: 81t C/ha (0-25cm); WHC:190mm

27 years (1978-2004);

7 obs. of SOC&SON; +yield, %N (grassland, maize)

Most grasslands are cut, but one is grazed

Lusignan

Degraded oceanic climate, 150 m a.s.l.

Treatment = rotation (4 rep.); 1 unit: 4000m²

4 rotations: 3 with 3 or 6 year TG, 2 PG

SOM: 1.9%; SOC: 48t C/ha (0-30cm); WHC:180mm

15 years (2005-2020);

6 obs. of SOC&SON;+ yield and %N (grassland, maize, wheat, barley); root BM %N %C (grassland); soil water and Nmin

Theix

Semi-continental climate on **mountain margins**, 890 m a.s.l.

Treatment = fert x soil (4 rep.); 1 unit: 350m²

4 PG

SOM: 7%; COS 69 t C/ha (0-20cm); WHC: 80mm

14 years (2004-2017);

3 obs. of SOC&SON + yield, %N (grassland)

Calculs pour évaluer STICS

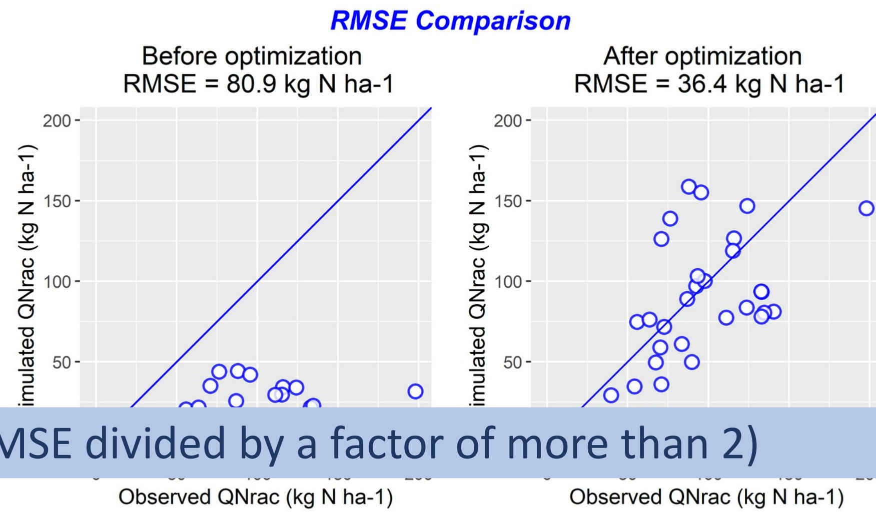
- Calcul des stocks observés (kg/ha)
  - SOC = masse de terre fine (M, t de terre fine/ha) x teneur en C (g C/kg terre fine)
  - SON = masse de terre fine (M, t de terre fine/ha) x teneur en N (g N/kg terre fine)

  Avec M = épaisseur (cm) x densité intrinsèque de terre fine (g/cm^3) x (1 – Volume de cailloux (%) /100) *x 100

- Calcul des variations de stocks sur la période (kg/ha/an)
  - var_stock = (stock final – stock initial) / nombre N d'années

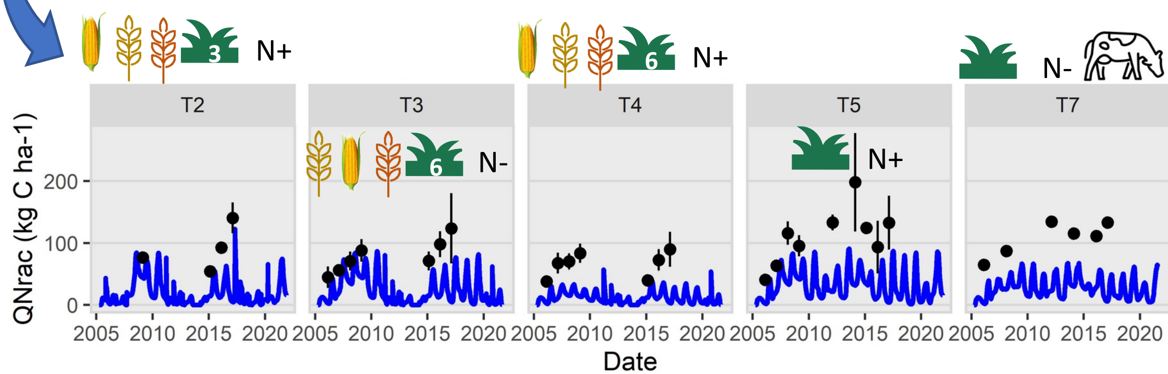
	Kerbernez	Lusignan	Theix
début	1978	2005	2005
fin	2004	2016	2012
N	27	12	8

Comparison of root N (opti N°3)

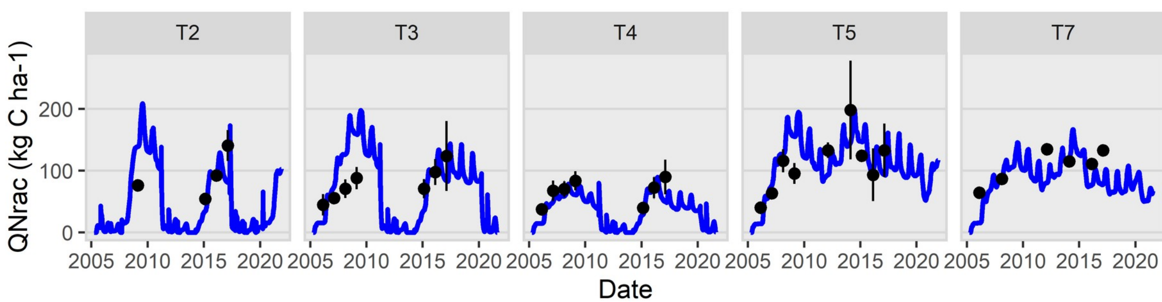


Same as root C dynamics (RMSE divided by a factor of more than 2)

Before optimization



After optimization



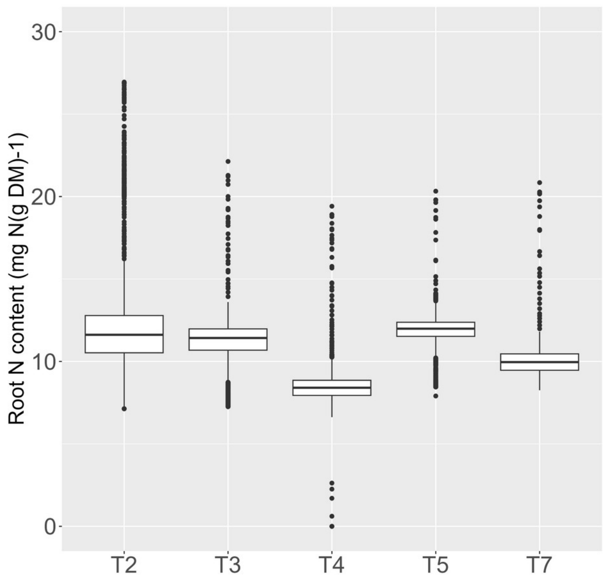
Model assessment - orders of magnitude

- Simulated grass root biomass
  - **within the expected range** from **5 to 31 t DM ha^{-1}** (Legay et al., 2016; Mokany et al., 2006; Poeplau, 2016)
  - **lower** biomass **in unfertilized** or **lightly fertilized** treatments

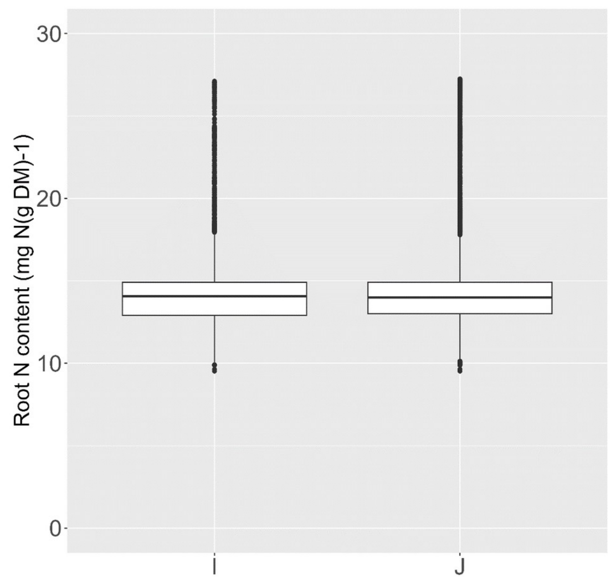
Model assessment - orders of magnitude

- Simulated grass N content
  - **within the expected range** from **1 to 40 mg N (g DM)$^{-1}$** (Freschet et al. 2017) with most values **from 4 to 12 mg N (g DM)$^{-1}$** (Legay et al., 2016) ;

Lusignan



Kerbernez



Theix