XIII STICS user seminar

13-16 November 2023

Simulation of long-term water, nitrogen and carbon dynamics for contrasted arable cropping systems with the STICS model

F. Ferchaud[1,2], P. Belleville[1], F. Bornet[1], J. Duval[1], F. Keuper[1], C. Valentin[1], G. Vitte[1], J. Léonard[1]

[1] *INRAE, UMR Transfrontalière BioEcoAgro*

[2] *INRAE, UMR Eco&Sols*

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INRAE

BioEcoAgro

ECO & SOLS

EJP SOIL
ΣOMMIT

Introduction

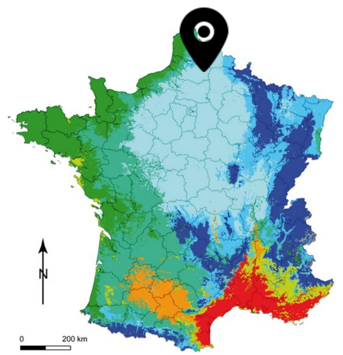
- Soil-crop models used as predictive tools to evaluate performances of cropping systems

- STICS mainly evaluated at the annual scale (Coucheney et al., 2015)

- Long-term experiments can provide relevant data to test STICS

- **Our aim was to assess STICS ability to simulate long-term water, nitrogen and carbon dynamics for contrasted arable cropping systems**

Experimental site and treatments: the ACBB trial



- Long-term field experiment established in 2009 in northern France

11.0 °C   660 mm yr^{-1} Deep loamy soil (Haplic Luvisol)

- 6 main treatments randomized in 4 blocks (11 ha) + 2 treatments in organic farming since 2016 (3 ha) + 2 large plots for eddy covariance measurements (8 ha: RN-LEG and RR-PER)

Treatment		Soil tillage	Crop residue management	Mineral N fertilization	Legume frequency	Perennial energy crop frequency	Chemical protection
CONV	**Conventional management**	Annual ploughing	Returned	Reference N	Low	Nil	High
RT	**Reduced Tillage**	Shallow tillage	Returned	Reference N	Low	Nil	High
RT-RR	**Reduced Tillage and Residue Removal**	Shallow tillage	Exported	Reference N	Low	Nil	High
RN	**Reduced Nitrogen**	Annual ploughing	Returned	35% Reference N	Low	Nil	High
RN-LEG	**Reduced Nitrogen and Legumes**	Annual ploughing	Returned	35% Reference N	High	Nil	Medium
RR-PER	**Residue Removal and Perennial crops**	Shallow tillage	Exported	Reference N	Low	High	High
ORG	**Organic farming**	Occasional ploughing	Returned	Nil	Medium	Nil	Nil
ORG-LEG	**Organic farming with perennial legumes**	Occasional ploughing	Returned	Nil	High	Nil	Nil

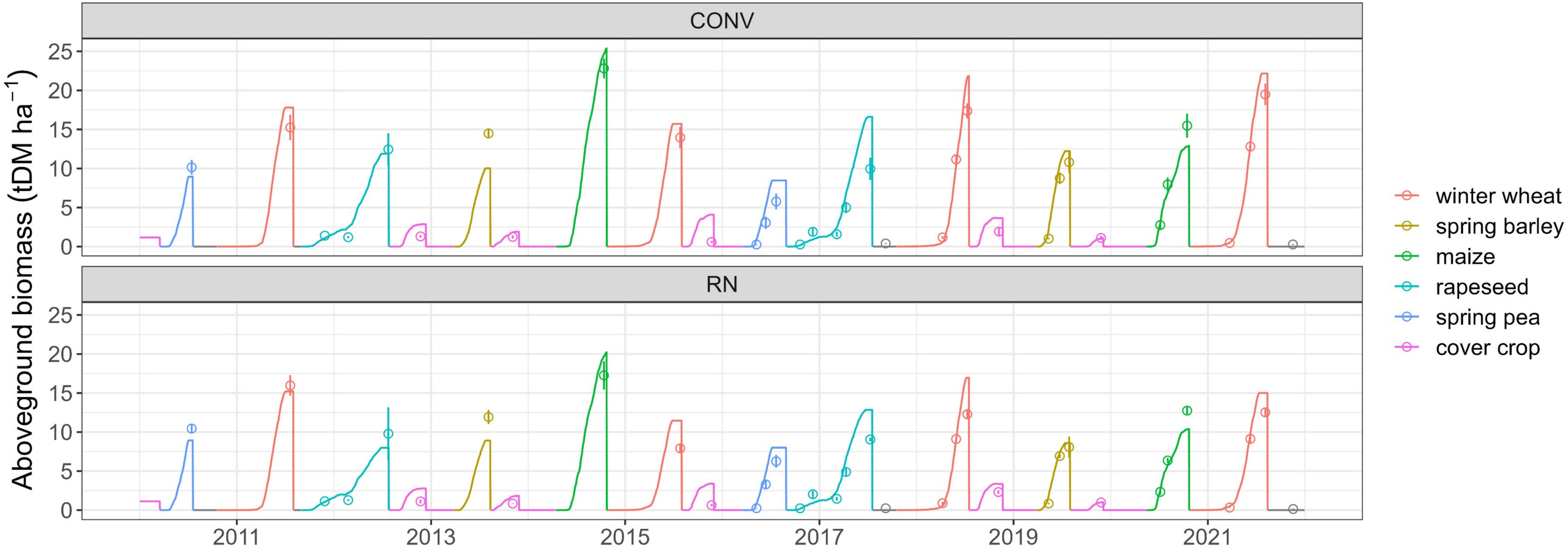
6-year annual crop rotation in all treatments

Crop-soil measurements and simulation procedure

- Crop measurements:
  - ✓ Aboveground crop biomass and nitrogen: 1-3 dates per crop and year
  - ✓ Grain yield and nitrogen: at harvest
- Soil measurements:
  - ✓ Soil mineral N and soil water content (0-150 cm): 2-3 dates per year
  - ✓ SOC and SON stocks: in 2010 (initial stocks) and 2015 (end of first rotation)
- Evapotranspiration measured by eddy covariance (2017-2021) for RN-LEG

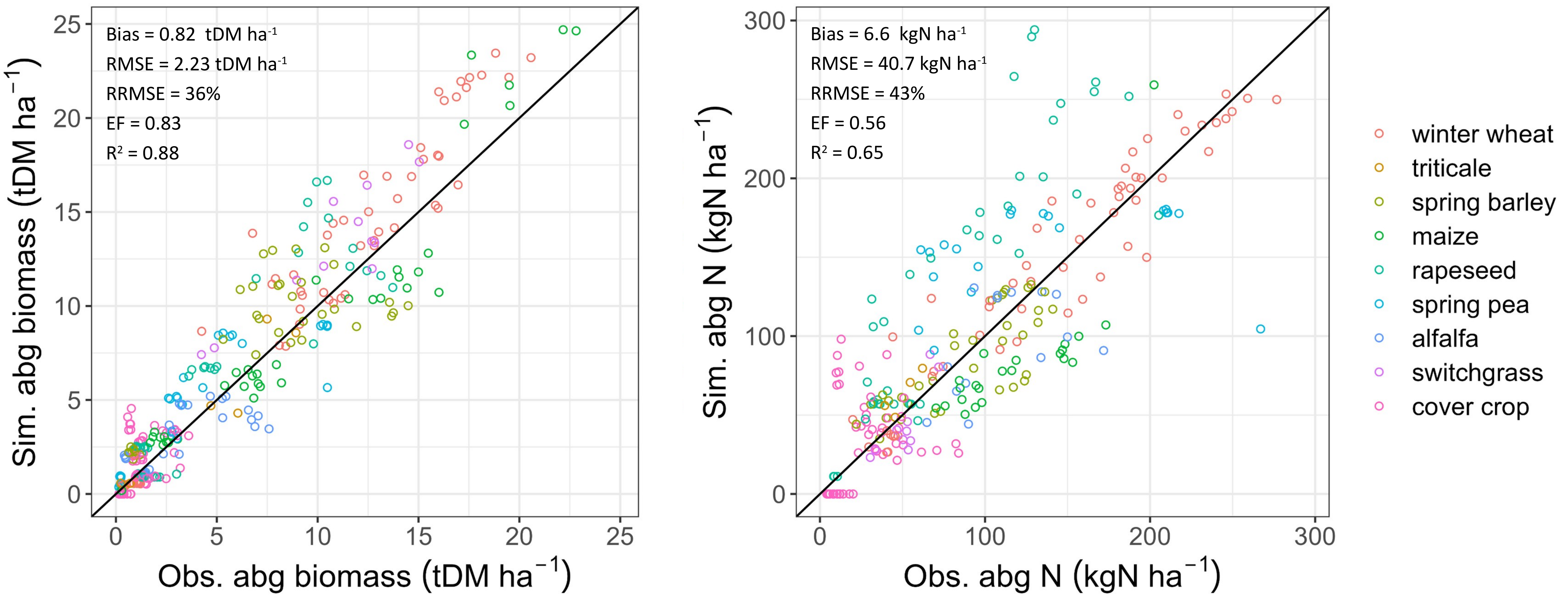
- Simulation procedure:
  - ✓ STICS v10.0.0
  - ✓ Simulations started in February 2009 and ran continuously until 2021
  - ✓ No site-specific crop calibration, but plant files modified to consider dynamic N accumulation in the roots and root turnover during crop growth

Crop aboveground biomass: conventional (CONV) and reduced N (RN)



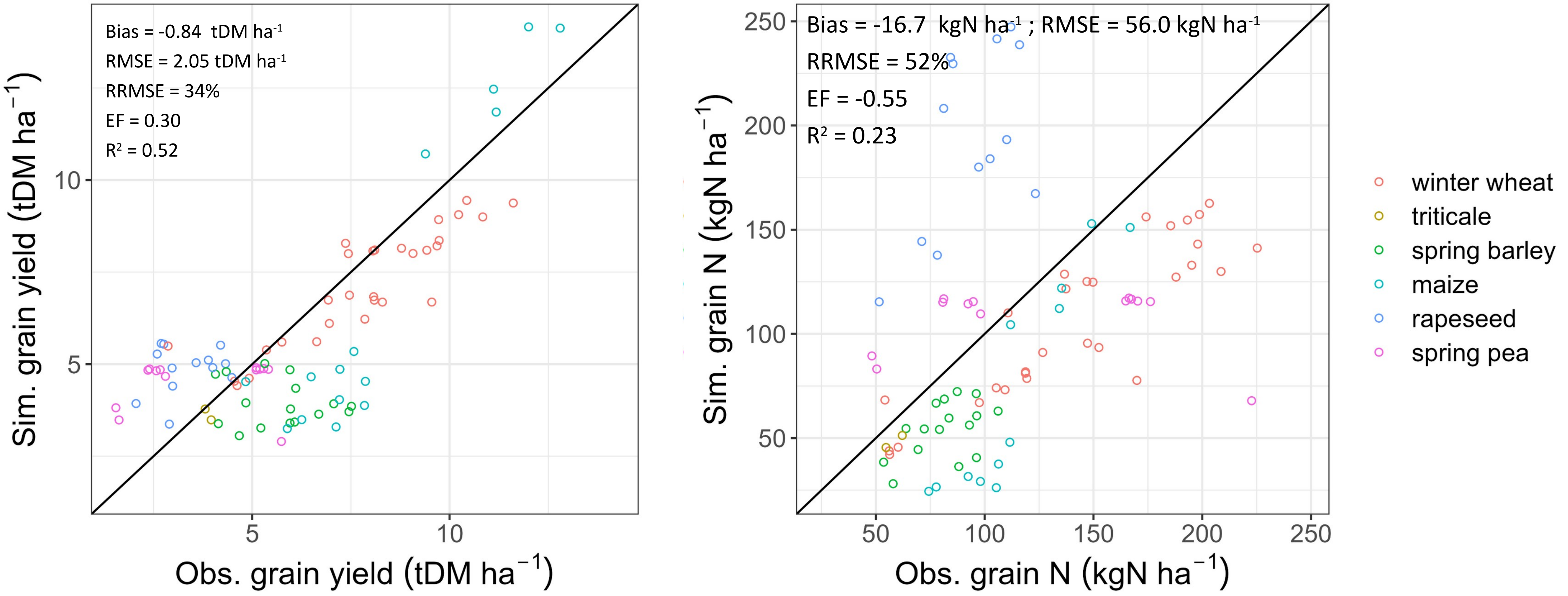
- Aboveground biomass dynamic rather well simulated
- Similar performance in CONV and RN (RRMSE = 30% in both treatments)
- Effect of long-term reduced N fertilization well predicted (obs.: -19% / sim.: -20%)

Crop aboveground biomass and nitrogen: all treatments



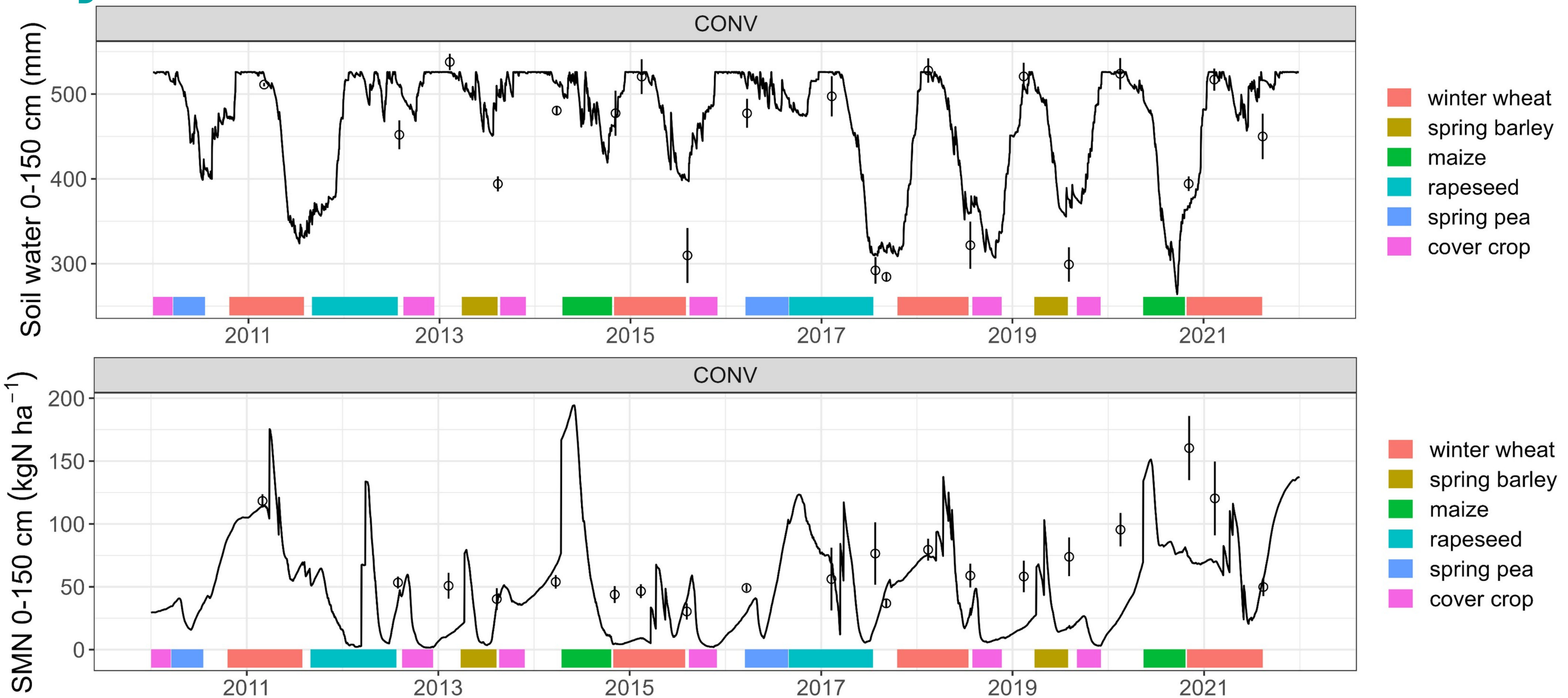
- Overall good performance but crop biomass better predicted than crop nitrogen
- Slight positive bias for both variables

Crop grain yield and nitrogen: all treatments



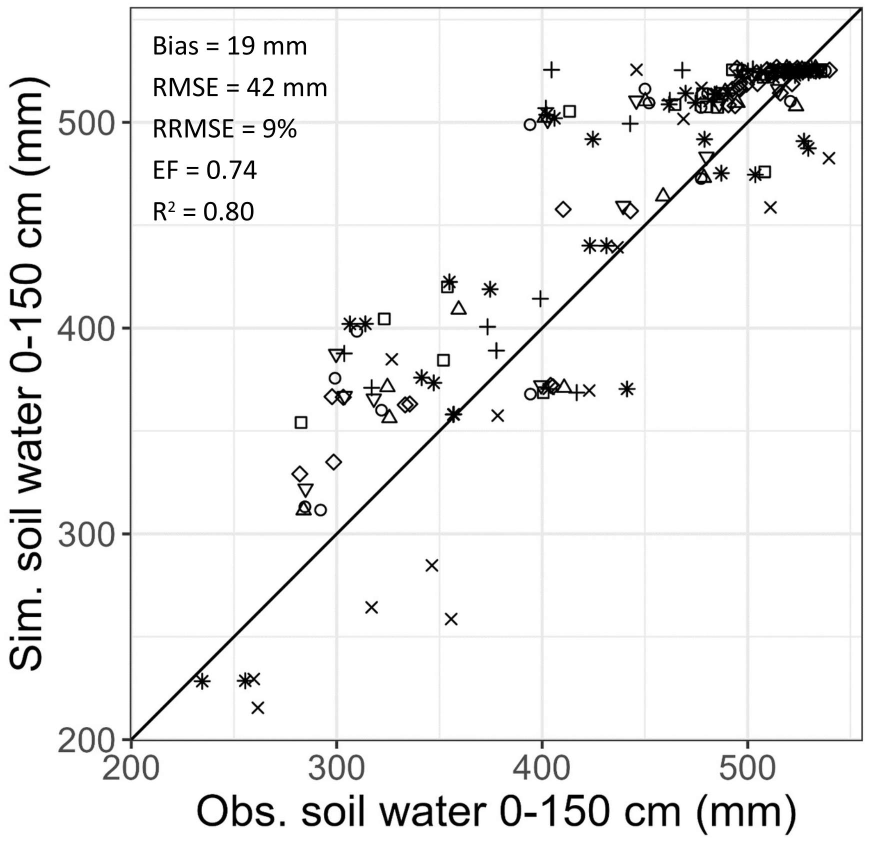
- Positive or negative bias according to the crop species
- But intra-species variability rather well predicted

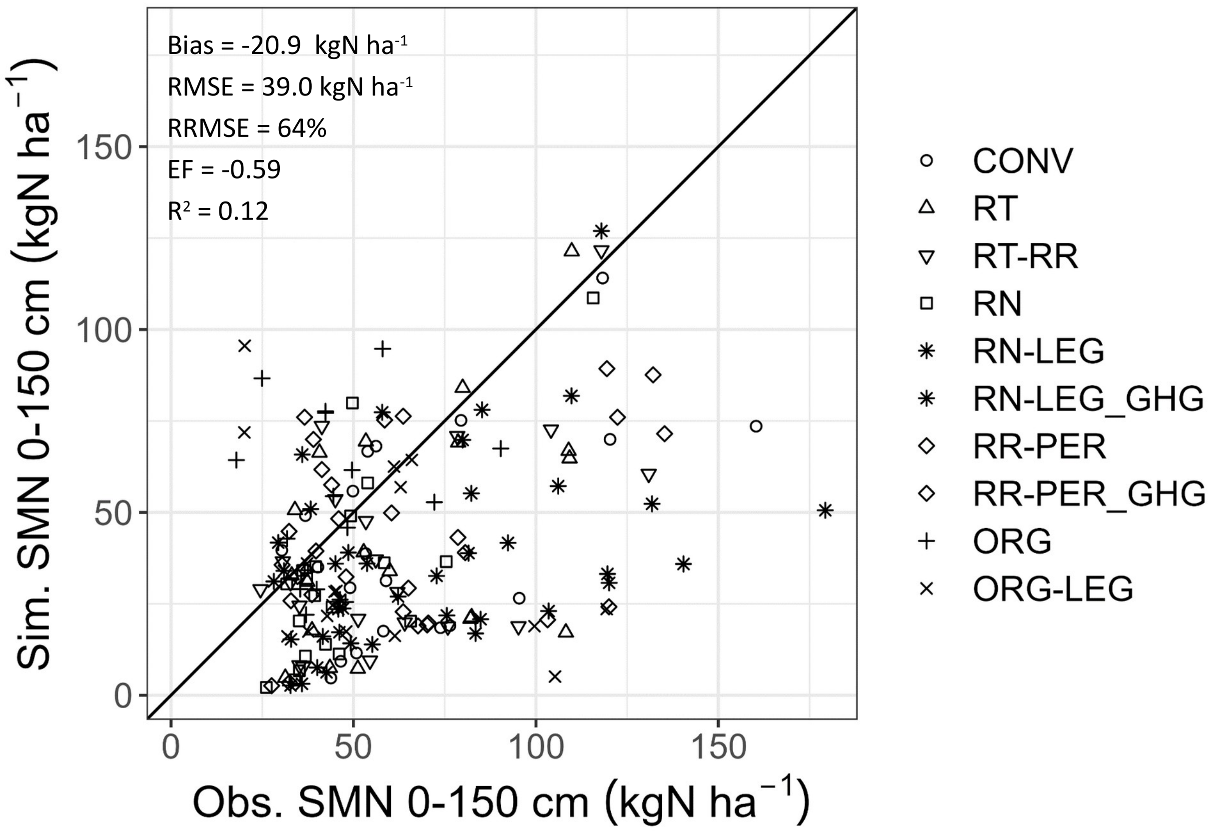
Soil water and soil mineral N 0-150 cm: conventional system (CONV)



- Simulated water and N dynamics consistent with measurements
- Positive bias for soil water and negative bias for soil mineral N

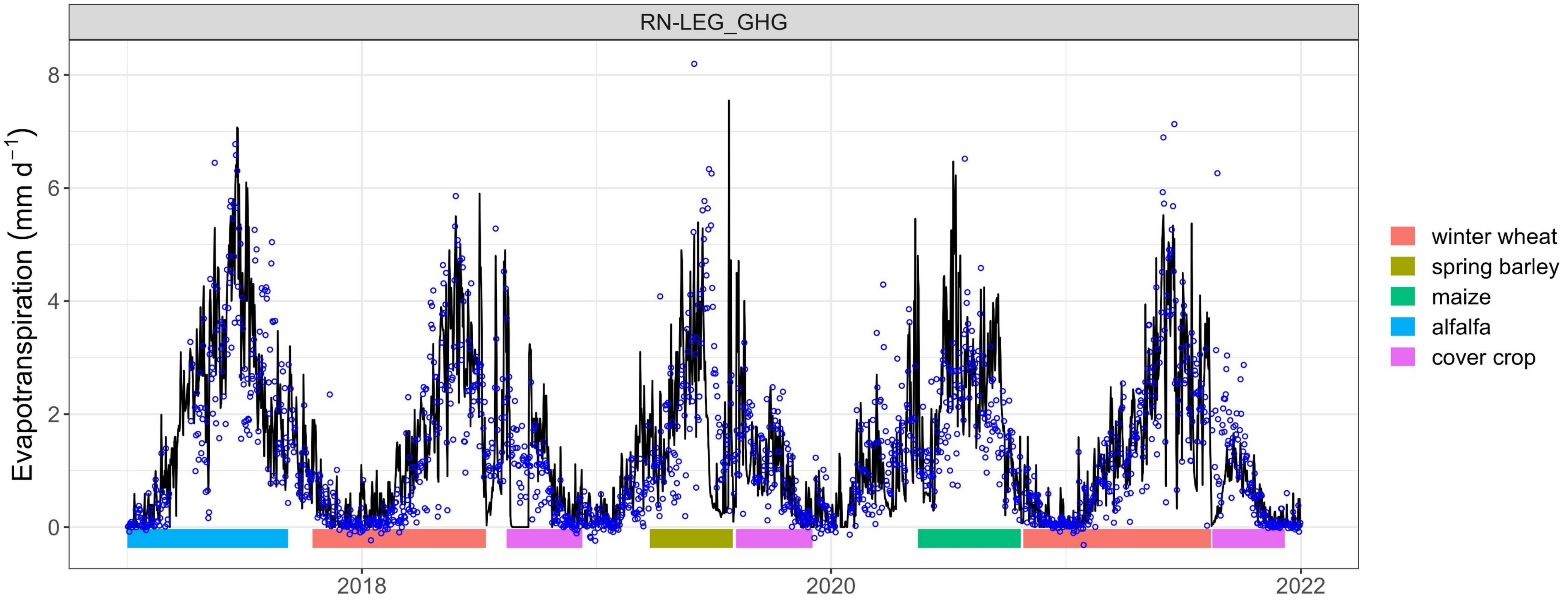
Soil water and soil mineral N 0-150 cm: all treatments





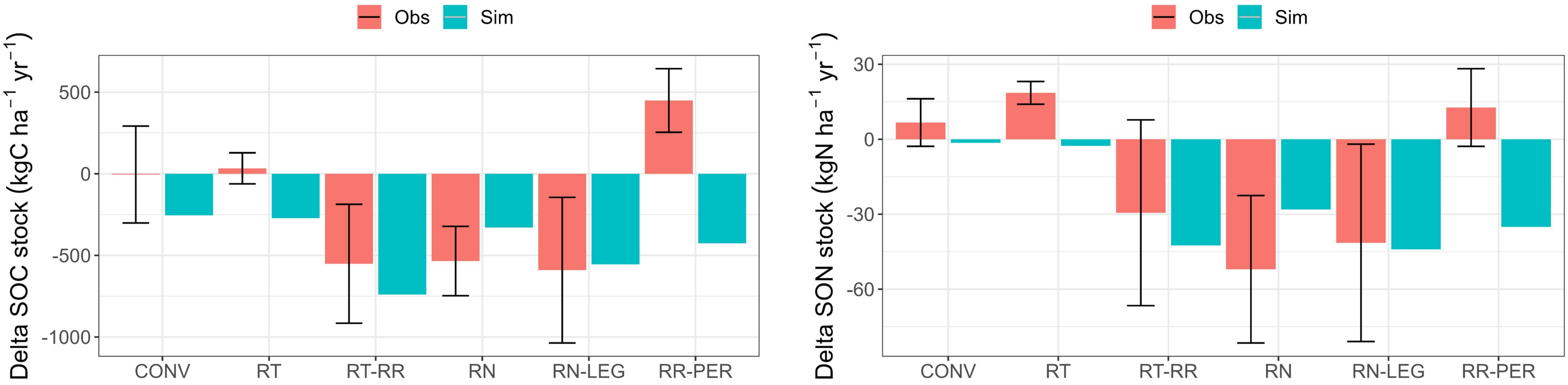
- Overall good performance for soil water but less satisfactory for SMN
- Large SMN values underestimated (in 2020-2021 or after alfalfa destruction)

Evapotranspiration: RN-LEG cropping system



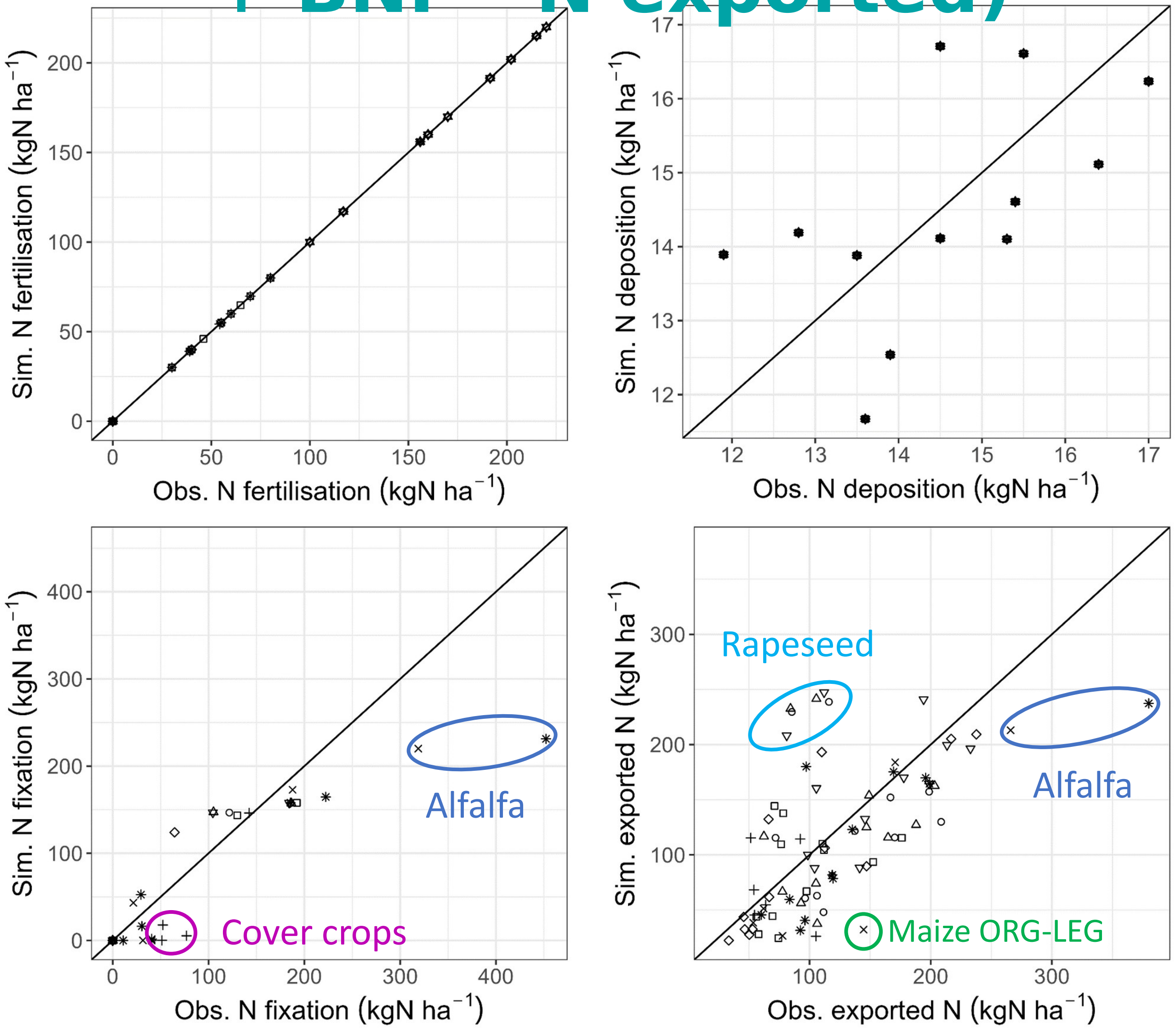
- Range and temporal dynamic of daily evapotranspiration well predicted
- Simulated cumulative evapotranspiration over five year close to eddy covariance measurements (519 vs 495 mm yr^{-1})

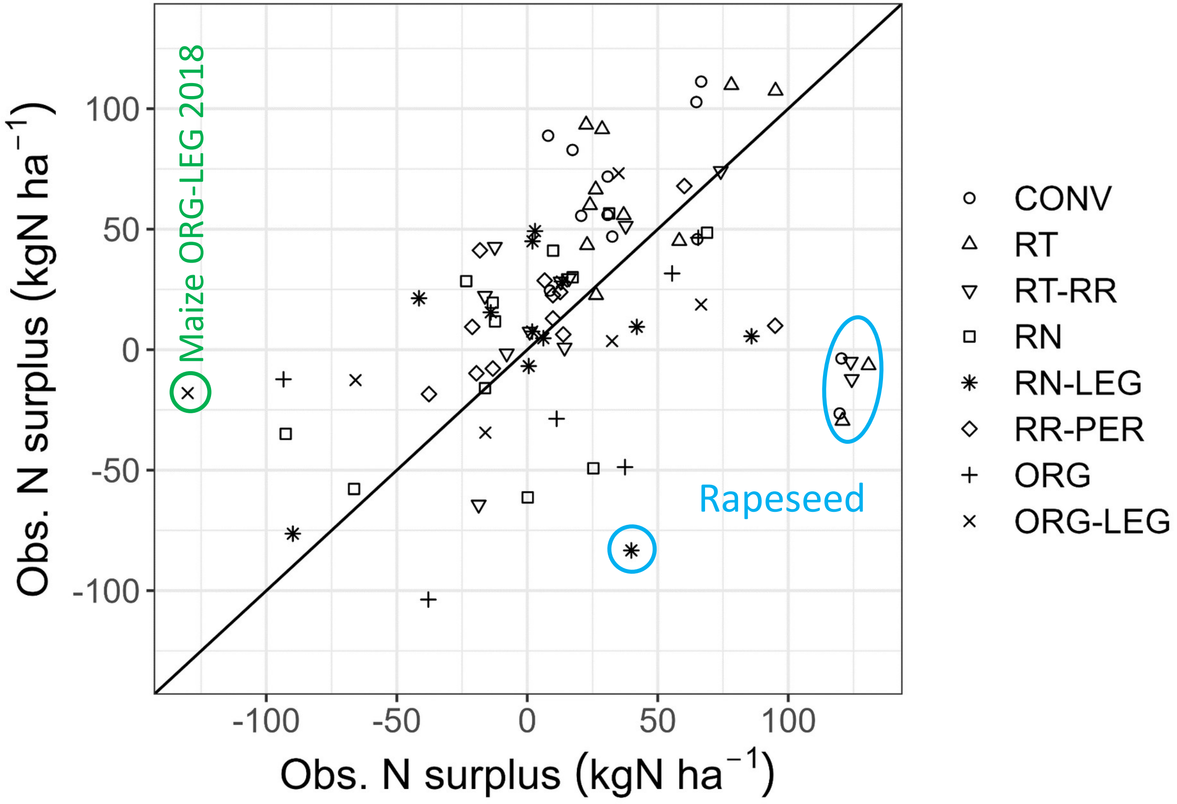
SOC and SON stock evolution between January 2010 and September 2015



- Results satisfactory except in RR-PER (after 6 years of switchgrass), where SOC and SON stocks are underestimated
- The negative effect of reduced N fertilization (RN vs CONV) is underestimated

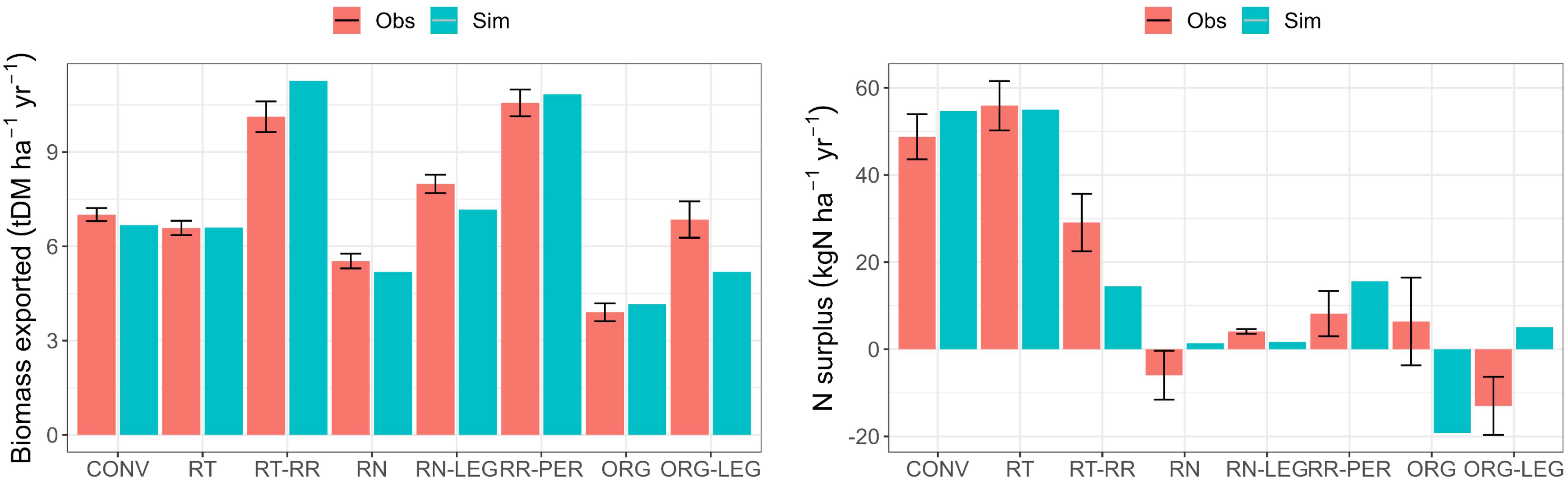
› Annual N surplus (= N fertilizer + atm. N deposition + BNF - N exported)





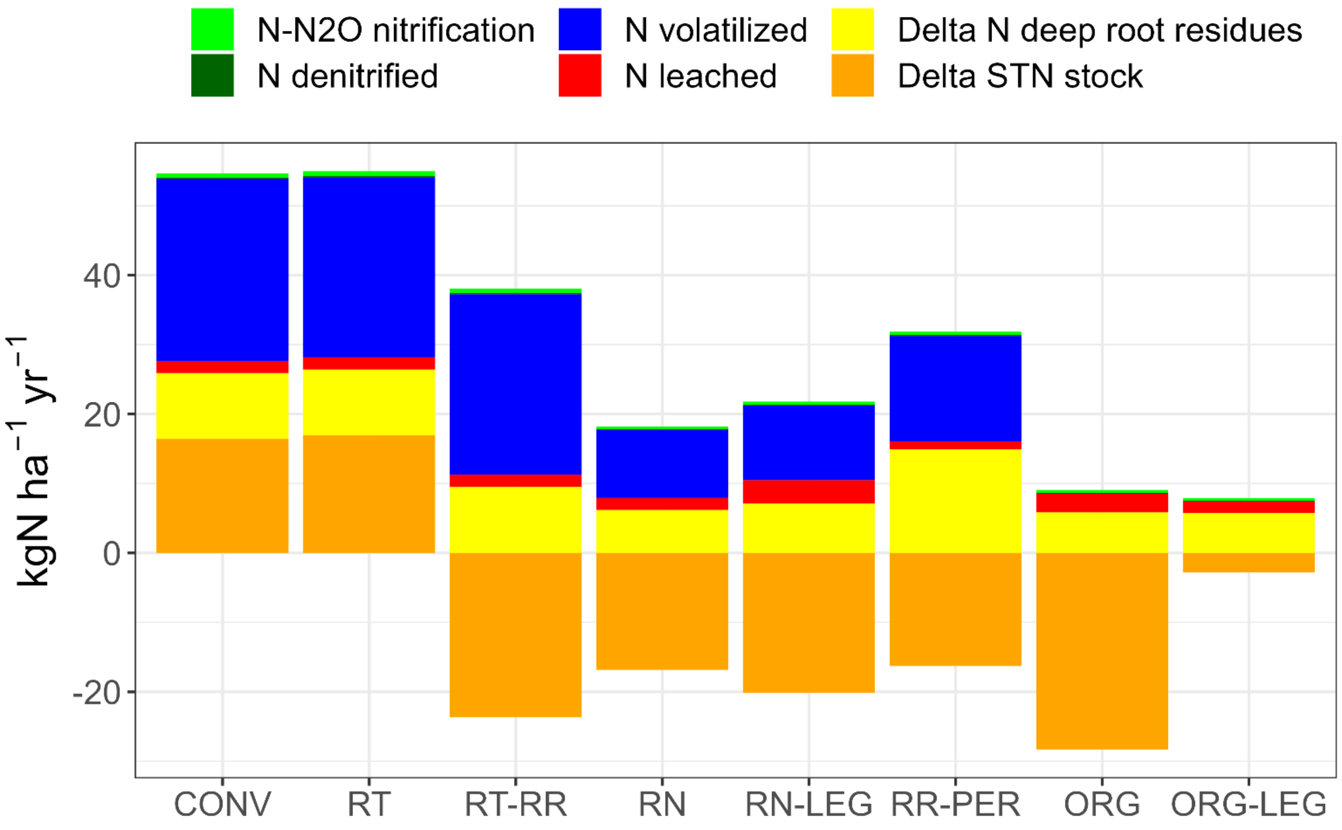
- Overall good performance
- Some bad estimations of N surplus mainly due to over- or under-estimation of N outputs

Biomass exported and N surplus 2010-2021 (2016-2021 for ORG systems)



- Exported biomass: total amounts and differences between treatments generally well simulated
- N surplus: STICS is able to restitute the ranking between treatments with CONV & RT > RT-RR > other treatments

Simulated N fate 2010-2021 (2016-2021 for ORG systems)



- Decrease in N stock (-2 to -28 kg N ha^{-1} yr^{-1}) except for CONV and RT (+ 16 kg N ha^{-1} yr^{-1})
- N volatilization is the main pathway of N losses, except in ORG systems

Conclusions

- Model performance for crop and soil variables was similar to that achieved previously for simulations at the annual scale (Coucheney et al., 2015), with the same level of accuracy for conventional and low input treatments
- The release of mineral N after alfalfa destruction was underestimated
- Trends of SOC stock evolution were well reproduced except under switchgrass (root C inputs too low?)
- Long-term biomass production and N surplus were relatively well predicted for all treatments, but simulations could benefit from an improved crop parameterization for some species (*e.g.* rapeseed N uptake and harvest index)
- The fate of dead roots simulated in deep soil layers should be investigated (What's happening in the field? How can we simulate it?)
- N_2O emissions need to be considered to complete the GHG budget of the systems (see P. Belleville et al., next presentation!)

Thank you for your attention!

EJP SOIL
ΣOMMIT

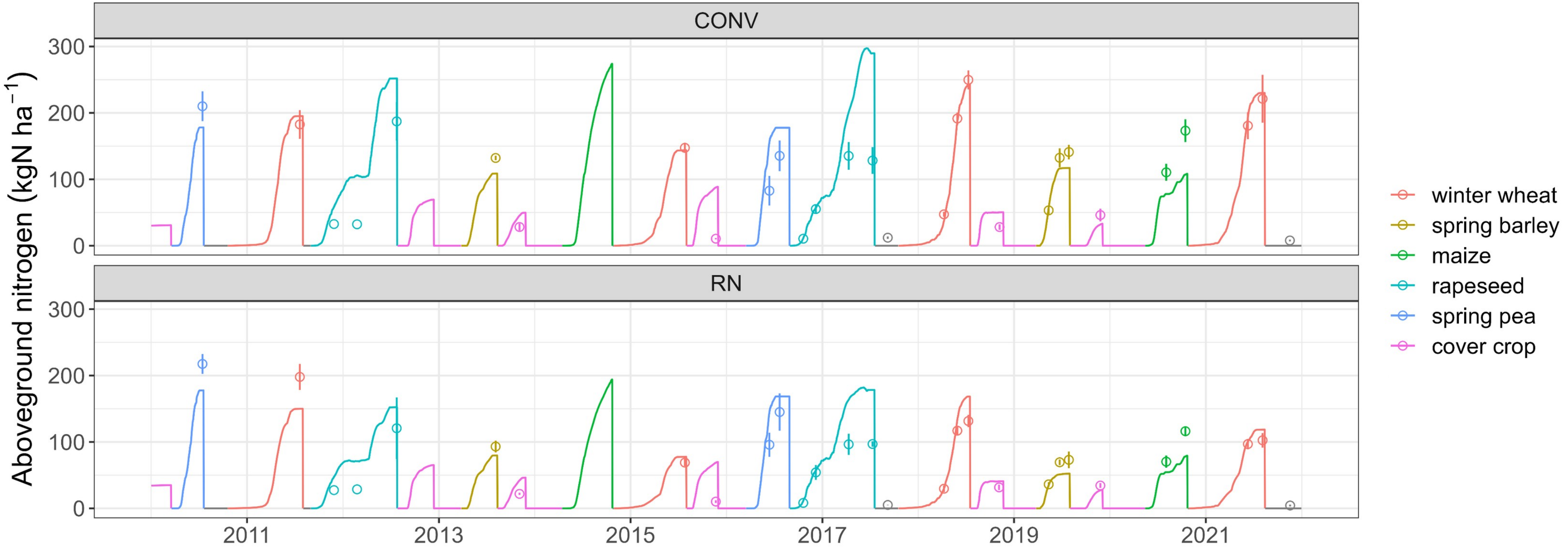
EJP SOIL has received funding from the European Union's Horizon 2020 research and innovation programme: Grant agreement No 862695

Contact: fabien.ferchaud@inrae.fr

Statistical criteria for model evaluation

Variable	n	Mean obs.	Bias	RMSE	rRMSE (%)	R^2	EF
Aboveground biomass (t DM ha^{-1})	326	6.3	0.8	2.2	35.6	0.88	0.83
Grain yield (t DM ha^{-1})	108	6.0	-0.8	2.0	34.3	0.52	0.30
Aboveground N (kg N ha^{-1})	266	95.2	6.6	40.7	42.8	0.65	0.56
Grain N (kg N ha^{-1})	105	107.1	-16.7	56.0	52.2	0.23	-0.55
Aboveground N concentration (%)	249	1.90	0.11	1.06	55.7	0.54	0.01
Grain N concentration (%)	105	1.93	-0.16	0.65	33.6	0.56	0.23
Water content 0-30 cm (%)	182	21.2	1.0	2.5	11.7	0.78	0.73
Soil water stock 0-150 cm (mm)	182	446	19	42	9.3	0.80	0.74
N-NO_3 0-30 cm (kg N ha^{-1})	182	20.3	-6.2	17.8	87.7	0.04	-0.50
N-NH_4 0-30 cm (kg N ha^{-1})	182	5.7	0.6	4.1	70.9	0.04	-0.12
Mineral N 0-150 cm (kg N ha^{-1})	182	61.4	-20.9	39.0	63.6	0.12	-0.59
SOC stock 0-35 cm (t ha^{-1})	16	48.6	-0.8	1.7	3.5	0.49	0.24
SON stock cm (t ha^{-1})	16	5.3	0.0	0.1	2.1	0.42	0.05

Crop aboveground nitrogen: conventional (CONV) and reduced N (RN)



- Aboveground N dynamic rather well simulated but less than biomass
- Similar performance in CONV and RN (RRMSE = 42% in both treatments)
- Effect of long-term reduced N fertilization well predicted (obs.: -31% / sim.: -31%)

SOC stock evolution

SON stock evolution

INRAE