Predictive performance of Sentinel-2 based models for estimating canopy nitrogen content in wheat

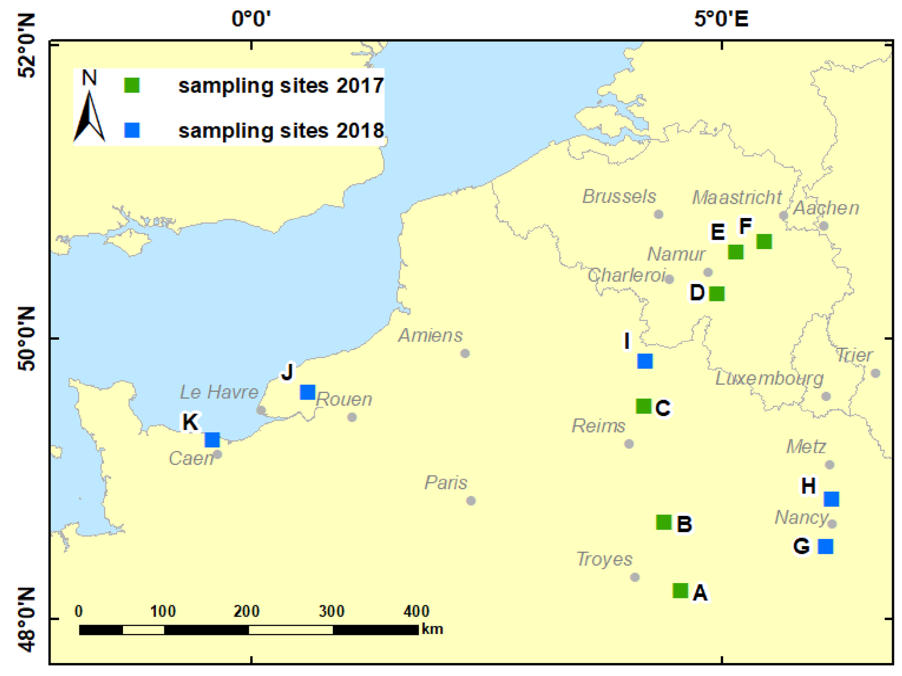
Christian Bossung[1], Miriam Machwitz[1], Martin Schlerf[1]

[1]Luxembourg Institute of Science and Technology, L-4362 Esch/Alzette – Grand-Duchy of Luxembourg

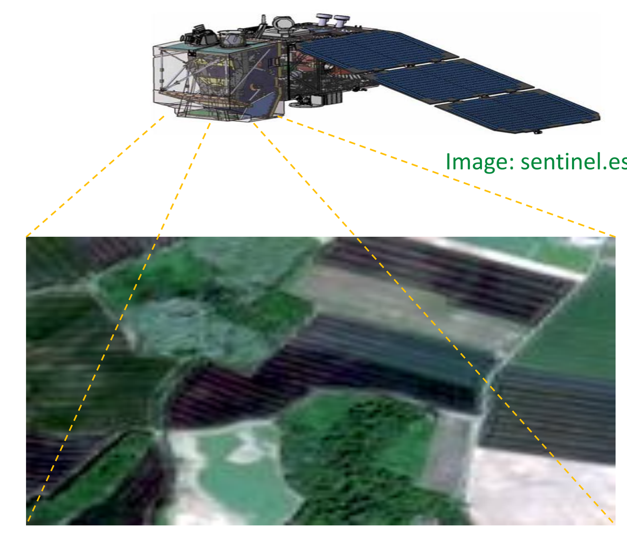
Introduction: Nitrogen (N) fertilization according to the **actual plant needs** is essential for farmers as an over-fertilization can cause negative impacts to water resources and increase the costs for farmers. An under-fertilization leads to limited plant development and to a reduced yield. The freely available **Sentinel-2 A/B** satellites provide spatial information for retrieving the **actual N status** of crops to support a **variable rate application** according to the plant needs. In this study, the predictive performance of the inversion of the radiative transfer model (RTM) **PROSAIL, PLS regression (PLSR)** and **Vegetation Indices (VI)** were compared for estimating actual **canopy nitrogen content** (CNC, [kg/ha]) on winter wheat fields. The models were tested with two validation schemes: A **rigorous validation** with samples of other regions and of a different year to assess the transferability in space and time (scheme A) and a cross-validation approach using a pooled dataset (scheme B, 70 % calibration and 30 % validation).

Field Work and Image Data

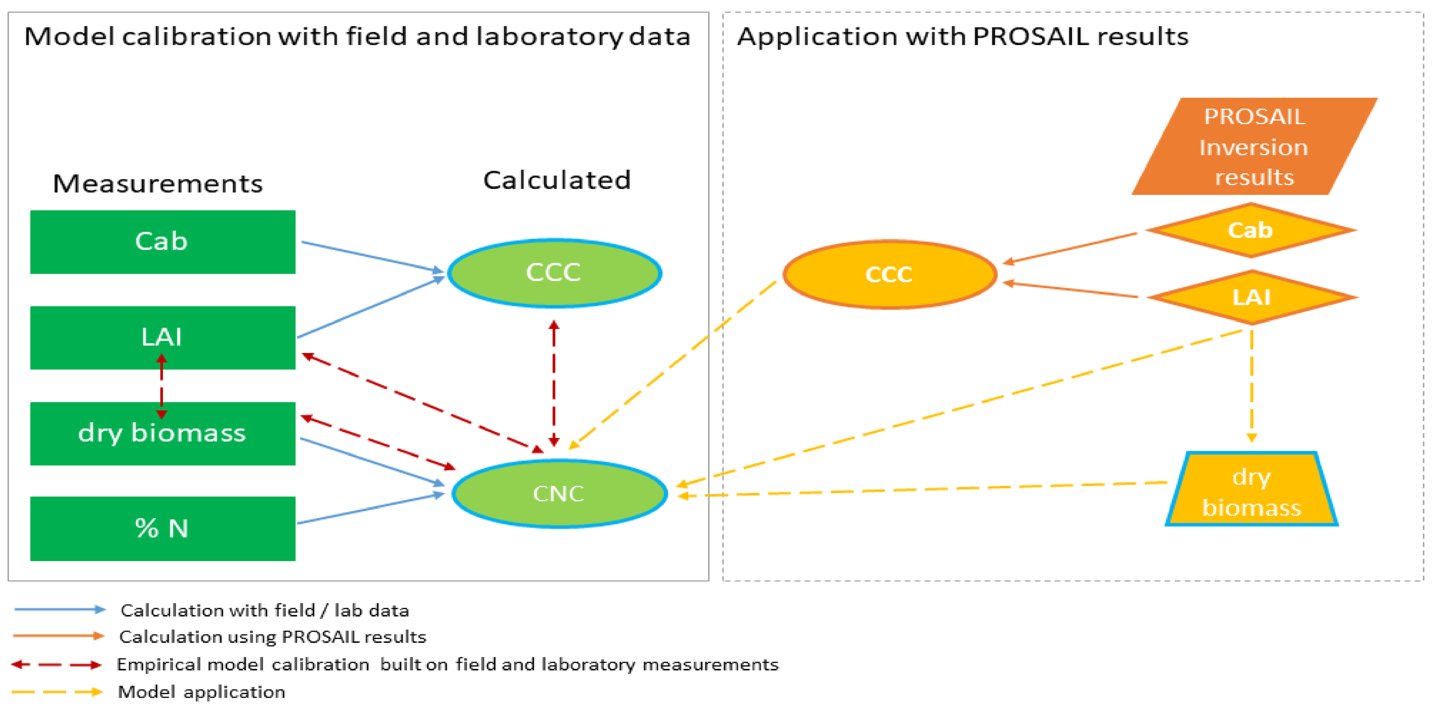
- April - early June 2017 on 3 sites in France and 3 sites in Belgium:
  - LAI, chlorophyll (Minolta – SPAD), fresh and dry biomass, CNC
  - n = 181 for empirical modelling between field data (LAI, fresh biomass, SPAD) and laboratory measurements
  - n = 126 for PLSR and PROSAIL
- May 2018: 5 sites in France (n = 21):
  - Fresh and dry biomass, CNC
  - PROSAIL and PLSR: n = 18



Sentinel-2 images were selected next to the field sampling dates



Methods:



- VIs integrate the spectral information of Sentinel-2 according to their respective formula to one single value and estimate CNC with a linear empirical relationship.
- PLSR uses the direct link between the full spectral information and the laboratory determined CNC
- RTM inversion can make use of different strategies to retrieve CNC:
  - link between LAI and biomass (dry / fresh) to derive CNC (empirical relation)
  - link between LAI, Cab to derive Canopy Chlorophyll Content (CCC) and afterwards CNC (empirical relation)

The Inversion of PROSAIL with a cost-function (sum of squared errors, SSE) derived the closest members of the PROSAIL-LUT to a real Sentinel-2 observation. LAI and Cab was calculated as the average of the 100 best solutions. CNC was calculated with the empirical models calibrated with field and laboratory data.

Results

R	LAI	Cab	FM	DM	LNC	CNC	CCC
LAI	**1**						
Cab	0.31	**1**					
FM	**0.86**	0.34	**1**				
DM	0.73	0.38	**0.92**	**1**			
LNC	-0.32	-0.08	-0.58	-0.7	**1**		
CNC	**0.81**	0.44	**0.84**	**0.81**	-0.23	**1**	
CCC	**0.9**	0.68	**0.81**	0.74	-0.3	**0.81**	**1**

Table left: Correlation coefficient (R) between the field and laboratory measurements

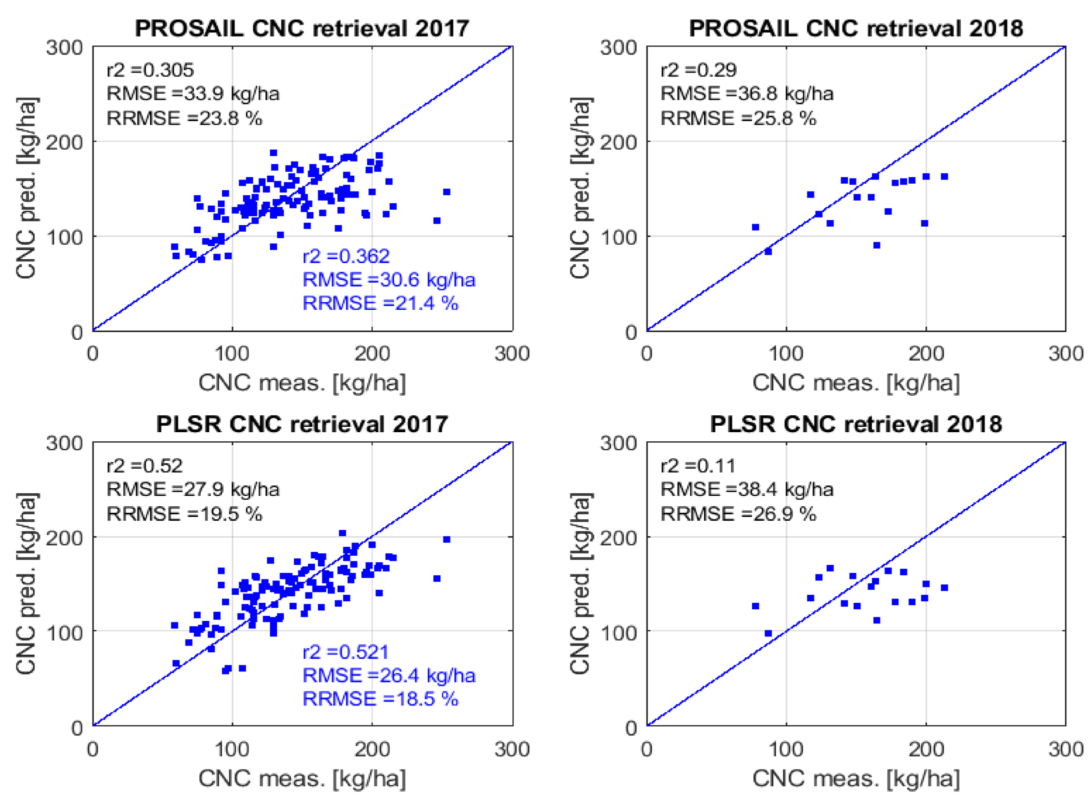


Figure left: Results of the PROSAIL - based CNC retrieval and the PLSR estimation of CNC for the 2017 and 2018 samples. Values in blue are results excluding two high CNC samples.

CNC estimation of PLSR, PROSAIL inversion and the VI based estimation for the two different validation schemes:

- VIs have a lower accuracy using the independent validation
- PLSR showed a decrease in accuracy using unknown samples from a different year and region
- PROSAIL based approach showed the least change in prediction accuracy between the two validation schemes

		PLSR	PRO - SAIL	NDVI	REP	NDRE	NDRE2	MCARI	MTCI	EVI2	CI-RE	CI green
Validation scheme A												
2017 CAL	R2	0.52	0.3	0.4	0.49	0.5	0.38	0.02	0.4	0.41	0.39	0.15
n=126	RMSE	**27.9**	33.9	33.1	30.4	**30**	33.7	**42.3**	33	32.7	33.2	39.4
	RRMSE	19.5	23.8	23.5	21.6	21.3	23.9	29.9	23.4	23.2	23.6	27.9
2018 VAL	R2	0.11	0.29	0.06	0.03	0.05	0.05	0.02	0	0.05	0.01	0.04
n=18	RMSE	38.4	**36.8**	49.7	**49**	51.9	51	49.8	52.3	51.1	**54.9**	53.3
	RRMSE	26.9	25.8	35.3	34.8	36.8	36.2	35.3	37.1	36.3	38.9	37.8
Validation scheme B												
70% CAL	R2	0.44	0.25	0.33	0.42	0.41	0.31	0.02	0.32	0.34	0.3	0.12
n=101	RMSE	**31**	36.9	35	**32.7**	32.8	35.6	**42.5**	35.3	34.9	35.8	40.3
	RRMSE	21.6	25.7	24.8	23.2	23.3	25.3	30.2	25	24.7	25.4	28.6
30% VAL	R2	0.35	0.26	0.32	0.4	0.4	0.29	0.04	0.3	0.32	0.29	0.13
n=43	RMSE	**33.9**	**33.9**	36.8	**34.8**	35	37.5	**61.4**	37.7	36.7	38.2	45.4
	RRMSE	23.6	23.6	26.1	24.7	24.8	26.6	43.5	26.7	26.1	27.1	32.2

Discussion

- Transferability of the VI and PLSR models to other regions and years is less accurate (RMSE: 28 kg N/ ha to 38.4 kg N /ha).
- RTM inversion showed higher transferability with a RMSE of 34 kg N/ha and 36.8 kg N/ha to other regions and years.
- PLSR and VIs show higher accuracies for known regions (as indicated with the pooled data approach)
- A significant advantage of the PROSAIL approach is the flexibility to use every sensor system in the range of 400 – 2500 nm by resampling the LUT to the specific sensor characteristics

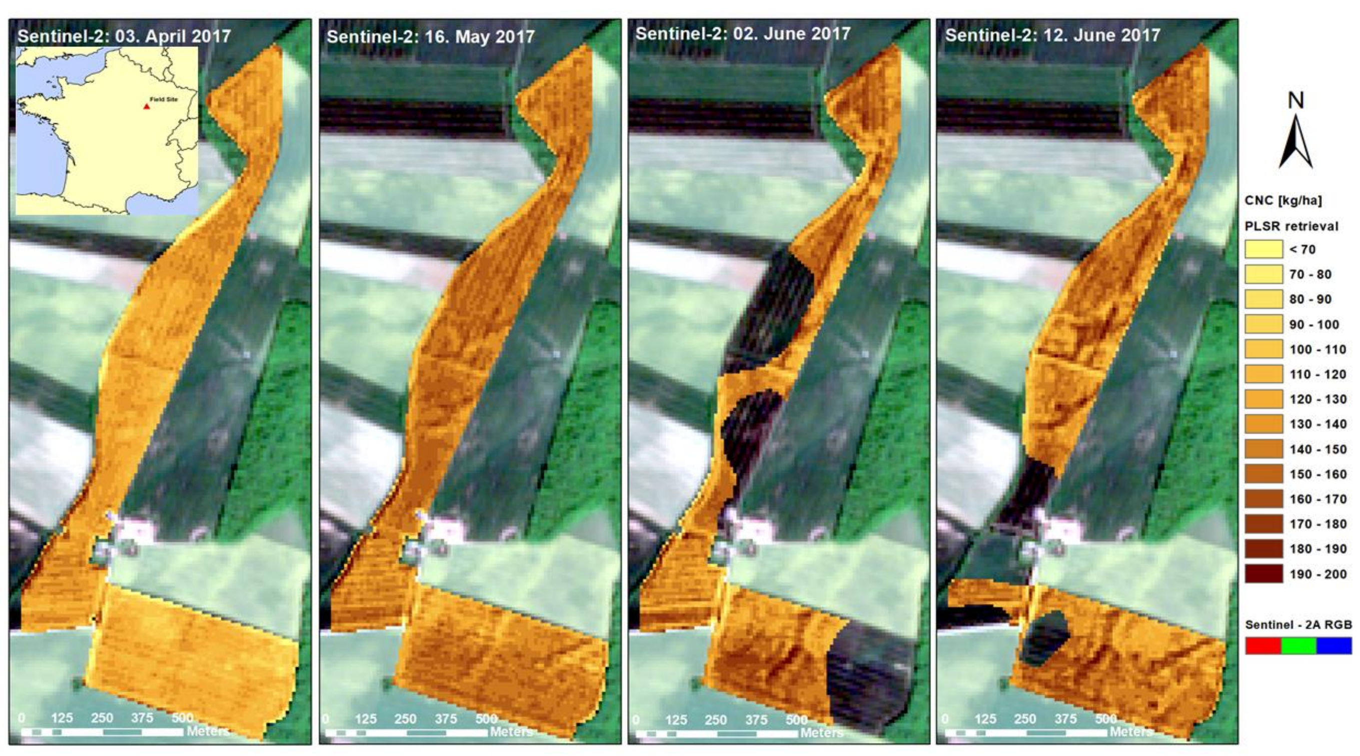


Figure left: Application of the PLSR – CNC-DM model (cloud influences were masked out)

- Image 1-3 shows an increase of CNC (BBCH stages 33-39).
- Image 4: decrease of CNC visible, but already outside the calibration range

Further Reading: Bossung, C., Schlerf, M. & Machwitz, M. Estimation of canopy nitrogen content in winter wheat from Sentinel-2 images for operational agricultural monitoring. *Precision Agric* (2022). https://doi.org/10.1007/s11119-022-09918-y

Luxembourg Institute of Science and Technology

5, avenue des Hauts-Fourneaux
L-4362 Esch/Alzette

phone: (+352) 275 888 - 1
fax: (+352) 275 885

christian.bossung@list.lu
LIST.lu

In cooperation with: agroptimize