Assessing Low-Input Crops and Crop Rotations to Reduce Nitrate Leaching in Water Catchment Area with the STICS model

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Introduction

Context and hypotheses

Between 1994 and 2013, 7716 WCAs used for drinking water supply were abandoned in France, 39% due to nitrate and pesticide contamination.

Despite regulations promoting “Best Management Practices”, water quality often remains unsatisfactory.

This study aimed to perform an agronomic diagnosis of agricultural practices affecting water quality and to assess the potential of alternative crop rotations including low-input (LI) crops or practices to mitigate nitrate leaching at WCA scale.

Hypotheses :

H1: Model spatialization (different soil types) and agricultural practices reproduction (crop rotations, fertilization and irrigation notably) allow the simulation of soil x agricultural practices x climate x crop rotations interactions on crops yield and water quality.

H2 : Introduction of LI crops or crop rotations with low N fertilization if ever, could improve significantly water quality in terms of nitrate concentration.

Materials & Methods

Simulations at the WCA scale

Simulations were carried out with the STICS model at the scale of the Mérobert WCA (3,670 ha), located near Chartres (France). The area is 93% cropland, dominated by arable farming.

Climatic data were calculated from Météo-France datasets from physical meteorological stations of the Eure-Et-Loir department (2000–2022).

Cultural practices were determined with help of the departmental CA of Eure-Et-Loir :

- Nitrogen fertilization was calculated using the COMIFER balance-sheet method (see my poster!) and applied according to technical institute recommendations.
- Automatic irrigation was calibrated to reproduce irrigation amounts observed in the WCA.
- Sowing date and density were fixed per crop and there is no straw exportation nor organic fertilization.
- CC were adapted in function of following crop and dates of sowing and destruction respect strictly the regulations.
- Rapeseed were followed by regrowing crops and destruction date respect strictly the regulations.

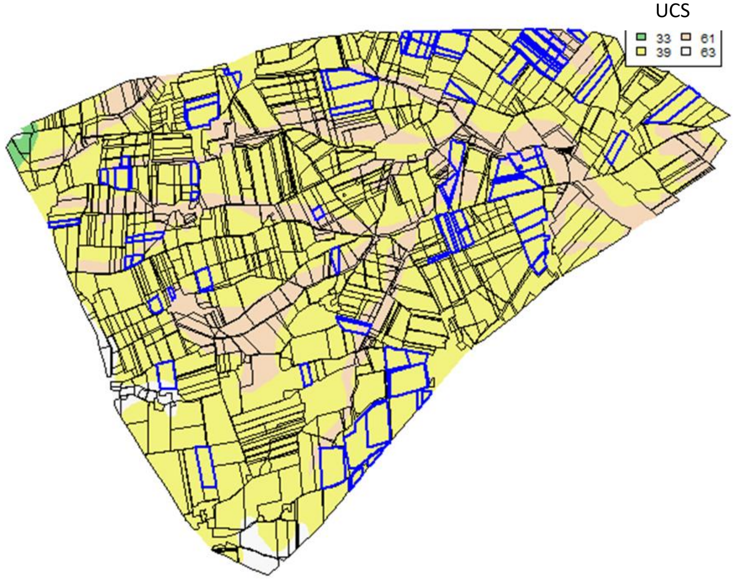
Materials & Methods

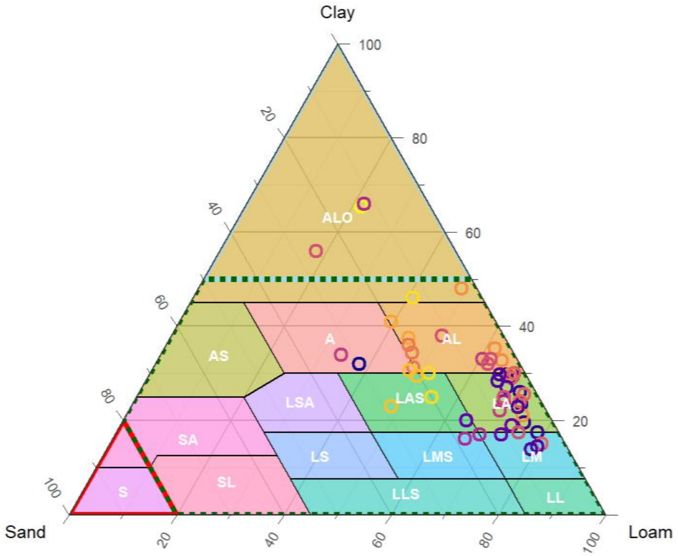
Soils parameterization

Soils were identified from the 1:250,000 soil database of the Eure-et-Loir department, and six main soil types were selected (Luvisol, Truncated Luvisol, Eutric Cambisol, Colluvic Regosol (with or without pebbles), and Hydromorphic Planosol) (WRB classification, FAO, 2022).

STICS soil parameters were extracted from the soil database or calculated with pedotransfer functions (Jamagne et al., 1977 ; Beaudoin et al., 2023 ; Bruand et al., 2004 ; Roman-Dobarco et al., 2019).

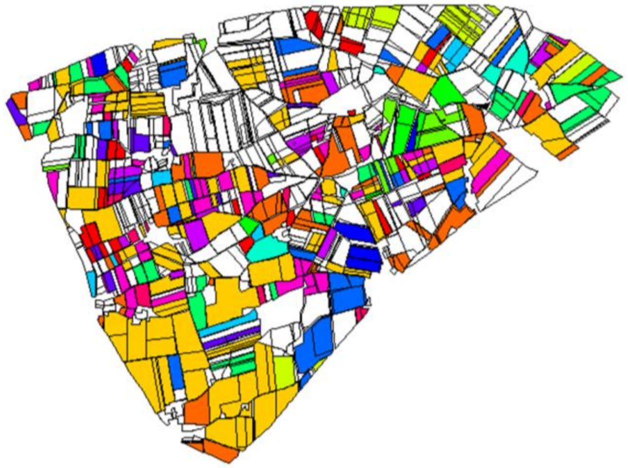
A specific yield target was assigned to the different soil types (« Arrêté établissant le référentiel régional de mise en œuvre de l'équilibre de la fertilisation azotée pour la région CENTRE-VAL DE LOIRE (2018) »)





Materials & Methods

Definition of the reference scenario



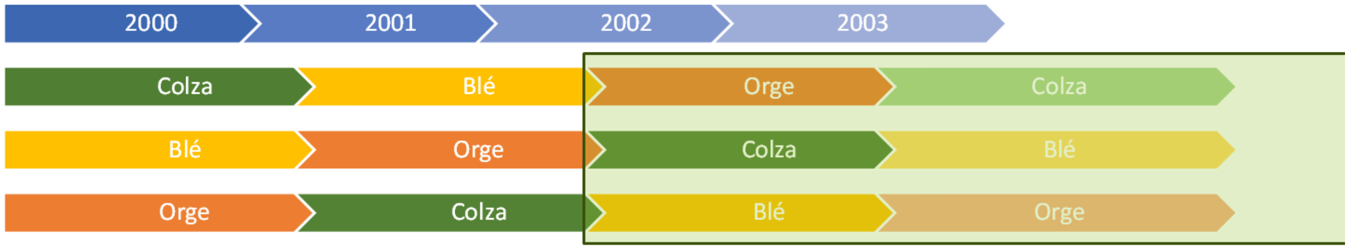
Determination of crop rotations with a R script:

- Use of LPIS information at the field scale (2015-2023)
- Selection of main crops :
  - Crops covering less than 1% of the cultivated area or not parameterized in the model were excluded
  - Crop rotations covering less than 1% of the cultivated area were excluded

Determination of 15 crops rotations, covering 60 % of the cultivated area, allowing to reproduce the sole.

These simulations, considered as the reference scenario, were used for model calibration (N fertilization, irrigation) and outputs validation at the WCA scale (yield, nitrate content in drained water) and to realize an agronomical diagnosis.

Simulations plan :



Materials & Methods

Definition of LI scenario

Insertion of sunflower, a LI crop, instead of wheat-wheat succession in 2 crop rotations with high N leaching (10.1 %)

Insertion of Miscanthus, a LI perennial crop (10 %)

Insertion of organic farming with a dedicated crop rotation (1 %)

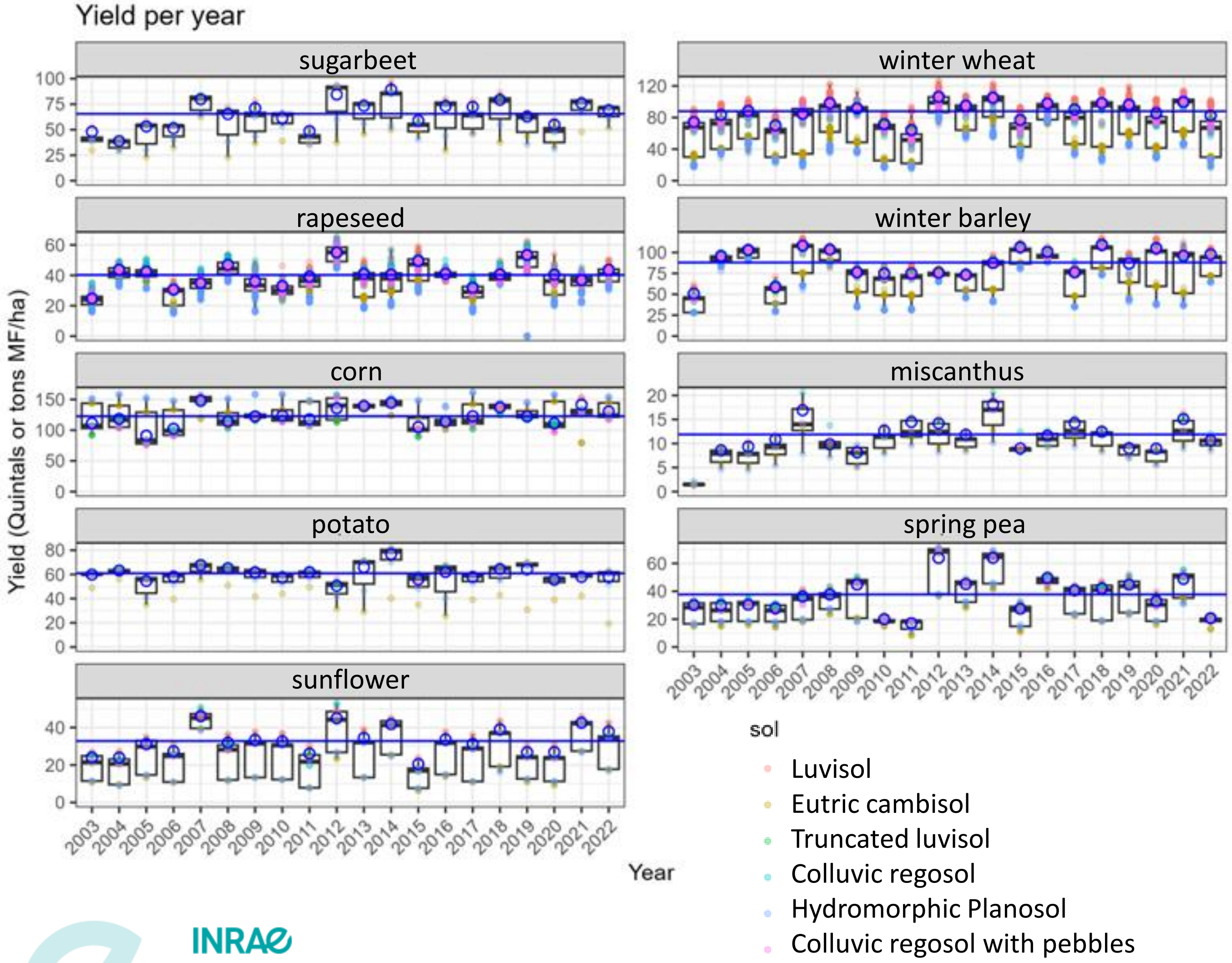
NB : Soil type was not taken into account for new crops and new cropping systems insertion

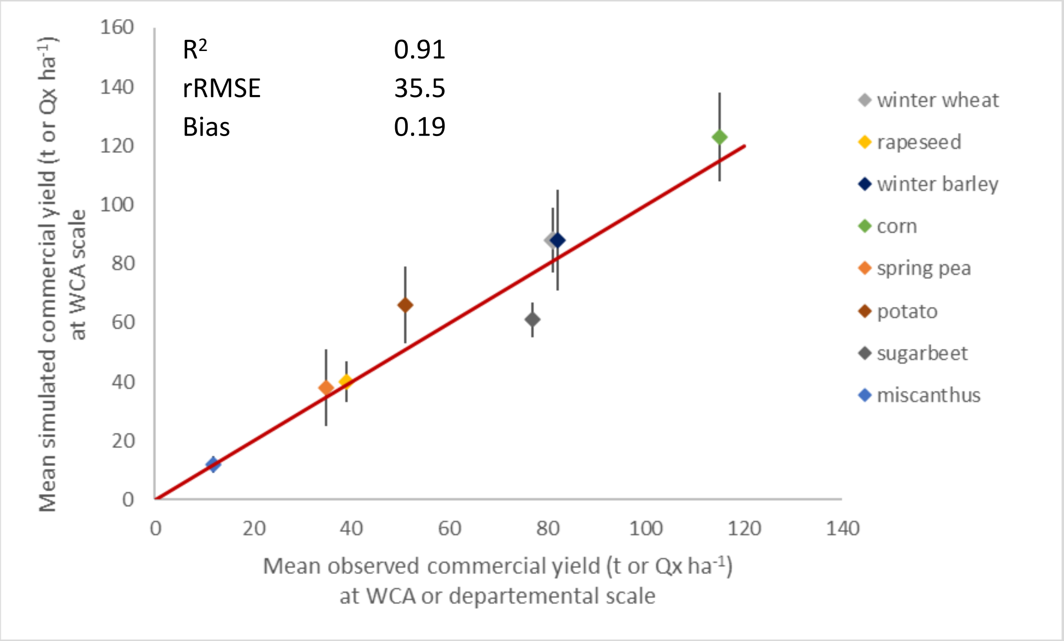
The part of each crop in the arable land is modified as follow :

	Winter wheat (%)	Rapeseed (%)	Winter barley (%)	Corn (%)	Spring pea (%)	Potato / Sugar beet (%)	Sunflower (%)	Miscanthus (%)	Others (%)	Total (%)
Actual sole	51.1	25.3	9.7	4.1	1.7	1.2				93
Simulated sole	51.7	28.1	8.6	2.4	1.3	1.0				93
LI scenario	-8.4	-3.8	-1.1	+0.1	0	+0.2	+2.4	+10	+0.6	93

Results

Simulated yield of different crops





Simulated yields at WCA scale are consistent with observations

Simulated yield is significantly impacted by the year of growth and soil

Rapeseed yield is significantly impacted by crop rotation

Results

Simulated yield vs yield objective

	Winter wheat		Winter barley		Rapeseed	
	simulation	objective	simulation	objective	simulation	objective
Luvisol (73.6%)	97	80 to 90	93	85	42	40
Troncated Luvisol (6.4 %)	84	75 to 85	85	80	38	38
Colluvic regosol (3.8 %)	82	75 to 85	87	85	42	38
Colluvic regosol with pebbles (2 %)	83	80 to 90	86	85	39	40
Eutric Cambisol (10.8 %)	49	70 to 80	65	80	34	35
Hydromorphic Planosol (3.4 %) *	39	70 to 80*	55	80*	29	35*

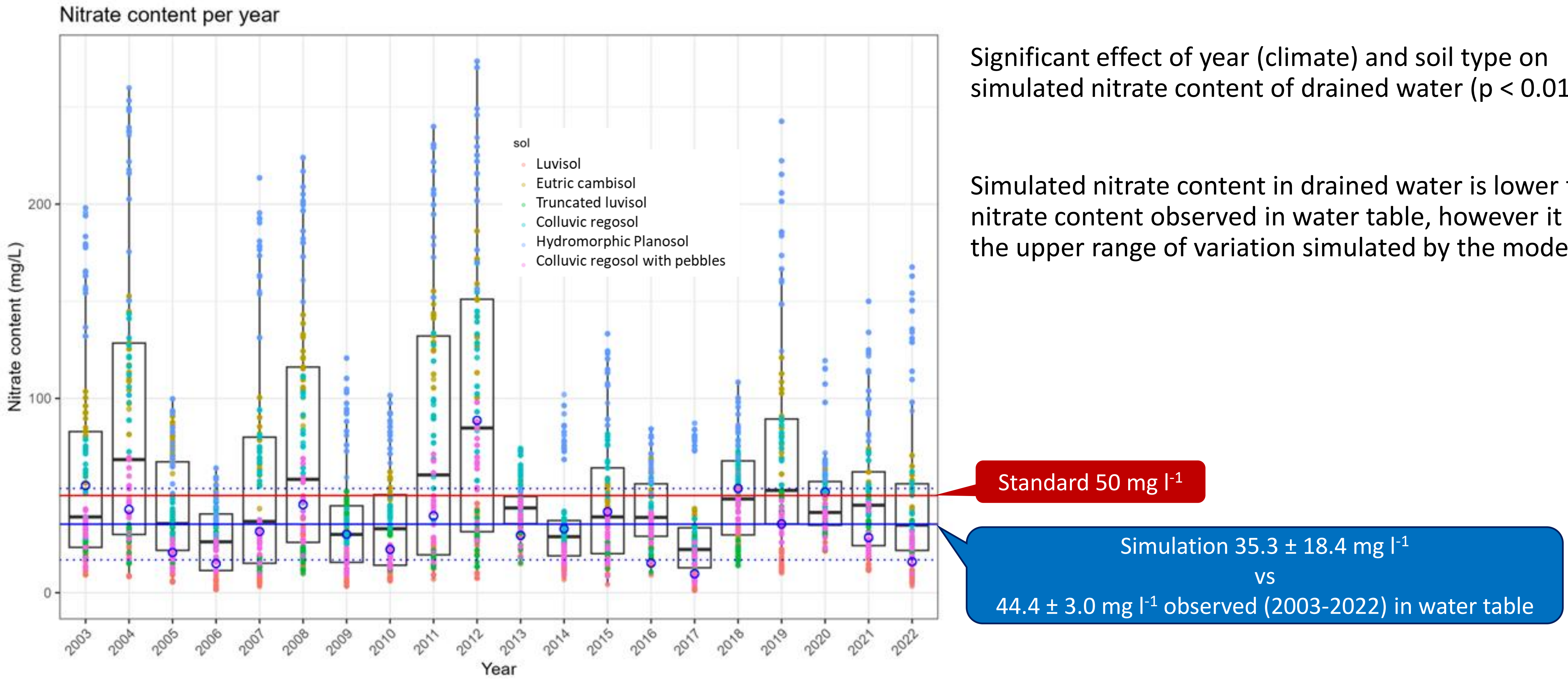
Simulated yield are higher or similar to the yield target for most of soil types.

Simulated yield are lower than the yield target on Eutric Cambisol and Hydromorphic Planosol.

Simulated yield seems consistent with water holding capacity of the different soil types.

Results

Simulated nitrate content

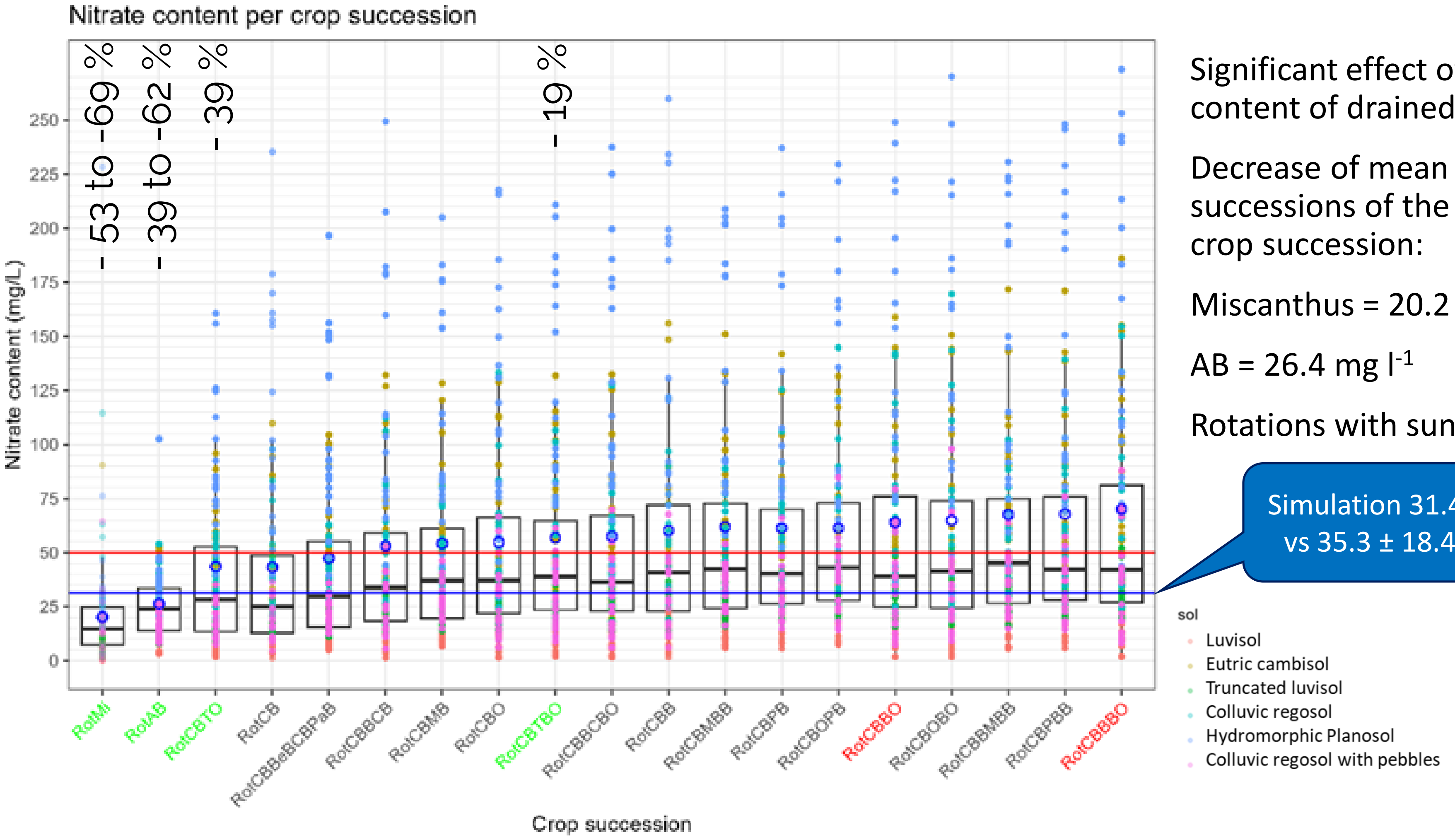


Significant effect of year (climate) and soil type on simulated nitrate content of drained water ($p < 0.01$).

Simulated nitrate content in drained water is lower than nitrate content observed in water table, however it is in the upper range of variation simulated by the model.

Results

Simulated nitrate content



Significant effect of crop rotations on simulated nitrate content of drained water ($p < 0.01$).

Decrease of mean nitrate content in drained water for crop successions of the BNI scenario compared to reference crop succession:

Miscanthus = 20.2 mg l^{-1}

AB = 26.4 mg l^{-1}

Rotations with sunflower = 43.6 and 56.9 mg l^{-1}

Simulation 31.4 ± 15.0 mg l^{-1} in BNI scenario vs 35.3 ± 18.4 mg l^{-1} in reference scenario

Conclusions and perspectives

Hypothesis H1 is partially validated: the model reproduces key interactions between soil, climate and management, but some limitations prevent a full validation

Simulated nitrate content of drained water is lower than observed in the water table (35.5 vs 44.4 mg l^{-1}) due to several limitations :

N fertilization was adapted yearly at field scale, which is a better practice than in reality

Yield objectives were assigned assuming homogeneous soil conditions within fields

Simulated farmers' agricultural practices follow technical institute recommendations as the administration regulation, contrary to observations (DREAL Centre-Val de Loir, 2022)

Simplifications which were necessary to perform simulations at the WCA scale

STICS was not paired with an hydrological model

How to manage better with soil heterogeneity, agricultural practices variability and lack of inputs data precision ?

A sensitivity analysis of model outputs to inputs data precision would be a useful next step.

Conclusions and perspectives

Hypothesis H2 is validated for low-input crops or rotations, provided that the area converted is sufficiently large to impact water nitrate content at the WCA scale.

The soil type is the first factor impacting nitrate losses in accordance with different authors (Hall et al., 2001 ; Liburne et al., 2003 ; Beaudoin et al., 2005)

There is a significative impact of crop rotations on nitrate losses, in accordance with the bibliography (Justes et al., 1999 ; Schnebelen et al., 2004 ; Jégo et al., 2008 ; Constantin et al., 2010 ; Beaudoin et al., 2012 ; Plaza-Bonilla et al., 2015)

The methodology applied in this study allowed to simulate accurately agricultural practices (fertilisation and irrigation), crops yield and satisfactorily nitrate concentration in drained water

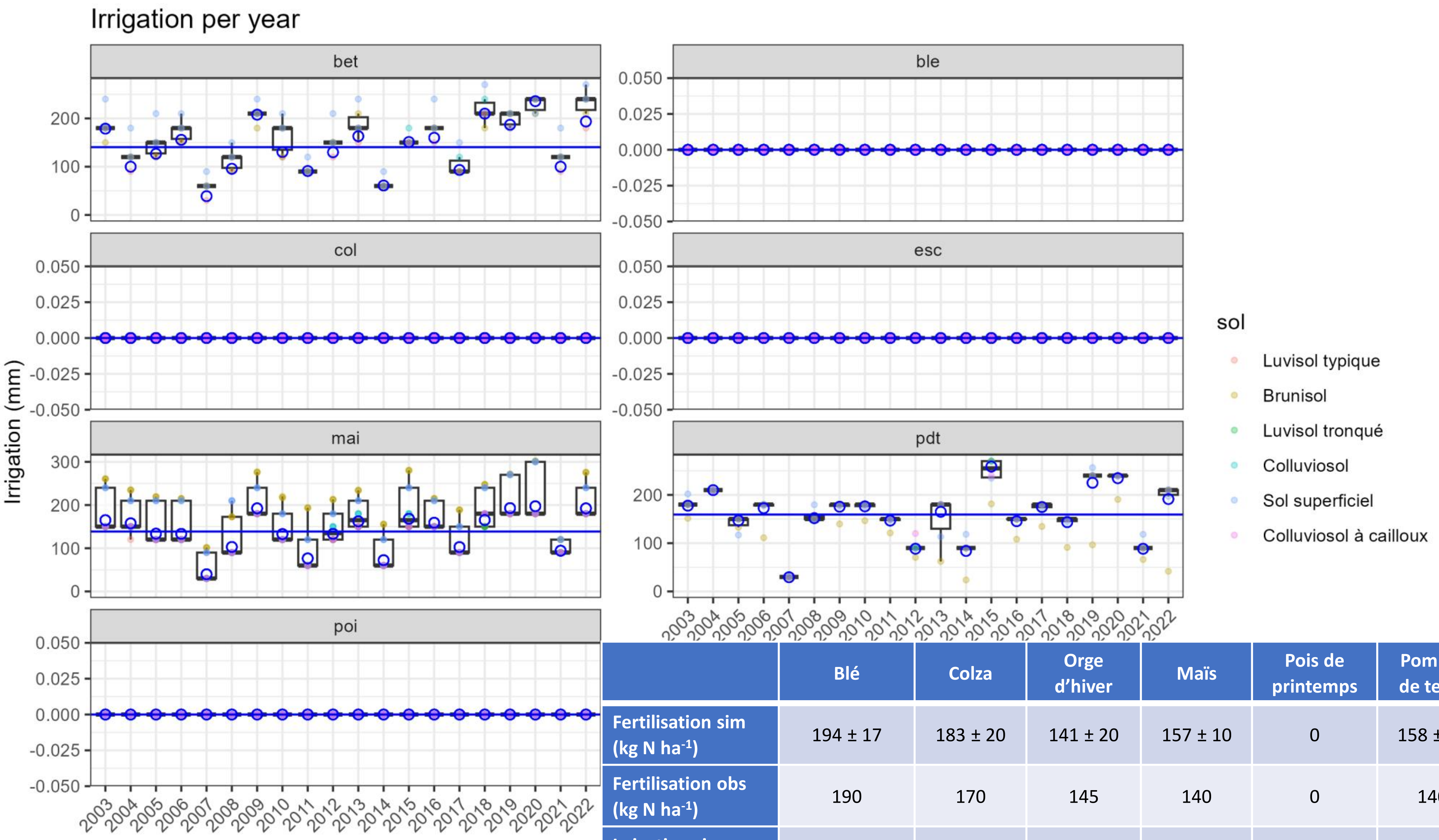
Nitrate content of drained water can be significantly reduced by LI crops and LI rotations:

- Sunflower: water nitrate content decreased by 6.0 % the at WCA scale
- Miscanthus: drainage and water nitrate content decreased by 2.4 % and 5.0 % at WCA scale
- Organic farming had no significant impact at WCA scale due to a too low surface of arable land converted to these environmentally friendly practices

All together the LI scenario allows a decrease by 11% of water nitrate content

Merci pour votre attention

Results



	Blé	Colza	Orge d'hiver	Maïs	Pois de printemps	Pomme de terre	Betterave	Tournesol	Miscanthus
Fertilisation sim (kg N ha^{-1})	194 ± 17	183 ± 20	141 ± 20	157 ± 10	0	158 ± 10	108 ± 8	26 ± 15	0
Fertilisation obs (kg N ha^{-1})	190	170	145	140	0	140	90	NA	0
Irrigation sim (mm)	0	0	0	139 ± 44	0	159 ± 54	140 ± 52	0	0
Irrigation obs (mm)	0	0	0	139	0	159	105	NA	0

Résultats : Simulations à l’échelle de l’AAC

Concentration en nitrate et sol

sol	Mean nitrate concentration per soil (mg l^{-1})	Groupe
Luvisol	23.7 *(23.0)*	a
Troncated Luvisol	26.2 *(25.4)*	a
Colluvic Regosol with pebbles	37.5 *(36.4)*	b
Colluvic regosol	68.3 *(66.2)*	c
Eutric Cambisol	70.6 *(68.8)*	c
Hydromorphic Planosol	119.8 *(117.1)*	d

Les sols à potentiel de rendement élevé et forte RU ont des concentrations en nitrates faibles

Les sols à potentiel de rendement plus faible avec une RU moyenne à faible ont des concentrations en nitrates plus élevées