Regional modelling of nitrate leaching from Swiss organic and conventional cropping systems under climate change

Francesca Calitri[1], Magdalena Necpalova[2], Juhwan Lee[2], Claudio Zaccone[1], Ernst Spiess[3], Juan Herrera[4], Johan Six[2]

[1] Dept. of the Sciences of Agriculture, Food and Environment, University of Foggia, Foggia, Italy

[2] Sustainable Agroecosystems Group, Department of Environmental Systems Science, Swiss Federal Institute of Technology, Zurich, Switzerland

[3] Agroscope Reckenholz, Zurich, Switzerland

[4] Agroscope Changins, Nyon, Switzerland

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

Agroscope

1 Introduction

Organic cropping systems have been promoted as a sustainable alternative to minimize the environmental impacts of conventional practices. Relatively little is known about the potential to reduce NO_3-N leaching through the adoption of organic practices. In this study, we compared regional NO_3 leaching from organic and conventional cropping systems in Switzerland using an ecosystem biogeochemical model DayCent.

The objectives of this study were:

- To calibrate and validate the model for NO_3 leaching measured under various management practices from three experiments;
- To estimate regional NO_3 leaching patterns and their spatial uncertainty in conventional and organic cropping systems (with and without cover crops);
- To explore the sensitivity of NO_3 leaching to changes in soil and climatic variables;
- To assess the nitrogen use efficiency (NUE) for conventional and organic cropping systems with and without cover crops under current and future climate change.

2 Materials and Methods

Experimental data

The experimental data for DayCent calibration and evaluation were obtained from three field experiments in Liebefeld and Lindau (Table 1). These two sites were assumed to represent typical cropping systems in Bern and Zürich cantons. Experiment I and II evaluated the effect of various crop rotations on NO_3^- leaching, and experiment III investigated effects of various cover crops and levels of N fertilization on NO_3 leaching.

DayCent description and modeling approach

The DayCent ecosystem model simulates major ecosystem processes that affect soil C and N dynamics, including plant production, water flow, heat transport, soil organic C decomposition, N mineralization and immobilization, nitrification, denitrification, and methane oxidation. The water flow is simulated with the tipping-bucket approach and applies Richards' equation for water re-distribution after the drainage from saturation to field capacity. Proportion of NO_3^- subjected to downward transport with the water flow is a function of the sand content.

Site level model calibration was based on crop yields, annual water fluxes and NO3- leaching data. The calibrated model was evaluated against an independent proportion of the data based on coefficient of determination (R2), root mean square error (RMSE) and relative root mean square error (rRMSE).

The calibrated/validated model was used in regional simulations across agricultural areas in Bern and Zürich (at 2.2 km spatial resolution). Regional simulations were carried out for organic and conventional cropping systems over 30 years (1981-2013). Organic practices included slurry application, winter cover cropping, and combinations of these.

Table 1. Characterization of the experiments considered in this study.

Experiment (duration)	Location (canton)	Number of treatments	Mean annual temperature (°C)	Mean annual precipitation (mm)	Treatments investigated
Experiment I (1993-2000)	Liebefeld (Bern)	6+1	8.7	1061	Crop rotations [a)] (with and without CC [b)]) + grass-clover
Experiment II (2002-2007)	Liebefeld (Bern)	3	8.7	1061	Crop rotations [a)] (with CC [c)])
Experiment III (2000-2002)	Lindau (Zurich)	6	9.3	1130	Spring wheat with CC [d)] and two levels of N input [e)]

a) Silage maize; spring wheat; potatoes; winter wheat; rapeseed; field pea; sugar beet; winter barley; oats; hemp.
b) CC=cover crop (summer vetch, canola/sunflower/summer vetch mix)
c) CC=cover crop (oilseed radish, chinese cabbage)
d) CC=cover crop (sunflower vs. white mustard/hybrid turnip, rape, chinese cabbage mixture vs. phacelia)
e) 20 kg ha^{-1} y-1; 270 kg ha^{-1}y-1

3 Results and discussion

Results for model calibration and validation are shown in Figure 1 and Figure 2, respectively. Model evaluation against an independent proportion of the data shows that DayCent was able to simulate the measured magnitude and variability in crop yields satisfactorily (Table 2). The model was also able to explain 54 to 87% of the inter-annual variability in the measured water fluxes across treatments and experiments. The annual NO_3-N leaching was simulated reasonably well, but the model had difficulty to accurately reproduce the inter-annual variability in the NO_3-N leaching losses (R^2 up to 0.35).

Under conventional cropping systems, the regional NO_3-N leaching (Table 3) was estimated to be 6.00 ± 2.14 g N m^{-2} y^{-1} in Zurich and 5.51 ± 2.16 g N m^{-2} y^{-1} in Bern. The NO_3-N leaching tended to decrease when only organic fertilizers (specifically slurry) were applied, while the system N balance could be improved by cover cropping (CC).

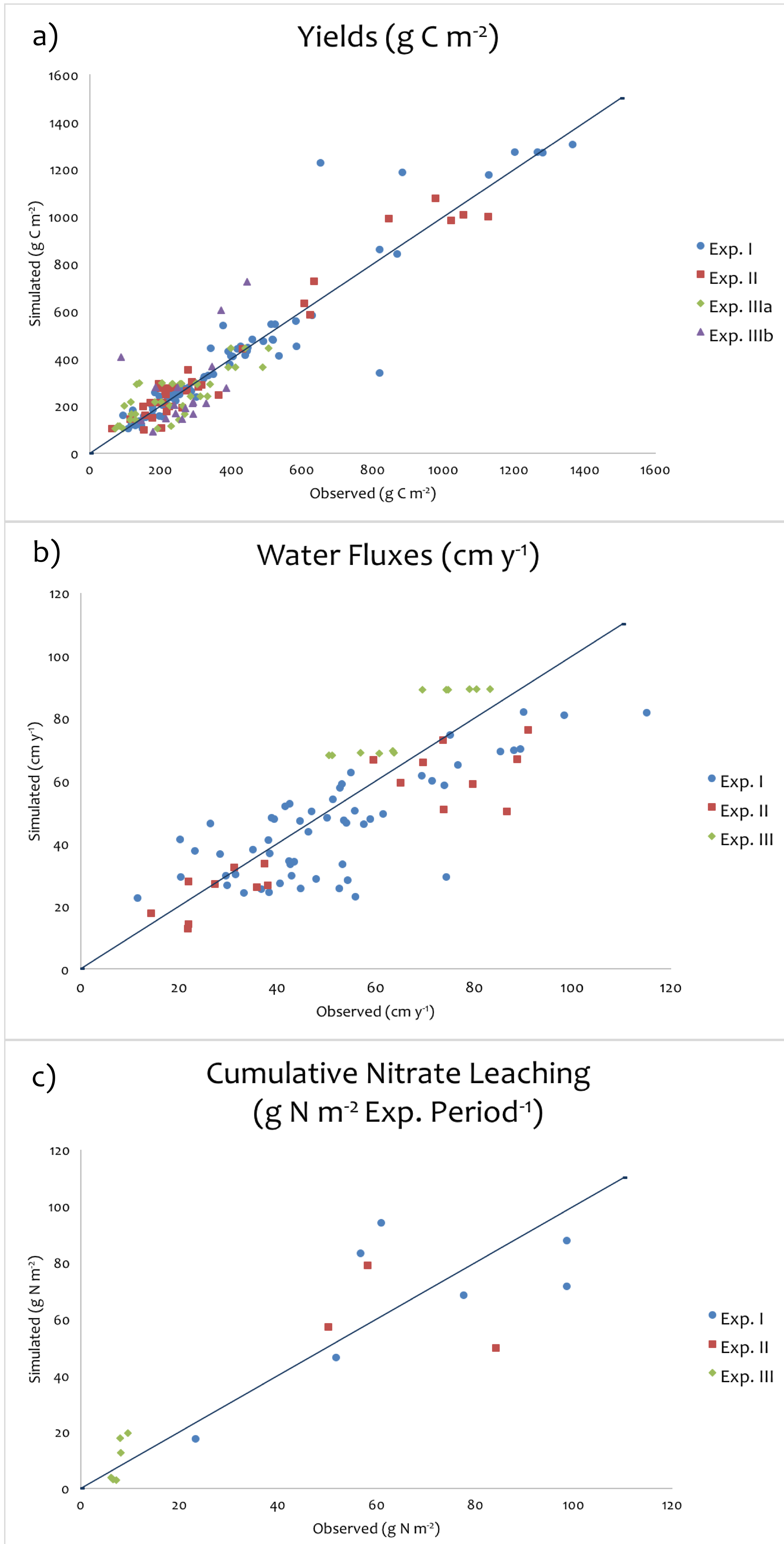

Figure 1. Simulated versus observed crop productivity (a), water fluxes (b) and NO_3^- leaching (c) of the three experiments for model calibration.

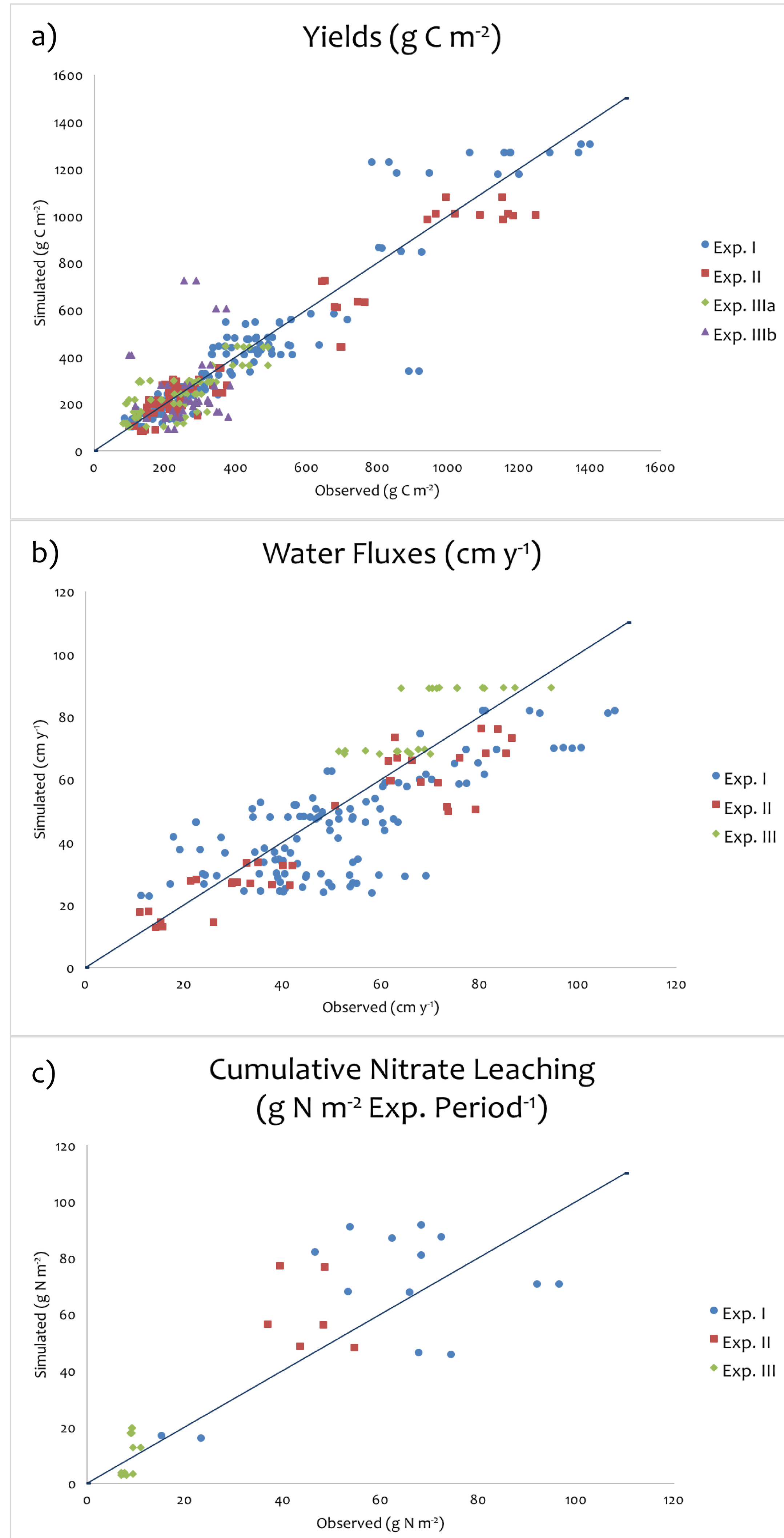

Figure 2. Simulated versus observed crop productivity (a), water fluxes (b) and NO_3^- leaching leaching (c) of the three experiments for model validation.

Table 2. Statistical indicators applied to the model calibration and validation for the Experiment I, II and III. RMSE= root mean square error; rRMSE= relative root mean square error, R^2 = coefficient of determination

	N	bias	RMSE	rRMSE	R^2
Calibration Exp. I					
Yields (g C m^{-2})	76	-5.81	101.59	0.26	0.895***
Water fluxes (cm y^{-1})	56	6.07	14.61	0.29	0.590***
NO_3 leaching (g N m^{-2} y^{-1})	56	-0.03	10.39	1.25	0.003 n.s.
Validation Exp. I					
Yields (g C m^{-2})	152	9.16	107.38	0.27	0.883***
Water fluxes (cm y^{-1})	112	6.39	15.16	0.29	0.548***
NO_3 leaching (g N m^{-2} y^{-1})	112	-0.56	9.67	1.26	0.002 n.s.
Calibration Exp. II					
Yields (g C m^{-2})	34	-7.21	62.71	0.17	0.956***
Water fluxes (cm y^{-1})	18	8.32	13.90	0.27	0.827***
NO_3 leaching (g N m^{-2})	18	0.37	10.30	0.96	0.073 n.s.
Validation Exp. II					
Yields (g C m^{-2})	68	25.48	85.50	0.21	0.943***
Water fluxes (cm y^{-1})	36	5.58	10.50	0.21	0.869***
NO_3 leaching (g N m^{-2} y^{-1})	36	-2.55	8.10	1.07	0.102 n.s.
Calibration Exp. III					
Yields wheat (g C m^{-2})	36	-4.03	70.37	0.30	0.635***
Yields cover crops (g C m^{-2})	18	0.40	136.84	0.51	0.280*
Water fluxes (cm y^{-1})	12	-11.72	12.63	0.19	0.811***
NO_3 leaching (g N m^{-2} y^{-1})	12	-1.21	3.67	0.97	0.620**
Validation Exp. III					
Yields wheat (g C m^{-2})	72	-1.11	69.09	0.29	0.641***
Yields cover crops (g C m^{-2})	36	-2.85	168.03	0.64	0.018 n.s.
Water fluxes (cm y^{-1})	24	-9.61	12.32	0.18	0.537***
NO_3 leaching (g N m^{-2} y^{-1})	24	-0.70	3.94	0.92	0.348**

Table 3. Region-level N balance and leaching under convetional and alternative management practices (area-weighted average ± standard deviation). Values are reported in g N m^{-2} y^{-1}.

Canton	Management	Total N input	N leaching	N balance
Zurich (n = 382)	CT	11.70 ± 0.34	6.00 ± 2.14	-1.42 ± 2.98
	CT+CC	12.63 ± 0.37	6.07 ± 2.32	-1.24 ± 2.87
	CT+S	10.80 ± 2.16	4.98 ± 1.65	-1.96 ± 4.42
	CT+CC+S	11.76 ± 2.17	4.85 ± 2.00	-1.70 ± 4.15
Bern (n = 688)	CT	11.63 ± 0.30	5.51 ± 2.16	-2.10 ± 3.02
	CT+CC	12.56 ± 0.31	5.54 ± 2.28	-1.83 ± 3.04
	CT+S	10.74 ± 2.15	4.47 ± 1.60	-2.16 ± 4.22
	CT+CC+S	11.61 ± 2.15	4.41 ± 1.93	-1.85 ± 4.34

Abbreviations: CT = convetional tilage; S = slurry application; CC = cover cropping.
Annual N balance was calculated as the sum of external inputs (e.g. slurry N), N gas losses (e.g. N_2O, NO, N_2), and other N losses (e.g. biomass N removed by harvest, NO_3-N leaching).

4 Conclusions

- Model evaluation shows that calibrated DayCent was able to reproduce the magnitude and variability in cumulative NO3-N leaching across all treatments and experiments satisfactorily.
- The regional predictions indicate that NO3-N leaching from organic cropping systems across Zurich and Bern cantons is 17 to 19% lower than NO3-N leaching from conventional systems.

5 Future modelling tasks

- To estimate regional NO_3 leaching patterns and their spatial uncertainty in conventional and organic cropping systems (with and without cover crops) for future climatic change scenario A1B;
- To explore the sensitivity of NO_3 leaching to changes in soil and climatic variables;
- To assess the NUE for conventional and organic cropping systems with and without cover crops under climate change.

Parton W.J. et al. 1998. DAYCENT: its land surface submodel: description and testing. Global and Planetary Change, 19: 35-48