Supplementary Materials

Table S1. Probability used for generating crop rotation for DayCent modelling (Lee et al., 2020a, 2020b). Values are probability of crops that will be planted (the 1st row) following the current crop (or crop sequence) (the 1st column). BR-sugar beet, BW-barley, CO-grain maize, CS-silage maize, GC-grass-clover mixture, OA-oat, PO-potato, PW-pea, RP-rapeseed, RY-rye, SB-soybean, SP-spelt, SU-sunflower, TR-triticale, WW-winter wheat. [a]Two years of grass-clover mixture in a roll. [b]Three years of grass-clover mixture in a roll. [c]Two years of grass-clover mixture followed by winter wheat.

|	BR	BW	CO	CS	GC	OA	PO	PW	RP	RY	SB	SP	SU	TR	WW
BR	0.08	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.50
BW	0.00	0.00	0.33	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80
CS	0.06	0.00	0.00	0.06	0.00	0.06	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.80
GC	0.00	0.00	0.00	0.00	1.00[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OA	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
PO	0.00	0.30	0.08	0.08	0.00	0.00	0.08	0.15	0.07	0.00	0.00	0.00	0.00	0.01	0.23
PW	0.00	0.50	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
RP	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
RY	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.50
SP	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
TR	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WW	0.22	0.04	0.15	0.11	0.04	0.00	0.15	0.07	0.07	0.00	0.11	0.00	0.04	0.00	0.00
GCGC	0.00	0.00	0.00	0.50[b]	0.50[c]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GCGCGC	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
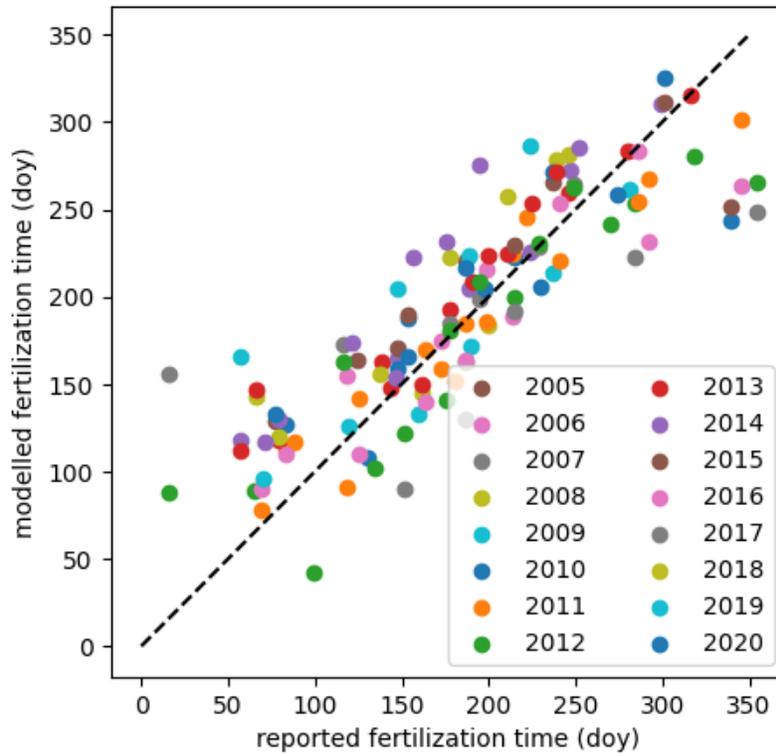
Figure. S1. Reported and modelled timing (day of the year) of fertilizer application of an intensively-managed grassland in Chamau, Switzerland between 2005 and 2020 (Feigenwinter et al., 2023a, 2023b).
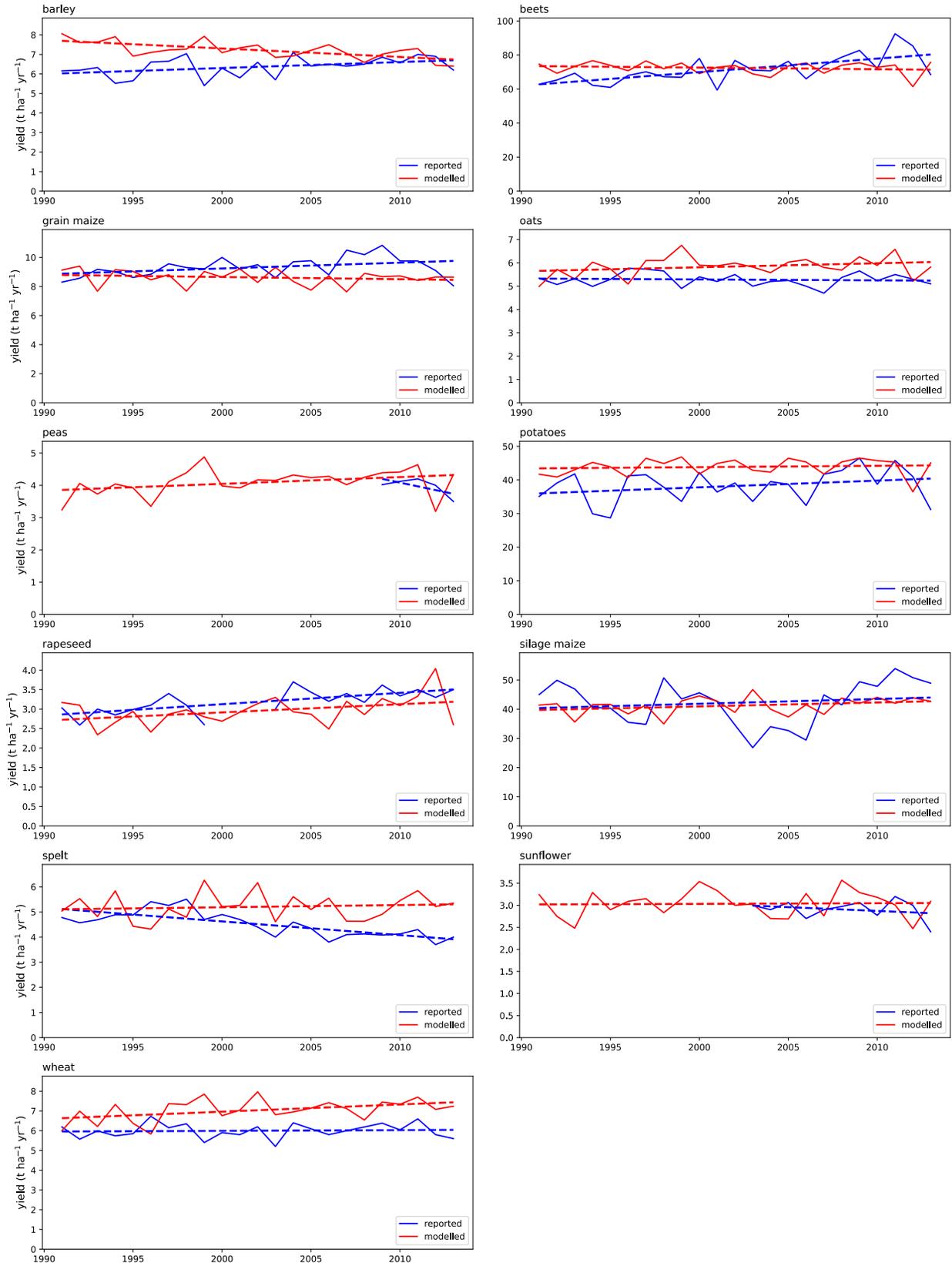
Figure. S2. Reported and modelled yields for 11 crops from 1991 to 2013 in Switzerland. All yields are

national mean expressed on a wet matter basis at harvest. The dashed black lines indicate fitted linear changes between 1991 and 2013.
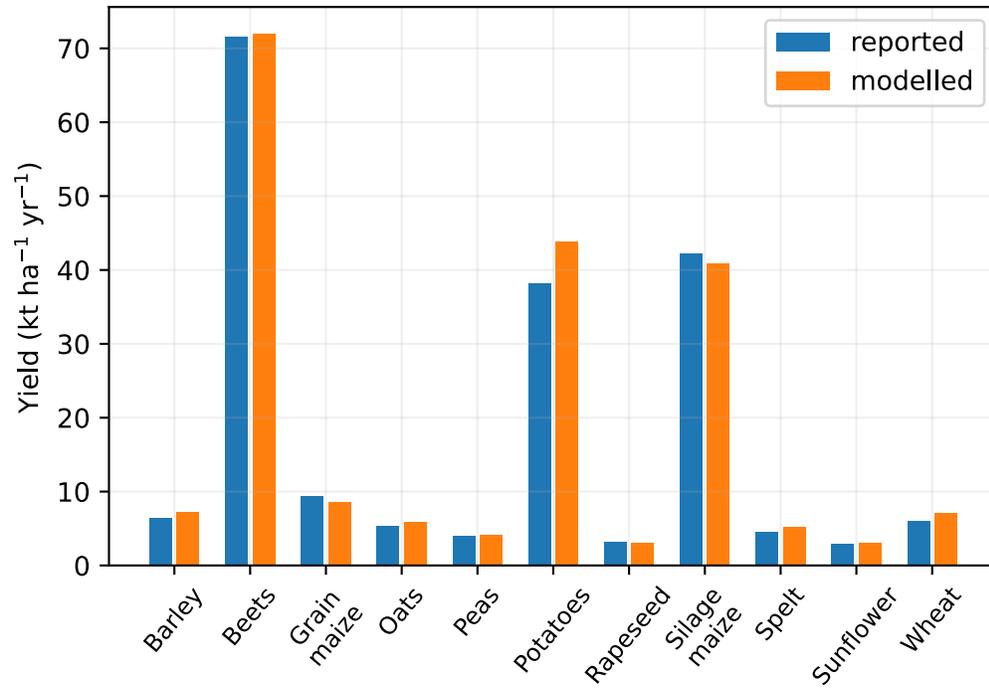
Figure. S3. Comparisons between modelled and reported yields for 11 crops from 1991 to 2013 in Switzerland. All yields are national mean expressed on a wet matter basis at harvest.
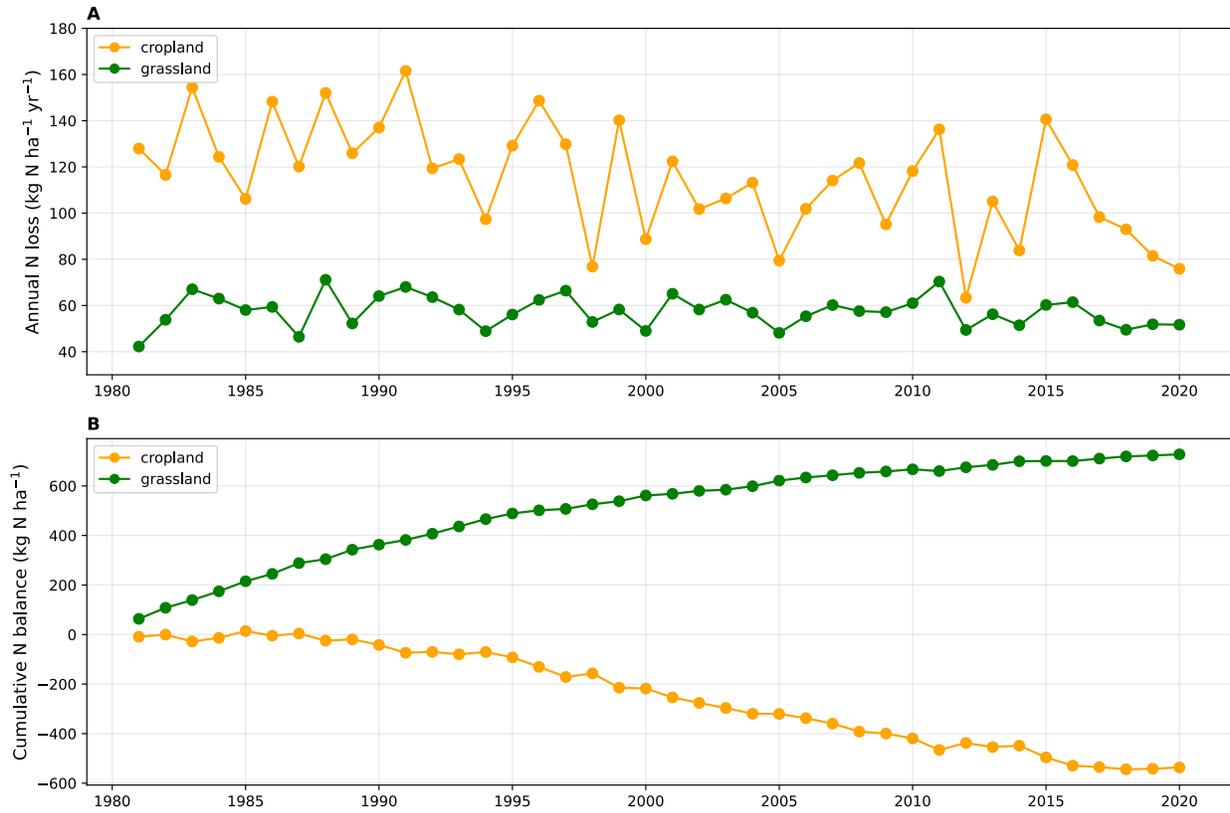
Fig. S4. Annual mean N losses and soil N change in Swiss agroecosystems from 1981-2020. (A) Annual mean N losses, including gaseous emissions and leaching. Note that y-axis starts from 40 kg N ha^{-1} yr^{-1}. **(B)** Cumulative changes of soil N balance. Positive values indicate N accumulation, and negative values indicate N depletion.
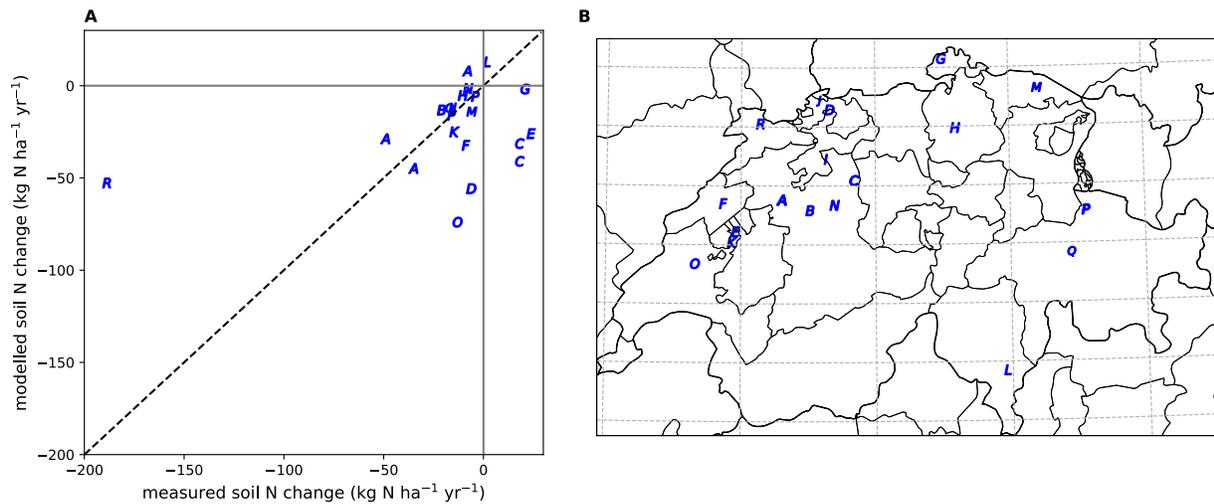
Figure. S5. (A) Comparisons between modelled and measured soil N change (kgN ha⁻¹ yr⁻¹) in croplands. **(B)** Locations of measuring sites. Measurements are from NABO long-term soil monitoring data. Multiple occurrences of the same symbol in panel a represent soil N changes in different time periods at the same location. There are 18 sites and 22 site-year measurements (n=22) chosen for comparison. DayCent simulations capture 77% of the trend (soil N depletion or soil N accumulation) correctly, with 50% modelled values within a factor of 2 (FAC=0.5) compared with measurements.
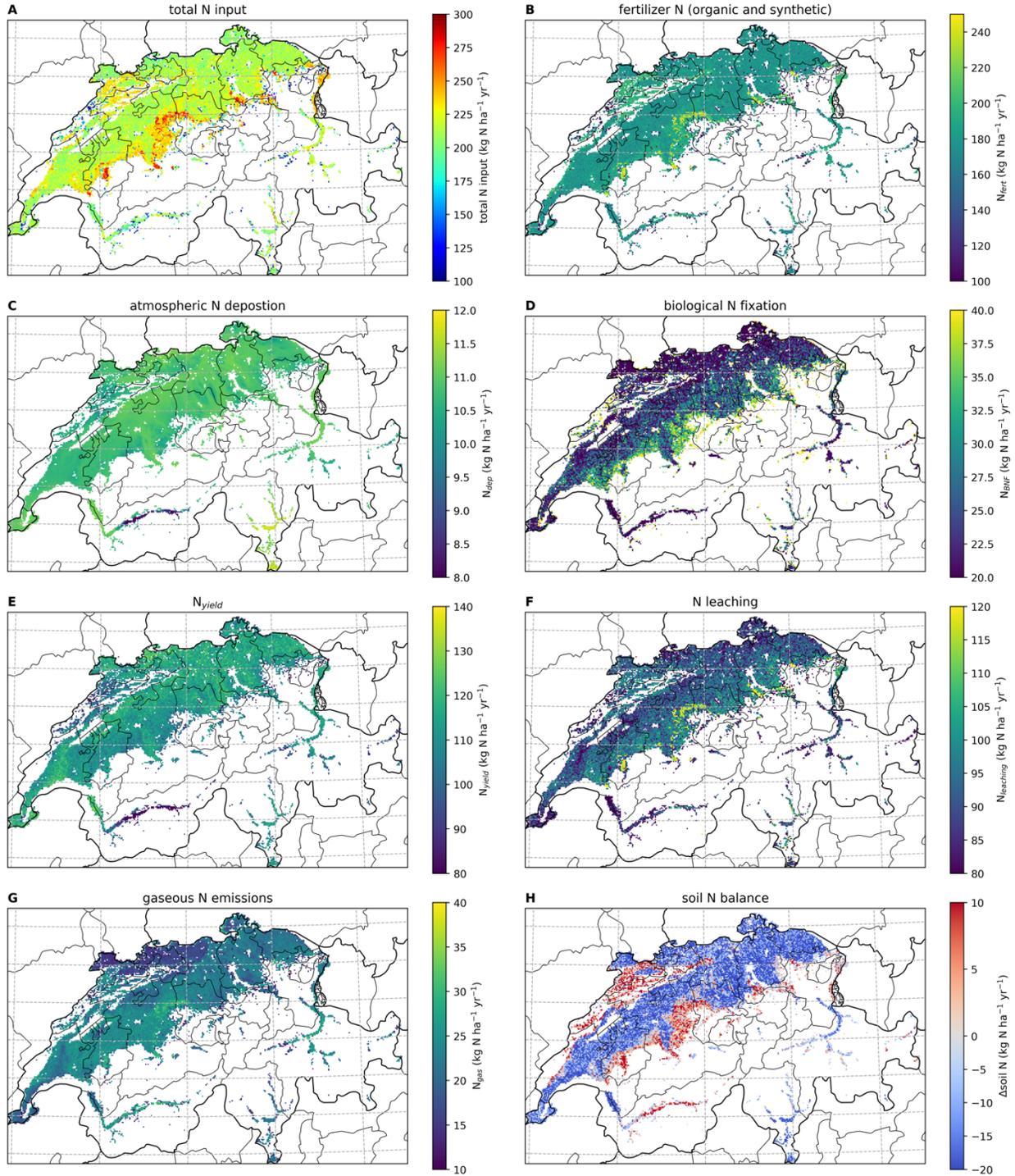
Figure. S6. Spatial maps of N budgets and soil N balance of Swiss croplands over 1981-2020. (A) total N input **(B)** fertilizer N including manure and synthetic fertilizers **(C)** atmospheric N deposition **(D)** BNF **(E)** NUE **(F)** N leaching **(G)** gaseous emissions **(H)** soil N balance. All variables have the unit kgN ha^{-1} yr^{-1} (note the difference in scales). See Fig. 4 in main text for maps shown budgets expressed in percentage.
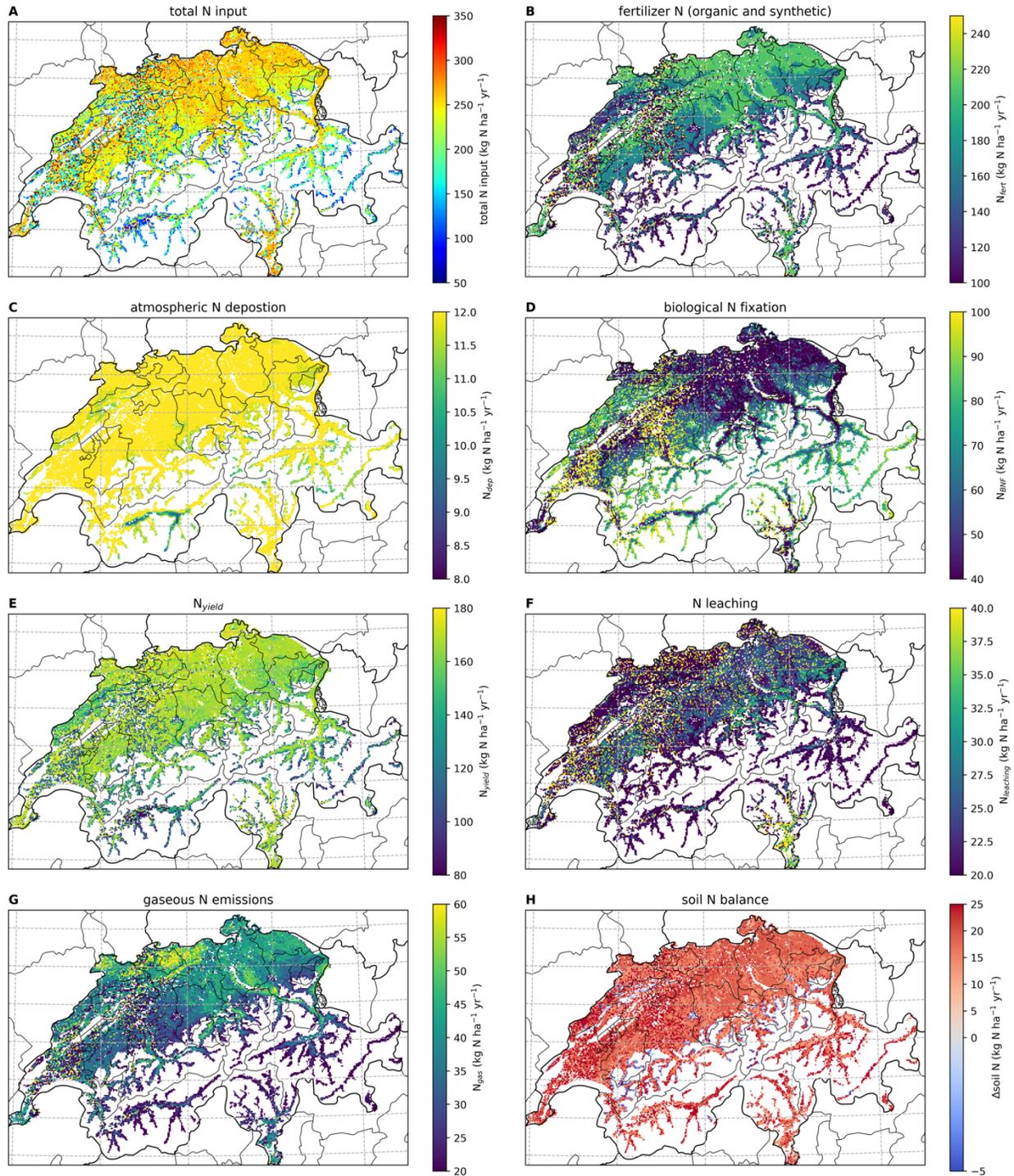
Figure. S7. Spatial maps of N budgets and soil N balance of Swiss grasslands over 1981-2020. (A) total N input **(B)** fertilizer N including manure and synthetic fertilizers **(C)** atmospheric N deposition **(D)** BNF **(E)** NUE **(F)** N leaching **(G)** gaseous emissions **(H)** soil N balance. All variables have the unit kgN ha^{-1} yr^{-1} (note the difference in scales). See Fig. 5 in main text for maps shown budgets expressed in

percentage. Grasslands refer to managed meadows only, while managed pastures and summer pastures for grazing are not included.

Reference

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