NutriBudget

Optimisation of nutrient budget in agriculture

D2.3 Publishing the first NutriModel

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Cover Delivery Report

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Reviewers	Salim Belyazid (SU) and Else Bünemann-König (FiBL)
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Preface

The NutriBudget project aims to help the agricultural sector towards a sustainable transition by developing and implementing a prototype of an integrated nutrient management platform. This platform includes a decision support tool (DST) that operates at field level to serve local stakeholders, and provides insights in nutrient (N, P, K, S, Mg, Ca, Cd, Zn) and carbon (C) budgets to serve regional, national and European stakeholders. The models (i.e., NutriModels) and datasets that are used to assess the nutrient budgets at field and regional scale are aligned, which stimulates the conversation on sustainable nutrient and carbon management options among stakeholders. The NutriModels will, in the end, be able to assess the effect of nutrient and carbon mitigation measures. The effect of measures will be pictured along five goals (e.g., soil quality, water quality, GHG emission, biodiversity, and agricultural production). In this way, users will get insight in the opportunities and trade-offs regarding the optimisation of agronomically and environmentally sustainable nutrient use in the area where they operate. This full picture can stimulate the implementation of measures as it helps making well-founded decisions at different scales.

The publication of this first NutriModel, i.e. MITERRA-Europe, includes (i) a model description on the assessment of soil carbon and nutrient budgets at regional level (NUTS2) for agricultural regions in Europe (EU-27, Switzerland, and the United Kingdom), (ii) the input data used to run MITERRA-Europe, and (iii) a description of the downscaling procedure. The results provide insight in the current soil nutrient and carbon state of agricultural soils in Europe. This will be used as a baseline to assess the distance to the desired state (WP2, T2.2) and the potential of bridging this distance when applying nutrient mitigation measures (WP2, T2.3). The results of MITERRA-Europe will become available on a webserver developed by WR. Users (e.g., policy makers and regional authorities) will retrieve the results through a Decision Support Tool on the NutriPlatform, which is currently being designed by WP5.

We greatly acknowledge all partners that contributed to the Nutribudget project and the development to the Nutrimodels, directly or indirectly: Ghent University (Belgium), Luke (Finland), Yara International (Norway), PWC (France), Arvalis (France), Beta Technology Center (Spain), Wageningen University & Research (the Netherlands), the Rural Investment Support for Europe Foundation (RICE), the Universita Degli Studi di Milano (Italy), Proman Management (Austria), Sveriges Landbruks-unversitet (Sweden), the Nutrient Management Institute (the Netherlands), Acqua & Sole (Italy), Impact (Belgium), Stockholms Universitet (Sweden) and the Forschungsinstitut fur Biologischen Landbouw Stiftung (Switzerland). Lastly we thank Salim Belyazid and Else Bünemann-Köning for reviewing this report.

Summary

The report is entitled ‘Publishing the first Nutrimodel’ and implies the publication of the MITERRA-Europe model. This deterministic nutrient (N, P, K, S, Mg, Ca, Cd, Cu, Zn) and carbon (C) flow model assesses soil nutrient and carbon budgets in European agriculture (EU-27, Switzerland, and the United Kingdom) at regional (NUTS2) level. Besides a detailed description of the model, this report describes the input data and parameters used to run MITERRA-Europe, results on the current soil nutrient and carbon state, and a methodology on downscaling some of the input parameters. The report is part of Work Package 2 (WP2) of the NutriBudget project, more specifically part of Task 2.1. This task aims to develop and implement measure-impact models for the nutrient management platform.

Insight into soil nutrient and carbon budgets is agronomically and environmentally important for a sustainable agricultural transition. **Chapter 1** provides a general introduction on how MITERRA-Europe contributes to the overall project goal. The publication of the current state of nutrient and carbon budgets in agricultural soils in Europe is an important baseline that helps assessing the distance to the desired state (WP2, T2.2) and the potential of bridging this distance when applying nutrient mitigation measures (WP2, T2.3).

A description of the required parameters and input data to run the regional-scale MITERRA-Europe model, and a summary description of the methodology used to calculate the nutrient and carbon flows is provided in **Chapter 2.** A full description of the model is available in Annex 5. The level of complexity depends on the data availability at the required level of detail (NUTS2) or the required context (e.g., land use type, crop category, livestock category).

In **Chapter 3** the results of MITERRA-Europe provide insights in the current soil nutrient and carbon state, by providing national soil nutrient and carbon balances (i.e., all inputs – all outputs), and spatial maps on the nutrients surpluses (i.e., all inputs minus crop uptake).

Some of the input parameters are used at NUTS2 level in the calculations, while the source data are available at finer resolution. Using a finer resolution before calculating the nutrient flows, the so-called ‘calculate-first, interpolate-later’ approach, is assumed to improve the calculations on P, cation, and heavy metal flows. Therefore, a downscaling procedure is proposed in **Chapter 4**.

The next steps to fulfil Task 2.1, and to connect to Taks 2.2, 2.3 and 2.4 within the NutriBudget project are described in **Chapter 5**.

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List of Abbreviations

BIO	Microbial biomass
C	Carbon
Ca	Calcium
Cd	Cadmium
CEC	Cation Exchange Capacity
CH_4	Methane
CO_2	Carbon dioxide
CORINE	Coordination of Information on the Environment
Cu	Copper
DPM	Decomposable plant material
DST	Decision Support Tool
GAINS	Greenhouse Gas - Air Pollution Interactions and Synergies
HUM	Humified organic matter
IOM	Inert organic Matter
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
LAI	leaf area index
Mg	Magnesium
N	Nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia
NO_x	Nitrogen oxide
P	Phosphorus
RPM	Resistant plant material
S	Sulphur
Zn	Zink

1. Introduction

To reach the goals regarding nutrient pollution reduction, climate change mitigation and food security in European agriculture, insights in the current soil nutrient and carbon state is needed. Based on these insights, the distance to target (i.e., desired state) and the potential of closing this distance by implementing most effective nutrient mitigation measures can be assessed. The Horizon Europe project NutriBudget was launched to help decision makers in their choice selecting sustainable agronomic and environmental nutrient management practices by developing and implementing a prototype of an integrated nutrient management platform as a decision-support tool (DST) for farmers, advisors, European policymakers and regional authorities.

This report (D2.3), the publication of the first NutriModel, provides all background information on the operational regional model MITERRA-Europe. The targeted stakeholders are policy makers and regional authorities, because the model assesses soil nutrient and carbon budgets at regional NUTS2 level for agricultural areas in Europe (EU-27, Switzerland and the United Kingdom). At the moment, the model provides results on the current soil nutrient and carbon budgets, but it is designed in such a way that it can assess the effect of measures and the distance to a target or threshold value in the near future (D2.5 and D2.6). The model results and the input data, that serve as default data for the NutriFarm model (D2.4), will be placed on a webserver. The results can be requested through a Decision Support Tool on the NutriPlatform. The model will not run on demand and the model is not publicly available, but requests for showing the calculated soil nutrient budgets for specific regions or nutrients can be made, just like the effect on the current and desired state, and the effect of roadmaps or measures through a DST that is built under WP5. The full description of the model is publicly available through the webpage: https://ssm-wenr.github.io/miterra-site, and updates on the model will be placed on the website: MITERRA-EUROPE - WUR.

From the results on the current soil nutrient and carbon budgets, we can identify areas with nutrient surpluses and deficits, and areas with soil carbon sequestration potential. The model also helps to test or evaluate the effect of nutrient and carbon management measures at regional scale. The latter links to the research carried out in the nutrient management mitigation measures catalogue (WP1), the key performance indicators (WP3), the case studies (WP4), and the Decision Support Tool (WP5) within the project, as well as to other tasks within WP2 (e.g., on the desired state and the effect of different roadmaps).

2. Description of regional model MITERRA-Europe

2.1 Parameters and input data

The MITERRA-Europe model V2.0 assesses soil nutrient (N, P, K, S, Mg, Ca, Cd, Cu, Zn) and carbon (C) flows at Nomenclature of territorial units for statistics 2 (NUTS 2) level (Eurostat, 2020) for all agricultural areas in Europe. The model, a deterministic carbon and nutrient flow model, was developed based on MITERRA-Europe v1.0 (Velthof et al., 2009; Lesschen et al., 2011) and INTEGRATOR (Reinds et al., 2012; De Vries et al., 2023). The agricultural coverage is assessed by CORINE Land Cover 2018 (Copernicus Land Monitoring Service, 2018). MITERRA-Europe focusses on three land use types: arable land (including the classes non-irrigated arable land, permanently irrigated land, rice field, and complex cultivation patterns of the CLC2018 map), grassland (including the classes pastures and land principally occupied by agriculture, with significant areas of natural vegetation), and perennial crops (including the classes vineyards, fruit trees and berry plantations, olive groves, and annual crops associated with permanent crops).

The temporal scale of MITERRA-Europe is annual, but some processes were calculated at monthly (e.g., C) or daily time scale (e.g., P), before aggregation to the annual scale.

The parameters which MITERRA-Europe require can roughly be divided into eleven categories. The sources that are being used per category are included in Annex 1 – Table 1A.

1. Soil properties. This category includes physical and chemical soil properties as well as categorical soil characteristics such as textural class or soil type. The physical and chemical soil properties were obtained from the European Land Use/Cover Area frame statistical Soil Survey (LUCAS) (Ballabio et al., 2019; Fernandez-Ugalde et al., 2022; Orgiazzi et al., 2018). The categorical soil characteristics were obtained from the European Soil Database (ESDB) (Panagos, 2006). The base cation weathering rate is a combination of the textural class and the acidity of the parent material and is assessed based on Reinds et al. (2001).
2. Livestock properties. This category includes the median livestock numbers between 2019 and 2021, and excretion rates per animal type. The livestock categories considered within MITERRA-Europe are included in Annex 1 - Table 1B. The livestock numbers come from Eurostat, except for fur animals. These data were not updated and are still based on GAINS. The excretion rates were obtained from Common Reporting Formats 2019-2021 (UNFCCC, 2025).
3. Crop areas. This category includes information on crop areas including grassland (i.e., rough grazings, permanent pastures and meadows) and 34 arable crops (Annex 1 – Table 1C). Temporary grassland is a fraction of the crop category ‘fodder other on arable land'. Data on crop area come from Eurostat, except for Germany for which Eurostat only has NUTS1 level data. Median crop areas for the period 2019-2021 were taken. For some crops (e.g., flowers), we had to rely on older data because there were no data available on the area between 2019 and 2021.
4. Crop yields. This category includes data on the yields of all crop and grass categories included in MITERRA-Europe. Depending on the available data, median (2019-2021) crop yields were provided at NUTS2 or NUTS0 level from Eurostat. For some countries only NUTS0 data were available for specific crops (e.g., fodder other on arable land), whereas other countries had data at NUTS2 level available. For these countries, the NUTS0 data were disaggregated to NUTS2 using the CORINE land cover map.

5. Fertilizer use and type. This category includes data on the national (NUTS0) amount of chemical fertilizer used expressed in nutrients and in fertilizer type. The total amount of nutrients available from the different fertilizers is redistributed over the crops within a NUTS2 region based on the crop nutrient requirements. The data were obtained from Food and Agriculture Organisation of the United Nations (FAOSTAT) and the International Fertilizer Association (IFASTAT). The fertilizer types included in MITERRA-Europe are listed in Annex 1– Table 1D.
6. Farm properties. This category includes information on e.g., farm size, farming system, crop rotation, land and residue management, nitrogen vulnerable zones, and derogation areas. The data mainly comes from EUROSTAT, the Farm System Survey of Eurostat, and the European Environmental Agency. Residue management was obtained from Smerald et al. (2023).
7. Emission factors. These data are used to assess the emissions from livestock (e.g., enteric fermentation, excretion, and fertilizer management) and soil. The factors were derived from IPCC (2019), EMEP-EEA guidebook (European Environmental Agency, 2023), and the national inventory reports on GHG emissions (UNFCCC, 2020).
8. Climate properties. This category includes monthly averaged data on evapotranspiration, temperature, and wind speed, and the monthly summed precipitation. Monthly averages over the climatic period 1990-2010 were taken from the ERA5 climatic database (Hersbach et al., 2023). Monthly effects of climatic properties on nutrient fluxes are aggregated to annual time steps after the calculations.
9. Water fluxes. The water flux data, including precipitation surplus, surface runoff and groundwater leaching fractions, were derived from Keuskamp et al. (2012).
10. Nutrient composition. Crop, fertilizer, and manure composition data are used to assess the nutrient input from fresh inputs. The composition data are derived from multiple sources and are attached in Annex 2 – Table 2A, 2B and 2C respectively.
11. Nutrient deposition. This category includes atmospheric deposition data of all nutrients. The data come from EMEP-EEA guidebook (European Environmental Agency, 2023) or from the previous version of MITERRA-Europe/INTEGRATOR.

The base year is set at 2020, although data are often based on de median of 2019-2021 to correct for extremes. For the United Kingdom (UK), no Eurostat data were collected after 2019. Within NutriBudget calculations for the UK are included, using data of 2018 and 2019. Therefore, the results can be slightly outdated.

2.2 Summary description of MITERRA-Europe

In Annex 5, a full description of the MITERRA-Europe model is given. The general structure of the model is visualized in Figure 1.

As described in D2.2, the regional model MITERRA-Europe builds upon the existing nutrient flow models MITERRA-Europe (Velthof et al., 2009) and INTEGRATOR (Reinds et al., 2012; De Vries et al., 2023). These models have been applied successfully in European studies (e.g., Duan et al., 2020; Lesschen et al., 2011; Velthof et al., 2014; Kros et al., 2018). The algorithms of INTEGRATOR (for P, K, S, Mg, Ca, Cl, Cu, Zn) based on De Vries et al. (2023) were integrated into MITERRA-Europe which assesses N and C flows based on Velthof et al. (2009) and Coleman and Jenkinson (2014). The model was further elaborated to improve NH_3 emissions from manure application using the semi-empirical ALFAM model (Hafner et al., 2019), and the model now also considers C and N interactions.

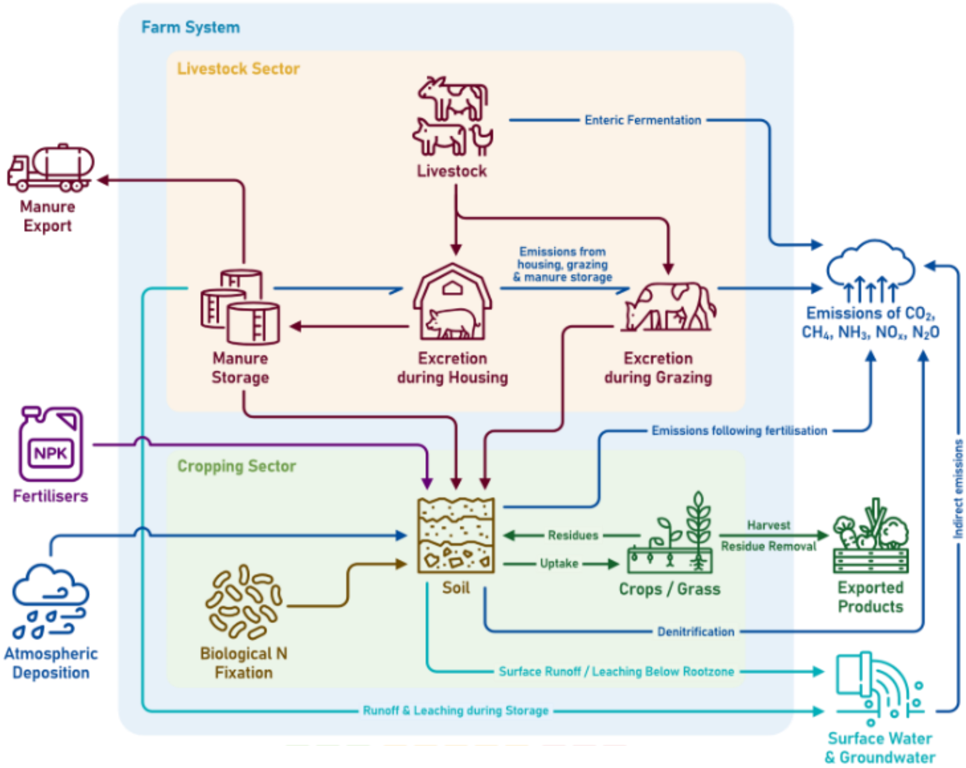


Figure 1. General structure of the model MITERRA-Europe. The model assesses C, N, P, S, K, Na, Ca, Mg, Cd, Cu and Zn fluxes.

A summary description of the carbon and nutrient modelling in the renewed MITERRA-Europe model are described below:

- Carbon: in mineral soils, the turnover of carbon (C) pools is calculated with the RothC model (Coleman and Jenkinson, 2014). This model requires relatively little input data, including soil, climate and farm activity data, which is available at European level and often also collected at farm level. Therefore, the model is implementable at different scales. The model distinguishes 5 carbon pools: decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO), humified organic matter (HUM) and inert organic matter (IOM). The model is linked to the mineralisation of organic N in a RothCN module. The current carbon inputs are used to distribute the initial soil organic carbon stock over the different pools.
- Nitrogen: the nitrogen fluxes are assessed using a steady state linear approach (Velthof et al., 2009). Emissions of ammonia and nitrous oxides and N surface runoff are included as a non-linear function of N input, and N leaching as a function of N surplus, while accounting for relevant site properties, including soil texture, soil organic matter content, ground water level and precipitation surplus. The soil organic nitrogen (SON) turnover is included by introducing C:N ratios to each RothC carbon pool.
- Phosphorus: the phosphorus in soil and soil solution is assessed by the Langmuir adsorption model supplemented with a rate limited diffusion based on De Vries et al. (2023). Phosphorus is partly in equilibrium and partly not, and therefore initialisation is required. The input data of 2020 (i.e., the base year) is used to run the model for 10 years using the same input data for each year. The calculated P balance in year 10 is taken as the initial starting point to run the model.

- Sulphur: sulphur in soil and soil solution is assessed by an extended Freundlich equation, where extended refers to the inclusion of pH impacts on the adsorption constant (Gustafsson et al., 2015). The amount of $S_{adsorbed}$ is set in equilibrium with S inputs and outputs in 2020 for the initialisation. Note that this implies that we assume that there is no S adsorption at the starting year.
- K, Mg, Ca: the sum of these base cations (BC) is included by a charge balance relationship where BC release is derived by equating BC leaching to anion leaching (where anions include NO_3, SO_4, Cl and HCO_3) and accounting for BC input and BC uptake to get BC release according to De Vries et al. (2023). The change in pH-H_2O is then derived by a simple literature-based pH-base saturation relationship. Finally, the division in Ca, Mg and K is based on the fractions of Ca, Mg and K on the exchange complex. These nutrients do not require initialisation, because it is a well buffered system. A change in base cations results in a change in pH that is affected by the Cation Exchange Capacity (CEC).
- Cu, Cd, and Zn: for these heavy metals a Freundlich equation is used with an adsorption constant that depends on clay, SOM and pH (De Vries et al., 2022; De Vries et al., 2023). These nutrients do not require initialisation, because accumulation or release is based on the input minus the crop uptake and leaching. The initial soil Cu, Cd and Zn content is determined by: (i) the dissolved concentrations in solution and thereby the leaching, and (ii) the concentrations in the crop and thereby the crop uptake. Crop uptake depends on the soil conditions for Cd and Zn, but for Cu it depends on a bio-concentration factor because Cu uptake is independent of soil concentration.

2.3 Assessing current soil nutrient and carbon budgets

The carbon and nutrient inputs and outputs are described in Table 1. The annual balances were assessed at national level by subtracting all outputs from all inputs. A negative balance indicates nutrient mining, whereas a positive balance indicates nutrient accumulation in the soil. The carbon balance indicates the SOC stock change under current management. Carbon inputs to the soil are: manure, grazing manure, compost, sludge and crop residues (including roots), whereas the CO_2 is released through mineralization. Dissolved organic carbon is not included as output. Inputs of the other nutrients are: mineral fertilizer, manure, grazing excretion, atmospheric deposition, compost/sludge (in the case of N and P), bio-fixation (only for N), and liming (in the case of K, Ca^{2+} and Mg^{2+}) and outputs are: crop harvest, residue removal, leaching, surface runoff (in the case of N) or subsurface runoff (in the case of other nutrients), and atmospheric emissions (for NH_3, N_2O, NO_x). Besides balances, spatial soil nutrient surpluses or deficits were assessed at NUTS2 level for European agricultural soils by subtracting the crop uptake from the inputs.

Table 1. The soil nutrient and carbon inputs and outputs considered by the MITERRA-Europe model to assess the balances (inputs minus outputs) and surpluses (inputs minus crop harvest).

		C	**N**	**P**	**K**	**S**	**Ca^{2+}, Mg^{2+}**	**Cu, Zn, Cd**
Inputs	Mineral fertilizer		X	X	X	X	X	X
	Manure	X	X	X	X	X	X	X
	Grazing manure	X	X	X	X	X	X	X
	Crop residues	X						
	Compost/sludge	X	X	X				
	Bio-fixation		X					
	Deposition		X	X	X	X	X	X
	Liming				X		X	
Outputs	CO2 emissions	X						
	Crop harvest		X	X	X	X	X	X
	Residue removal		X	X	X	X	X	X
	Leaching		X	X	X	X	X	X
	(sub)surface runoff		X	X	X	X	X	X
	NH_3 emissions		X					
	N_2O and NO_x emissions		X					

3. Soil nutrient and carbon budgets

The results of soil carbon and nitrogen balances are provided in Figure 2. For all countries, the carbon balance is on average slightly positive or negative. Highest carbon inputs take place in Ireland and the Netherlands, where the emissions are also highest. In Annex 3 the soil carbon balance per land use type (grassland, arable land and perennials) is provided as well, which illustrates that arable land has more negative balances compared to grassland.

The nitrogen (N) inputs are highest in animal dense countries such as Belgium and the Netherlands, but crop uptake is also highest in these countries. Ireland also shows a high crop uptake, but slightly lower N inputs, which results in a neutral N balance. Livestock dense countries show highest leaching to groundwater, surface runoff, and NH_3, N_2O or NO_x emissions to the atmosphere.

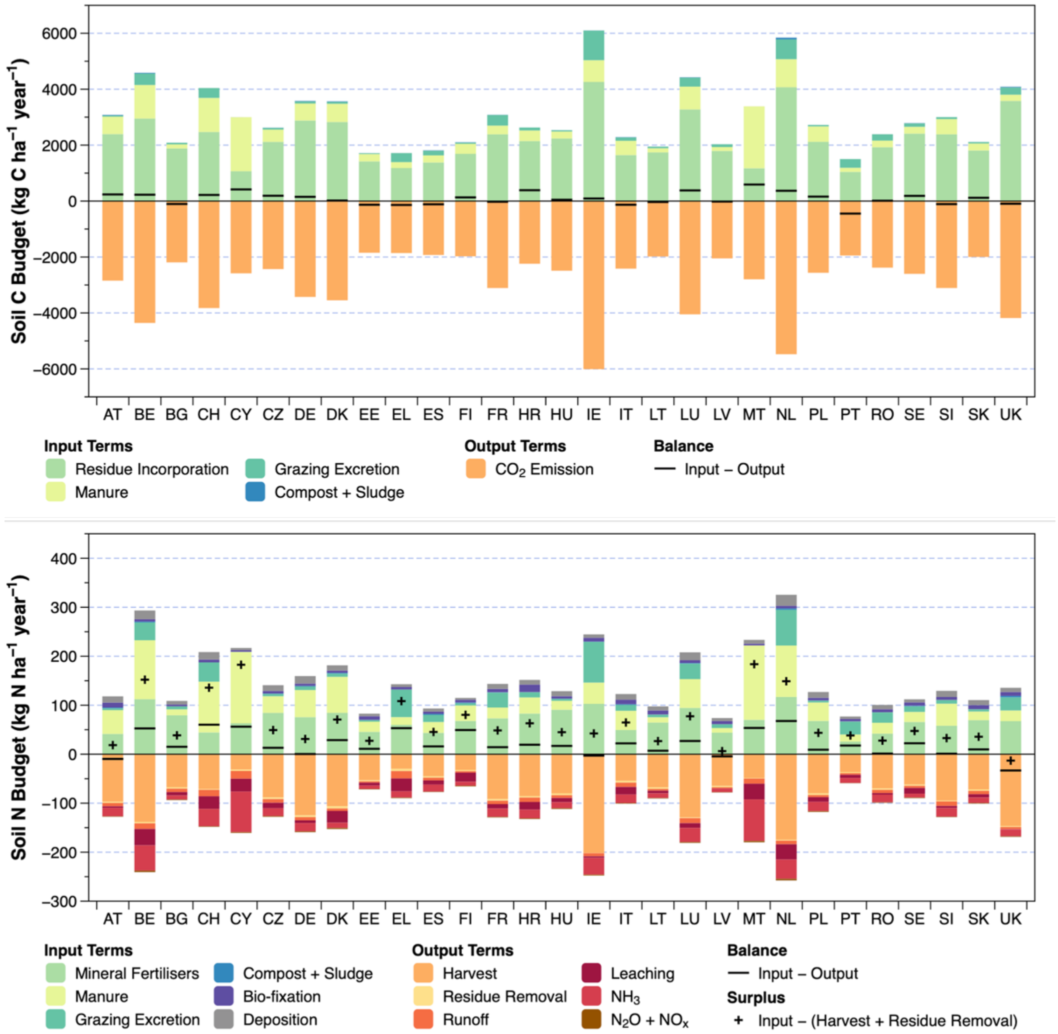


Figure 2. National soil carbon (C) and nitrogen (N) balances for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex .

The phosphorus (P) inputs are highest in livestock dense countries such as Belgium, Ireland and the Netherlands (Figure 3). The high P inputs in Malta and Cyprus are caused by the high livestock density (Eurostat data). The manure surplus is applied to arable crops, as outdoor grazing does not take place (according to the National Inventory Reporting). The correctness of these values can, for example, be verified during the next co-creation workshop. Highest losses of P to the environment occur in the Netherlands. These results are in line with e.g., Duan et al. (2020). In general, we can conclude that N and P balances in (almost) all European countries are positive.

Looking at the K balance (Figure 3), there are countries with negative balances (e.g., Germany, Czech Republic, Denmark and the United Kingdom), but also countries with positive balances. The countries with positive balances are, again, the livestock dense countries (Belgium, Netherlands, Ireland, and Switzerland).

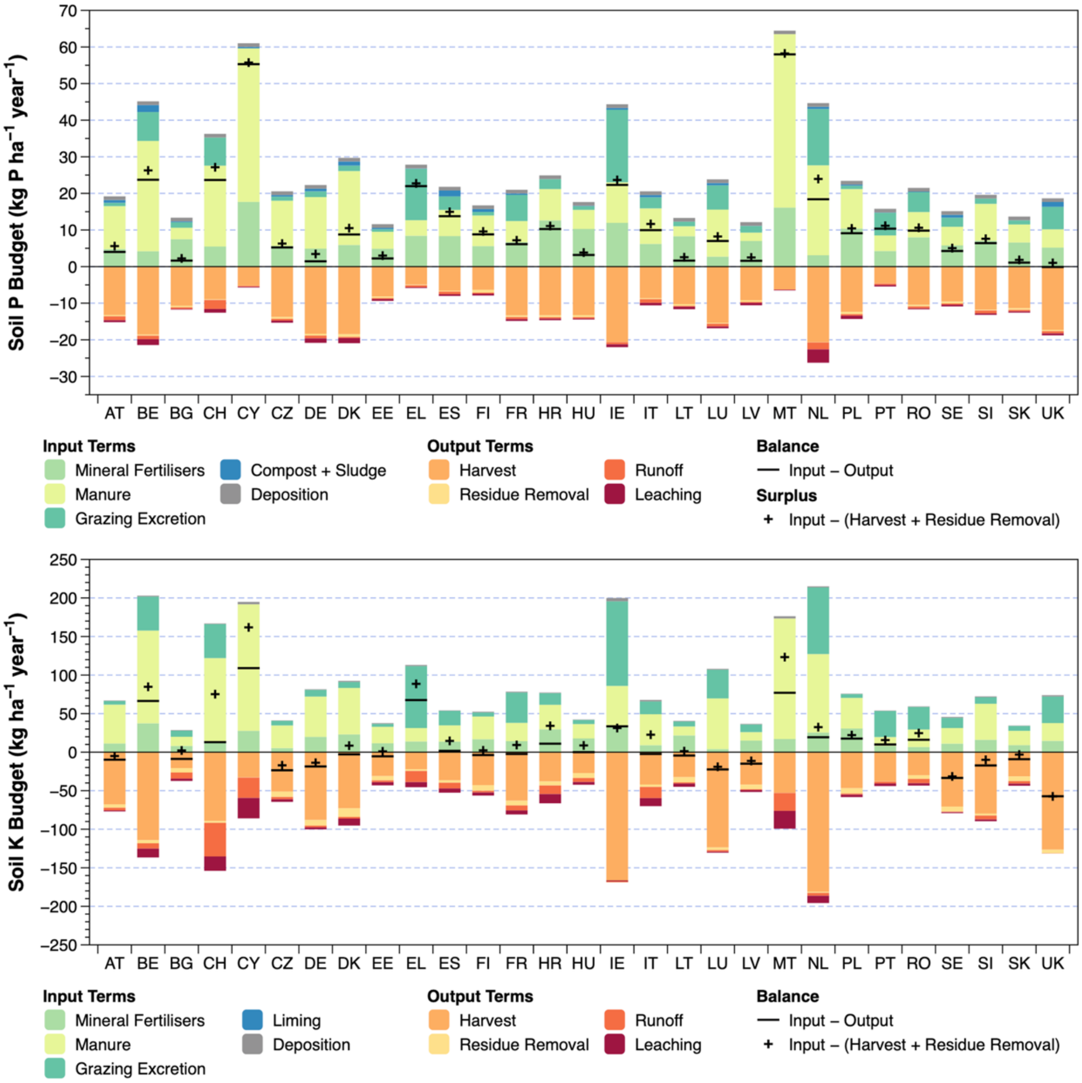


Figure 3. National phosphorus (P) and potassium (K) balances for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex 4.

Subsurface runoff and leaching of sulphur (S) and magnesium (Mg^{2+}) can be a significant loss in some countries (e.g., Switzerland, Greece, Malta and Cyprus) (Figure 4). This can either be caused by a high runoff/leaching fraction (in the case of Switzerland), or a relatively high base saturation (in the case of the Mediterranean countries). In the Netherlands and Belgium, the S inputs but also the S uptake is high, which results in a neutral balance for S. The Mg subsurface runoff and leaching in these countries is only limited, which results in positive Mg balances. Ireland shows an extremely high deposition rate caused by one Mg deposition observation in one of the NUTS regions. This deposition rate was clearly influenced by the so-called ‘sea-salt-effect' causing an extremely high Mg deposition.

Subsurface runoff and leaching of calcium are highest in Italy and Greece, probably caused by the parent material, resulting in the most negative balances in these countries (Figure 4). Liming occurs in some other countries (e.g., Germany, Belgium, Denmark, Ireland, and the United Kingdom) and therefore these countries show positive Ca^{2+} balances.

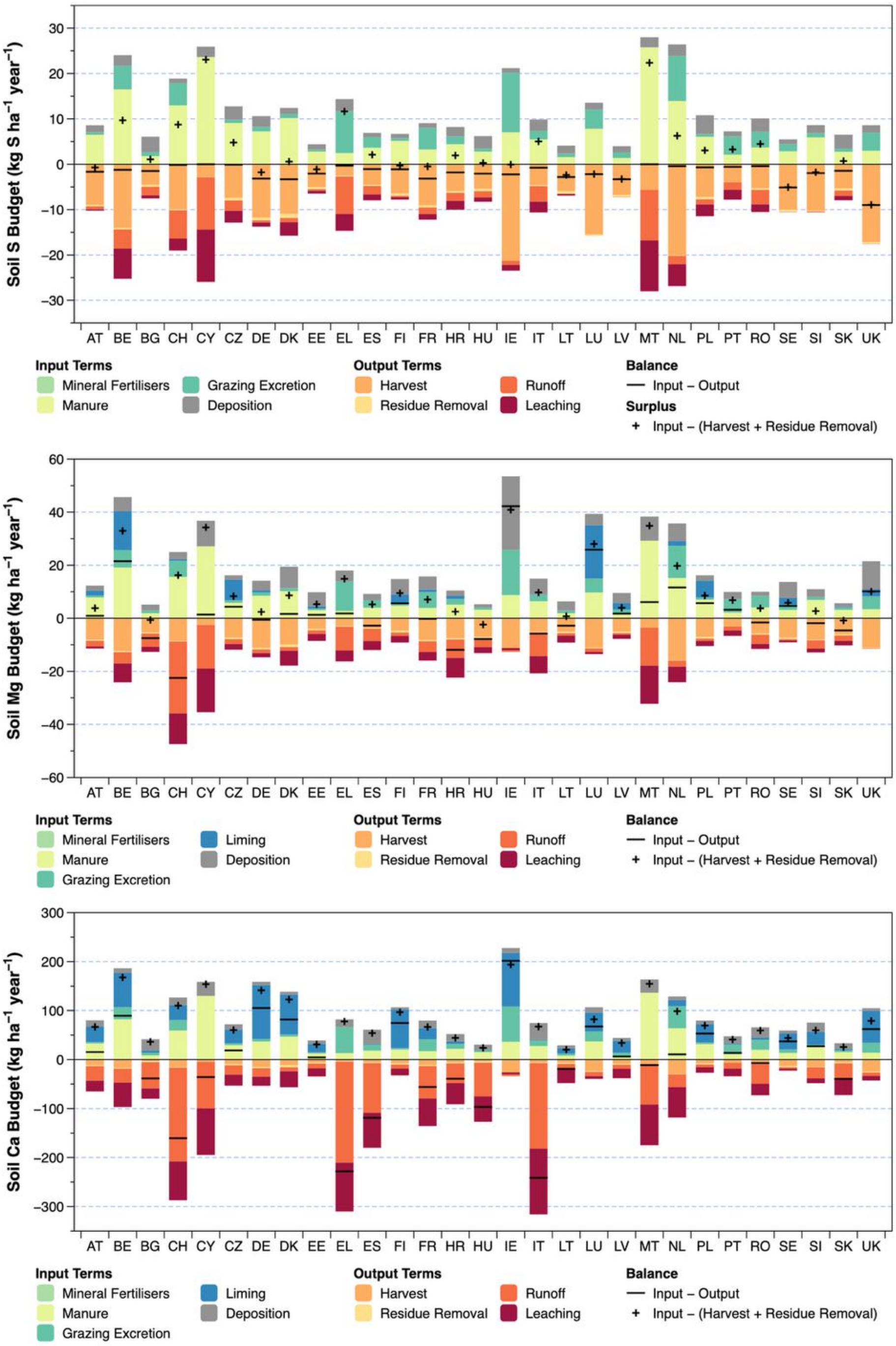


Figure 4. National soil sulphate (S), Magnesium (Mg^{2}+) and calcium (Ca^{2+}) balances for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex 4.

Copper (Cu) inputs are mainly caused by high Cu values in the manure caused by feed supplements (Figure 5). Naturally, copper also occurs in the parent material and cause, for example, high runoff and leaching values in parts of Italy and Switzerland. Cadmium inputs are limited, but the uptake can be significant in Ireland, Belgium and the Netherlands for example. Zink also accumulates in most European agricultural soils because of manure application. In Ireland the uptake of Zn is higher compared to other countries. This can be caused by the relatively high Zn content (45-57 mg/kg) in the soil and the feed supplements that cause high Cu values in the manure.

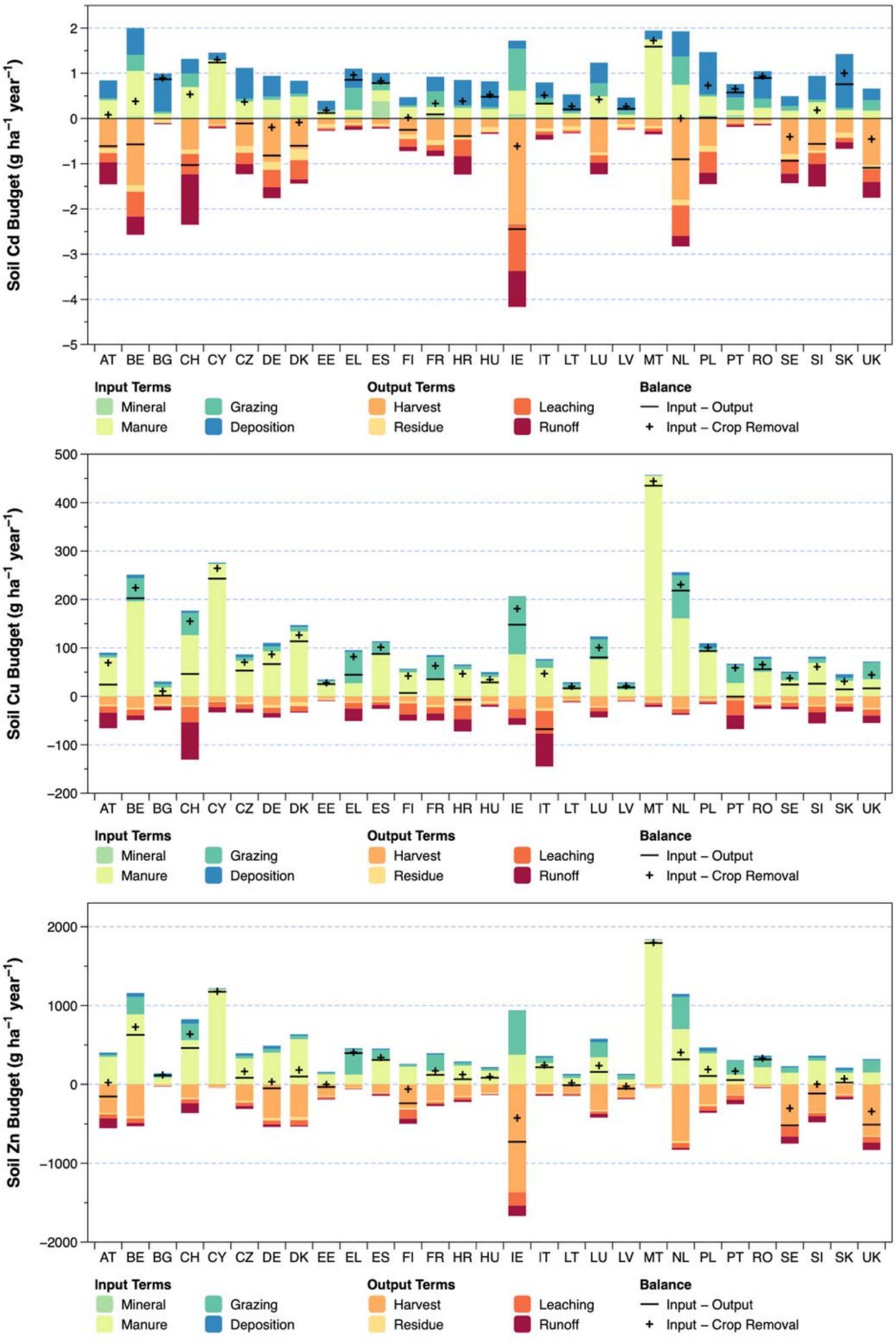


Figure 5. National cadmium (Cd), copper (Cu) and zinc (Zn) balances for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex 4.

Besides soil carbon and nutrient balances, it is interesting to indicate areas where soil nutrient surpluses or deficits occur (Figure 6, 7 and 8). A surplus or deficit indicates the imbalance between nutrient inputs and crop uptake, and can cause environmental losses. The spatial distribution of soil nutrient surpluses is provided in Figure 3.

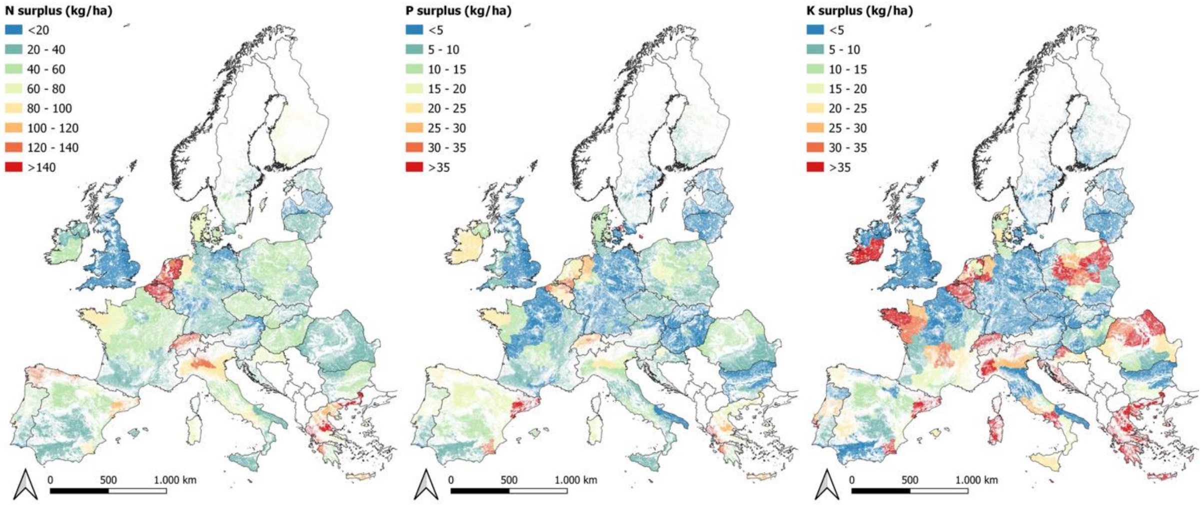


Figure 6. Nitrogen (N), phosphorus (P) and potassium (K) surplus for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex 4.

Livestock dense regions like northwestern Europe, the Po-region in Italy, Catalunya in Spain and Britanny in France, show high N and P surpluses. In some regions in Eastern Europe and the Mediterranean, high K and S inputs are caused by the application of mineral fertilizer. The high Mg surplus in Ireland, caused by Mg deposition from the sea, is also visible in Figure 7. Calcium surpluses mainly occur in Ireland, Germany, Denmark and Belgium.

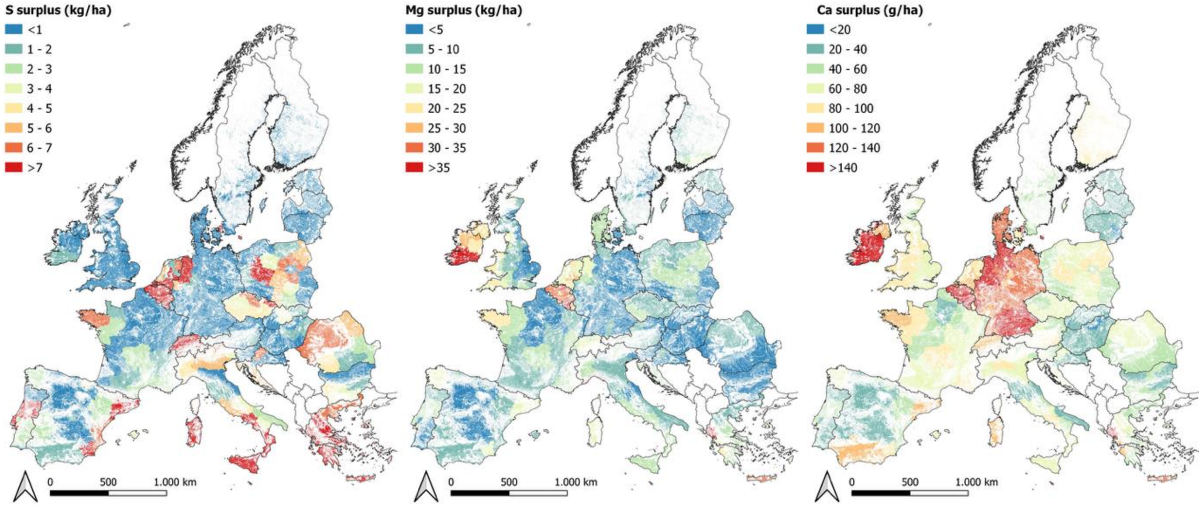


Figure 7. Sulphate (S), Magnesium (Mg^2+) and calcium (Ca^{2+}) surplus for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex 4.

Copper and zinc surplus is strongly linked to the livestock dense region (Figure 8), because high Cu concentrations can occur in the manure caused by the supplements fed to livestock. A Cd deficit mainly occurs in the Mediterranean region.

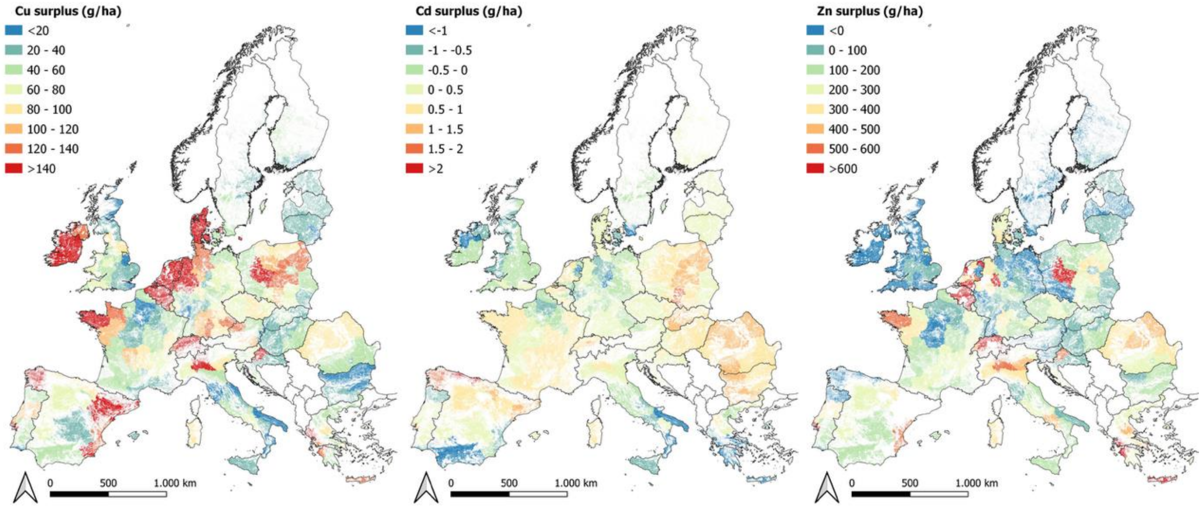


Figure 8. Cadmium (Cd), copper (Cu) and zinc (Zn) surplus for EU-27, Switzerland and the United Kingdom. The country codes are described in Annex 4.

Soil organic carbon (SOC) stock and balance maps are provided in Figure 9. A negative SOC balance illustrates a decline in SOC stock, whereas a positive balance shows carbon sequestration. Although this is land use dependent (Annex 3), we see that especially Portugal and some parts of Italy, the UK and France show quite negative carbon balances.

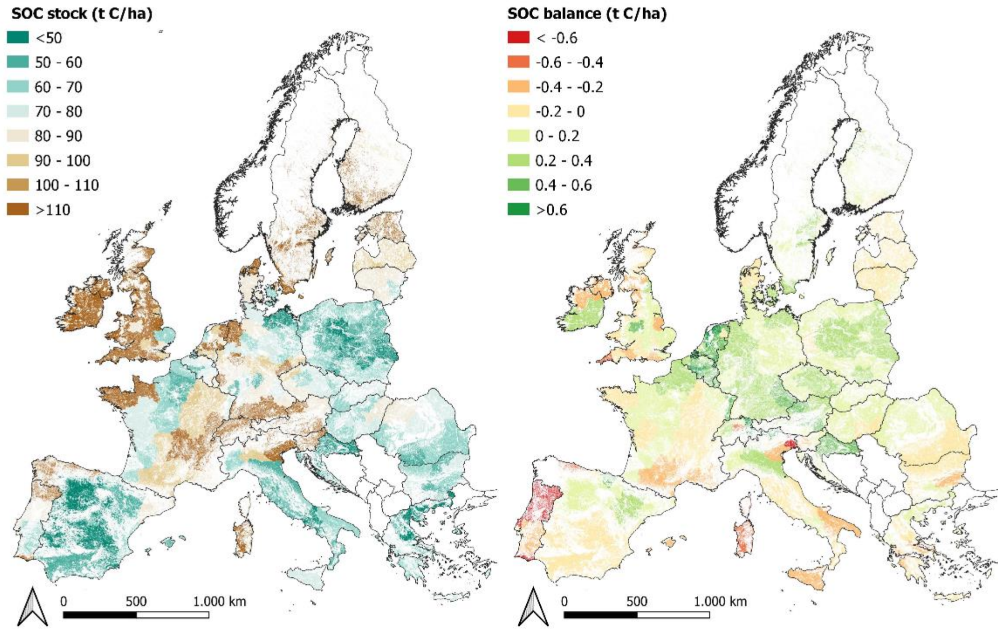


Figure 9. Soil organic carbon (SOC) stock and balance maps (in t C/ha).

4. Downscaling procedure

The MITERRA-Europe model runs at the moment on NUTS 2 level as important activity data such as livestock numbers, crop areas and crop yields are not available yet at a more detailed level. Spatial data are typically aggregated to this resolution based on land use type (arable, grassland, perennial), animal type, or crop type. There is evidence that calculating the nutrient flows first, and aggregating these later, increases the accuracy of the calculations (Heuvelink and Pebesma, 1999). This approach is called the 'calculate first, interpolate later' approach (CFIL). This applies specifically to nutrient calculations that involve soil properties. Besides, the spatial soil data are also used as default data to run the NutriFarm model.

This disaggregation will affect especially phosphorus, base cations and heavy metals, and therefore the spatial data that influence these nutrient flows were selected (Table 2). Phosphorus budget in the soil is influenced by the soil P content, soil bulk density, the atmospheric P deposition and the texture class. Sulphur is influenced by pH and atmospheric deposition, whereas K, Mg and Ca flows depend on the CEC, weathering rate, temperature, bulk density, pH and atmospheric deposition. Metals depend on pH-H_2O, soil organic matter content, clay, and Cd and Zn concentration in the soil. Based on the spatial resolution and spatial availability of the data (point versus grid), the following parameters were selected to replace current NUTS2 input data: pH-H_2O, clay, and Zn and Cd content in the soil. The soil organic carbon content would also be of influence, and therefore good to include as well, but the LUCAS soil dataset has only point observations available, and other SOC maps do not consider the SOC content under different land use (grassland, arable land and perennial land) separately, while this can be of significant influence (Lesschen et al., 2021). So we need to explore whether SOC has a comparable CEC, clay and pH based on widely used pedotransfer functions, before we can implement this parameters in the CFIL-approach.

Table 2. Parameters in MITERRA-Europe that influence P, base cations and heavy metal flows. Besides, the unit and spatial resolution at which the source data is available, and the reasoning why (not) to select the parameter for the calculate-first-interpolate-later (CFIL) approach.

Parameter	**Unit**	**Spatial resolution**	**Source**	**Selected for the CFIL-approach**
Al and Fe oxalate	g/kg		Fernandez-Ugalde et al., 2018.	No, only point observations available from LUCAS 2009 soil survey (often < 10 observations per NUTS2 region)
Bulk density	g/cm3		Ballabio et al., 2016	No, only point observations available from LUCAS 2009 soil survey (around 20,000 points)
P deposition	kg/m2	0.5º x 0.5º	Mahowald et al (2008)	No, map shows inconsistency. At the moment assumed to be 1 kg/ha.
Texture	(-)		Ballabio et al., 2016	No, only point observations available from LUCAS 2009 soil survey (around 20,000 points)
pH-H_2O	(-)	500m	Ballabio et al., 2016	Yes, a map was developed based on the point observations available from LUCAS 2009 soil survey (around 20,000 points)

S, K, Mg, Ca deposition	kg/ha	0.1º x 0.1º	Simpson et al., 2003	No, data has too low resolution to disaggregate.
CEC	cmol/kg	500m	Fernandez-Ugalde et al., 2018.	No, because weathering rate is influencing the current base cation flows, not CEC. The weathering rate depends on soil texture and parent material.
Clay	%	500m	Fernandez-Ugalde et al., 2018.	Yes, a map was developed based on the point observations available from LUCAS 2009 soil survey (around 20,000 points)
SOC	%		Fernandez-Ugalde et al., 2018.	Maybe, because only point observations available. Test whether SOC has a comparable CEC, clay and pH based on widely used pedotransfer function.
Base cation deposition	kg/ha	50x50km	Van Loon et al., 2005	No, data has too low resolution to disaggregate.
Zn soil	mg/kg	250m	Fernandez-Ugalde et al., 2022	Yes, the map of Fernandez-Ugalde et al. (2022) can be used.
Cd soil	mg/kg	raster based on points, sampling density 1 site/2500 sq. km	Fernandez-Ugalde et al., 2022	Yes, the map of Fernandez-Ugalde et al. (2022) can be used.
Weathering rate			De Vries et al., 1991	No, these rates are already assessed based on a combination of parent material and texture class.
Precipiation	mm	0.5x0.5	Hersbach et al., 2023	No, data has too low resolution to disaggregate.
Temperature	°C	0.5x0.5	Hersbach et al., 2023	No, data has too low resolution to disaggregate.
Evapotranspiration	mm	0.5x0.5	Hersbach et al., 2023	No, data has too low resolution to disaggregate.

To implement the CFIL approach, the selected spatial data will be resampled to a 5x5km resolution. This resampling is required, because values are assessed based on land use type (grassland, arable land or perennial), and NUTS2 region, which results in an exponential increase in the number of combinations. The 5x5km resolution makes the run-time of the MITERRA-Europe model still within boundaries. Besides, the LUCAS soil property maps are based on a limited number of observations, and the 1:250.000 soil map is used as one of the explanatory variables. Soil maps do not always improve at finer resolution (Hendriks et al., 2016).

Each parameter (pH, clay, and concentration of Cd and Zn in the soil) gets a unique value for arable, grassland, and perennial land based on an overlay with the Corine land use map on a 1x1km resolution. The average value at 5x5km resolution will be extracted per land use type. Each grid cell is connected to a NUTS2 region. If a grid is located in two NUTS2 regions, the region where the centroid of the grid cell falls in is chosen. The file containing the information on grid level and the related NUTS2 region will be used as an input to the model. After calculating the processes influenced by the replaced parameters (Tale 3), the results will be aggregated to NUTS2 level.

Table 3. The downscaled parameters and the processes they influence.

Downscaled parameter	**Soil processes influenced**
Soil pH	S: adsorption/desorption dynamics Heavy metal: adsorption/desorption ratio Cation: base saturation
Clay	P: Langmuir adsorption constant and the rate constant for the transfer from the stable pool to soil solution Heavy metal: adsorption/desorption ratio Soil organic C decomposition rate
Zn soil	Heavy metal: adsorption/desorption ratio
Cd soil	Heavy metal: adsorption/desorption ratio
SOM/SOC*	Heavy metal: adsorption/desorption ratio

*The downscaling of the soil organic carbon (SOC) content depends the test where SOC values at point level are compared to the results of a pedotransfer function (depending on CEC, clay and pH).

The effect of using a calculate first, interpolate later (CFIL) approach on P, base cations and heavy metal flows will be compared. There is assumed that the CFIL approach is more accurate compared to the initial approach as validation data is lacking. Because this approach does not influence all nutrients, and it costs significant amounts of calculation time, it will be implemented in the MITERRA-Europe model as an optional element that can be switched on and off.

5. Next steps

The output on the current soil nutrient and carbon budgets of the MITERRA-Europe model will be used as a baseline to assess the distance to a targeted or desired situation in terms of soil nutrient budgets (D2.5, as part of T2.2) and to assess how nutrient mitigation measures can close the distance between the current and desired situation in different roadmaps (D2.6, as part of T2.3).

A quality performance of the model was not included in this deliverable, but this will be covered in D2.7 (as part of T2.4). The model will keep on developing over the whole project period (e.g., the implementation of the CFIL approach), and therefore updates of the model will also be provided in D2.7.

Besides these model developments, the results of MITERRA-Europe will become available on a webserver and specific requests on the current and desired state or the effect of measures/roadmaps can be done through a DST on the NutriPlatform (WP5).

Annexes

Annex 1. Parameters and input data of MITERRA-Europe

Table 1A. Input data of MITERRA-Europe

Category	Parameter	Datasets	Source
Soil properties	Soil pH, CEC, availability of CaCO3, NPK content	Soil Chemical properties at European scale based on LUCAS 2009/2012 topsoil data	Ballabio, C., Lugato, E., Fernández-Ugalde, O., Orgiazzi, A., Jones, A., Borrelli, P., Montanarella, L. and Panagos, P., 2019. Mapping LUCAS topsoil chemical properties at European scale using Gaussian process regression. Geoderma, 355: 113912.
Soil properties	Soil organic carbon (SOC) content	LUCAS 2018 TOPSOIL data	Fernandez-Ugalde, O; Scarpa, S; Orgiazzi, A.; Panagos, P.; Van Liedekerke, M; Marechal A. & Jones, A. LUCAS 2018 Soil Module. Presentation of dataset and results, EUR 31144 EN, Publications Office of the European Union, Luxembourg. 2022, ISBN 978-92-76-54832-4, doi:10.2760/215013, JRC129926. Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A., Fernández-Ugalde, O. 2018. LUCAS Soil, the largest expandable soil dataset for Europe: A review. European Journal of Soil Science, 69(1): 140-153. https://doi.org/10.1111/ejss.12499.
Soil properties	Soil texture, coarse fractions, bulk density, rooting depth	Topsoil physical properties for Europe (based on LUCAS topsoil data)	Ballabio C., Panagos P., Montanarella L. Mapping topsoil physical properties at European scale using the LUCAS database (2016) Geoderma, 261 , pp. 110-123.
Soil properties	Soil type ('WRB-LEV1'), soil texture class ('TEXT-SRF-DOM'), soil depth to rock ('DR'), rooting depth ('ROO'), soil erosion, organic carbon class ('OC_TOP'), parent material ('PAR-MAT-DOM'). Base cation weathering	ESDB v2.0 and soil erosion maps (JRC)	The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004. Panagos Panos. The European soil database (2006) GEO: connexion, 5 (7), pp. 32-33. Reinds, G. J., Posch, M., & de Vries, W. (2001). *A semi-empirical dynamic soil acidification model for use in spatially explicit integrated assessment models for Europe*. (Alterra-rapport; No. 84). Alterra. https://edepot.wur.nl/33685
Soil properties	Slope	EU-DEM	European Environmental Agency, 2024. European Digital Elevation Model (EU-DEM). DOI: https://ec.europa.eu/eurostat/web/gisco/geodata/digital-elevation-model/eu-dem#Slope (Accessed on 01-08-2024).
Soil properties	C-factor, erosion	USLE model	Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E., Montanarella, L., 2015. Estimating the soil erosion cover-management factor at European scale. Land Use policy journal. 48C, 38-50.
Livestock properties	livestock units, animal numbers	Eurostat	Animal populations by Nuts 2 region. https://ec.europa.eu/eurostat/databrowser/view/agr_r_animal__custom_12229743/default/table?lang=en Poultry types by utilized agricultural area, size classes of livestock and NUTS 2 region.

			https://ec.europa.eu/eurostat/databrowser/view/ef_lsk_poultry__custom_12234613/default/table?lang=en Main livestock indicators by NUTS 2 region. https://ec.europa.eu/eurostat/databrowser/view/ef_lsk_main__custom_12234655/default/table?lang=en
Livestock properties	Excretion rates	Common Reporting Format of 2019 – 2021.	UNFCCC, 2025. Reporting requirements | UNFCCC
Crop area	Percentage and area of natural grassland (not fertilized land) and rough grazing, crop areas,	Eurostat and Agrarstrukturerhebung for Germany	Crop production in EU standard humidity by NUTS 2 region. https://ec.europa.eu/eurostat/databrowser/view/apro_cpshr/default/table?lang=en&category=agr.apro.apro_crop.apro_cp.apro_cpsh Agrarstrukturerhebung 2020. https://www.regionalstatistik.de/genesis/online?language=de&sequenz=statistikTabellen&selectionname=41141#abreadcrumb
Crop yield	Crop yields	Eurostat and Agrarstrukturerhebung for Germany	Crop production in EU standard humidity by NUTS 2 region. https://ec.europa.eu/eurostat/databrowser/view/apro_cpshr/default/table?lang=en&category=agr.apro.apro_crop.apro_cp.apro_cpsh Agrarstrukturerhebung 2020. https://www.regionalstatistik.de/genesis/online?language=de&sequenz=statistikTabellen&selectionname=41141#abreadcrumb
Fertilizer use and type	Fertilizer use and type	FAOSTAT and IFASTAT	Food and Agriculture Organization of the United Nations, 1997. FAOSTAT statistical database. Rome: FAO. International Fertilizer Association, 2024, https://www.ifastat.org/.
Farm properties	Arable farm size, farming system, crop rotation, areas with organic farming, irrigation, crop cover (arable land), perennial grass cover (used for C balance) Nitrogen Vulnerable Zones (NVZs)	EUROSTAT and Agrarstrukturerhebung (2020) for Germany Farm Structure Survey	European Commission, 2020. Eurostat statistical database. Brussels: European Commission. Agrarstrukturerhebung, 2024, https://www.regionalstatistik.de/genesis/online?operation=previous&levelindex=0&step=0&titel=Statistik+%28Tabellen%29&levelid=1727099952945&acceptscookies=false. European Environmental Agency, 2024. WISE WFD Protected Areas under the Water Framework Directive - PUBLIC VERSION - version 5.1, Jul. 2024
Farm properties	Soil cover and Tillage practice	FSS	European Commission, download September 2009 URL:https://ec.europa.eu/eurostat/web/microdata/farm-structure-survey
Farm properties	Areas under derogation	EC	European Commission, downloaded May 2019. URL: https://ec.europa.eu/environment/water/water-nitrates/index_en.html
Farm properties	Crop residue removal index	Smerald et al. (2023)	Dataset: Global crop residue management dataset (1997 - 2021)
Emission factors	N excretion of animals, CH$_4$ emissions from manure	National GHG inventory submissions	United Nations Framework Convention on Climate Change, 2020. National Inventory Submissions 2020. Bonn: United Nations Climate Change.

	management system and enteric fermentation		
Emission factors	N_2O, CO_2 (peatland) emission factors, global warming potentials,	IPCC	IPCC, 2019. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use. IPCC National Greenhouse Gas Inventories Programme. Institute for Globa
Emission factors	NH_3 emission factors	EMEP	https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023, Table 3-9, Chapter 3.B for manure; Table 3-2, Chapter 3.D for mineral fertilisers.
Climate properties	Precipitation, evapotranspiration, temperature, wind speed	ERA5	Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., Thépaut, J-N. (2023): ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), DOI: 10.24381/cds.adbb2d47 (Accessed on 10-09-2024).
Water flux	Precipitation surplus, surface runoff and groundwater leaching fractions	Keuskamp et al. (2012)	J. A. Keuskamp, G. Van Drecht, A. F. Bouwman (2012). European-scale modelling of groundwater denitrification and associated N 2O production. Environmental Pollution, 165, pp. 67-76, doi: http://dx.doi.org/10.1016/j.envpol.2012.02.008.
Nutrient composition	Composition of organic fertilizers		Multiple sources based on literature and database study
Nutrient composition	Composition of crop (residues)		Multiple sources based on literature and database study
Nutrient composition	Composition of chemical fertilizers		Multiple sources based on literature and database study, including expert judgement of Römkens (2024)
Nutrient deposition	Ca, Cd, Cu, K, Mg, Na, NH_3, NO_x, SO_x, Zn deposition	EMEP	Van Loon, M., Tarrasón, L., Posch, M., 2005. Modelling Base Cations in Europe. EMEP/MSC-W&CCE Note2/2005. ISSN 0804-2446. EMEP MSC-W, https://emep.int/mscw/mscw_moddata.html.
Land use	Land use	CORINE Land Cover - 2018	European Union, Copernicus Land Monitoring Service 2021, European Environment Agency (EEA). Corine Land Cover. DOI: CORINE Land Cover 2018 (vector/raster 100 m), Europe, 6-yearly — Copernicus Land Monitoring Service (Accessed on 01-08-2024).

Table 1B. Livestock and manure categories in MITERRA-Europe.

Livestock type	Manure type	Description	Eurostat category
DAIRYCOWS	DAICOW_L	Dairy cows liquid manure	A2300F
OCOW	OCOW_L	Dairy cows solid manure	A2000 - A2300F
PIGS	PIGS_L	Other cows liquid manure	A3100
DAIRYCOWS	DAICOW_S	Other cows solid manure	A2300F
OCOW	OCOW_S	Pigs liquid manure	A2000 - A2300F
PIGS	PIGS_S	Pigs solid manure	A3100
LAYHENS	LAYHENS	Laying hens	A51100

OPOUL	OPOUL	Other poultry	A5000
SHEGOA	SHEGOA	Sheep and goat	A4100 + A4200
HORSES	HORSES	Horses	A1000
FURANI	FURANI	Fur animals	

Table 1C. Crop categories of MITERRA-Europe.

Crop code used in MITERRA-Europe	Description
APPL	Apples pears and peaches
BARS	Spring barley
BARW	Winter barley
CITR	Citrus fruits
DWHE	Durum wheat
FLOW	Flowers
GRAP	Permanent pastures and meadows
GRAR	Rough grazings
MAIF	Fodder maize
MAIZ	Grain maize
NURS	Nurseries
OATS	Oats and summer cereal without triticale
OCER	Other cereals including triticale
OFAR	Fodder other on arable land
OFRU	Other fruits
OIND	Other industrial crops
OLIV	Olives for oil
OOIL	Other oils
OVEG	Other vegetables
PARI	Paddy rice
POTA	Potatoes
PULS	Pulses
RAPE	Rape
ROOF	Fodder root crops
RYEM	Rye and meslin
SOYA	Soya
SUGB	Sugar beet
SUNF	Sunflower
SWHS	Soft spring wheat
SWHW	Soft winter wheat
TABO	Table olives
TAGR	Table grapes
TEXT	Flax and hemp
TOBA	Tobacco
TOMA	Tomatoes
TWIN	Wine

Table 1D. Chemical fertilizer types.

Fertilizer abbreviation	Description
N_AA	Ammonia, anhydrous
N_AN	Ammonium nitrate (AN)
N_AS	Ammonium sulphate
N_CAN	Calcium ammonium nitrate (CAN) and other mixtures with calcium carbonate
DAP	Diammonium phosphate (DAP)
F_NEC	Fertilizers n.e.c.
MAP	Monoammonium phosphate (MAP)
NPK	NPK fertilizers
N_ONF	Other nitrogenous fertilizers, n.e.c.
Other_NK	Other NK compounds
Other_NP	Other NP compounds
Other_P	Other phosphatic fertilizers, n.e.c.
Other_K	Other potassic fertilizers, n.e.c.
P_rock	Phosphate rock
PK	PK compounds
MOP	Potassium chloride (muriate of potash) (MOP)
KN	Potassium nitrate
N_SN	Sodium nitrate
Super_P	Superphosphates above 35%
Super_P_other	Superphosphates, other
N_Urea	Urea
UAN	Urea and ammonium nitrate solutions (UAN)

Annex 2 Composition data

Table 2A. Crop composition data.

Crop	Dry matter	N (g/kg)	P (g/kg)	Ca (g/kg)	Mg (g/kg)	K (g/kg)	Na (g/kg)	Cl (g/kg)	S (g/kg)	Cu *	Pb*	Zn*	Cd*	Harvest Index [1]	N Index [2]
APPL	0.14	0.5	0.1	0.1	0.1	1.3	0	0.6	0	0.3	0	0.3	0	0.8	2.1
BARW	0.85	14	3.5	0.5	1.2	4.9	0.1	1.1	1.3	0.3	0	0.8	0.2	0.5	2.4
BARS	0.85	14	3.5	0.5	1.2	4.9	0.1	1.1	1.3	0.3	0	0.8	0.2	0.5	2.4
CITR	0.15	0.5	0.4	0.5	0.1	1.8	0	0.4	0.1	0.3	0	0.3	0	0.8	2.1
DWHE	0.85	20	3.1	0.5	1	4.1	0.1	0.6	1.1	0.3	0	0.8	0.2	0.5	3
FLOW	0.25	5	0.8	0.8	1.2	6.8	0.1	0.6	1	0.3	0	0.3	0.6	0.6	2.1
GRAR	1	30	2.9	4.2	1.5	20.9	1.9	10.4	2.5	0.2	0	1	0.2	0.5	5
GRAP	1	30	2.9	4.2	1.5	20.9	1.9	10.4	2.5	0.2	0	1	0.2	0.5	5
MAIF	0.25	4.6	0.7	0.6	0.5	3.7	0.1	0.8	0.4	0.1	0	0.3	0.1	0.7	4.9
MAIZ	0.85	13.9	2.3	0.1	1.7	2.7	0.1	0.3	0.8	0.1	0	0.3	0.1	0.5	1.5
NURS	0.25	5	0.6	0.8	1.2	6.8	0.1	0.6	1	0.3	0	0.3	0.6	0.8	2.1
OATS	0.85	17	3.6	0.8	1.3	4.4	0.1	0.6	1.5	0.2	0	0.3	0.2	0.5	2.1
OCER	0.85	15	2.7	0.3	1.4	4.5	0.1	0.4	1.3	0.3	0	0.8	0.2	0.5	2
OFAR	0.25	5.8	0.9	0.9	0.4	5.4	0.1	1.7	0.4	0.1	0	0.3	0.1	0.5	2.4
OFRU	0.15	0.5	0.6	0.4	0.2	4.7	0.1	0.5	0.1	0.3	0	0.3	0	0.8	3
OIND	0.25	4	0.7	8.1	2.3	18.3	0.2	7.2	2	0.3	0	0.3	0.6	0.5	1.1
OLIV	0.85	0.5	0.4	0.7	0.4	9.3	0.2	0.5	0.1	0.3	0	0.3	0.6	0.6	2.1
OOIL	0.85	34	5.7	0.7	3.8	30.3	0.2	0.5	0.1	0.3	0	0.3	0.6	0.5	1.3
OVEG	0.1	2.5	0.4	0.6	0.2	3.3	0.3	0.6	0.4	0.4	0.1	1.6	4.5	0.4	1.2
PARI	0.85	20	3	0.3	1.2	2.5	0.1	0.6	0.8	0.1	0	0.1	0.3	0.5	3
POTA	0.24	3.5	0.4	0.1	0.3	5.4	0	0.8	0.3	0.3	0	0.1	0.3	0.7	3.1

PULS	0.85	42	3.7	1.1	1.2	9.7	0.2	0.7	2	0.3	0	0.8	0.3	0.7	2
RAPE	0.85	35	6.3	4.2	2.7	7	0.1	1.3	2.1	0.3	0	0.3	0.6	0.7	1.8
ROOF	0.15	1.9	0.3	0.2	0.2	3.5	0.3	1	4.3	0.3	0.1	0.4	0.6	0.7	1.8
RYEM	0.85	14	3.1	0.4	1.2	5.5	0.1	1.2	2	0.3	0	0.8	0.2	0.5	1.8
SOYA	0.85	58	8	2.4	2.2	17	0.1	0.3	1.2	0.3	0	0.3	0.6	0.7	3.9
SUGB	0.25	1.8	0.3	0.2	0.6	2.6	0.4	1	0.1	0.3	0.1	0.4	0.6	0.7	0.7
SUNF	0.85	32	5.2	1.4	2.8	7.8	0.1	0.2	1.7	0.3	0	0.3	0.6	0.5	1.8
SWHW	0.85	20	3.1	0.5	1.2	4.1	0.1	0.8	1.4	0.3	0	0.8	0.2	0.5	3
SWHS	0.85	20	3.1	0.5	1.2	4.1	0.1	0.8	1.4	0.3	0	0.8	0.2	0.5	3
TABO	0.15	5	2.1	0.7	0.4	9.3	0.2	0.5	0.1	0.3	0	0.3	0.6	0.6	2.1
TAGR	0.85	0.5	0.4	0.1	0.1	2.1	0	0.5	0	0.3	0	0.3	0.6	0.6	2.1
TEXT	0.85	4	4.2	3.4	2.5	11.1	0.2	2.7	0.3	0.3	0	0.3	0.6	0.9	1.1
TOBA	0.05	30	4	12.7	2.2	25.5	0.3	11.6	3.8	0.3	0	0.3	0.6	0.4	2.1
TOMA	0.15	1	0.2	0.1	0.1	2.3	0.1	0.3	0.1	0.6	0	0.9	0.5	0.8	3
TWIN	1	0.5	0.3	0.1	0.1	2.1	0	0.5	0	0.3	0	0.3	0	0.6	2.1

[1] Harvest index: ratio of harvested biomass to net primary production.

[2] N index: ratio of N in harvested products to N in residue.

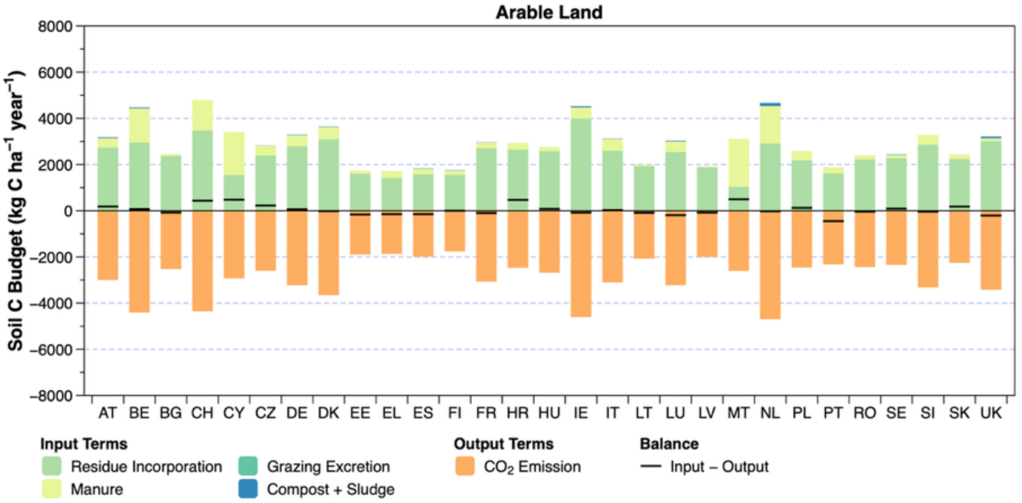
Table 2B. Manure composition data.

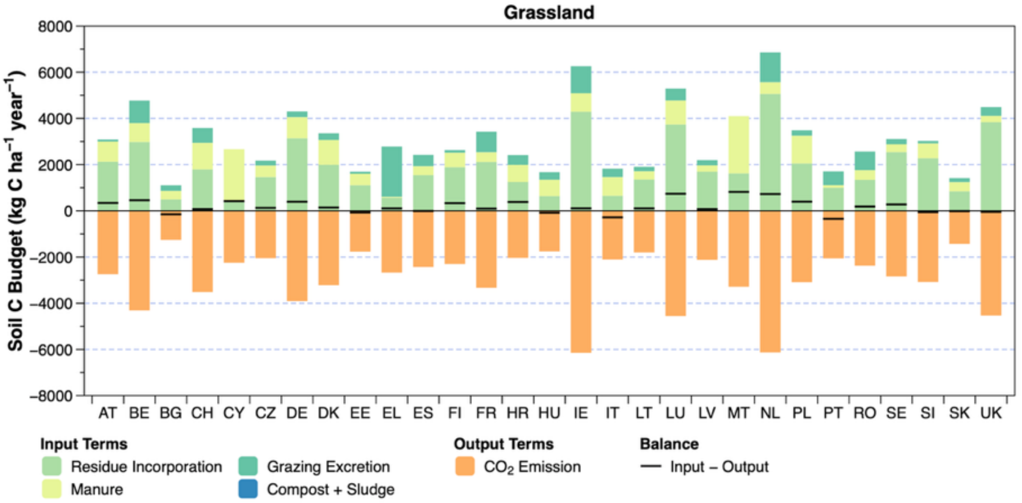
Livestock	DAICOW_L	OCOW_L	PIGS_L	DAICOW_S	OCOW_S	PIGS_S	LAYHENS	OPOUL	SHEGOA	HORSES	FURANI
Dry matter (kg DM/1000 kg fresh)	80	80	74	250	250	250	450	439	300	250	430
N total (g N/kg fresh)	3.8	3.5	5.2	6.0	5.5	7.0	20.9	19.9	8.3	4.7	18.5
N mineral (g N/kg fresh)	1.7	1.9	3.0	1.1	1.0	1.7	5.0	4.3	2.4	1.1	8.7
N:P ratio	5.8	5.7	3.4	4.3	4.2	2.4	2.6	2.9	4.0	2.5	1.8
N:OM_Ratio	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1
N:Ca ratio	2.0	2.5	1.9	1.0	1.3	1.1	1.1	1.1	1.0	0.8	1.1
N:Mg ratio	7.5	7.5	9.6	4.6	5.1	5.1	7.1	6.2	5.1	3.9	7.9
N:K ratio	0.9	1.0	1.9	0.8	0.8	1.2	1.7	1.5	0.7	0.9	3.5
N:Na ratio	3.9	7.2	6.4	6.9	8.5	9.6	6.7	6.7	5.8	13.5	6.0
N:Cl ratio	5.8	5.8	3.8	4.6	7.8	2.2	12.2	12.2	4.1	15.5	12.3
N:S ratio	8.5	9.1	10.7	6.6	6.2	5.2	5.7	5.7	6.1	6.5	2.0
N:Cd ratio	183924	169404	252635	90511	82968	69298	113564	110966	118323	70146	105199
N:Cu ratio	1098	1012	416	715	656	125	522	510	878	554	484
N:Zn ratio	248	228	101	152	139	37	101	99	180	118	94
C:N ratio	7.8	7.8	2.8	14.3	14.3	*5.1*	6.5	7.0	10.0	17.4	5.2
Humification Coefficient	0.5	0.5	0.4	0.5	0.5	*0.5*	0.5	0.5	0.5	0.8	0.3

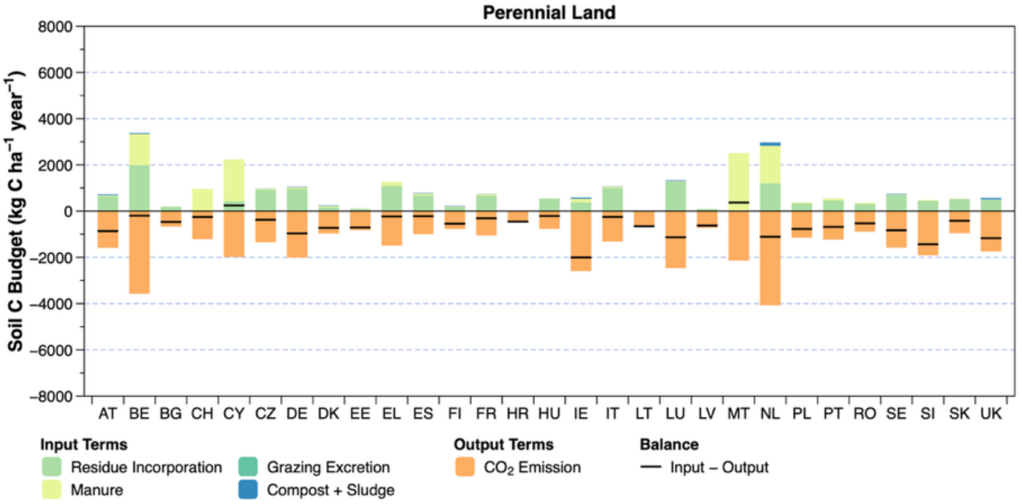
Table 2C. Chemical fertilizer composition

Product	**N (g/kg)**	**P (g/kg)**	**K (g/kg)**	**Cd (mg/kg)**	**Cu (mg/kg)**	**Zn (mg/kg)**	**Ca (mg/kg)**	**Mg (mg/kg)**	**S (mg/kg)**	**Cl (g/kg)**	**Na (g/kg)**
N_AA	8.2	0.0	0.0	0.0	6.3	2.3	0.0	0.0	0.0	0.0	0.0
N_AN	3.4	0.0	0.0	0.0	6.3	2.3	0.0	0.0	0.0	0.0	0.0
N_AS	2.1	0.0	0.0	0.0	2.5	4.7	0.0	0.0	2.4	0.0	0.0
N_CAN	2.4	0.0	0.0	0.3	5.0	55.0	0.8	0.0	0.0	0.0	0.0
DAP	1.8	2.0	0.0	10.2	24.8	115.0	0.0	0.0	0.0	0.0	0.0
F_NEC	0.0	0.0	0.0	0.1	4.0	3.1	0.0	0.0	0.0	0.0	0.0
MAP	1.2	2.7	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPK	1.5	0.7	1.2	0.1	5.2	4.0	0.0	0.0	0.0	0.0	0.0
N_ONF	2.0	0.0	0.0	0.1	5.2	4.0	0.0	0.0	0.0	0.0	0.0
Other_NK	2.0	0.0	1.7	3.6	17.4	139.0	0.0	0.0	0.0	0.0	0.0
Other_NP	2.0	0.9	0.0	3.6	17.4	139.0	0.0	0.0	0.0	0.0	0.0
Other_P	0.0	0.9	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Other_K	0.0	0.0	1.7	0.1	3.4	4.1	0.0	0.0	0.0	0.0	0.0
P_rock	0.0	1.3	0.0	0.0	1.0	0.0	3.5	0.1	0.0	0.0	0.0
PK	0.0	0.9	1.7	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
MOP	0.0	0.0	5.0	0.0	1.8	0.0	0.0	0.0	0.0	4.5	0.0
KN	1.3	0.0	3.8	0.1	1.0	1.0	0.0	0.0	0.0	0.0	0.0
N_SN	1.6	0.0	0.0	0.1	5.2	4.0	0.0	0.0	0.0	0.0	0.0
Super_P	0.0	2.0	0.0	3.1	4.0	3.1	1.5	0.0	0.0	0.0	0.0
Super_P_other	0.0	0.9	0.0	3.1	4.0	3.1	1.8	0.0	1.2	0.0	0.0
N_Urea	4.6	0.0	0.0	0.0	0.8	3.7	0.0	0.0	0.0	0.0	0.0
UAN	3.2	0.0	0.0	0.0	3.6	3.0	0.0	0.0	0.0	0.0	0.0

Annex 3 Soil carbon balance per land use type (grassland, arable land and perennials)







Annex 4 Country codes of Europe

Country abbreviation	Country
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech. Rep
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
EL	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden
UK	United Kingdom
CH	Switzerland
HR	Croatia

Annex 5 Description of MITERRA-Europe

The description of the MITERRA-model is available through this link:

https://ssm-wenr.github.io/miterra-site/miterra-docs/index.html

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Optimisation of nutrient budget in agriculture

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