Methodological Proposal and Results for compiling EU-level Spatial Nutrient Condition Accounts

A summary report on pilot EU Nutrient Accounts

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In cooperation with the European Topic Centre for Urban, Land and Soil Systems (ETC/ULS) and the World Conservation Monitoring Centre (WCMC)

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Overview and key findings

Maintaining the extent and condition of ecosystems is essential to achieving the European Union (EU) policy targets for maintaining Natural Capital. Natural capital accounting is increasingly seen as providing an essential information framework that can inform integrated management and policy responses to deliver on the EU's natural capital targets. The European Commission (in cooperation with the European Environment Agency - EEA) has therefore set up the EU INCA project to develop a natural capital accounting approach for the European Union.[1] This technical report presents work by the EEA (in cooperation with ETC/ULS and WCMC) in the context of the INCA project to develop pilot EU-level nutrient accounts.

Nutrient enrichment is a key pressure indicator for ecosystem condition, as all terrestrial and aquatic ecosystems are negatively affected by it (EC, 2016). Nutrients derive from a variety of sources, including agriculture, wastewater discharges and atmospheric deposition.

The EEA has cooperated with the EU Joint Research Centre to develop spatially explicit nutrient pressure accounts for the EU using various input data and modelling. These data sets include:

- gridded farm statistics provided by Eurostat
- atmospheric nitrogen deposition data from air monitoring programmes
- data on agricultural nutrient use generated by the common agricultural policy regionalised impact (CAPRI) agro-economic model.

The model-derived data on nutrient pressures (at the soil surface) are spatially allocated to different MAES ecosystem types by using the same CLC data underpinning the ecosystem extent accounts. This allows ecosystem condition accounting tables to be produced that can show:

- the average nutrient pressures on different ecosystem types over time, at EU, country or regional level
- a breakdown of nutrient pressure by varying input levels and their spatial distribution.

By developing a spatially explicit accounting approach, it is possible to identify areas where nutrient inputs exceed certain load levels. This adds a new analytical functionality, compared with standard nutrient balances that provide average values per country or at the large region level. Table 1 presents information on the trend in the

1 The INCA project's full title is 'Knowledge innovation project on an integrated system of natural capital and ecosystem services accounting in the EU'; for further detail please consult: https://ec.europa.eu/environment/nature/capital_accounting/index_en.htm

shares of four different nitrogen input levels for grassland ecosystems between 2000 and 2010.

Table 1 Spatial account for nitrogen input in grassland and cropland ecosystems, EU-27, 2000-2010

Accounting element	Nitrogen (N) input level	% share of all cropland	% share of all grassland
Starting year (2000)	a) < 50 kg/ha/year	59.3	47.3
	b) 50-100 kg/ha/year	31.2	33.7
	c) 100-150 kg/ha/year	6.6	10.8
	d) > 150 kg/ha/year	2.9	8.2
	Grand total	100.0	100.0
Closing year (2010)	a) < 50 kg/ha/year	66.6	55.6
	b) 50-100 kg/ha/year	22.5	29.8
	c) 100-150 kg/ha/year	7.7	8.8
	d) > 150 kg/ha/year	3.2	5.8
	Grand total	100.0	100.0
Trend in average N-input per ha/year	Overall trend index (%)	-7.8	-14.9
Share of area with low input level (< 50 kg/ha/year)	Low input trend index (%) (over 10 years)	7.3	8.3

Note: The trend figures presented above exclude data for Croatia, as it was not available.

The available data suggest that the area share of the N input category of below 50 kg N/ha has increased over the period monitored, whereas the area shares of all higher N input levels have decreased. Analysis based on the average N input level per hectare for the entire area covered would not have identified these sub-trends. However, the approach presented above includes only a coarse spatial representation and lacks sensitivity with regard to the response of different grassland ecosystem sub-types to N input. For example, highly productive grasslands are adapted to N input levels of 100kg N/ha or more but are often species poor. The botanical species diversity of semi-natural grasslands can only be maintained if yearly N input levels stay below 30 kg N/ha (in the table above 50 kg/ha was chosen as threshold for the low input category to take account of data distribution and uncertainty).

The pilot spatial nutrient accounts presented here are planned to be further developed to identify ecosystem sub-types and areas that require policy action to reduce nutrient pressures. Work is under way to add further spatial detail and extend the current times series to 2018. This will allow the presentation of spatial nutrient accounts that have more analytical power and provide concrete policy input, e.g. on the nutrient pressures inside Natura 2000 areas compared with those of general farmland.

The pilot nutrient ecosystem condition account shows how the accounting methodology can be used to show spatial trends for these key ecosystem condition parameters. Future work at EU level could develop such an accounting approach together with shared data platform for tracking the condition of European ecosystems over the coming years.

The spatial foundation for the pilot nutrient accounts enables the identification of pressure hot spots, where ecosystem thresholds have been exceeded. This adds spatial detail to the analysis of the condition of agro-ecosystems, which could be used to address nutrient reduction targets in the EU biodiversity strategy for 2030, for example.

The next sections review the following issues:

- Key policy questions the nutrient accounts can address
- Options for presenting the accounts in different formats
- Discussion of key European scale accounting results
- Review of the analytical uses the flexible spatial framework underpinning the accounts provides
- A summary of recommendations for further development of the accounts.

Key policy questions

Natural Capital Accounting

The European Union (EU) has set itself ambitious targets for the preservation and better management of natural capital in the 7th Environmental Action Programme of the EU (7th EAP) and the EU Biodiversity Strategy for 2030. To build the knowledge base for achieving these objectives a shared project was set up at EU level to develop an integrated system for natural capital and ecosystem services accounting (KIP INCA). As nutrient inputs into agriculture, grassland and forest ecosystems represent major impacts on their functioning and service provision measuring their spatial distribution is a critical information component to formulating the correct policy and management solutions to conserve and enhance Europe's Natural Capital stocks. This is also reflected in the EEA (2017a) information note on EU wide ecosystem condition indicators for ecosystem accounting.

In the context of delivering on the EU environmental policy targets for natural capital, spatial nutrient pressure condition accounts will yield essential cross-cutting indicators for informing on where to target investment in natural capital protection and track progress towards policy targets for natural capital.

Mapping and Assessment of Ecosystems and their Services (MAES)

EU Biodiversity Strategy to 2020 (target 2, Action 5) called on Member States to map and assess the state of ecosystems and their services in their national territories and integrate their values into EU and national scale accounting and reporting systems. The MAES initiative responds to the need for a consistent analytical framework to support this action across member states. MAES (2018) identifies nutrient balance as a key pressure indicator for ecosystem assessment. Specifically, MAES (2018) identifies nitrogen balance as one of the key pressure indicators for agro-ecological systems. Nutrient loading is also identified as an indicator for a number of ecosystems, expressed via the Streamlined Environmental Biodiversity Indicator (SEBI) 009 for critical load exceedance for nitrogen (see EEA, 2017). Accordingly, spatial nutrient pressure condition accounts will yield essential cross-cutting indicators that will directly support and operationalise the ambitions of the MAES initiative.

Other relevant policy applications

Fertiliser use in water basins and gross nutrient balance are also identified as important indicators for freshwater ecosystems. With respect to wider policy targets, these indicators are also highly relevant to the Water Framework Directive 2000). The Spatial Nutrient Pressure Condition Accounts would provide very useful information on where to focus efforts on the use of good farming practices to protect waters against agricultural pressures. Similarly they could be used to identify where a more efficient use of nutrient and soil resources needs to be achieved, a key challenge identified for the implementation of the EU Soil Thematic Strategy (EC, 2012).

Key policy applications for spatially disaggregated nutrient data are identified with respect to the call for monitoring the environmental impacts of agriculture under the

Common Agricultural Policy (CAP). Furthermore, environmental assessments are required at the regional level under the European Commission Rural Development Policy.

In consideration of the above, there are multiple policy entry points that Spatial Nutrient Pressure Condition Accounts can target. They could clearly inform on progress towards these multiple policy targets but, more importantly, support a coordinated approach to tackle nutrient based pollution problems in multiple contexts.

Methodological Overview

In broad terms, the Spatial Nutrient Pressure Condition Accounts seek to quantify the difference between nutrient inputs and nutrient outputs in a spatially explicit approach. A simplified approach is adopted that considered the major inputs as: Fertiliser use; Manure application; Biological fixation; and atmospheric deposition. The main nutrient output is represented by harvested products. By organising information on these inputs and outputs in a manner that is spatially integrable, the approach allows the nutrient surplus to be calculated in a spatially explicit fashion. This surplus is characterised as leaching / run-off or losses to atmosphere. The former impacting most on water systems and the latter on atmospheric conditions and subsequent deposition. Eight broad steps to compiling the Spatial Nutrient Pressure Condition Accounts for Europe are presented Figure 1. These steps can be broken down into three stages: 1) Getting the data together; 2) Calculating derived datasets; and, 3) Integrating data and compiling the accounts.

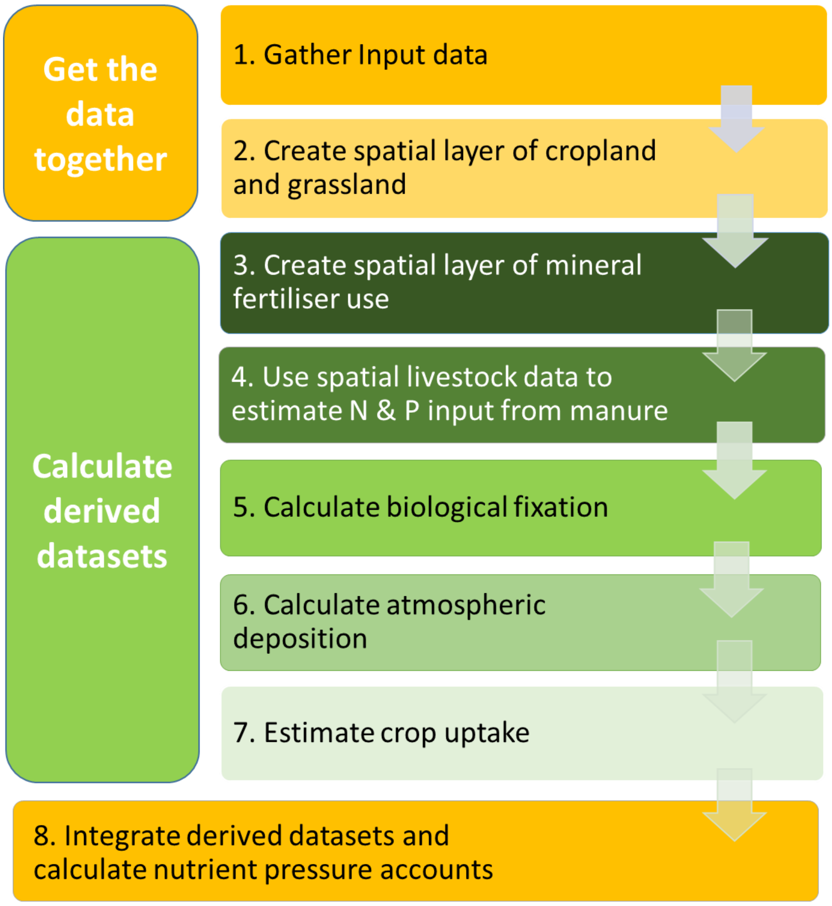


Figure 1 Stepwise approach for compiling Spatial Nutrient Pressure Condition Accounts

An expanded, detailed stepwise process to the workflow for calculating the Spatial Nutrient Condition Accounts is provided in Appendix A.

Getting the data together

The European nutrient accounts are based on the results provided by the CAPRI team of the Joint Research Centre (JRC) of the European Commission. The Common Agricultural Policy Regional Impact (CAPRI) model is a tool for ex ante impact assessment of agricultural and international trade policies with a focus on the European Union. As an economic partial comparative static equilibrium model for agriculture, its core consists of two interlinked modules: the supply module, covering about 280 regional aggregate programming models covering the EU-27 (minus Croatia), Norway, United Kingdom and Western Balkans at the NUTS 2 level and the market module, a global spatial multi-commodity model for about 50 agricultural commodities, which together allow calculation of a wide range of economic and environmental indicators. A spatial downscaling component allows impact assessment at the FSU level for EU-27 (minus Croatia) and the UK.[2]

The CAPRI modelling framework includes also a module which is used to estimate spatially distributed nitrogen balances at the level of Farm Structure Soil Units (FSU). The data used for the nitrogen balance is derived from disaggregated data from CAPRI time series. It relies on input data related to land use, manure and fertiliser input, atmospheric deposition, crop uptake etc. from different sources, but mainly based on official statistics (Eurostat) or sectoral information (e.g. fertiliser use). These data, available mainly at country level or NUTS2 level are transformed via downscaling (crop and livestock data) or disaggregation (for nutrient use data) procedures to provide a complete and consistent data bases at NUTS2 level in CAPRI, and further procedures to obtain the spatial nutrient accounting layers. The latter are described for each input in Appendix B.

[2] Further detailed information on the purpose and set-up of CAPRI is available via this Wikipedia link: https://en.wikipedia.org/wiki/CAPRI_model

Compiling the accounts

The spatially explicit nature of the Nutrient Pressure Condition Accounts builds on a geospatial data layer at a 1 x 1 km^2 resolution that can be used to generate accounts for a variety of scales. This fits with the EEA's ambition for a fully spatial approach to ecosystem accounting, underpinned by a 1 km grid based spatial referencing system. As such, the data underpinning the Spatial Nutrient Pressure Condition Accounts can be integrated into a wider geospatial database of information organised by 1 km grid cells. This will allow integration of multiple datasets (e.g., nutrient pressures, land cover, vegetation indices) and facilities a wide range analytical application. Figure 2 illustrates this graphically.

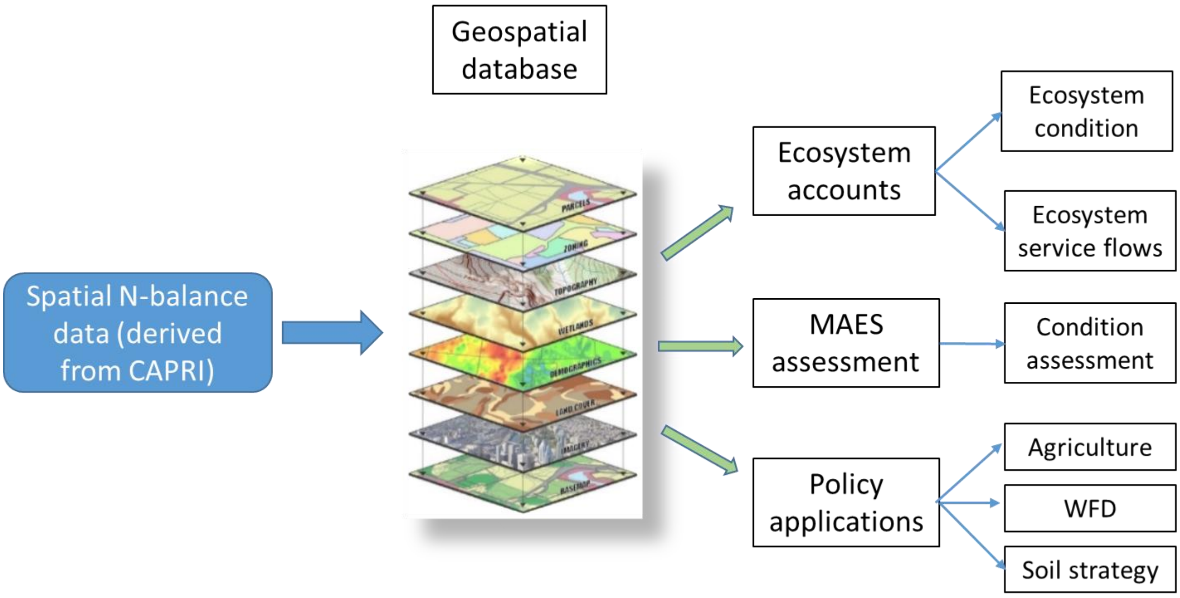


Figure 2 Applications of spatial nutrient balance data as part of a geospatial database

Whilst no hard and fast rules need to be developed on specifying certain Ecosystem Accounting Areas (EAAs)[3] for aggregating the 1km x 1km nutrient pressure data, it is useful to reflect on what may be the most pertinent possibilities. Furthermore, as Figure 2 reveals, the process of generating the spatial nutrient balances also yields a number of derived datasets (potential accounting items) whose accounting treatment needs to be considered.

Ecosystem Accounting Areas (EAAs)

A key driver of selecting the Ecosystem Accounting Area (EAA) for compiling the accounts will be the specific policy question to be addressed, the scale at which wider policy relevant data is organised and the scale at which management of policy decisions are implemented. This includes by ecosystem / land cover types, by ecologically

[3] The area for which an ecosystem account is produced (UN *et al.*, 2018)

relevant features, such as river basins or ecosystem types, and various different statistical management units (e.g., NUTS levels).

In the context of KIP INCA, EU scale accounts will be of interest, ideally disaggregated by ecosystem type. This is readily achievable where 1 km resolution data on spatial nutrient balance and Corine land cover (and other data sets) are integrated into one geo-spatial ecosystem accounting system. In the context of KIP INCA, it will be useful to identify where links can also be made between the Spatial Nutrient Pressure Condition Accounts and wider ecosystem accounts produced under this project. This should not just focus on exploring the trade-offs between condition and provisioning services (e.g., crops) but also provide insights into the implications for other ecosystem services. For instance, the mitigation of nutrient pressures on freshwater ecosystems is an important regulating service of ecosystems and it is important to understand where this service is being realised or where natural capital investment could improve the supply of this ecosystem service. This could have important implications for a range of cultural ecosystem services, the recreational potential of rivers and lakes is typically diminished when eutrophication takes place (e.g., activities such as fishing, swimming and boating may no longer be undertaken at a site). Furthermore, exceeding critical loads for nutrient is known to be more widely damaging to biodiversity (as discussed in the next sub section with respect to SEBI 009, EEA, 2017b). This will also affect the recreational amenity enjoyed by visitors to natural and semi-natural ecosystems (e.g., reduced opportunities to observe wildlife, pollinators and wild flowers).

Where the Common Agricultural Policy represents an entry point for spatial data, Farm Structure Soil Units (FSU) have been developed. These are determined on the basis of being approximately homogenous in terms of agro-ecological characteristics determining agricultural activities and thus nutrient flows. The FSUs may be discontinuous and consist of one or multiple 1km grid cells. They are confined on the basis of the administrative (NUTS 3) areas in which they occur and a regular grid of 10 km x 10 km on which agricultural statistics are made available. The units are also restricted to single soil mapping units, as well as to soil mapping units. Corine Land Cover information has been included to delineate units where agricultural activities do not happen or are unlikely. It will be useful to organise nutrient pressure data in a manner that is consistent with these units as it opens up pathways for multiple analysis. However, this use of discontinuous units is not consistent with the concept of ecosystem assets proposed in the SEEA EEA (UN *et al.*, 2014, 2018). As such, FSUs are best utilised as a vehicle for establishing a continuous spatial data set on agricultural nutrient input rather than as ecosystem accounting areas.

The objectives of the WFD are to be achieved via the implementation of river basin management plans. These are produced for geographically defined river basin districts, comprised of single or multiple, adjoined river basins. River basins are defined as "The area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta" (see EU Water Directors, 2016). These would appear to be highly useful Ecosystem Accounting Areas (EAAs) for which to compile spatial nutrient pressure condition accounts.

Accounting items and structure

Specifying accounting items and structures requires consideration in both ecological, measurement and policy relevance terms. A key decision is whether to focus purely on the balances (the net values) or to differentiate data compilation by establishing one data set on the gross input of nutrients and another on the reduction of nutrients within the (agro-)ecosystem via crop uptake. The latter is the more conventional accounting approach and this would derive a rich set of data that could support more analytical uses. For example, nutrient loading is identified as an indicator for a number of ecosystems in MAES (2018).

However, whilst information on nutrient load is important input data on the overall nutrient pressures that ecosystems face, they are currently recorded as trends over time at country level, rather than as spatially differentiated data sets (MAES, 2018). As such, they do not lend themselves to compilation per ecosystem accounting area. An accounting approach also requires data sets that require opening and closing stocks. Essentially, this comprises of recording the net balance of additions (e.g., these fertiliser application, manure and atmospheric deposition) and reductions (e.g., crop uptake) over the accounting period for different ecosystems in a spatially explicit fashion. This would also facilitate combined presentations with other accounts, for instance ecosystem extent accounts grounded in the Corine land cover data set.

To explain how the above accounting requirements can be implemented a possible example of such a 'Nutrient Pressure Condition Account' is presented in Table 2. The columns in Table 2 present the average nutrient balance for different ecosystem types within the Ecosystem Accounting Area (EAA). The final column of Table 2 provides an ecosystem area weighted average for aggregate ecosystem nutrient balances per hectare per year. As apparent from the structure of Table 2, this will only reflect the ecosystems for which nutrient balance is available.

Table 2 Option 1 for Nutrient Pressure Condition Account (2000 to 2018)

Nutrient Balance by MAES Types >>	Cropland (kg/ha /year)	Grassland (kg/ha /year)	Forest & Woodland (kg/ha /year)	Area weighted average (kg/ha /year)
2000	50	30	10	**39**
2006	55	30	12	**42**
2012	53	25	8	**39**
2018	67	23	8	**47**

Notwithstanding the above option of presenting trend information on average nutrient pressure per ecosystem type, information on the areas impacted by nutrient overloading is a key environmental policy concern. For instance, the SEBI 009 indicator is related to exceeding for critical loads for nitrogen deposition in (semi)-natural ecosystems

(EEA, 2017). This is used to inform on the potential for eutrophication and associated biodiversity impacts in Europe. As such, it would be useful to set critical thresholds for nutrient balances or loading (application + deposition) using data organised via the spatial nutrient accounts and account for the areas of different ecosystems affected over accounting periods. Particularly, given the ability to generate this data for a 1km grid (SEBI 009 is presented using a 50 km grid).

Table 3 sets out a different option which is to structure a nutrient account such that it presents information on the areas of different ecosystems exceeding critical nutrient deposition thresholds. This adds an important new dimension to the standard presentation which is the ability to identify the total size and relative share of areas where a given nutrient pressure threshold is exceeded. The account presents information on the area, in absolute terms, of each ecosystem exceeding the critical threshold within an Ecosystem Accounting Area (EAA). These ecosystem specific measures are then aggregated in the final column to show the total ecosystem area exceeding the critical threshold in the EAA. Whilst the account could also be presented in relative terms, this information on relative extent exceeding thresholds could readily be revealed by combined presentation with the ecosystem extent account for that EAA.

Table 3 Option 2 for proposed Nutrient Pressure (Threshold) Condition Account

Area Exceeding Nutrient Balance by MAES Types >>	Cropland (ha /year)	Grassland (ha /year)	Forest & Woodland (ha /year)	Total (/ha /year)
2000	10,000	6,500	900	**17,400**
2006	9,800	6,450	1,050	**17,300**
2012	12,000	5,000	800	**17,800**
2018	13,500	4,700	780	**18,980**

Accounting Results

The disaggregated nitrogen data from CAPRI time series is produced for a set of 27 EU Member States (EU-28 minus Croatia). The data is available for the years 2000-2012, in 2-year-steps, which can inform the Spatial Nutrient Condition Accounts for this Ecosystem Accounting Area (EEA). The accounting items and structures presented in **Error! Reference source not found.** and Table 3 have been calculated for each of these two year steps for each of the 27 EU Member States. These data have been aggregated in order to compile a Nutrient Pressure Condition Account for the EU 27 EAA as a whole (Table 4 and Table 5).

Table 4 presents the Nutrient Pressure Condition Account for Cropland and Grassland (the major agricultural ecosystems) for the EU-27 EAA. As it reveals, nutrient balances are positive in both cropland and grassland, implying nutrient surplus and leaching (e.g., to groundwater), run-off to other ecosystems or losses to the atmosphere from these ecosystems. Nutrient surplus is larger for grasslands, likely the result of grazing and associated animal execration. Whilst a downward trend is evident in the nutrient surplus in both these ecosystems, this is very marginal (around 3% between 2000 and 2012).

Table 5 presents the Nutrient Pressure (Threshold) Condition Account for the EU-27 EAA. This presents the extent of both croplands and grasslands where the critical thresholds for nutrient loads are exceeded. As per Table 4, Table 5 reveals decreases in the extent of both of these ecosystems exceeding critical thresholds between 2000 and 2012. The final column in Table 5 reveals the total area of these two ecosystems where critical thresholds are exceeded has decreased by nearly 10% between 2000 and 2012.

Table 5 reveals that the area of cropland exceeding critical load routinely exceeds that of grassland by a factor of two, in absolute terms. However, when evaluating this data alongside information on ecosystem extent the picture is reversed, reflecting the far greater extent of cropland in the EU-27 compared to grassland. In relative terms, approximately 24% of grassland is found to exceed the critical threshold (in 2012), whereas only approximately 14% of cropland exceeds this threshold (in 2012).

Table 4 Nutrient Pressure Condition Account for Cropland and Grasslands (EU-27 + UK, 2000 to 2012)

Nutrient Balance by MAES Types >>	Cropland (kg/ha /year)	Grassland (kg/ha /year)	Forest & Woodland (kg/ha /year)	Area weighted average (kg/ha /year)
2000	64	81	ND	**68**
2002	64	81	ND	**68**
2004	64	80	ND	**68**
2006	64	80	ND	**67**
2008	63	80	ND	**67**
2010	63	79	ND	**67**
2012	62	79	ND	**66**

ND' = No data at present

Table 5 Nutrient Pressure (Threshold) Condition Account for Cropland and Grassland (EU-27 + UK, 2000 to 2012)

Area Exceeding Nutrient Balance by MAES Types >>	Cropland (10^3 ha /year)	Grassland (10^3 ha /year)	Forest & Woodland (10^3 ha /year)	Total (/ha /year)
2000	23,646	12,374	ND	**36,020**
2002	23,567	12,306	ND	**35,874**
2004	23,050	12,101	ND	**35,151**
2006	22,769	12,072	ND	**34,842**
2008	22,360	11,897	ND	**34,257**
2010	22,024	11,606	ND	**33,631**
2012	21,653	11,713	ND	**33,366**

ND' = No data at present

It is highlighted that whilst Table 4 and Table 5 present information for the EU-27, the underlying input data are derived for each Member State. Further, the flexible nature of the geospatial data underpinning the accounts also allows for accounts to be compiled for various other EAAs of policy and analytical interest. As such, Spatial Nutrient Condition Accounts can be produced for further EAAs of relevance (including member state and biogeographical regions) following consolidation of the accounting data.

The next step for developing the analytical functionality of spatial nutrient accounts is to integrate the nutrient threshold approach proposed under option 2 and presented in schematic form in Table 3.

By developing a spatially explicit accounting approach in combination with thresholds, it is possible to identify areas where nutrient inputs exceed certain load levels. Table 1 presents information on the trend in the shares of four different nitrogen input levels for grassland ecosystems between 2000 and 2010.

Table 1 (repeated) - Spatial account for nitrogen input in grassland and cropland ecosystems, EU-27, 2000-2010

Accounting element	Nitrogen (N) input level	% share of all cropland	% share of all grassland
Starting year (2000)	**a) < 50 kg/ha/year**	**59.3**	**47.3**
	b) 50-100 kg/ha/year	**31.2**	**33.7**
	c) 100-150 kg/ha/year	**6.6**	**10.8**
	d) > 150 kg/ha/year	**2.9**	**8.2**
	Grand total	**100.0**	**100.0**
Closing year (2010)	**a) < 50 kg/ha/year**	**66.6**	**55.6**
	b) 50-100 kg/ha/year	**22.5**	**29.8**
	c) 100-150 kg/ha/year	**7.7**	**8.8**
	d) > 150 kg/ha/year	**3.2**	**5.8**
	Grand total	**100.0**	**100.0**
Trend in average N-input per ha/year	**Overall trend index (%)**	**-7.8**	**-14.9**
Share of area with low input level (< 50 kg/ha/year)	**Low input trend index (%) (over 10 years)**	**7.3**	**8.3**

Note: The trend figures presented above exclude data for Croatia, as it was not available.

The available data suggest that the area share of the N input category of below 50 kg N/ha has increased over the period monitored, whereas the area shares of all higher N input levels have decreased. Analysis based on the average N input level per hectare for the entire area covered would not have identified these sub-trends. However, the approach presented above includes only a coarse spatial representation and lacks sensitivity with regard to the response of different grassland ecosystem sub-types to N input. For example, highly productive grasslands are adapted to N input levels of 100kg N/ha or more but are often species poor. The botanical species diversity of semi-natural grasslands can only be maintained if yearly N input levels stay below 30 kg N/ha. However, in the table above 50 kg/ha was chosen as threshold for the low input category to take account of data distribution and uncertainty.

Analytical uses

Spatial Nutrient Pressure Condition Accounts are likely to have a fairly wide range of uses in a number of different policy contexts, notably with respect to the WFD and CAP. Some key analytical uses to improve land and environmental management decision with respect to natural capital include:

- Identifying which ecosystems are affected in a spatially explicit approach.
- Identifying where nutrient pressure hot-spots exists.
- Identifying where nutrient pressure may be impacting on particularly sensitive ecosystems assets, for example water courses, lakes and wetlands that may suffer from eutrophication.
- Providing aggregate measures of nutrient balances by land use for macro-level planning. For example, with respect to setting fertiliser taxes / subsidy reform.
- Informing combined presentations with other ecosystem accounts to understand where nutrient pressure threatens areas of high biodiversity or ecosystem service delivery.
- Exploring the trade-offs between agricultural output and ecosystem condition in a spatially explicit manner.

The flexible nature of the data underlying the accounts can also support spatial statistical or econometric modelling to explore the relationships between nutrient pressure and other environmental and economic data of interest. Key applications in this regard would be in relation modelling at FSUs in the context of CAPRI data or aligning data on nutrient pressures with WFD data on water quality at the waterbody scale (see EU Water Directors, 2016).

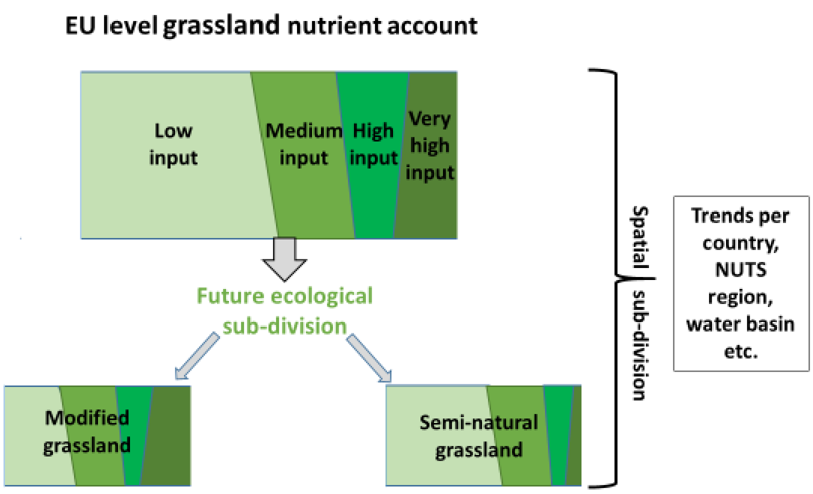
The capacity of ecosystems to mediate nutrient pollution could be related to their location with respect to Nitrate Vulnerable Zones. These are areas of land which drain into polluted waters or waters at risk of pollution and which contribute to nitrate pollution (EC, no date). Integration of spatial nutrient balance data with data on the location of Nitrate Vulnerable Zones can inform on where to target action to ameliorate wide spread nitrate impacts. However, designation of NVZ is not consistent across countries, some countries assess their entire territory as an NVZ (e.g., Germany, Romania and Sweden) (see JRC, no date).

Other data may provide more widespread insight into the capacity of ecosystems to mediate nutrient leaching and run-off, for instance soil structure, groundwater condition, slope and net primary production could all be key in determining this and should have spatial data that are readily available (e.g., the input data for defining FMUs). It is noted the primary production is closely related to the uptake of nutrients by crops, so there may be some circularity associated with including this as an indicator of such capacity. Nonetheless, this approach potentially offers a pathway to calculating ecosystem service accounts related to "Regulation of the chemical condition of freshwaters by living processes" (Haines-Young and Potschin, 2018). Understanding rates of application and location of freshwaters allows a level of demand for this service to be established. There will also be a wider ecosystem services where the links to these can be made (e.g., the cultural ecosystem services discussed in the preceding section).

Nutrient balances may also be useful for exploring where nutrient mining may be occurring, the converse to the issue of excessive nutrient loading. Given soil nutrients represent a significant natural capital asset with substantial socio-economic benefits identifying the scale and location of this problem is a key conceptual concern. However, it is not necessarily the case that this would be a significant issue for the European landscape.

Figure 3 illustrates how the spatial nutrient accounts could be further developed to identify ecosystem sub-types and areas that require policy action to reduce nutrient pressures. Work is under way to develop further spatial detail and extend the current times series to 2018. This will allow the presentation of spatial nutrient accounts that have more analytical power and provide concrete policy input, e.g. on the nutrient pressures inside Natura 2000 areas compared with those of general farmland.

Figure 3 Further development of spatial nutrient accounts for grassland ecosystems



The pilot nutrient ecosystem condition account shows how the accounting methodology can be used to show spatial trends for these key ecosystem condition parameters. Future work at EU level could develop such an accounting approach together with shared data platform for tracking the condition of European ecosystems over the coming years.

The spatial foundation for the pilot nutrient accounts enables the identification of pressure hot spots, where ecosystem thresholds have been exceeded. This adds spatial detail to the analysis of the condition of agro-ecosystems, which could be used to address nutrient reduction targets in the EU biodiversity strategy for 2030, for example.

Summary

The rich spatial data and spatial infrastructure underpinning the Nutrient Pressure Condition Accounts is very flexible and multiple analysis of the data is possible. However, given these manifold applications, some methodological recommendations for testing the compilation and use of the Spatial Nutrient Pressure Condition Accounts in the context of policy priorities are required. Key recommendations in this regard comprise the following:

- In order to support KIP INCA and MAES an EU scale account by MAES ecosystem type would be a key contribution and should be progressed. This should include on building on deposition data for ecosystems outside crop- and grassland ecosystem types. This would allow communication of macro level trends. Linking this approach to spatial data on the distribution of particularly sensitive ecosystems to nutrient pressure would be very relevant for directing sustainable management of ecosystems and natural capital.

- The stepwise approach summarised in Figure 1 reveals that multiple datasets are derived on the nature of nutrient inputs and outputs in a spatially explicit manner. As such, an accounting structure that can capture this rich set of information in a comprehensive manner could be developed.

- Ecosystems usually do not react immediately to changes in pressures and there may be significant time lags in their response time. As such pressure and environmental state indicators are both important measures and policy relevant. It would be useful to explore the potential for integration or combined presentation of Spatial Nutrient Pressure Condition Accounts and other ecosystem condition accounts being progressed by the EEA (e.g., biodiversity or water quality).

- It would be useful to explore combined presentations with other ecosystem accounts or spatially referenced data to understand links or correlations with ecosystem services. This could include providing information on "Regulation of the chemical condition of freshwaters by living processes", links to cultural ecosystems services based on the direct interaction with nature and trade-offs with respect to agricultural production.

- As part of a geospatial database the data underpinning the spatial nutrient pressure condition accounts is very flexible and can support many analytical applications of policy interest. Key possibilities for statistical spatial analysis of the relationships between nutrient pressures and other environmental concerns could be explored using by aligning nutrient data to water bodies (the spatial statistical unit for WFD reporting) or the FSU used by CAPRI.

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Appendix A: Spatial nutrient accounts data processing work flow

This workflow consists of 12 steps in total, several of which are broken down into sub-steps. They describe the data processing steps required for producing interim data layers and the final spatial nutrient accounts.

	Step	Input datasets	Processing	Result
1)	**Create a spatial layer of cropland and grassland farming across Europe**	• 1a) Farm Structure Survey crop area at 10 x 10 km grid, gap-filled, for the year 2010 (other years not yet available) • 1b) Distribute FSS gridded data into spatial units, taking into account land not available for agriculture. • 1c) CAPRI crop area at NUTS2 level for time series 2000 – 2018. This is done first for the CAPRI base year (2012) and then for the entire time series.	Distribute crop areas from 1c to FSU to (i) match regional totals and (ii) respect environmental limits for altitude and slope as derived from the LUCAS database.	A) Crop and grassland area at FSU level for time series (2000 – current year-2).
2)	**Create spatial layer on mineral N fertilizer application**	• 2a) Country statistics on the use and application of mineral fertilizer by major crops for time series • 2b) Mineral fertilizer application by crop at NUTS2 level from CAPRI for time series based on 2a) • Crop and grassland area at FSU level (Result A from step 1) for time series • Crop yield at FSU level (Result H from step 8) for time series • 2c) Crop nutrient requirements based on CAPRI look-up table of crop N contents	Disaggregate 2b) to the FSU level based on crop distribution, and crop N requirements, taking into account other sources of N and crop requirements The disaggregation of mineral fertilizer and manure application is done	B) Mineral N application to crops and grassland area at FSU level for time series (2000 – current year-2).

			simultaneously, taking into account available N from N deposition, biological fixation and crop residues.	
3)	**Create spatial layer for livestock distribution as preparation for step 4**	• 3a) Farm Structure Survey livestock numbers at 10 x 10 km grid, gap-filled, for the year 2010 (other years not yet available) • 3b) Distribute FSS gridded data into spatial units, taking into account land not available for agriculture. • 3c) CAPRI crop area at NUTS2 level for time series 2000 – 2018. This is done first for the CAPRI base year (2012, based on 2b) and then for time series ex-post (2000-2014; now-casting is possible for later years.	Distribute livestock to FSU to match regional totals. Non-grazing animals are distributed relative to agricultural area; animals grazing on farmland are distributed relative to agricultural area taking into account particularly roughage production; grazing outside farmland is based on CLC.	C) Livestock numbers (distinguishing dairy cattle, other cattle, sheep + goats, pigs, poultry and other animals) at FSU level for time series (2000 – current year-2)
4)	**Calculate nutrient excretion from livestock and create spatial layer for manure application to crops**	• 4a) Dynamic excretion rates calculated as animal budget: feed intake – retention in products and animal biomass = excretion. Combined with 3b) to calculate N excretion from livestock. • 4b) Application of manure N on crops based on CAPRI fertilizer module. The module takes into account crop N requirements, N availability and crop over-fertilization factors. CAPRI data at NUTS2 level for time series	Disaggregation of 4b) to the FSU level based on A) and C) taking into account other sources of N and crop requirements. The disaggregation of mineral fertilizer and manure application is done simultaneously, taking into account available N from N	D) Manure application to crops and manure deposition by grazing animals on grassland at FSU level for time series (2000 – current year-2)

			deposition, biological fixation and crop residues.	
5)	**Estimate amount of N fixed in crops**	Biological N fixation (BNF) data set; BNF is estimated as fraction of crop N uptake by crop type	Calculate N fixation from BNF, crop N requirements and crop type/yield (A and G)	E) BNF at FSU level for time series (2000 – current year-2)
6)	**Estimate total N deposition levels on cropland and grassland from air**	EMEP MSC-W modelled air concentrations and depositions	Data from the EMEP model, downscaled to 1km x 1km through distribution of 50x50km data to 1km grid <u>Note:</u> *atmospheric deposition depends on land cover. Assumption on land cover in EMEP must be considered during disaggregation.*	F) EMEP deposition data over grassland and cropland at FSU level Resolution required: preferably FSU, but also 1 km is OK, also NUTS2 if assumption that spatial variation small/uncertain
7)	**Create a spatial layer of crop yields**	7a) Eurostat statistics on crop production and yield at NUTS2 level for time series, checked for consistency within CAPRI Crop and grassland area at FSU level (Result A from step 1) for time series	Disaggregating crop production based on combining 7a) with A), taking additional information on irrigation, potential/rain-fed yield into account.	G) Crop yield at FSU level for time series (2000 – current year-2)
8)	**Estimate N contents in crops removed from the fields**	8a) Country-specific N contents for major crop groups / Eurostat 8b) Where data not available, CAPRI modelling *	CAPRI look-up table of crop N contents.	H) N removal with crop and grass biomass at FSU level for time series (2000 – current year-2)

			Combine with crop yield data (G) to estimate N removal at spatial level; straw and crop residues movements considered.	
Results				
9)	**Total Nitrogen input to cropland and grassland**	Datasets resulting from steps 2), 4), 5), 6)	Add up N inputs calculated in steps 2, 4, 5 and 6 at FSU level I=B+D+E+F	I) Total N input at FSU level for time series (2000 – current year-2) J) Total N input (K) mapped to 1x1 km raster layer
10)	**Total N output**	Dataset resulting from steps 7) + 8)	Take spatial N exports calculated in steps 8) per FSU and allocate values to each 1x1 grid cell per FSU	H) N removal with crop and grass biomass at FSU level for time series (2000 – current year-2) K) Total N output (J) mapped to 1x1 km raster layer
Accounting steps				
11)	**Produce accounting table for spatial N**	Combine 1x1 km raster layer results from steps 9) and 10)	Produce accounting tables with information at 1x1 km raster layer	L) N surplus for crops and grassland at FSU

	balance on spatial mask covered by results		L=J-K	level for time series (2000—current year-2) M) Corresponding accounting tables based on 1x1 km raster layer for agricultural land area
12)	**Relate results to MAES ecosystem types**	MAES dominant ecosystem type dataset to be produced for condition accounts	Overlay results on MAES dominant ecosystem type maps to produce information by ecosystem	N) Spatial data set on N-account at FSU level overlaid on relevant MAES ecosystem types (cropland and grassland)

*__Methodological note regarding N-removal with crops:__

- The CAPRI team points out that N removal concerns harvested material plus crop residues removed (as feed or bioenergy or burning or other use).
- Seeds for planting are currently not considered in the CAPRI N-balance at FSU level as input. This should ideally be changed. It is not clear whether it will be possible to work on this for the 2018 product.

**__Methodological note regarding denitrification:__

- Denitrification is part of the methodology proposed in the ecosystem accounting literature.
- Total soil N-surplus is differentiated into leaching and denitrification. However, the CAPRI team considers that the factual evidence that documents the denitrification process is low, data are uncertain. Therefore it is probably better to work with total surplus.

Appendix B: Input and derived CAPRI data used in the accounting approach

Since Eurostat has released gridded FSS data sets for Commission internal use the CAPRI team has built on this data set for producing a more accurate estimate of the spatial distribution of agricultural activity in Europe (led by staff at JRC Ispra). This builds on producing gap-filled 10 x 10 km data sets on basic agricultural statistics (crop areas, livestock numbers). EUROSTAT provided crop and livestock statistics for 3 grid levels (10x10km grid, 20x10 km grid and 60x60 km grid) and 3 administrative levels (NUTS3, NUTS2, Country). The gridded FSS data provided by EUROSTAT is subject to confidentiality rules. Values have been removed where they represented data from less than 5 holdings in each individual grid cell, or where 1 or 2 holdings explain at least 85% of the information in the spatial unit. The higher the resolution, the more data was subject to confidentiality treatment (i.e. the higher the resolution the more crop area / livestock units were missing).

The JRC Ispra CAPRI team used the information from the NUTS2/3, 60x60km and 20x20km grids to gap-fill the 10x10km grid data (for example areas of the single crops at 10km x 10km had to match the area of the crop at 20km by 20km and at 60km by 60km and at NUTS2/3 level). The 10km x 10km grid is thus the highest resolution with quasi-statistical information, and therefore in this project the spatial unit has been re-defined to take this grid as delineating factor (→ FSU = Farm Structure Unit), removing the previous delineation of a 0.25 x 0.25 lon-lat grid. As described above, in a first step, the FSS gridded data are distributed over the FSU. In subsequent steps the grid is not used any more in the disaggregation of CAPRI statistics, however, the algorithms is such to maximize 'stability' in the time series (see Bujnowska et al. (2019) for details).

It is therefore clear, that the regular 10km x 10km grid is visible in the map output.

Based on the parameters delivered in CAPRI, different aggregates can be calculated, based on accounting requirements. Some are already included as parameters in CAPRI, such as NinSoi or Sursoi, other such as the N-input from manure and mineral fertiliser or the Gross Nitrogen Budget can be calculated by using the following formula:

Total excretion of N in manure

EXCRET = NMANAP + NMANGR + MANLOSSES + MMSLOSSES

N input from manure and mineral fertilizer, with

N input = NMANAP + NMANGRA + MANLOSSES + NMINSL + MINLOSSES+ MMSLOSSES

N inputs to soil (NinSOI) refers to N that 'enters the soil' with possible fates being

uptake (NRET) and surplus (SURSOI), it represents input as the farmer applies, emissions from application have yet to occur

NinSOI = BIOFIX + NMINSL + NMANAP + NMANGR + ATMOSD + CRESID

Hence, the Total N input includes NinSOI and losses from mineral fertiliser and manure applications: NinSoi + MINLOSS+MANLOSS

Soil surface surplus all gaseous emissions from manure and mineral fertilizer as well as runoff already subtracted. It equals N-leaching and denitrification (N_2)

SURSOI = NinSOI – NRET

Gross Nitrogen Budget

GNB = SURSOI + MANLOSSES + MINLOSSES + MMSLOSSES.

The aggregates are calculated per FSU and can be mapped using the FSU reference layer.

The geo-spatial processing of the data for the purpose of this analysis consists of the following steps: [*to be completed*]

Table 6 Overview of input data for CAPRI

Data and model inputs	Data producer / main data source	Spatial Resolution / countries covered	Time series / regularity	Any future improvement envisaged	Disaggregation process or other data preparation (if required)? By whom and how ?	Data set owner (in context of producing derived data sets)
1a) Land use	FSS 10 km gap-filled i.e. Gridded Farm Structure Survey data (Eurostat)	10km	2010 (2000 if possible), every 10 years (envisaged)		Based on nested FSS data at 10x10 km2, 20x20 km2 and 60x60 km2, Nuts2 and Nuts3 keeping confidentiality rules. Gap-filled	Eurostat/JRC
1b) Land use	CAPRI (i) constrained at 10 km; (ii) constrained at CAPRI NUTS2	FSU (from CAPRI approach)	2000-2012 (CAPRI base year) + individual points until current year - 2		Combining 1a and 1b – constraining 1a to 1b, then constraining result to CAPRI NUTS regions for base year, then to time series	JRC-CAPRI
2a) N fertilizer application	Country data on use and application of mineral fertilizer	NUTS0	Yearly			EFMA
2b) N fertilizer application	Mineral N application rate by crop	NUTS2	Yearly			CAPRI team
2c) N fertilizer application	Mineral N application rate by crop	FSU	Same as 1c		Disaggregated from 2b)	JRC-CAPRI

3a) Livestock numbers	Gridded Farm Structure Survey data (Eurostat) – Gap-filled	10km	2010 (2000 envisaged), every 10 years		Further processing is currently required to integrate data set into CAPRI model / for other uses	Eurostat / CAPRI team
3b) Animal livestock numbers	CAPRI livestock disaggregation	FSU	Reference year 2012		CAPRI regional data building on Eurostat statistics, distinguishing dairy cattle, other cattle, sheep + goats, pigs, poultry and other cattle; disaggregation data from 3b)	JRC-CAPRI
4a) Manure	Dynamic excretion rates	NUTS0	Yearly		Calculated as animal budget Feed intake – retention in products and animal biomass = excretion	CAPRI team
4b) Manure	Application of manure N on crops	NUTS2	Yearly		Based on CAPRI fertilizer module, application rates depending on crop N requirements and N availability, crop over-fertilization factors. Data calculated at NUTS2 and disaggregated to FSU level	CAPRI team
4c) Manure	Application of manure N on crops	FSU	Same as 1c)		Data from 4b) disaggregated to FSU level.	JRC-CAPRI
5e) Biological N fixation (BNF) rates	Biological N fixation	NUTS0			BNF as fraction of crop N uptake by crop type	CAPRI team
6a) Total N deposition levels	EMEP MSC-W modelled air		Yearly			

	concentrations and depositions					
7a) Crop yields	Eurostat statistics on crop production of major crop groups	NUTS2	Yearly (2000-2010)	Review needed	Eurostat statistics downscaled according to CAPRI to NUTS2 level.	CAPRI team
7a) Crop yields	Crop production of major crop groups	1km	Yearly (2000-2010)	Review needed	Disaggregation of 7a) to FSU level using additional information on irrigation (FAO and FSS) and potential and rain-fed yield (PESETA project).	JRC-CAPRI
8) N and P contents in crops	Country-specific N and P contents for major crop groups / Eurostat	EU	Static		CAPRI look-up table of crop N contents. Calculation with crop yield data.	na

Table 7 Overview of delivered parameters of the CAPRI model

Parameters	Definition
ATMOSD	Atmospheric N deposition (kg/ha)
BIOFIX	Biological N fixation (kg/ha)
CRESID	Crop residuals (kg/ha)
MANLOSSES	Manure losses from manure after application (NH_3, N_2O, NOX, run-off) (kg/ha)
MINLOSSES	Mineral fertiliser losses (NH_3, N_2O, NOx, runoff) (kg/ha)
MMSLOSSESS	Losses from manure management systems (kg/ha)
NMANAP	Manure input net of all surface losses. Part applied intentionally to agricultural land (kg/ha)
NMANGR	Manure input net of all surface losses. Part deposited by grazing animals (kg/ha)
NMINSL	Mineral fertilizer N input net of gaseous losses and run-off (kg/ha)
NRET	N Uptake (kg/ha)
NinSOI	N input to the soil (kg/ha)
SURSOI	Surplus to soil (kg/ha)
YILD	Crop yields (kg/ha)
LEVL	Cultivation of crops [1000 ha] (1000 ha)
LEVLLIVESTOCK	Number of animals [1000 head] or [1000000 head for poultry]