FERTIMANURE
Innovative nutrient recovery from secondary sources – Production of high-added value **FERTI**lisers from animal **MANURE**

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D1.4.

REPORT ON THE NUTRIENT IMBALANCE ANALYSIS

FERTIMANURE

This project has received funding from
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Deliverable

Project Acronym: FERTIMANURE

Project full name: Innovative nutrient recovery from secondary sources – Production of high-added value FERTIlisers from animal MANURE

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D1.4. Report on the nutrient imbalance analysis

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Executive summary

In FERTIMANURE WP1 (*FERTIMANURE framework*), the animal manure value chain was evaluated by (i) analysing the current scenario in the on-farm experimental pilots, (ii) defining the current market situation of bio-based fertilizer products, and (iii) identifying the main barriers (i.e. politic, economic, social, environmental and legal). Task 1.4 (*Regional nutrient imbalance analysis*) aimed to review the literature of nutrient imbalances between regions in Europe to better predict where the nutrients recovered in FERTIMANURE can contribute in the long-term sustainability of production agriculture.

Deliverable 1.4 (*Report on the nutrient imbalances analysis*, deadline M13) aims to understand if the need of nutrients for national agricultural production can be satisfied with only the recovery of nutrients derived from animal manure and other biomasses. Specifically, D1.4 reports the results of the nutrients imbalance analysis carried out in Task 1.4.

The deliverable is structured as follow:

- General introduction describing Task 1.4, the deliverable structure and the methodology used to perform the nutrients imbalances analysis;
- Results analysis divided into chapters, one for each country;
- Comparison of the results obtained with additional local data, when available;
- Overall conclusions.

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List of Abbreviations

BL: Belgium

DE: Germany

ES: Spain

FR: France

IT: Italy

NL: The Netherlands

APF: Arjan Prinsen Farm

BNAE: Balance of Nitrogen and Phosphorus in Spanish Agriculture

EMEP/EEA: European Environmental Assessment and Control Programme

EUROSTAT: European statistics

ha: hectar

IPCC: Intergovernmental Panel on Climate Change

kg: kilogram

NUTS: nomenclature of territorial units for statistics

SD: standard deviation

SEI: Spanish Inventory System

ton: tone

WP: work package

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Main definitions

compost N: N input to soil from compost application

compost P: P input to soil from compost application

grazing N: N input to soil from grazing activity (i.e. N or P contained in the excreta of grazing animals)

grazing P: P input to soil from grazing activity (i.e. N or P contained in the excreta of grazing animals)

manure N: N input to soil from animal manure application

manure P: P input to soil from animal manure application

mineral fertilizer N: N input to soil from mineral fertilizers application

mineral fertilizer P: P input to soil from mineral fertilizers application

N crop uptake: N output from soil to plants

non anthropic N: N input to soil from atmospheric deposition and N bacterial fixation

P crop uptake: P output from soil to plants

sludge N: N input to soil from sludge application

sludge P: P input to soil from sludge application

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1. Introduction

The FERTIMANURE concept integrates a set of innovative treatment schemes aiming to efficiently valorise animal manure and obtain fertilizing products with high added-value. FERTIMANURE pursues the improvement of several technologies that are either currently under development or that have been successfully used for other similar applications and proposes innovative integrated solutions to finally reach a zero-waste manure management approach. In WP1 (*FERTIMANURE framework*), the animal manure value chain was evaluated by (i) analysing the current scenario in the on-farm experimental pilots, (ii) defining the current market situation of bio-based fertilizer products, and (iii) identifying the main barriers (i.e. politic, economic, social, environmental and legal).

Task 1.4 (*Regional nutrient imbalance analysis*, M1-M13, Task leader: UMIL) aimed to review the literature of nutrient imbalances between regions in Europe to better predict where the nutrients recovered in FERTIMANURE can contribute in the long-term sustainability of production agriculture. The activity of Task 1.4 was carried out by reviewing and analysing available literature, databases and results from recently completed and ongoing projects on nutrient flows at field and farm level (e.g. H2020 Nutri2Cycle SFS-30-2017-H2020).

Deliverable 1.4 (*Report on the nutrient imbalances analysis*, deadline M13) reports the results of the nutrients imbalance analysis carried out in Task 1.4. Following a general introduction describing Task 1.4 and the methodology used to perform the nutrients imbalances analysis, the deliverable reports the results divided in six subsequent chapters, each dedicated to one country. D1.4 reports the data regarding the annual inputs and uptake of nitrogen (N) and phosphorus (P) from the soils of six European countries: Netherlands, Spain, Germany, Belgium, France and Italy. The data were aggregated according to the “Nomenclature of Territorial Units for Statistics criterion”, at level 2 (NUTS2) and were obtained from EUROSTAT database.

For each of the six nations, the inputs of nitrogen and phosphorus to the soil from manure, mineral fertilizers and other sources of secondary importance (sludge, compost, grazing and non-anthropogenic sources) are reported. In addition to the inputs, the document also reports the uptake data for nitrogen and phosphorus from the same soils.

This allows to calculate the annual nitrogen and phosphorus balances for the soils of the countries analysed, however without considering the outputs such as emissions and losses, due to volatilization (for nitrogen) and leaching (for nitrogen and phosphorus).

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For each of the nations analysed in this deliverable, two balances were calculated. The first evaluates the nutrient situation in the soils at the current state, thus adding all the available inputs and subtracting the uptake, according to the formula below:

N balance:

$$(manure\ N + mineral\ fertilizer\ N + sludge\ N + compost\ N + grazing\ N + non\ anthropic\ N) - N\ crop\ uptake$$

P balance:

$$(manure\ P + mineral\ fertilizer\ P + sludge\ P + compost\ P + grazing\ P) - P\ crop\ uptake$$

The second balance, called "sustainability of nitrogen and phosphorus from animal sources", evaluates the scenario that completely excludes the use of mineral fertilizers. To calculate it, the following formula was used:

Sustainability of nitrogen from animal manure sources:

$$(manure\ N + sludge\ N + compost\ N + grazing\ N + non\ anthropic\ N) - N\ crop\ uptake$$

Sustainability of phosphorus from animal manure sources:

$$(manure\ P + sludge\ P + compost\ P + grazing\ P) - P\ crop\ uptake$$

Results of the nutrient imbalance analysis using EUROSTAT data were commented by each WP1 partner.

The exclusion of N and P inputs from mineral fertilizer sources from the balance is particularly useful to understand if the need of nutrients for national agricultural production can be satisfied with only the recovery of nutrients derived from animal manure and other biomasses. The overview of soil N and P balances on a NUTS2 scale also allows for the organization of a possible redistribution of recovered nutrients within the countries.

A comparison of the results obtained with NUTS2 data and local data is included in the deliverable. Each partner provided information based on national and regional data (when available), indicating if they agreed or not with EUROSTAT data.

Overall conclusions are reported in the last chapters of the deliverable.

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2. Data

2.1. Netherlands

In the Netherlands, an intensification of animal production has taken place since approximately 1950 (Lesschen et al. 2013). This development has led to a high production of manure in areas of the Netherlands where the intensity of farms is high, especially in regions in the south-eastern provinces with mainly sandy soils. This surplus of manure production causes environmental problems due to the emission of nutrients as nitrogen (N) and phosphorus (P) to the air and to surface and groundwater systems.

Agriculture in the Netherlands is one of the most productive in the world, due to in part its soil fertility (Reijneveld, 2013). Part of this soil fertility was inherited from the sea and the river delta made up by the Rhine, Meuse and Scheldt. The other part is man-made, because the soils in the eastern and southern parts of the country originally were poor sandy soils and during decades have been fertilised with manure and mineral fertilizer nutrients. Although the expansion of agricultural production has slowed down from the mid-1980s, The Netherlands is still a major producer and international trader of flowers, meat, meat product, fruit, vegetables, beer, dairy product, starch derivatives and seed (Reijneveld, 2013). It ranks together with France on the second place on the list of exporters of agricultural products, behind the United States. Its production per hectare and per cow are among the highest in the world.

Governmental policies have resulted in strongly decreased N and P surpluses, ammonia emissions, and nitrate leaching to groundwater and surface waters in the last decades (Reijneveld, 2013). However, targets for surface water quality, groundwater quality, and nature (biodiversity) protection have not been achieved in all regions yet.

At present as one of the measures to reduce the nutrient surplus from manure and mineral fertilizer, the Dutch government is aiming for feed-manure cycles that should be principally closed on a regional, national or Northwest European level (Lesschen et al. 2013). The question is now how such a closed feed-manure cycle can be best achieved. The feed-manure cycle includes the import of feed from outside the Netherlands, but also the export of the food produced (meat, eggs and dairy products) to other markets outside the Netherlands. Although, a small part of the manure is exported as well, most of the manure that is produced in the Netherlands remains in the country and is used as a fertilizer or is being processed.

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2.1.1. Nitrogen and phosphorus from animal manure sources

The average annual supply of nitrogen from manure to soils in the Netherlands is 175 ± 11 kgN ha^{-1} and is above average in 4 out of 12 provinces. The small standard deviation indicates that all regions have values in any case very similar to the average, indicating that a large part of the country is heavily devoted to breeding.

The soils that receive the minimum amount of nitrogen from manure (Table 2.1.1) are those of the province of Noord-Brabant (164 kgN ha^{-1}), a southern area of the country (Figure 2.1.1). The province of Friesland instead, in the northern part of the Netherlands, receives the maximum annual nitrogen supply from manure (194 kgN ha^{-1}). This area is in fact heavily devoted to agriculture and breeding.

The input of phosphorus from manure is also uniform in the country, with 8 provinces slightly above the national average (37.9 ± 3.7 kgP ha^{-1}). The minimum input is observed for the province of Limburg (28.7 kgP ha^{-1}), which has a low agricultural vocation. The maximum input is instead observable for Groningen province (41.5 kgP ha^{-1}), a cultivated area.

Table 2.1.1. Nitrogen (N) and phosphorus (P) from animal manure and mineral fertilizer sources. The table reports the total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input from animal manure and mineral fertilizer sources on soils for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N from manure (kgN ha^{-1})	Mineral N (kgN ha^{-1})	P from manure (kgP ha^{-1})	Mineral P (kgP ha^{-1})
NL12	Friesland	194	141	39.6	2.42
NL31	Utrecht	191	128	41.4	2.41
NL21	Overijssel	185	145	38.8	2.88
NL33	Zuid-Holland	181	136	35.6	1.9
NL32	Noord-Holland	175	135	39.0	2.12
NL13	Drenthe	174	135	39.4	2.37
NL22	Gelderland	174	142	40.0	1.84
NL11	Groningen	172	142	41.5	2.16
NL23	Flevoland	164	154	39.2	2.04
NL34	Zeeland	163	134	33.6	1.95
NL42	Limburg	162	142	28.7	1.64
NL41	Noord-Brabant	160	147	37.5	2.23
Mean ± SD		175 ± 11	140 ± 6.9	37.9 ± 3.7	2.16 ± 0.3

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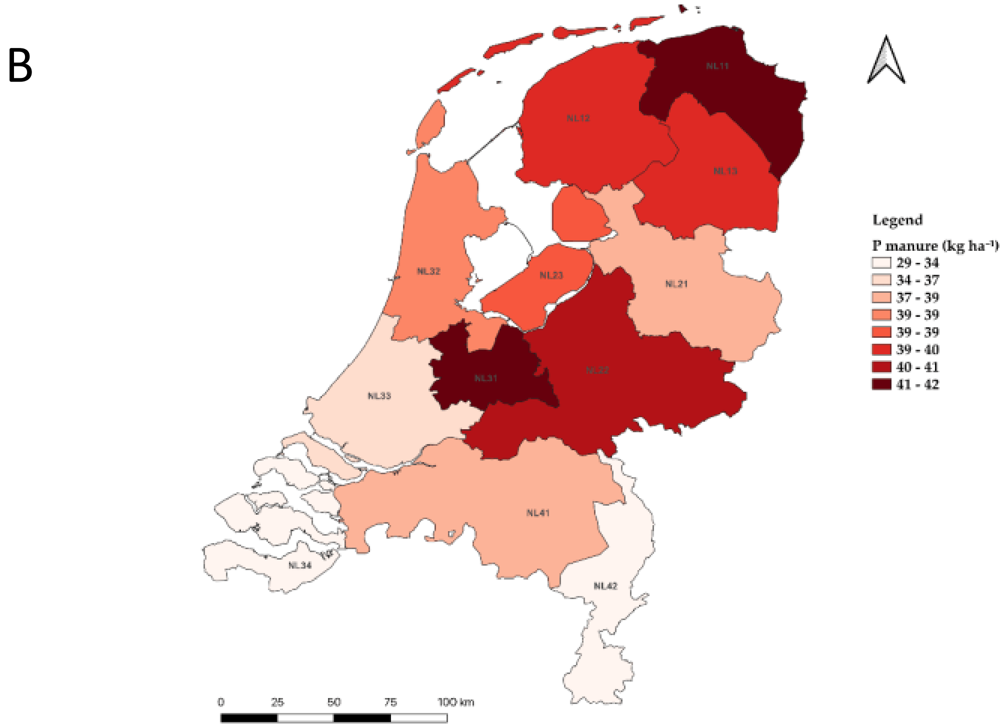
The Netherlands: N from animal manure sources



The Netherlands: P from animal manure sources

Figure 2.1.1. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources (kg ha^{-1}) in the Netherlands.

2.1.2. Nitrogen and phosphorus from mineral fertilizer sources

The average annual supply of mineral fertilizer nitrogen to Dutch soils is 140 ± 6.9 kgN ha^{-1}, an amount similar to that of nitrogen from animal manure sources (Table 2.1.1). The provinces that show an input of mineral fertilizer nitrogen to the soil equal to or higher than the national average is 6 out of 12. Also in this case, the standard deviation is very low, indicating that most of the provinces have at least partially agricultural vocation.

The soils that receive a lower annual amount of mineral fertilizer nitrogen (Table 2.1.1) are those of the province of Utrecht (128 kgN ha^{-1}), located in the centre of the country (Figure 2.1.2), while the greatest input is received by the soils of the province of Flevoland (154 kgN ha^{-1}), an area with clay soils and larger share in arable production.

The amounts of mineral phosphorus exploited are extremely low and uniform (Table 2.1.1), since animal manure is available and used in large quantities across the country. The national average is in fact 2.16 ± 0.3 kgP ha^{-1}, an order of magnitude lower than the amount of phosphorus from animal manure sources. The lower input is observed for the soils of Limburg (1.64 kgP ha^{-1}) in the extreme east of the country (Figure 2.1.2). The soils that receive the higher input are those in the province of Overijssel (2.88 kgP ha^{-1}), in the north east.

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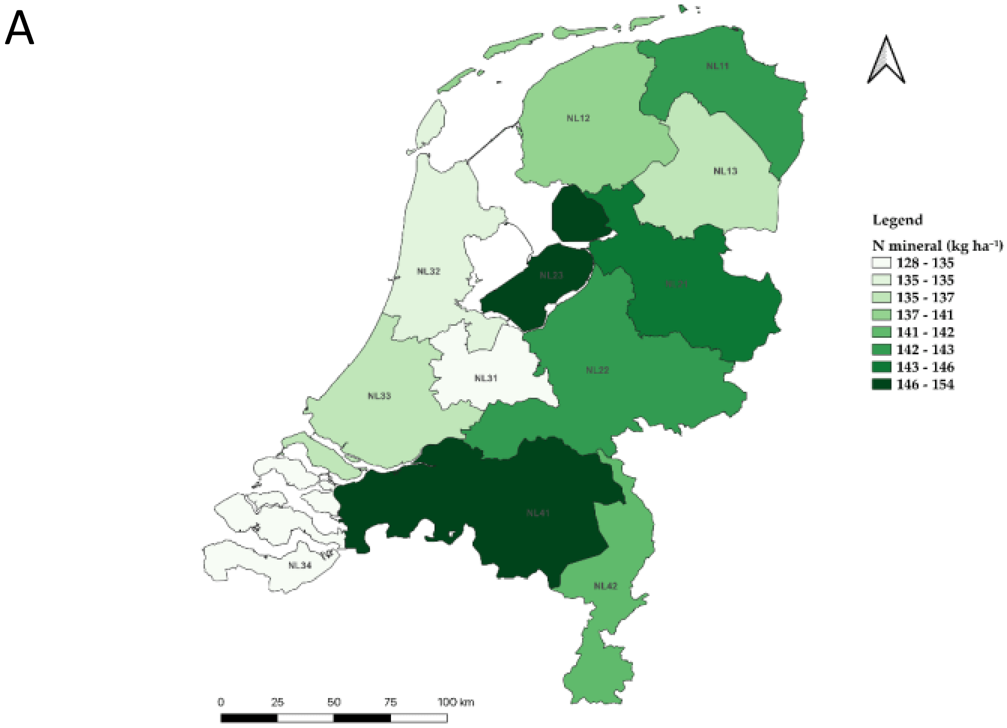
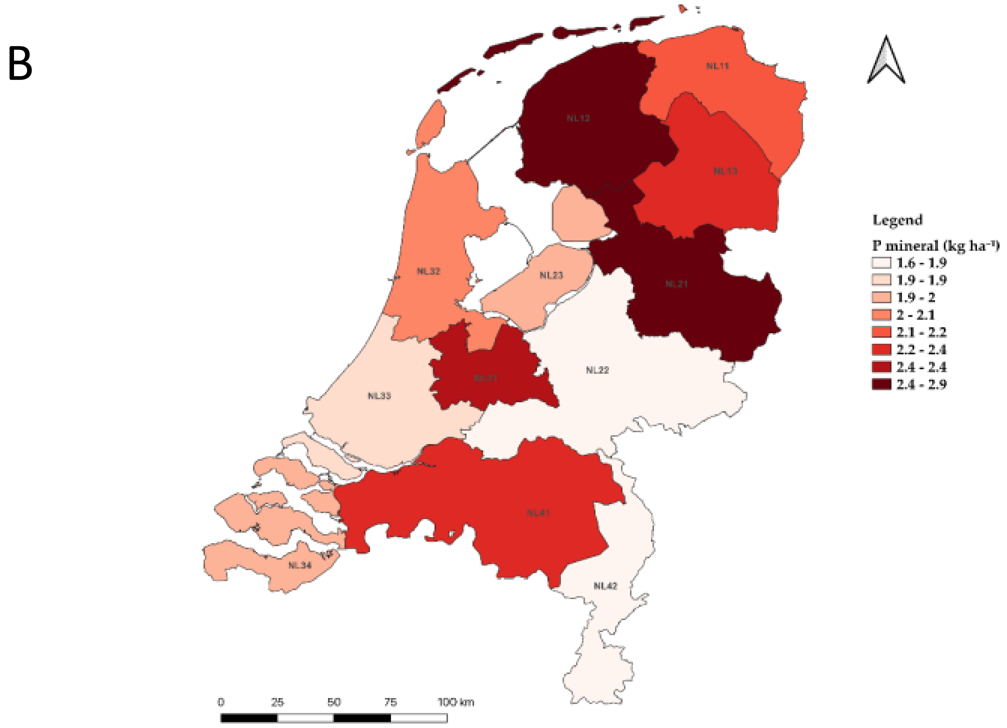


The Netherlands: N from mineral fertilizer sources



The Netherlands: P from mineral fertilizer sources

Figure 2.1.2. Thematic map for nitrogen (A) and phosphorus (B) from mineral fertilizer sources (kg ha^{-1}) in the Netherlands.

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2.1.3. Nitrogen and phosphorus from other sources

The input of nitrogen and phosphorus from other sources (

Table **2.1.2**) includes that deriving from the use of sewage sludge as fertilizers, compost, nitrogen and phosphorus contained in the excreta of grazing animals and the share of nitrogen received by the soil from non-anthropogenic sources, such as atmospheric deposition and nitrogen bacterial fixation.

As for nitrogen, of these four sources, excluding non-anthropic nitrogen, the largest fraction is on average the nutrient input from the excreta of grazing animals. The national average for nitrogen input to the soil at pastures is 31.4 ± 12 kgN ha^{-1}, with 6 out of 12 provinces showing amounts above average. The province that shows the lowest value is Zeeland (10.6 kgN ha^{-1}), in the south west of the country and overlooking the sea. Instead, the province characterized by the highest nitrogen input from pastures, is Utrecht (46.1 kgN ha^{-1}). On the other hand, the nitrogen input from sewage sludge is zero throughout the country. In the Netherlands the use of sludge from communal wastewater treatment in agriculture is practically zero. There are some small inputs by the use of sludge from industrial sources. The amounts of nitrogen from compost are also very low, the national average is 2.8 ± 1.1 kgN ha^{-1}.

Also in the case of the phosphorus input from other sources, the majority share is represented by the phosphorus from grazing animals, with a national average of 5.23 ± 2.5 kgP ha^{-1}. The province with the lower input of phosphorus on pastures is Gelderland (1.81 kgP ha^{-1}), while the highest input of phosphorus from pastures is in Utrecht region (9.46 kgP ha^{-1}). Finally, also in the case of phosphorus, the share of sewage sludge is practically zero throughout the country, while the compost phosphorus is extremely low (0.55 ± 0.2 kgP ha^{-1}).

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Table 2.1.2. Nitrogen (N) and phosphorus (P) from other sources. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soils from sources other than animal manure and mineral for each region analysed. Non-anthropic considers both inorganic deposition and biological fixation. Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})				**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**N from sludge**	**N from compost**	**N from grazing**	**Non-anthropic N**	**P from sludge**	**P from compost**	**P from grazing**
NL22	Gelderland	0	2.21	43.5	51.0	0	0.9	1.81
NL41	Noord-Brabant	0	3.54	39.0	49.0	0	0.85	2.01
NL42	Limburg	0	3.60	25.6	48.9	0	0.32	2.36
NL21	Overijssel	0	2.04	42.7	48.1	0	0.39	8.14
NL31	Utrecht	0	1.13	46.1	43.4	0	0.22	9.46
NL13	Drenthe	0	3.21	26	40.2	0	0.46	6.42
NL33	Zuid-Holland	0	2.17	32.1	39.2	0	0.76	3.76
NL11	Groningen	0	3.14	24.3	35.8	0	0.39	5.59
NL34	Zeeland	0	4.23	10.6	35.2	0	0.65	8.45
NL12	Friesland	0	1.22	42.5	35.0	0	0.51	6.27
NL23	Flevoland	0	4.25	16.1	34.6	0	0.57	4.07
NL32	Noord-Holland	0	2.85	28.5	30.6	0	0.53	4.47
Mean ± SD		0	2.8 ± 1.1	31.4 ± 12	40.9 ± 6.9	0	0.55 ± 0.2	5.23 ± 2.5

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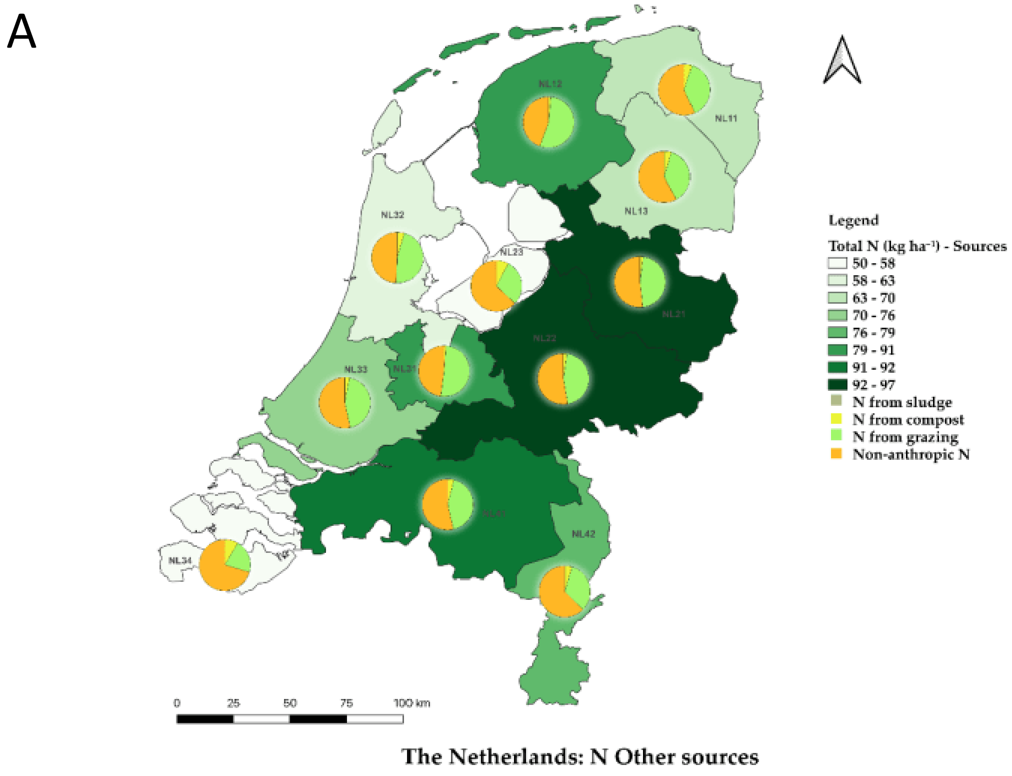

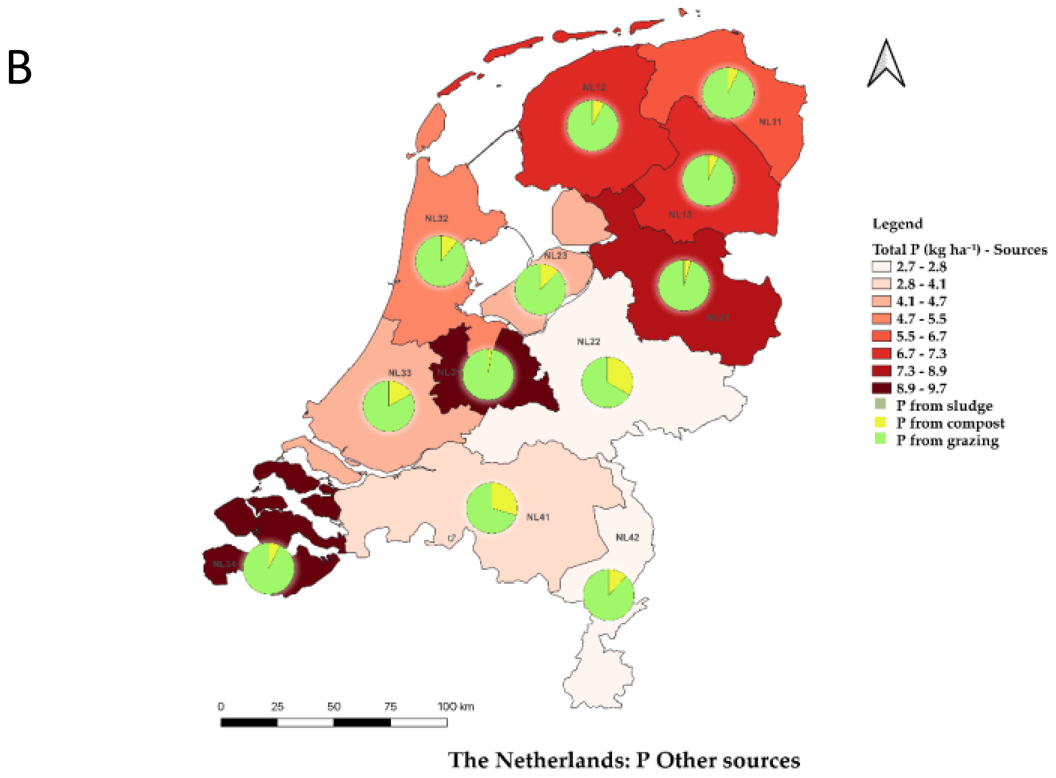

Figure 2.1.3. Thematic map for nitrogen (A) and phosphorus (B) from other sources (kg ha^{-1}) in the Netherlands.

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2.1.4. Nitrogen and phosphorus uptake by crops

The uptake of nitrogen and phosphorus from the soils (Table 2.1.3) depends on many factors, including mainly how much area is left to pasture, how much is put into cultivation and the types of crops grown.

The national average annual nitrogen uptake is 176 ± 37 kgN ha^{-1} and is fairly uniform across the country (Figure 2.1.4), demonstrating the strong and intensive agricultural production in the Netherlands. The province that shows the lowest nitrogen uptake is Groningen (97.6 kgN ha^{-1}), located north of the country and with a strong vocation for breeding. The maximum annual nitrogen uptake can be found in the province of Utrecht (237 kgN ha^{-1}), which is a central area of the country rich in pastures.

Annual phosphorus uptake is also uniform across the country and is proportionate and in line to nitrogen uptake in almost all provinces. The national average annual uptake for phosphorus is 25.8 ± 3.1 kgP ha^{-1}. The province that shows the least phosphorus uptake is Flevoland (20 kgP ha^{-1}) with a large share in arable farming, while the highest uptake is observed for the soils of the province of Friesland (30.8 kgP ha^{-1}) where large areas of grassland with dairy farming are situated.

Table 2.1.3. Nitrogen (N) and phosphorus (P) uptake. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual uptake by cultivated plants for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N uptake (kgN ha^{-1})	P uptake (kgP ha^{-1})
NL31	Utrecht	237	28.4
NL21	Overijssel	226	30.0
NL23	Flevoland	204	20.0
NL13	Drenthe	190	25.9
NL22	Gelderland	179	27.3
NL33	Zuid-Holland	178	24.1
NL41	Noord-Brabant	168	25.3
NL42	Limburg	168	23.2
NL12	Friesland	164	30.8
NL34	Zeeland	162	22.7
NL32	Noord-Holland	137	25.8
NL11	Groningen	97.6	26.5
Mean ± SD		176 ± 37	25.8 ± 3.1

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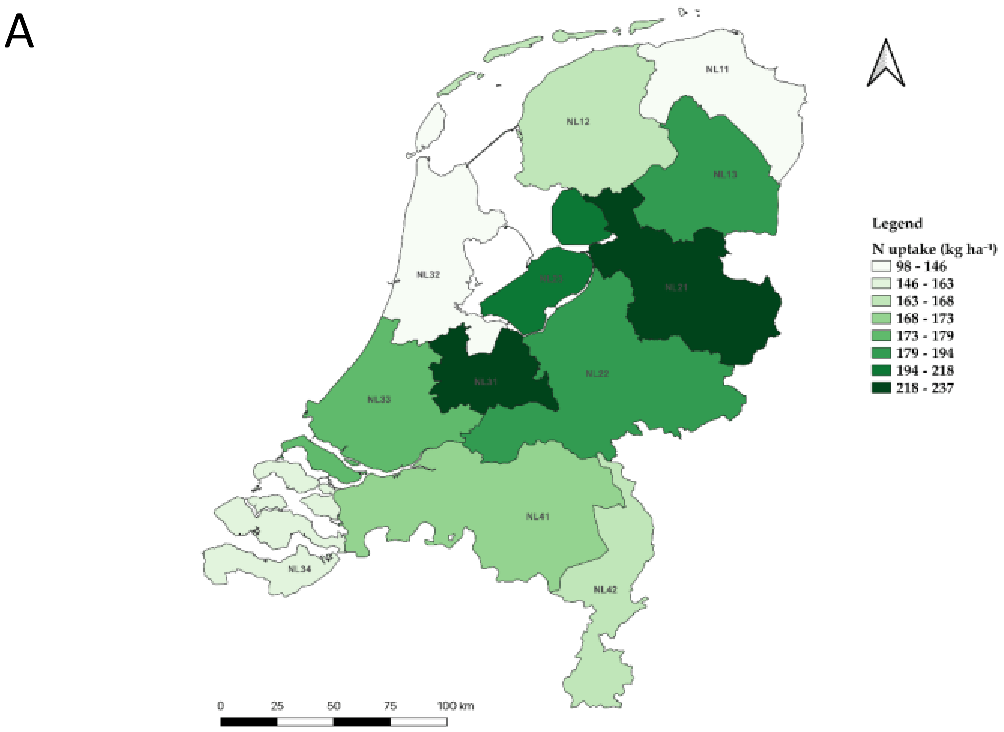
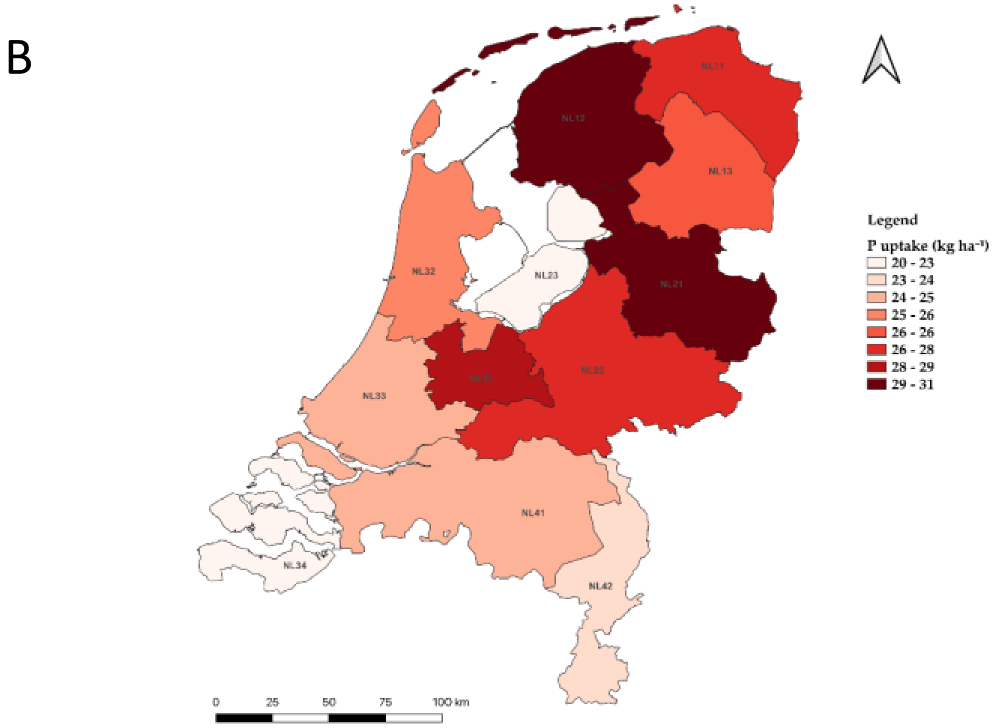


The Netherlands: N uptake by crops



The Netherlands: P uptake by crops

Figure 2.1.4. Thematic map for nitrogen (A) and phosphorus (B) uptake (kg ha^{-1}) in the Netherlands.

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2.1.5. Nitrogen and phosphorus soil balances

The results obtained for the annual soil nutrient balance (Table 2.1.4) describe a general situation for the Netherlands of strong positive nutrient balances, showing an excess for both nitrogen and phosphorus.

The country's average annual nitrogen balance is 214 ± 33 kgN ha^{-1}, with the province of Flevoland showing the lowest positive balance (168 kgN ha^{-1}), while the highest annual nitrogen excess is for the soils of the province of Groningen in the north of the Netherlands, with 280 kgN ha^{-1} surpluss.

The annual balance phosphorus in soils is instead less critical, with a national average of 20 ± 4.3 kgP ha^{-1}. The province that shows the lowest excess of phosphorus is Limburg, with 9.87 kgP ha^{-1}, while the highest observed excess is in the province of Flevoland, with 25.8 kgP ha^{-1}.

Table 2.1.4**.** Nitrogen (N) and phosphorus (P) balances. The table reports the difference between total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil and their annual uptake by crops by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**Total N input**	**N uptake**	**N excess**	**Total P input**	**P uptake**	**P excess**
NL11	Groningen	377	97.6	280	49.7	26.5	23.1
NL12	Friesland	414	164	250	48.8	30.8	18.0
NL32	Noord-Holland	372	137	235	46.2	25.8	20.4
NL22	Gelderland	413	179	234	44.6	27.3	17.3
NL41	Noord-Brabant	398	168	230	42.6	25.3	17.3
NL42	Limburg	382	168	214	33.0	23.2	9.87
NL33	Zuid-Holland	391	178	213	42.0	24.1	17.9
NL21	Overijssel	423	226	197	50.2	30.0	20.2
NL13	Drenthe	379	190	189	48.6	25.9	22.8
NL34	Zeeland	347	162	185	44.6	22.7	21.9
NL31	Utrecht	410	237	172	53.5	28.4	25.1
NL23	Flevoland	372	204	168	45.9	20.0	25.8
Mean ± SD		390 ± 22	176 ± 37	214 ± 33	43.8 ± 5.2	25.8 ± 3.1	20 ± 4.3

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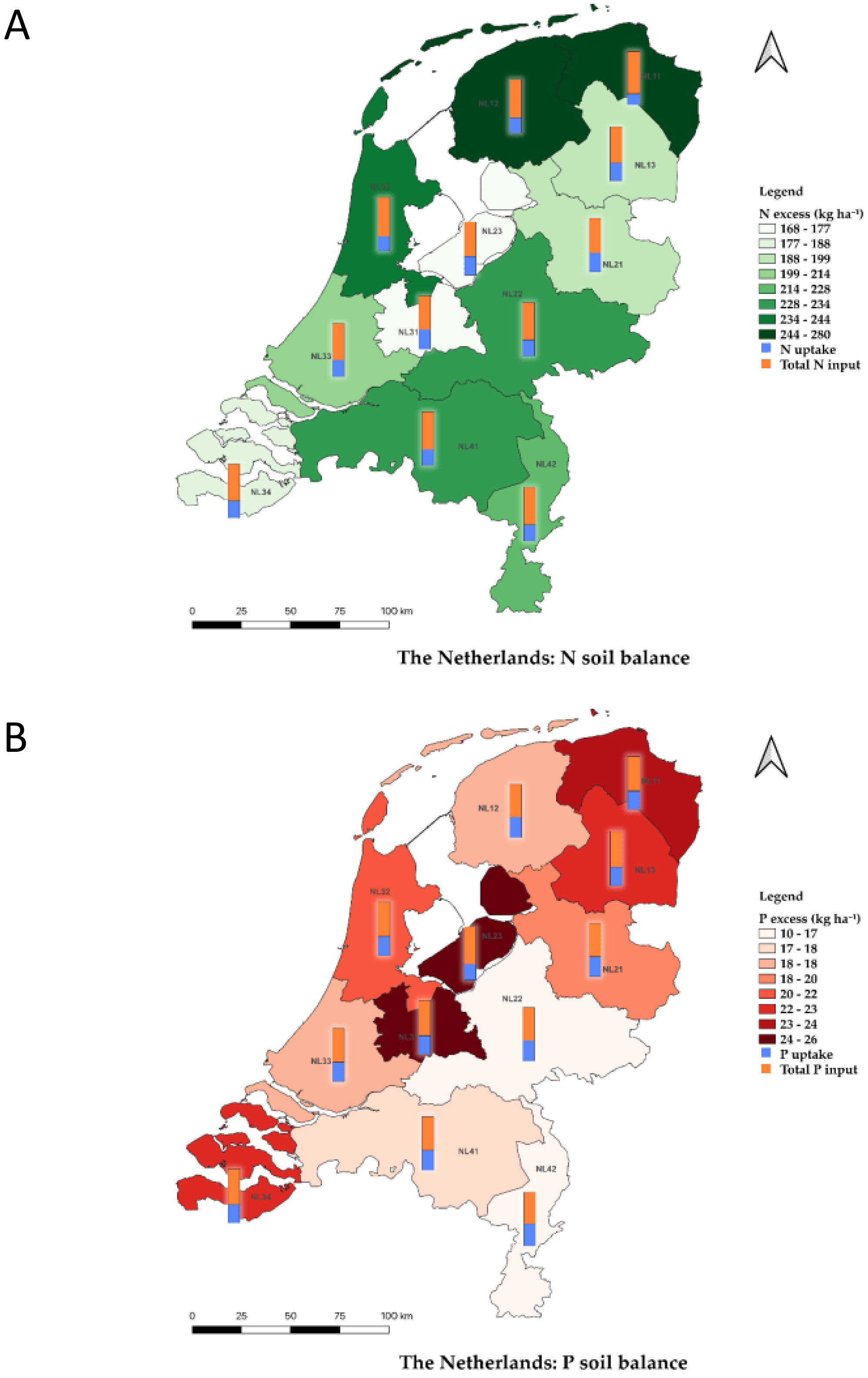

Figure 2.1.5. Thematic map for nitrogen (A) and phosphorus (B) balance (kg ha^{-1}) in the Netherlands.

2.1.6. Sustainability of animal manure sources

The exclusion of inputs from mineral fertilizer sources from the balance is particularly useful to understand if the need of nutrients for national agricultural production can be satisfied with only the recovery of nutrients deriving from manure and other biomasses. The balance on a NUTS2 scale also allows for the organization of a possible redistribution of recovered nutrients within the country. Data for this indicator in

Table 2.1.5 shows that all the provinces in the Netherlands maintain an excess of nitrogen and phosphorus (Figure 2.1.6), but with general reduced values compared to the scenario which also includes the use of mineral fertilizers.

The average annual balance obtained for nitrogen in this case is 73.9 ± 33 kgN ha^{-1}. None of the provinces has a nitrogen deficit even without using mineral fertilizer N.

The average annual budget for phosphorus for this indicator (17.8 ± 4.2 kgP ha^{-1}) is actually very similar to that obtained considering also the mineral fertilizer sources, since the annual mineral fertilizer phosphorus contribution to the soils of the Netherlands is very small (Table 2.1.1).

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Table 2.1.5. Nitrogen (N) and phosphorus (P) from animal manure sources vs uptake by crops. The table reports the difference between nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil (excluding the share deriving from mineral fertilizers) and their annual uptake by crops by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			Phosphorus (kgP ha^{-1})		
NUTS2	**Name**	**N input excluding mineral**	**N uptake**	**N excess**	**P input excluding mineral**	**P uptake**	**P excess**
NL11	Groningen	236	97.6	138	47.5	26.5	21.0
NL12	Friesland	273	164	109	46.4	30.8	15.6
NL32	Noord-Holland	237	137	99.8	44.0	25.8	18.2
NL22	Gelderland	271	179	91.7	42.7	27.3	15.4
NL41	Noord-Brabant	252	168	83.5	40.4	25.3	15.1
NL33	Zuid-Holland	255	178	77.0	40.1	24.1	16.0
NL42	Limburg	240	168	72.6	31.4	23.2	8.23

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NL13	Drenthe	244	190	53.9	46.3	25.9	20.4
NL21	Overijssel	278	226	51.8	47.4	30.0	17.3
NL34	Zeeland	213	162	50.6	42.7	22.7	19.9
NL31	Utrecht	282	237	44.5	51.1	28.4	22.7
NL23	Flevoland	219	204	14.3	43.9	20.0	23.8
Mean ± SD		250 ± 23	176 ± 37	73.9 ± 33	43.6 ± 5	25.8 ± 3.1	17.8 ± 4.2

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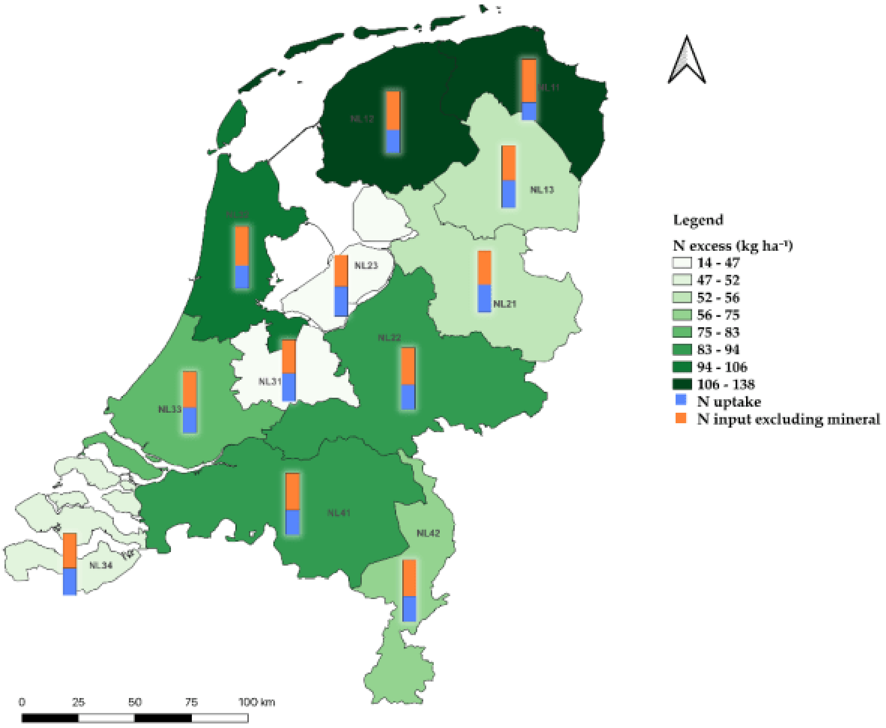
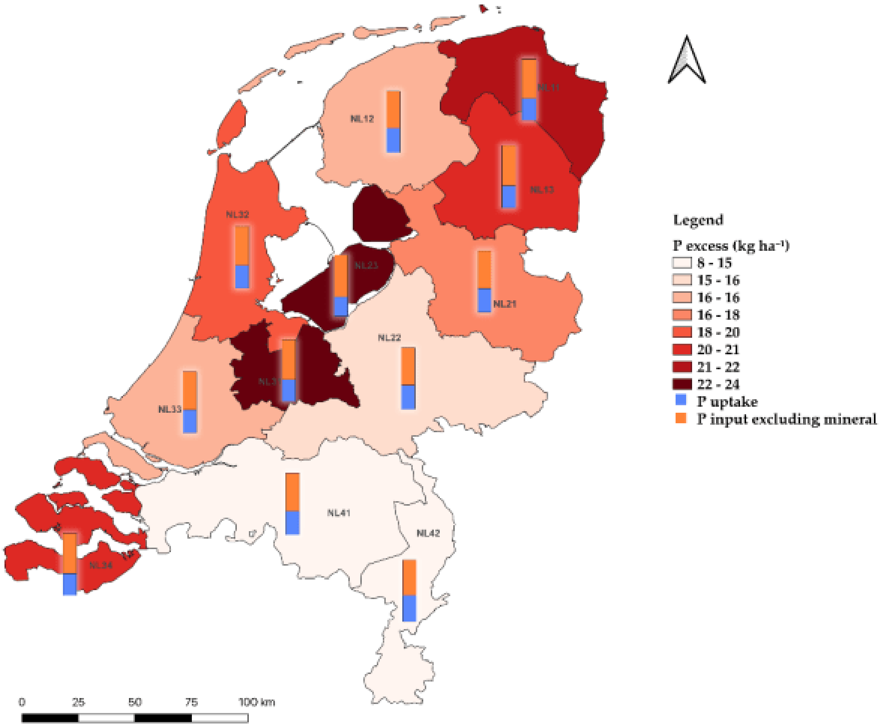


The Netherlands: N Sustainability of animal manure sources

B



The Netherlands: P Sustainability of animal manure sources

Figure 2.1.6. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources vs uptake by crops (kg ha^{-1}) in the Netherlands.

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The annual nitrogen and phosphorus balances for the soils of the Netherlands clearly indicate that the country can cover the soil needs of all the provinces with the sole use of animal manure sources. Nitrogen and phosphorus inputs from mineral fertilizer sources are therefore superfluous and eliminating them can help drastically reduce excess nitrogen in all the country's soils.

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2.2. Spain

Although Spain has a high density of livestock production, it is mainly concentrated in the Northeast (pig and poultry) and the Northwest (cattle) - this makes the distribution (even spreading) and the management of these wastes as fertilizer throughout the territory rather complicated. These are not the only critical waste sources which face difficulties for proper management. Other organic wastes facing similar density and distribution challenges are those from sewage treatment, which are mainly generated in those municipalities/regions with a high population density and low agricultural area, requiring their management as fertilizer to be carried out over large distances.

2.2.1. Nitrogen and phosphorus from animal manure sources

The average annual flow of nitrogen from manure to Spanish soils is 33.1 ± 22 kgN ha^{-1} and is above average in 5 out of 17 autonomous regions. There is a high standard deviation, indicating that there are large many differences between regions. The areas with higher values are situated in the Northern parts of the country where beef cattle production is prominent.

The soils that receive the lowest amount of nitrogen from manure (**Erreur ! Source du renvoi introuvable.**) are those of the autonomous region of Comunidad Valenciana (12.7 kgN ha^{-1}), situated in the east. On the other end of the spectrum, the autonomous region of Cantabria instead, in the northern part of Spain, receives the greatest annual nitrogen supply from manure (76.9 kgN ha^{-1}). In northern Spain, cattle production is prominent, specialized basically in breeding.

The input of phosphorus from manure is also variable in the country, with six autonomous regions with values which are significantly above the national average (9.12 ± 6 kgP ha^{-1}). Like the case of nitrogen above, the lowest input is also observed for the autonomous regions of Comunidad Valenciana (3.37 kgP ha^{-1}), which has a low livestock production but high agricultural productions where fruits trees are the crops that occupy the most land area, especially citrus. Once again, the highest inputs are found in the Cantabria autonomous region (20.4 kgP ha^{-1}).

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Table 2.2.1. Nitrogen (N) and phosphorus (P) from animal manure and mineral fertilizer sources. The table reports the total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input from animal manure and mineral fertilizer sources on soils for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N from manure (kgN ha^{-1})	Mineral N (kgN ha^{-1})	P from manure (kgP ha^{-1})	Mineral P (kgP ha^{-1})
ES13	Cantabria	76.9	174	20.4	19.7
ES11	Galicia	72.6	179	19.2	29.0
ES51	Cataluña	71.9	39.5	19.1	4.50
ES12	Principado de Asturias	55.3	186	14.7	28.3
ES24	Aragón	43.8	73.1	11.6	10.5
ES21	País Vasco	30.0	125	7.95	18.7
ES7	Canarias	27.9	22.9	13.1	4.02
ES62	Región de Murcia	25.6	9.50	6.78	0.88
ES22	Comunidad Foral de Navarra	25.0	118	6.62	20.9
ES43	Extremadura	21.3	39.2	5.64	7.76
ES41	Castilla y León	20.5	58.6	5.43	11.8
ES3	Comunidad de Madrid	17.7	46.7	4.70	7.91
ES23	La Rioja	16.5	105	4.38	18.4
ES42	Castilla-La Mancha	15.5	42.1	4.10	8.38
ES61	Andalucía	15.4	32.8	4.09	5.14
ES53	Illes Balears	14.4	81.2	3.81	19.4
ES52	Comunidad Valenciana	12.7	13.1	3.37	2.06
Mean ± SD		33.1 ± 22	79.1 ± 59	9.12 ± 6	12.8 ± 8.9

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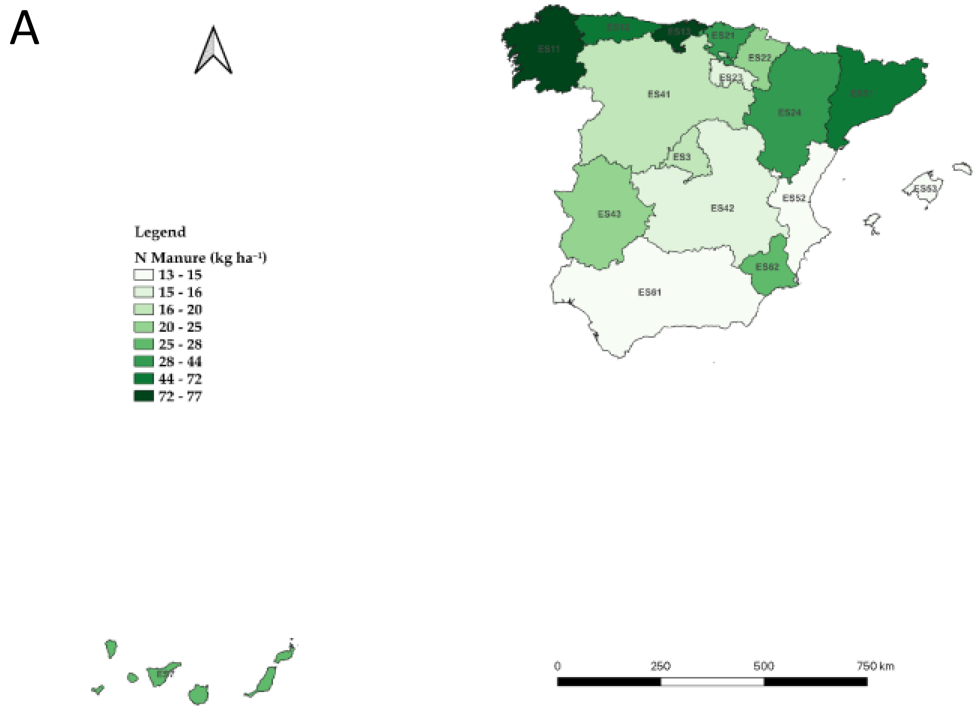
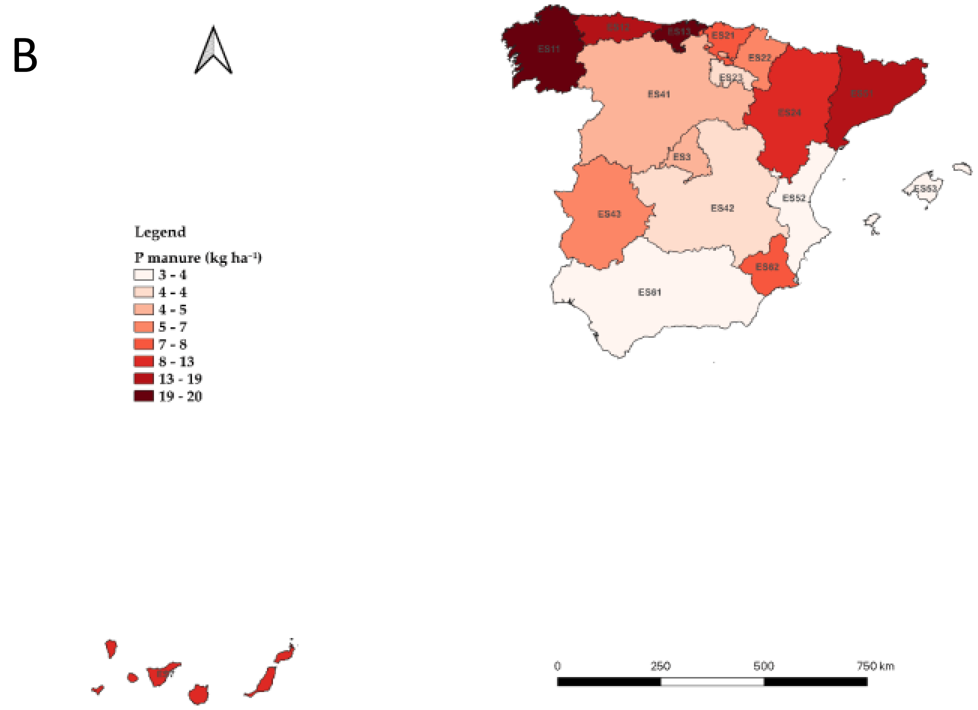


Spain: N from animal manure sources



Spain: P from animal manure sources

Figure 2.2.1. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources (kg ha^{-1}) in Spain.

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2.2.2. Nitrogen and phosphorus from mineral fertilizer sources

The average annual supply of mineral fertilizer nitrogen to Spanish soils is 79.1 ± 59 kgN ha^{-1}. This value is very high compared to animal manure sources (**Erreur ! Source du renvoi introuvable.**). The provinces that have an input of mineral fertilizer nitrogen to the soil equal to or higher than the national average is 7 out of 17. In this case, the standard deviation is also very high, with the highest values found in Northern Spain, in particular, in Principado de Asturias with 186 kgN ha^{-1}.

In case of mineral phosphorous supply, the average is 12.8 ± 8.9 kgP ha^{-1}, whereas the highest values are found in Galicia (29 kgP ha^{-1}).

The soils that receive the lowest annual amounts of mineral fertilizer nitrogen and phosphorous (**Erreur ! Source du renvoi introuvable.**) are those of the province of Murcia (9.5 kgN ha^{-1} and 0.88 kgP ha^{-1} respectively), located in the south-east of the country (**Erreur ! Source du renvoi introuvable.**).

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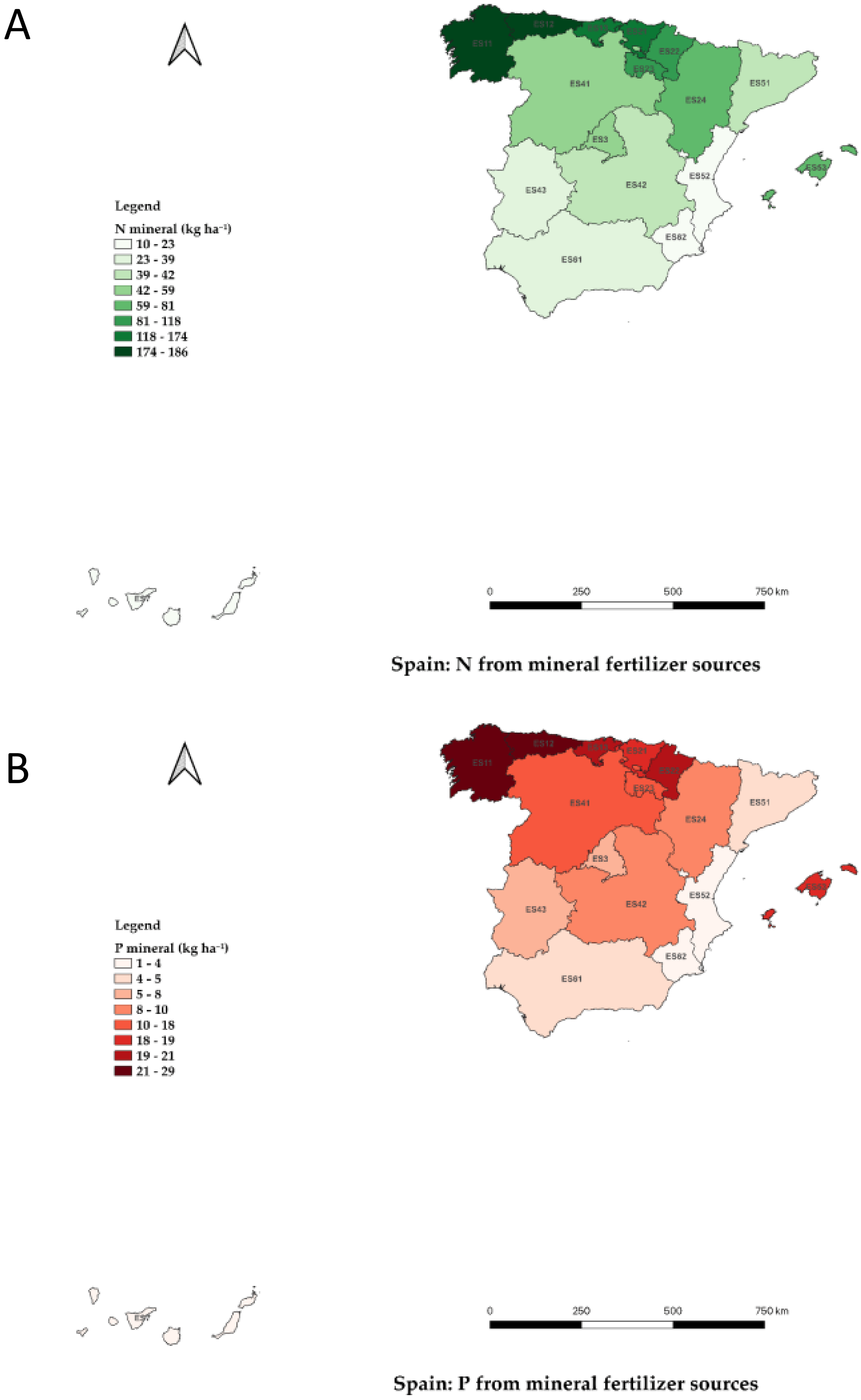

Figure 2.2.2. Thematic map for nitrogen (A) and phosphorus (B) from mineral fertilizer sources (kg ha^{-1}) in Spain.

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2.2.3. Nitrogen and phosphorus from other sources

Based on data from compost productions, sewage sludge, excreta of grazing animals and other non-anthropogenic sources, such as microorganisms for example, amounts of organic N and P of other sources are calculated.

Based on the data available (**Erreur ! Source du renvoi introuvable.**), in Spain, the majority of nitrogen entering the soil from other sources, came from the excreta of grazing animals and from non-anthropogenic sources. There is a low nitrogen portion, which comes from sludge and compost (1.35 ± 0.6 kgN ha^{-1} and 0.12 ± 0 kgN ha^{-1} respectively).

The average from nitrogen input to the soil deriving from pastures is 27.3 ± 22 kgN ha^{-1}; where higher values are observed in Cantabria (92.1 kgN ha^{-1}) and the lowest values are in Comunidad Valenciana (0.41 kgN ha^{-1}). As from phosphorous, most of these inputs are from excreta of grazing animals (4.7 ± 3.8 kgP ha-1), while the highest input observed are in Cantabria 16.2 kgP ha^{-1}).

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Table 2.2.2. Nitrogen (N) and phosphorus (P) from other sources. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soils from sources other than animal manure and mineral for each region analysed. Non-anthropic considers both inorganic deposition and biological fixation. Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})				**Phosphorus (kgP ha^{-1})**		
NUTS 2	**Name**	**N from sludge**	**N from compost**	**N from grazing**	**Non-anthropic N**	**P from sludge**	**P from compost**	**P from grazing**
ES13	Cantabria	0.71	0.06	92.1	16.9	0.58	0.01	16.2
ES12	Principado de Asturias	0.27	0.02	53.0	18.6	0.22	0.00	9.24
ES21	País Vasco	0.66	0.06	46.2	18.4	0.54	0.01	8.45
ES43	Extremadura	0.95	0.08	39.2	12.0	0.77	0.02	7.22
ES7	Canarias	1.01	0.09	36.5	3.77	0.63	0.01	3.09
ES11	Galicia	0.94	0.08	31.4	15.8	0.77	0.02	5.49
ES51	Cataluña	1.78	0.16	23.2	18.3	1.46	0.03	4.19
ES22	Comunidad Foral de Navarra	1.30	0.11	22.4	17.2	1.06	0.02	4.17
ES41	Castilla y León	1.40	0.12	19.7	15.9	1.15	0.03	3.59
ES3	Comunidad de Madrid	1.09	0.10	18.3	15.0	0.89	0.02	3.28
ES24	Aragón	1.63	0.14	17.4	19.8	1.33	0.03	3.27
ES42	Castilla-La Mancha	1.89	0.17	16.0	14.6	1.55	0.04	3.00
ES23	La Rioja	1.26	0.11	15.7	14.9	1.03	0.02	2.87
ES61	Andalucía	1.68	0.15	14.6	12.2	1.38	0.03	2.70
ES62	Región de Murcia	2.07	0.18	9.12	14.2	1.70	0.04	1.61
ES53	Illes Balears	2.09	0.18	8.07	18.2	1.71	0.04	1.42
ES52	Comunidad Valenciana	2.19	0.19	0.41	14.0	1.79	0.04	0.07
Mean ± SD		1.35 ± 0.6	0.12 ± 0	27.3 ± 22	15.3 ± 3.7	1.09 ± 0.5	0.02 ± 0	4.7 ± 3.8

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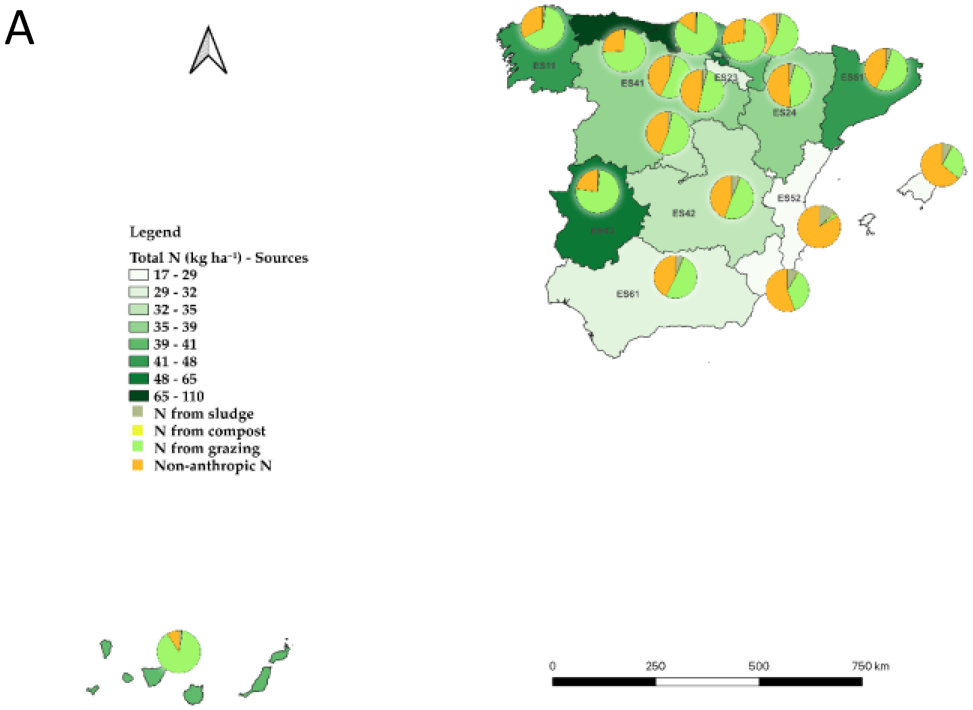
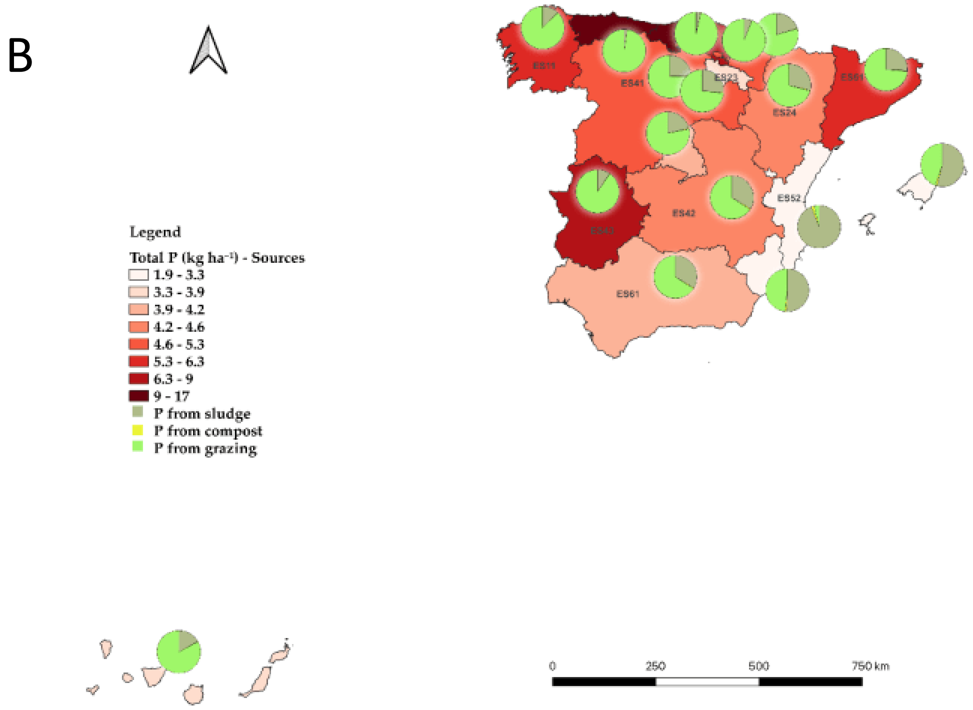


Spain: N Other sources



Spain: P Other sources

Figure 2.2.3. Thematic map for nitrogen (A) and phosphorus (B) from other sources (kg ha^{-1}) in Spain.

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2.2.4. Nitrogen and phosphorus uptake by crops

As nutrient fixation or uptake by crops not depends only on the nutrients available on the soil that also effect other factors like climate, the genetics of the plant and its state of development, the physical and chemical properties of the soil and cultural practices. In Spain, there exists a large diversity of agricultural systems due to the varied climates and soil types between regions, so that this nutrient and phosphorous annual uptake has some differences between the regions.

The average annual nitrogen uptake in Spain is 72.4 ± 52 kgN ha^{-1}, the high deviation indicates lack of uniformity over the country, observing the highest values in Cantabria (170 kgN ha^{-1}) and the lowest in the Comunidad Valenciana (11.5 kgN ha^{-1}). Similar pattern is observed in phosphorous uptake, where the annual uptake is 10.9 ± 6.6 kgP ha-1, so there are differences between the autonomous regions, while the maximum annual nitrogen uptake is also found in Cantabria (23.3 kgP ha^{-1}).

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Table 2.2.3. Nitrogen (N) and phosphorus (P) uptake by crops. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual uptake by cultivated plants for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	**Name**	**N uptake (kgN ha^{-1})**	**P uptake (kgP ha^{-1})**
ES13	Cantabria	170	23.3
ES12	Principado de Asturias	169	22.0
ES11	Galicia	153	21.4
ES21	País Vasco	116	15.8
ES22	Comunidad Foral de Navarra	99.3	15.1
ES23	La Rioja	83.6	11.8
ES24	Aragón	77.4	11.8
ES53	Illes Balears	54.7	9.07
ES41	Castilla y León	55.0	8.91
ES43	Extremadura	47.8	7.14
ES3	Comunidad de Madrid	47.2	7.43
ES51	Cataluña	45.4	7.94
ES42	Castilla-La Mancha	36.5	6.32
ES61	Andalucía	33.8	5.10
ES7	Canarias	16.5	8.58
ES62	Región de Murcia	13.4	2.20
ES52	Comunidad Valenciana	11.5	1.95
Mean ± SD		72.4 ± 52	10.9 ± 6.6

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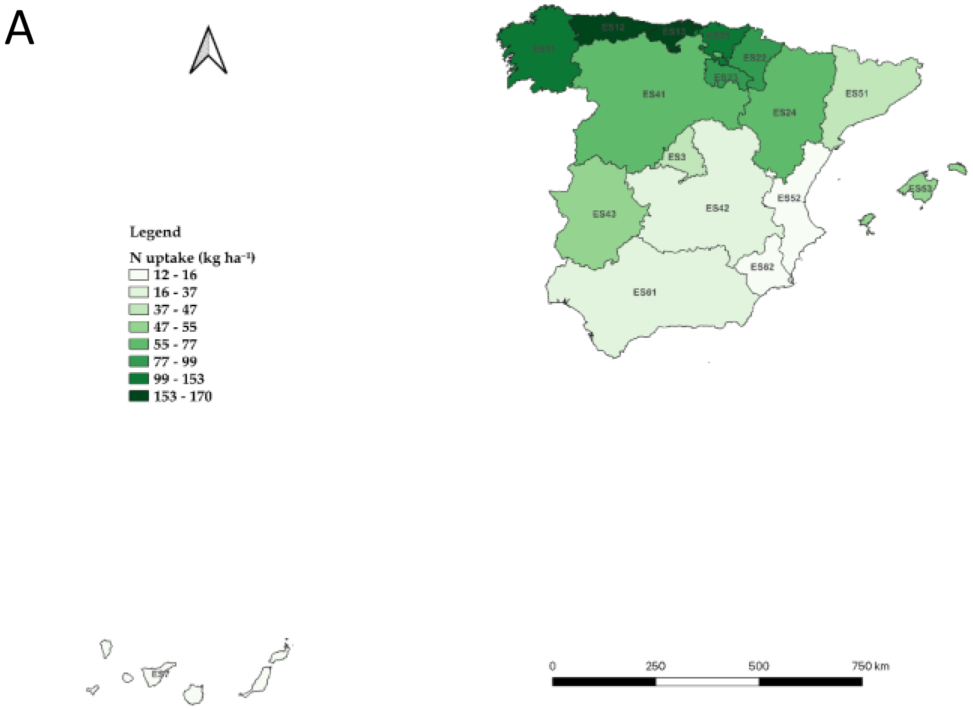
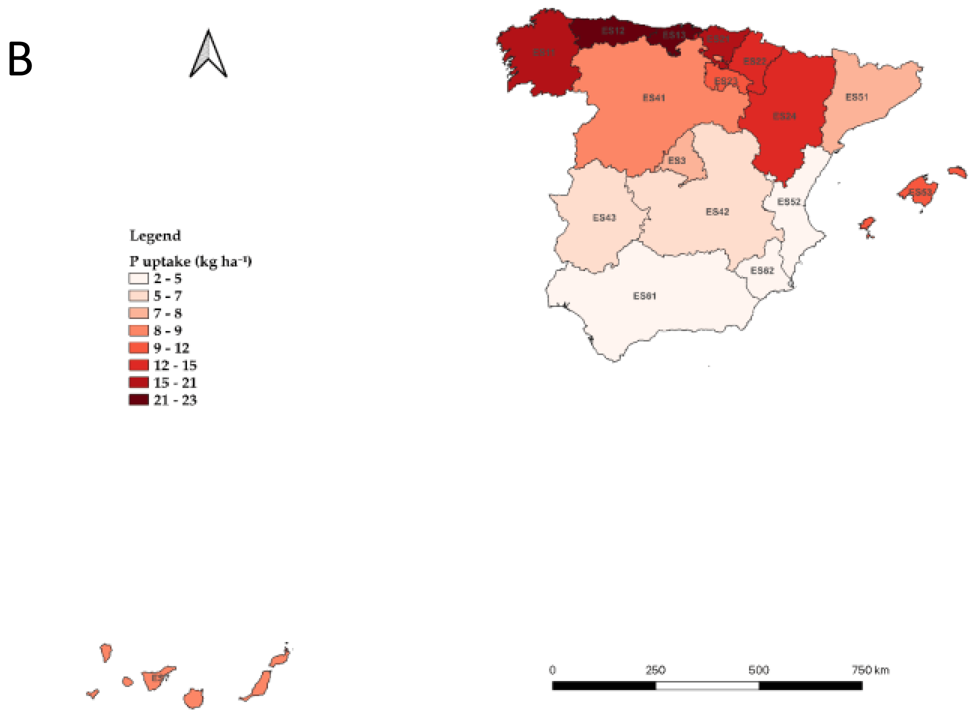


Spain: N uptake by crops



Spain: P uptake by crops

Figure 2.2.4. Thematic map for nitrogen (A) and phosphorus (B) uptake by crops (kg ha^{-1}) in Spain.

2.2.5. Nitrogen and phosphorus soil balances

The results obtained for the annual soil nutrient balance in **Erreur ! Source du renvoi introuvable.** show an excess of nitrogen and for phosphorous but these values are not too high comparing other European countries. The average annual nitrogen balance is 83.8 ± 42 kgN ha^{-1}, with the autonomous regions of Cantabria with the highest values 190 kgN ha^{-1} and the lower value (31 kgN ha^{-1}) is Comunidad Valenciana. In terms of annual balance phosphorous in soils, the average is 16.8 ± 8.6 kgP ha^{-1} that is considered less critical. Cantabria is the autonomous region with higher values 33.6 kgP ha^{-1} and Comunidad Valenciana the ones with lower values, with 5.38 kgP ha^{-1}.

Table 2.2.4. Nitrogen (N) and phosphorus (P) balances. The table reports the difference between total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**Total N input**	**N uptake**	**N excess**	**Total P input**	**P uptake**	**P excess**
ES13	Cantabria	361	170	190	56.9	23.3	33.6
ES11	Galicia	299	153	146	54.6	21.4	33.2
ES12	Principado de Asturias	313	169	144	52.5	22.0	30.5
ES51	Cataluña	155	45.4	109	29.3	7.94	21.3
ES21	País Vasco	220	116	104	35.6	15.8	19.8
ES22	Comunidad Foral de Navarra	184	99.3	84.5	32.8	15.1	17.8
ES24	Aragón	156	77.4	78.4	26.7	11.8	14.9
ES7	Canarias	92.2	16.5	75.7	20.9	8.58	12.3
ES23	La Rioja	153	83.6	69.8	26.7	11.8	14.9
ES53	Illes Balears	124	54.7	69.5	26.4	9.07	17.3
ES43	Extremadura	113	47.8	64.9	21.4	7.14	14.3
ES41	Castilla y León	116	55.0	61.3	21.9	8.91	13.0
ES3	Comunidad de Madrid	99.0	47.2	51.9	16.8	7.43	9.38
ES42	Castilla-La Mancha	90.2	36.5	53.7	17.1	6.32	10.7
ES62	Región de Murcia	60.7	13.4	47.2	11.0	2.20	8.80
ES61	Andalucía	76.9	33.8	43.1	13.3	5.10	8.24
ES52	Comunidad Valenciana	42.5	11.5	31.0	7.34	1.95	5.38
Mean ± SD		156 ± 92	72.4 ± 52	83.8 ± 42	25.7 ± 15	10.9 ± 6.6	16.8 ± 8.6

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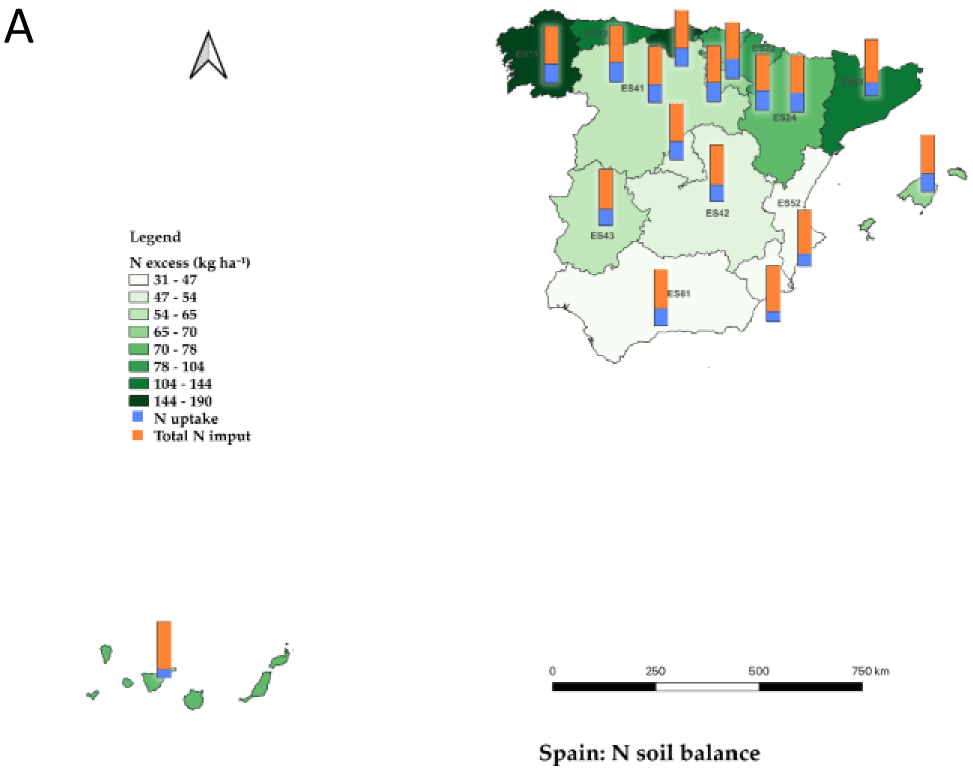

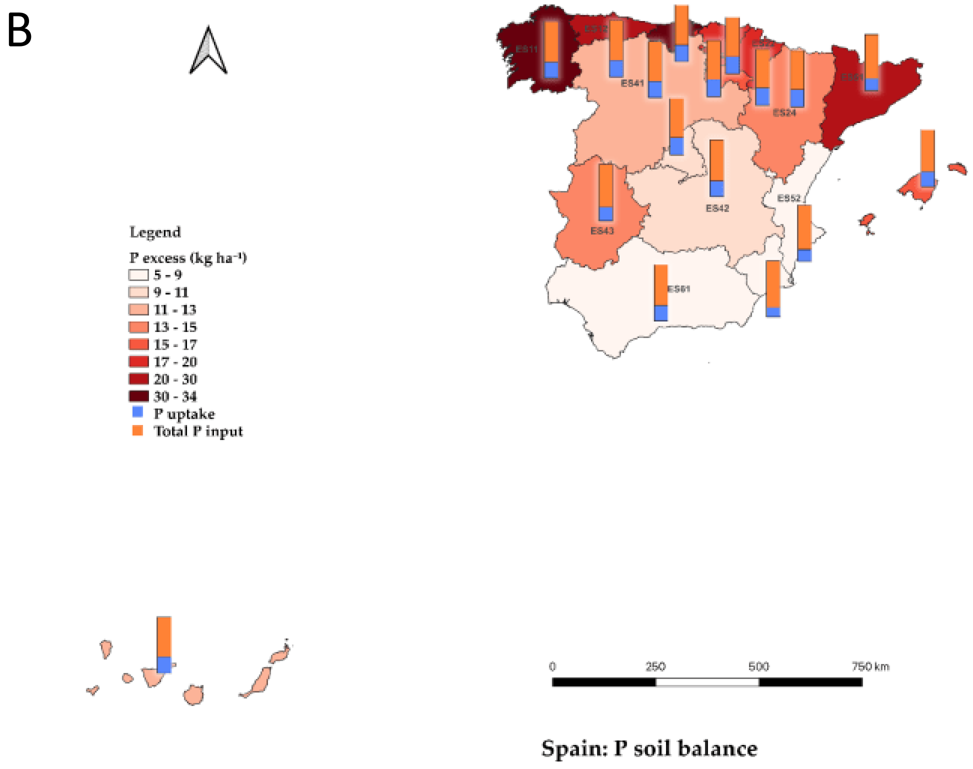

Figure 2.2.5. Thematic map for nitrogen (A) and phosphorus (B) balance (kg ha^{-1}) in Spain.

2.2.6. Sustainability of animal manure sources

It is important to estimate nutrient balances in order to detect negative balances (the input of smaller amounts of nutrients than are extracted with crops), which causes a decrease in soil fertility, affecting the productivity and profitability of the system and degrading the soil resource. On the other hand, positive balances result in low nutrient use efficiencies and can lead to nutritional imbalances or environmental pollution. Moreover, in order to guarantee the viability and the sustainability of the agricultural sector, an adequate use of organic fertilizers must be made in order to improve the soil quality. For this reason, data on overall nutrient balances and use of organic sources are important to take into account.

Erreur ! Source du renvoi introuvable. shows that there are many differences between autonomous regions. There are some regions with negative balances in terms of nitrogen (nitrogen deficit) like Galicia, Principado de Asturias, País Vasco, Navarra, La Rioja and Islas Baleares. The other governmental jurisdictions have positive balances, whereas Catalonia and Islas Canarias had the highest excesses of nitrogen, with 51.4 and 52.8 kgN ha^{-1}, respectively.

The average annual balance for P in Spain was 4 ± 5.5 kgP ha^{-1}. There is only phosphorous deficit in La Rioja, Navarra and Illes Balears. All other autonomous regions have phosphorus surpluses.

The balance on a NUTS2 scale also allows for the organization of a possible redistribution of recovered nutrients within the country.

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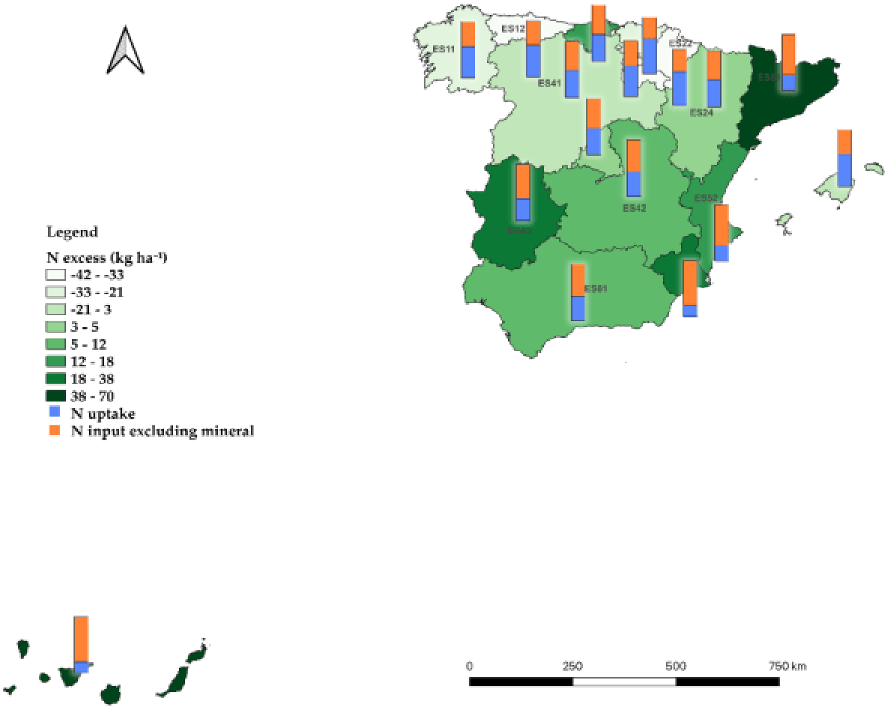
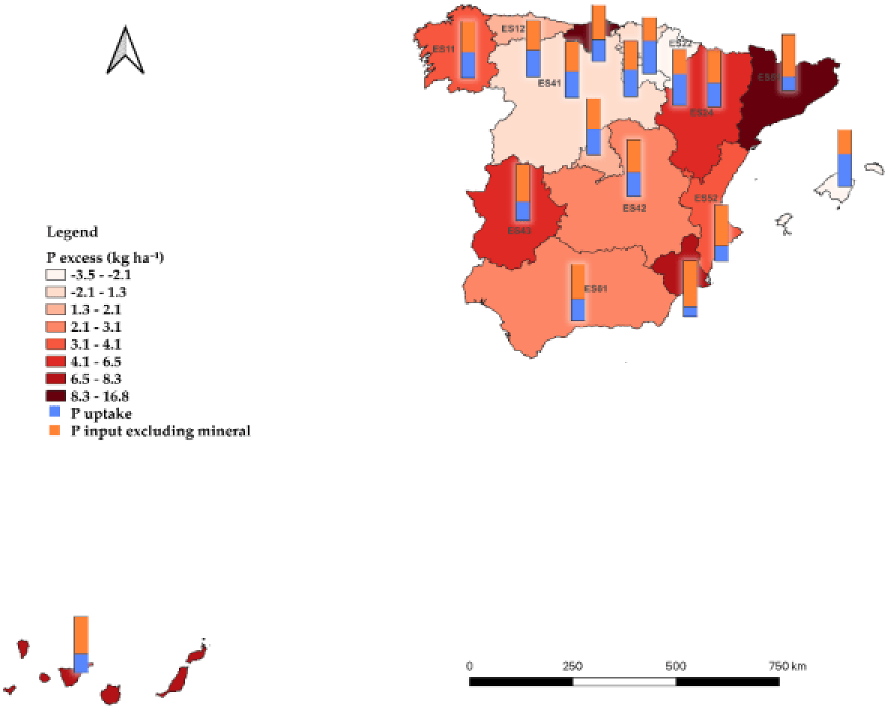
Table 2.2.5. Nitrogen (N) and phosphorus (P) from animal manure sources vs uptake by crops. The table reports the difference between nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil (excluding the share deriving from mineral fertilizers) and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**N input excluding mineral**	**N uptake**	**N excess**	**P input excluding mineral**	**P uptake**	**P excess**
ES51	Cataluña	115	45.4	69.9	24.8	7.94	16.8
ES7	Canarias	69.3	16.5	52.8	16.9	8.58	8.31
ES62	Región de Murcia	51.2	13.4	37.7	10.1	2.20	7.92
ES43	Extremadura	73.5	47.8	25.7	13.7	7.14	6.52
ES52	Comunidad Valenciana	29.5	11.5	18.0	5.27	1.95	3.32
ES13	Cantabria	187	170	16.2	37.2	23.3	13.9
ES42	Castilla-La Mancha	48.1	36.5	11.6	8.68	6.32	2.36
ES61	Andalucía	44.1	33.8	10.3	8.21	5.10	3.10
ES24	Aragón	82.8	77.4	5.32	16.2	11.8	4.41
ES3	Comunidad de Madrid	52.3	47.2	5.14	8.89	7.43	1.46
ES41	Castilla y León	57.7	55.0	2.71	10.2	8.91	1.28
ES53	Illes Balears	43.0	54.7	-11.7	6.98	9.07	-2.08
ES21	País Vasco	95.2	116	-20.6	16.9	15.8	1.14
ES11	Galicia	121	153	-32.7	25.5	21.4	4.12
ES22	Comunidad Foral de Navarra	66.0	99.3	-33.3	11.9	15.1	-3.17
ES23	La Rioja	48.5	83.6	-35.1	8.30	11.8	-3.50
ES12	Principado de Asturias	127	169	-42.2	24.1	22.0	2.12
Mean ± SD		77.1 ± 41	72.4 ± 52	4.62 ± 32	14.9 ± 8.6	10.9 ± 8.6	4 ± 5.5



Spain: N Sustainability of animal manure sources

A



B

Spain: P Sustainability of animal manure sources

Figure 2.2.6. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources vs uptake by crops (kg ha^{-1}) in Spain.

In terms of nutrient balances, Spain consumes 987,155 tons of nitrogen from mineral fertilizers despite having a surplus of 618,050 tons of nitrogen. This suggests that there is a large opportunity and need for transforming part of the 318,365 tons of organic nitrogen from intensive livestock farm waste in order to better distribute this source throughout the country, reducing the surplus and reducing overall consumption of nutrients and associated waste management problems (Nitrógeno Balance, 2016). The same situation is encountered with phosphorous: Spain has a surplus of 108,963 tons of P whereas the input of phosphorus from mineral sources is 181,103 tons. In this sense, it is necessary to be able to transform part of organic phosphorus (83,608 tons) into a fertilizer that can be distributed throughout the country and thus be able to reduce importation of mineral sources (Phosphorus Balance, 2016).

The balances made at the level (NUTS2) allow a first approximation of reality, but the fact that the surfaces of the provinces are large and/or livestock ends up concentrating in some municipalities, means that the balances of nutrients at the municipal level can differ greatly between the different municipalities of the same province or region.

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2.3. Germany

This section deals with the nitrogen and phosphorous sources and balances in Germany and its regions at NUTS2 level. The sections 2.3.1 to 2.3.3 show the nitrogen and phosphorous supply from animal manure, mineral fertilizers as well as other sources. Following, section 2.3.4 shows the nitrogen and phosphorous uptake in the country, section 2.3.5 shows the data of balancing the nutrient supply against its uptake and section 2.3.6 deals with the sustainability of the of the animal nutrient supply, focusing on the balance of non-mineral nutrient sources against the yearly nutrient uptake in each NUTS2 region.

2.3.1. Nitrogen and phosphorus from animal manure sources

The average annual supply of nitrogen from manure sources in German soils is 57.7 ± 31 kgN ha^{-1}, meaning that there are considerably differences between regions in Germany. The maximum nitrogen supply from manure is accounted in Weser-Ems (DE94) with 153 kgN ha^{-1} and the lowest supply was in Dessau (DEE1) and Halle (DEE2) with only 10.9 kgN ha^{-1}. These big differences in nitrogen supply are visible in Figure 2.3.1 (upper map), which shows heavily breeding areas in the north-west and south-east and a central stripe extending from south-west to north-east, showing significant lower intensity of livestock activities.

The input of phosphorus from manure equals to 13 ± 7 kgP ha^{-1} and is also significantly different between regions, following a similar regional distribution as the nitrogen supply from manure. The maximum P input is observed for the province of Weser-Ems (DE94) with 34.5 kgP ha^{-1} and the lowest again in Dessau (DEE1) and Halle (DEE2) with only about 2.5 kgN ha^{-1}. Figure 2.3.1 (bottom map) shows again heavily breeding areas in the north-west and south-east and a central low intensive breeding stripe extending from south-west to north-east.

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Table 2.3.1. Nitrogen (N) and phosphorus (P) from animal manure and mineral fertilizer sources. The table reports the total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input from animal manure and mineral fertilizer sources on soils for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N from manure (kgN ha^{-1})	Mineral N (kgN ha^{-1})	P from manure (kgP ha^{-1})	Mineral P (kgP ha^{-1})
DE94	Weser-Ems	153	81.0	34.5	4.06
DEA3	Münster	135	84.0	30.4	4.70
DEA1	Düsseldorf	105	103	23.7	5.76
DEA5	Arnsberg	85.9	103	19.4	6.53
DE27	Schwaben	88.0	90.7	19.8	5.88
DE14	Tübingen	73.9	85.2	16.7	5.68
DE93	Lüneburg	76.4	112	17.2	7.37
DEB2	Trier	70.9	81.2	16.0	5.32
DE23	Oberpfalz	72.6	92.5	16.4	5.96
DE21	Oberbayern	71.6	103	16.1	6.91
DEA4	Detmold	70.4	102	15.9	6.83
DEF	Schleswig-Holstein	69.2	90.6	15.6	5.92
DE22	Niederbayern	66.1	107	14.9	6.94
DE25	Mittelfranken	62.8	83.2	14.1	5.66
DE11	Stuttgart	60.4	90.3	13.6	5.99
DE24	Oberfranken	57.3	84.1	12.9	5.82
DEA2	Köln	56.5	127	12.7	8.05
DE73	Kassel	54.9	111	12.4	7.48
DE92	Hannover	52.9	130	11.9	8.32
DED	Sachsen	52.8	109	11.9	6.99
DE13	Freiburg	51.6	92.1	11.6	6.32
DEC	Saarland	47.0	102	10.6	7.01
DE72	Gießen	44.3	112	10.0	7.96
DE4	Brandenburg	39.4	85.7	8.87	5.69
DEG	Thüringen	41.1	113	9.27	7.51
DE12	Karlsruhe	38.1	100	8.58	6.76
DE8	Mecklenburg-Vorpommern	37.2	122	8.38	8.00
DE71	Darmstadt	35.2	119	7.93	7.98

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DEB1	Koblenz	34.4	103	7.76	7.22
DE26	Unterfranken	33.8	99.4	7.62	6.67
DE91	Braunschweig	25.9	151	5.83	9.62
DEB3	Rheinhessen-Pfalz	22.0	92.8	4.95	5.99
DEE3	Magdeburg	11.3	133	2.55	9.15
DEE1	Dessau	10.9	134	2.45	9.21
DEE2	Halle	10.9	133	2.46	9.20
Mean ± SD		57.7 ± 31	105 ± 18	13 ± 7	6.87 ± 1.3

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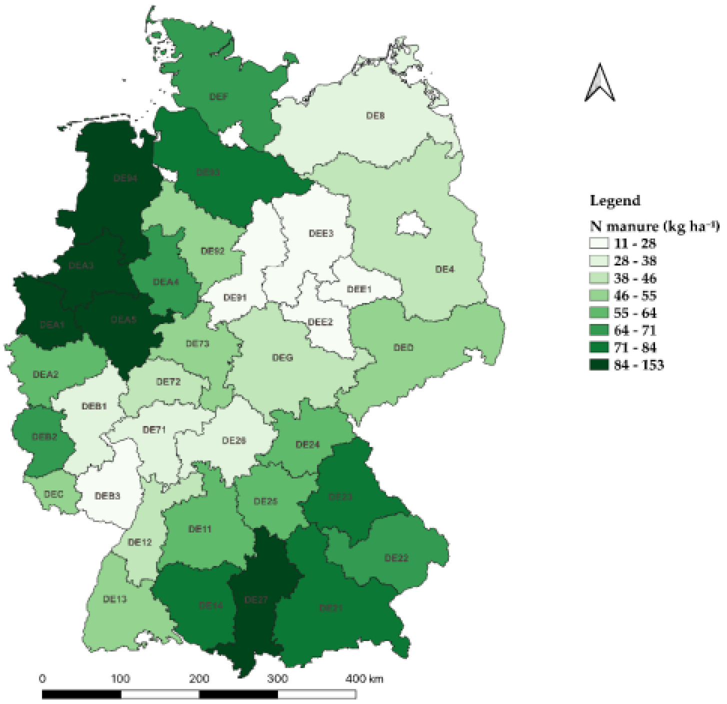
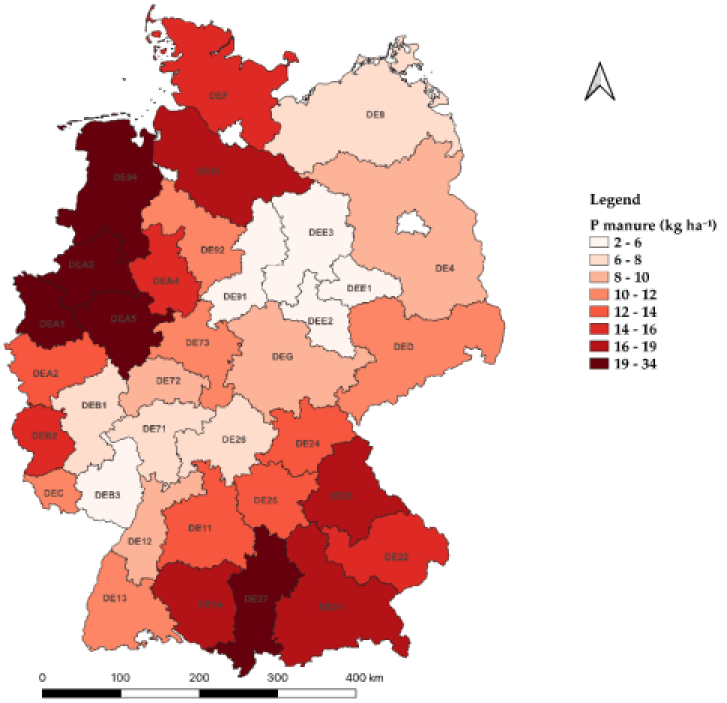


Germany: N from animal manure sources

B



Germany: P from animal manure sources

Figure 2.3.1. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources (kg ha^{-1}) in Germany.

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2.3.2. Nitrogen and phosphorus from mineral fertilizer sources

The average annual supply of mineral nitrogen in the German regions is 105 ± 18 kgN ha^{-1}, almost the double supply of nitrogen from animal sources (Table 2.1.1). The application of mineral nitrogen compensates the nitrogen from manure. That means that the regions with low nitrogen manure supply apply in general more mineral nitrogen. This effect can be seen in the fact that the regions with maximum nitrogen from manure supply like Weser-Ems (DE94) show the minimum mineral nitrogen supply with 81 kgN ha^{-1}. On the other hand, regions like Dessau (DEE1) and Halle (DEE2) show the maximum mineral nitrogen supply with around 133 kgN ha^{-1} and the lowest supply from manure as shown in the section 2.3.1. Additionally Figure 2.3.2 (upper map) shows a stripe of high application of mineral nitrogen in a middle stripe going from south-west to north-east and lower mineral nitrogen supply in the north-west and south-east parts of Germany.

The amounts of mineral phosphorus applied are more uniform than the nitrogen ones (Table 2.1.1). The national average is in fact 6.9 ± 1.3 kgP ha^{-1}, approx. the half of the phosphorous supply from manure. Again, the maximum supply comes out in Dessau (DEE1) and Halle (DEE2) with 9.2 kgP ha^{-1} and the minimum supply in Weser-Ems (DE94) with 4.1 kgP ha^{-1}. As in the case of mineral nitrogen, Figure 2.3.2 (bottom map) shows a stripe of high application of mineral phosphorous in a middle stripe region going from south-west to north-east and lower mineral phosphorous supply in the north-west and south-east parts of the country.

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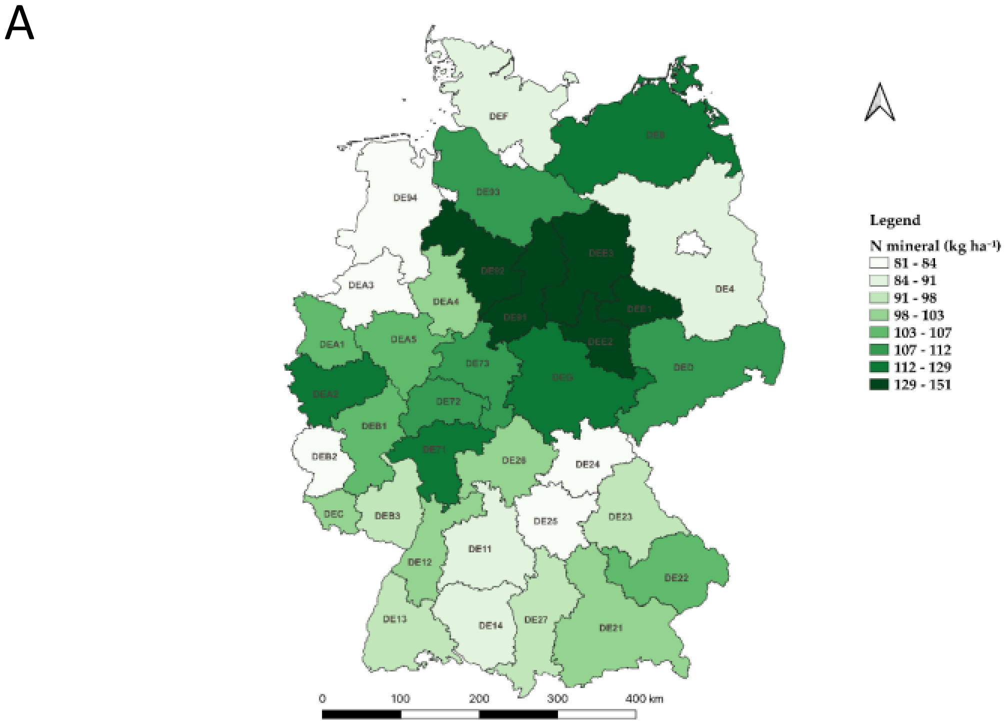
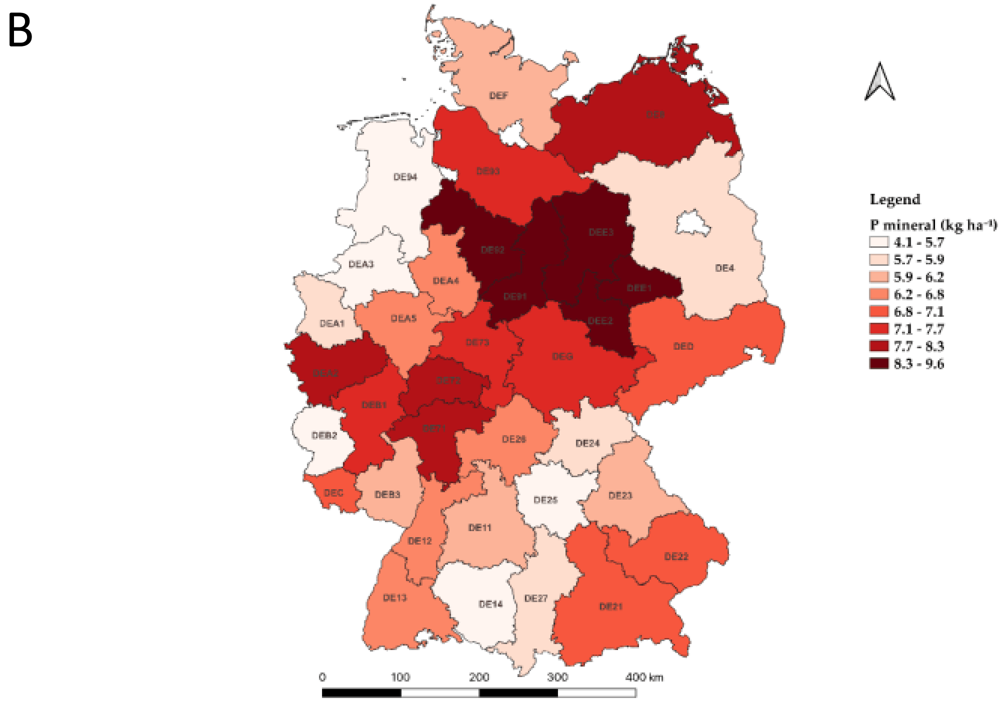


Germany: N from mineral fertilizer sources



Germany: P from mineral fertilizer sources

Figure 2.3.2. Thematic map for nitrogen (A) and phosphorus (B) from mineral fertilizer sources (kg ha^{-1}) in Germany.

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2.3.3. Nitrogen and phosphorus from other sources

The input of nitrogen and phosphorus from other sources (

Table **2.1.2**) includes the application of sewage sludge and compost in the fields, the excreta of grazing animals and the share of nitrogen received by the soil from non-anthropogenic sources, such as atmospheric events or nitrogen bacterial fixation.

Among the nitrogen sources, the highest source is the non-anthropogenic with a national average of 29.5 ± 5.5 kgN ha^{-1} followed by the nitrogen from grazing animals with an average of 9.8 ± 3.7 kgN ha^{-1}. The nitrogen derived from sewage sludge and compost application is very low. This means that only few amounts of sewage sludge are being applied in the field, since most of the sewage sludge is being incinerated in dedicated facilities. The role of compost as nitrogen source is almost insignificant with only 0.65 ± 0.1 kgN ha^{-1} in average.

In the case of phosphorous, the dominant source are the gazing animals followed by the sewage sludge, both with > 1.2 kgN ha^{-1}. The compost contributes only with 0.13 kgN ha^{-1}. The distribution of these sources between regions show a slight tendency of higher nutrient supply in the north-west and in the south-east (Figure 2.3.3). This is similar but not as distinct to the distribution of nutrients from manure.

Table 2.3.2. Nitrogen (N) and phosphorus (P) from other sources. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soils from sources other than animal manure and mineral for each region analysed. Non-anthropic considers both inorganic deposition and biological fixation. Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})				**Phosphorus (kgP ha^{-1})**		
NUTS 2	**Name**	**N from sludge**	**N from compost**	**N from grazing**	**Non-anthropic N**	**P from sludge**	**P from compost**	**P from grazing**
DEA3	Münster	1.90	0.75	9.16	45.5	1.42	0.16	1.49
DEA1	Düsseldorf	1.93	0.76	17.3	44.3	1.44	0.16	2.72
DE94	Weser-Ems	1.48	0.59	14.0	41.6	1.11	0.12	2.21
DEA4	Detmold	1.73	0.68	7.42	35.2	1.29	0.14	1.23
DEA5	Arnsberg	1.38	0.55	12.9	33.9	1.04	0.11	2.12
DEA2	Köln	1.49	0.59	11.8	33.2	1.12	0.12	1.89
DEF	Schleswig-Holstein	1.34	0.53	12.8	33.2	1.00	0.11	2.06
DE92	Hannover	1.96	0.78	6.90	33.0	1.47	0.16	1.15
DE93	Lüneburg	1.49	0.59	12.4	32.5	1.12	0.12	1.98

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DE27	Schwaben	1.05	0.42	15.7	31.6	0.79	0.09	2.44
DE14	Tübingen	1.35	0.54	12.7	31.0	1.01	0.11	2.03
DE22	Niederbayern	1.61	0.64	9.92	30.7	1.21	0.13	1.60
DE25	Mittelfranken	1.66	0.66	11.7	30.4	1.25	0.14	1.90
DE21	Oberbayern	1.17	0.46	13.6	29.9	0.88	0.10	2.13
DE11	Stuttgart	1.66	0.66	9.40	29.2	1.24	0.14	1.56
DEB2	Trier	0.97	0.39	14.0	28.0	0.73	0.08	2.24
DE24	Oberfranken	1.69	0.67	11.4	27.7	1.27	0.14	1.85
DE23	Oberpfalz	1.62	0.64	13.9	27.4	1.21	0.13	2.20
DE13	Freiburg	1.28	0.51	11.4	27.3	0.96	0.10	1.88
DE73	Kassel	1.45	0.57	10.3	27.2	1.09	0.12	1.70
DE72	Gießen	1.25	0.50	10.1	26.7	0.94	0.10	1.70
DEG	Thüringen	1.82	0.72	8.01	26.5	1.36	0.15	1.36
DED	Sachsen	1.90	0.75	9.37	26.2	1.43	0.16	1.53
DEE3	Magdeburg	2.02	0.80	2.78	26.1	1.52	0.17	0.46
DEE2	Halle	2.02	0.80	2.06	25.8	1.52	0.17	0.31
DE26	Unterfranken	1.94	0.77	7.11	25.7	1.45	0.16	1.22
DE91	Braunschweig	2.04	0.81	5.48	25.7	1.53	0.17	0.93
DEB1	Koblenz	1.47	0.58	7.87	25.6	1.10	0.12	1.32
DEC	Saarland	1.13	0.45	11.3	25.6	0.85	0.09	1.89
DE4	Brandenburg	1.91	0.76	7.72	25.0	1.43	0.16	1.29
DE71	Darmstadt	1.67	0.66	8.37	24.8	1.25	0.14	1.41
DEE1	Dessau	2.02	0.8	1.96	24.8	1.52	0.17	0.29
DE12	Karlsruhe	1.95	0.77	9.39	24.7	1.46	0.16	1.61
DE8	Mecklenburg-Vorpommern	1.87	0.74	7.22	24.6	1.41	0.15	1.20
DEB3	Rheinhessen-Pfalz	2.16	0.86	5.80	23.2	1.62	0.18	1.01
Mean ± SD		1.64 ± 0.3	0.65 ± 0.1	9.81 ± 3.7	29.5 ± 5.5	1.23 ± 0.2	0.13 ± 0	1.60 ± 0.6

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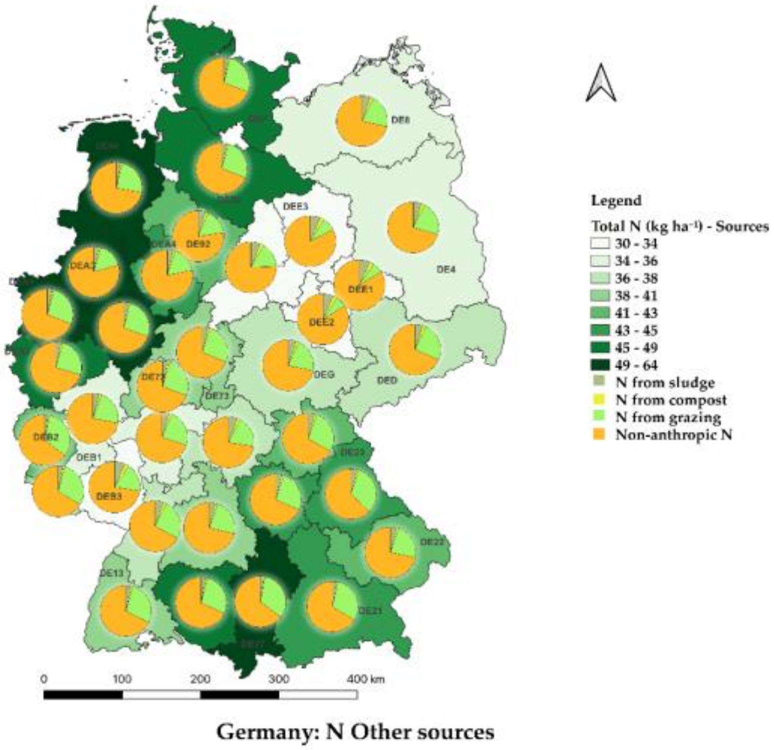

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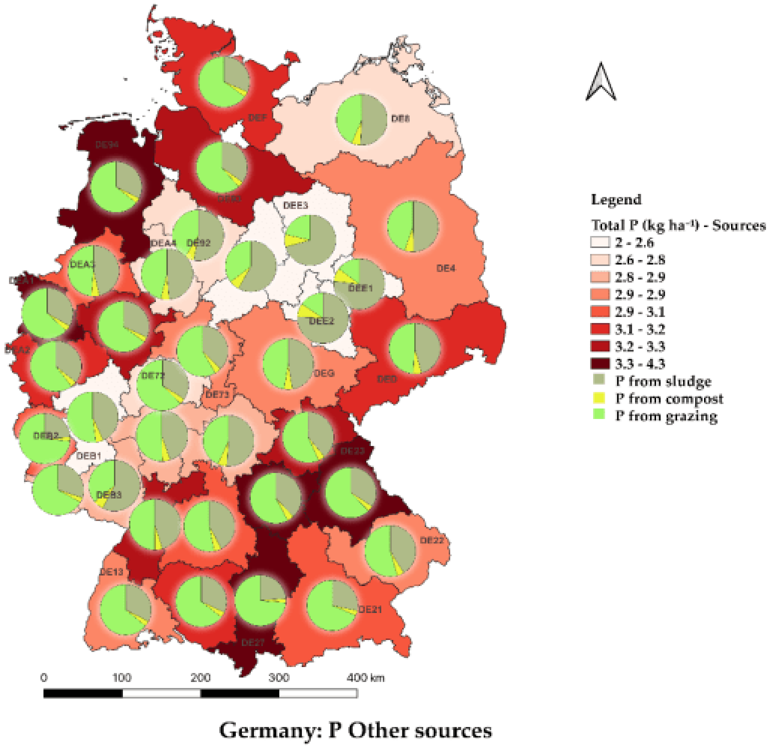

Figure 2.3.3. Thematic map for nitrogen (A) and phosphorus (B) from other sources (kg ha^{-1}) in Germany.

2.3.4. Nitrogen and phosphorus uptake by crops

The uptake of nitrogen and phosphorus from the soils (Table 2.1.3) depends on many factors including mainly the pasture area share, the nutrient supply and plant availability, the crop types, among other factors.

The national average nitrogen uptake is 131 ± 15 kgN ha^{-1} and it is quite uniform across the country. The region with the lowest nitrogen uptake is Rheinhessen-Pfalz (93 kgN ha^{-1}), which has a strong vocation of viniculture. The maximum annual nitrogen uptake is observed in Weser-Ems (158 kgN ha^{-1}), which is rich in pastures, permanent cultures and has a high livestock density. The nitrogen uptake corresponds in general with the nitrogen supply from manure, showing more intensive uptake areas in the north-west and the south-east of the country.

Annual phosphorus is pretty uniform across the country with an average of 20.5 ± 2.1 kgP ha^{-1}. The region that shows the lowest phosphorus uptake is Brandenburg (DE4) with 16.5 kgP ha^{-1}, while the highest uptake is observed in Münster (DE3) with 24.6 kgP ha^{-1} where a high share of phosphorous from animal sources is applied.

Table 2.3.3. Nitrogen (N) and phosphorus (P) uptake by crops. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual uptake by cultivated plants for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N uptake (kgN ha^{-1})	P uptake (kgP ha^{-1})
DE94	Weser-Ems	158	23.2
DEA1	Düsseldorf	153	23.6
DE93	Lüneburg	152	22.2
DEA2	Köln	152	22.9
DEA3	Münster	151	24.6
DEA5	Arnsberg	150	22.9
DE92	Hannover	146	23.6
DE21	Oberbayern	145	20.9
DE27	Schwaben	145	20.8
DE91	Braunschweig	145	23.8
DE22	Niederbayern	139	21.3
DE73	Kassel	138	21.3
DEA4	Detmold	138	22.3

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DE72	Gießen	137	20.6
DE71	Darmstadt	131	20.6
DEF	Schleswig-Holstein	130	19.9
DE14	Tübingen	129	19.2
DE23	Oberpfalz	129	19.8
DE8	Mecklenburg-Vorpommern	129	21.3
DEC	Saarland	129	18.8
DED	Sachsen	126	20.8
DEE1	Dessau	126	20.9
DEE2	Halle	126	20.9
DEE3	Magdeburg	126	20.9
DEG	Thüringen	126	20.7
DEB2	Trier	125	17.6
DE13	Freiburg	122	18.1
DE11	Stuttgart	121	19.1
DE25	Mittelfranken	119	18.3
DEB1	Koblenz	119	18.6
DE24	Oberfranken	115	18.1
DE12	Karlsruhe	114	18.8
DE26	Unterfranken	111	18.3
DE4	Brandenburg	101	16.5
DEB3	Rheinhessen-Pfalz	93.0	15.8
Mean ± SD		131 ± 15	20.5 ± 2.1

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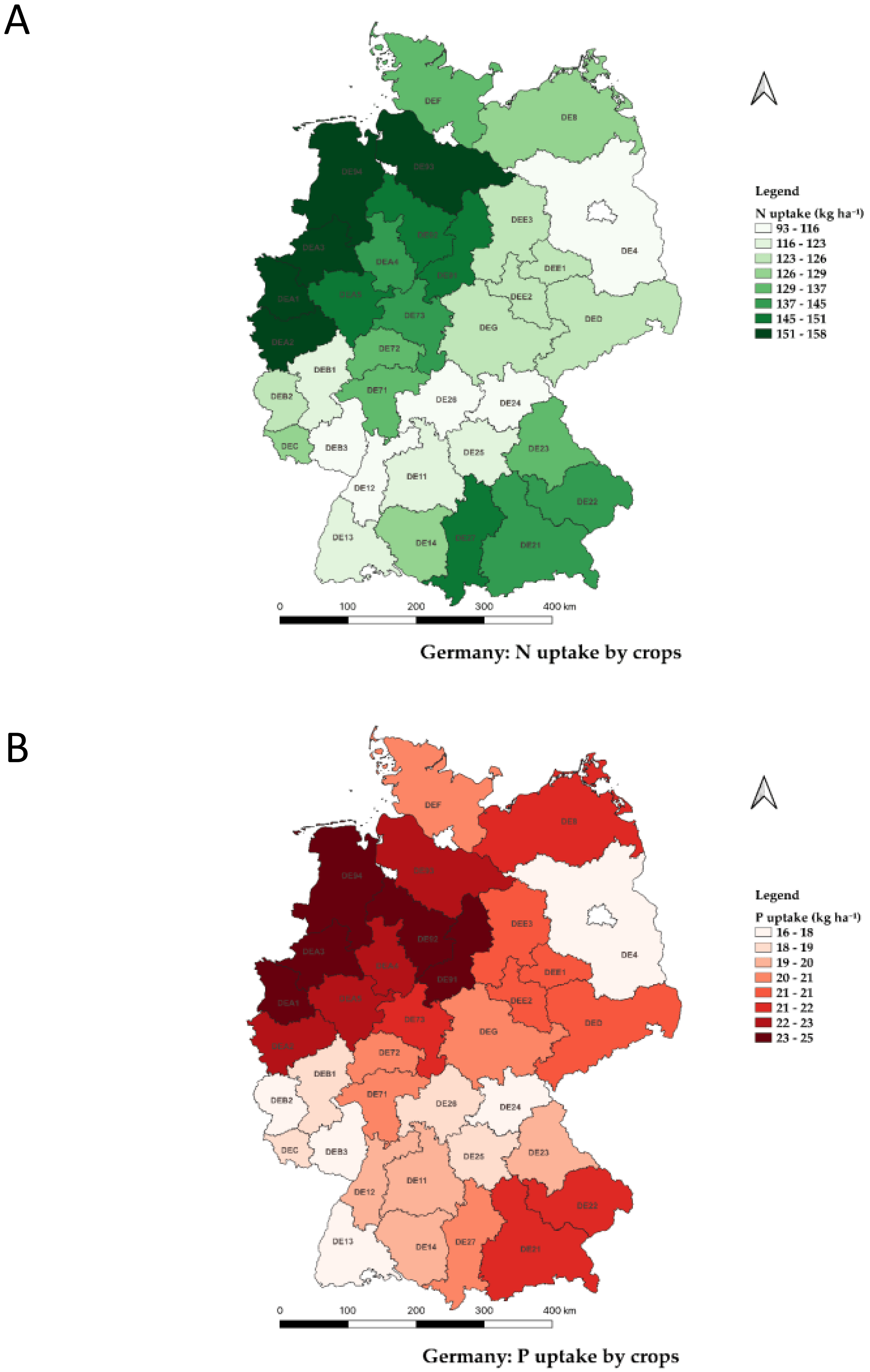

Figure 2.3.4. Thematic map for nitrogen (A) and phosphorus (B) uptake by crops (kg ha^{-1}) in Germany.

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2.3.5. Nitrogen and phosphorus soil balances

The results obtained for the annual soil nutrient balance (Table 2.1.4) describe a general situation of middle to strong excess of nitrogen and a low excess of phosphorus with localised lacks in some regions.

The country's average annual nitrogen excess is 72.5 ± 20 kgN ha^{-1}. This means that in all considered regions there is an excess of nitrogen. The lowest nitrogen excess is observed in Dessau (DEE1) and Halle (DEE2) with about 49 kgN ha^{-1}, while the highest annual nitrogen excess is observed in Weser-Ems (DE94) with 133 kgN ha^{-1}.

The annual phosphorus balance is instead pretty much closed, with a national average of 2.3 ± 5.6 kgP ha^{-1}. This means that some regions have a negative phosphorous balance. The region that shows the lowest excess of phosphorus is again observed Dessau (DEE1) and Halle (DEE2) with about -7.2 kgN ha^{-1}, while the highest observed excess is observed also in Weser-Ems (DE94) with 18.8 kgP ha^{-1}.

Figure 2.3.5 shows that the nitrogen and phosphorous balance corresponds to the nutrient supply from animal manure. Nitrogen is supplied in excess in all regions. On the other hand, a phosphorous balance could be achieved by transporting the excess phosphorous between regions.

Table 2.3.4. Nitrogen (N) and phosphorus (P) balances. The table reports the difference between total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**Total N input**	**N uptake**	**N excess**	**Total P input**	**P uptake**	**P excess**
DE94	Weser-Ems	292	158	133	42.0	23.2	18.8
DEA3	Münster	276	151	125	38.2	24.6	13.6
DEA1	Düsseldorf	272	153	119	33.8	23.6	10.2
DEA5	Arnsberg	238	150	87.3	29.2	22.9	6.23
DE93	Lüneburg	235	152	82.9	27.8	22.2	5.55
DE27	Schwaben	227	145	82.1	29.0	20.8	8.23
DEA4	Detmold	218	138	80.2	25.4	22.3	3.10
DE23	Oberpfalz	209	129	79.3	25.9	19.8	6.05
DE92	Hannover	225	146	79.1	23.0	23.6	-0.54
DEA2	Köln	230	152	78.9	23.9	22.9	1.05

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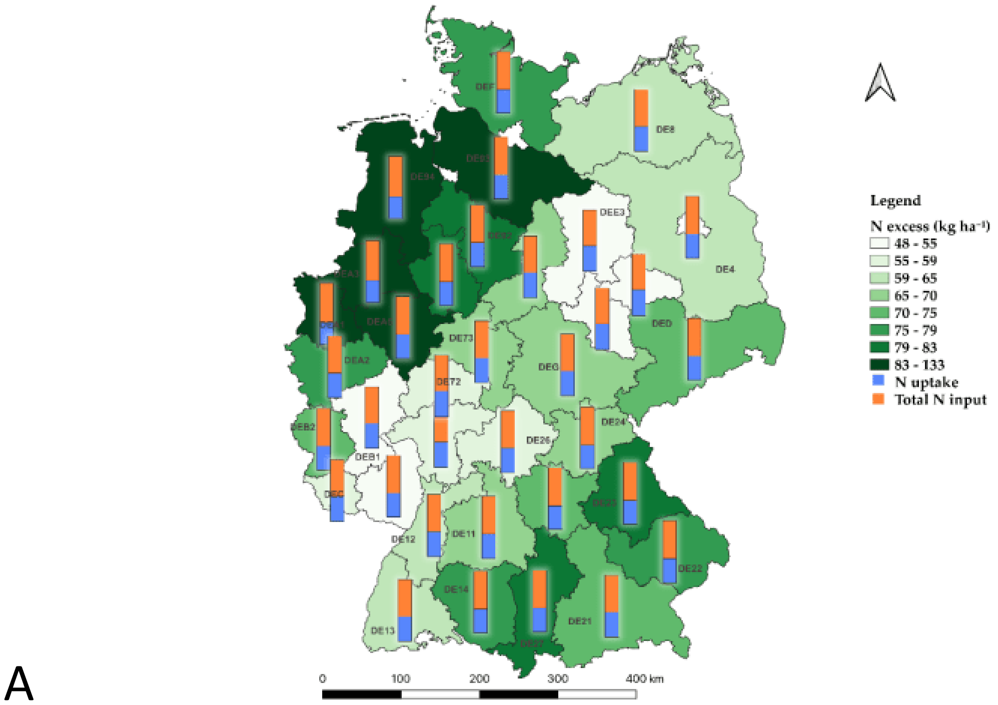
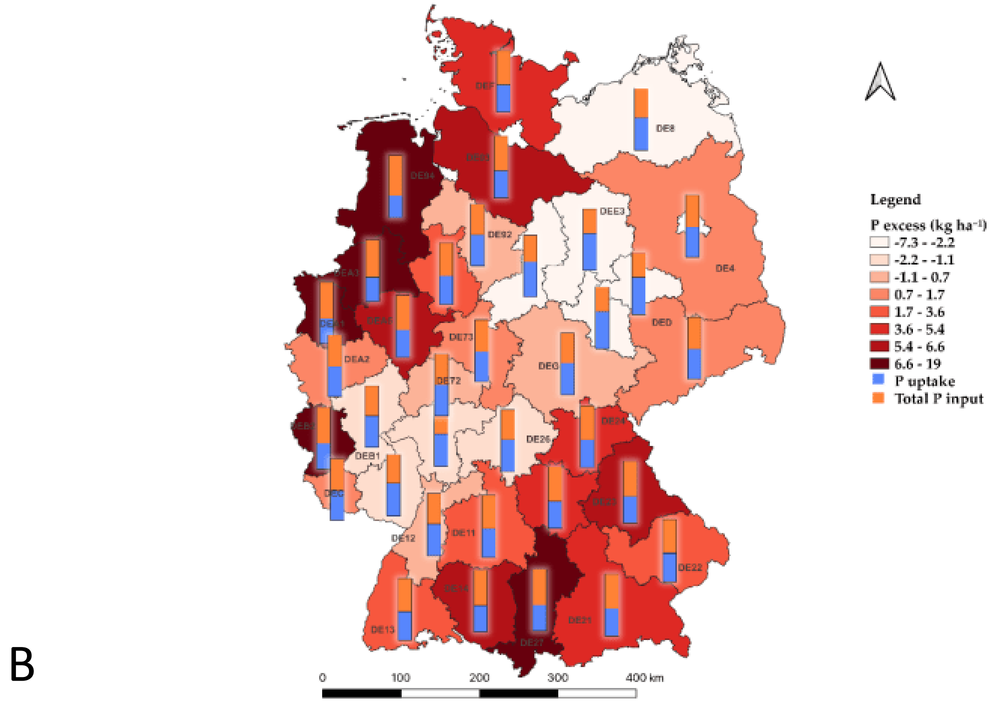
DEF	Schleswig-Holstein	208	130	77.9	24.7	19.9	4.82
DE22	Niederbayern	216	139	76.9	24.8	21.3	3.47
DE14	Tübingen	205	129	75.5	25.5	19.2	6.25
DE21	Oberbayern	220	145	74.5	26.1	20.9	5.22
DED	Sachsen	200	126	74.1	22.0	20.8	1.18
DE25	Mittelfranken	190	119	71.2	23.1	18.3	4.80
DEB2	Trier	196	125	70.7	24.4	17.6	6.72
DE11	Stuttgart	192	121	70.1	22.5	19.1	3.43
DE73	Kassel	206	138	68.1	22.8	21.3	1.45
DE24	Oberfranken	183	115	67.7	22.0	18.1	3.89
DEG	Thüringen	191	126	64.9	19.6	20.7	-1.01
DE91	Braunschweig	211	145	65.1	18.1	23.8	-5.71
DE8	Mecklenburg-Vorpommern	193	129	64.5	19.1	21.3	-2.19
DE13	Freiburg	184	122	62.1	20.9	18.1	2.78
DE12	Karlsruhe	175	114	60.9	18.6	18.8	-0.26
DE4	Brandenburg	160	101	59.6	17.4	16.5	0.96
DEC	Saarland	187	129	58.4	20.4	18.8	1.67
DE26	Unterfranken	169	111	58.2	17.1	18.3	-1.16
DE71	Darmstadt	189	131	58.0	18.7	20.6	-1.89
DE72	Gießen	195	137	57.7	20.7	20.6	0.06
DEB1	Koblenz	173	119	53.9	17.5	18.6	-1.13
DEB3	Rheinhessen-Pfalz	147	93.0	53.7	13.8	15.8	-2.04
DEE3	Magdeburg	176	126	49.7	13.8	20.9	-7.05
DEE2	Halle	175	126	49.0	13.7	20.9	-7.23
DEE1	Dessau	174	126	48.5	13.6	20.9	-7.25
Mean ± SD		204 ± 32	131 ± 15	72.5 ± 20	22.8 ± 6.4	20.5 ± 2.1	2.34 ± 5.6



Germany: N soil balance



Germany: P soil balance

Figure 2.3.5. Thematic map for nitrogen (A) and phosphorus (B) balance (kg ha^{-1}) in Germany.

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2.3.6. Sustainability of animal manure sources

The exclusion of inputs from mineral sources from the balance is particularly useful to understand if the need of nutrients for national agricultural production can be satisfied with only the recovery of nutrients deriving from manure, sewage sludge, compost and other biomasses. The balance on a NUTS2 scale also allows for the organization of a possible redistribution of recovered nutrients within the country.

Data in

Table 2.1.5 shows that there is a general lack of both nitrogen and phosphorous if mineral supply is excluded. Only few regions show an excess of nitrogen or phosphorous. The general average for nitrogen is -32 ± 31 kgP ha^{-1}. The minimum value for nitrogen is observed in the region Braunschweig (DE91) and Dessau (DEE1) with about -85.5 kgN ha^{-1}. The highest excess of nitrogen is shown in Weser-Ems (DE94) with 52.3 kgN ha^{-1}.

The average annual balance for phosphorus is -4.5 ± 6.7 kgP ha^{-1}, meaning a general lack of phosphorous without counting the mineral supply. The lowest values are observed in Dessau (DEE1)

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and Halle (DEE2) with about -16.4 kgP ha^{-1} and the highest value is again observed in Weser-Ems (DE94) with 14.7 kgP ha^{-1}.

The annual nitrogen and phosphorus balances for the regions in Germany indicate that the country still needs external sources in order to sustainable cover the needs of nitrogen and phosphorous. The actual mineral nitrogen and phosphorous supply could be covered by importing excess nutrients i.e. nutrients recovered in a concentrated form from manure in Belgium or the Netherlands could be transported to central and eastern Germany.

Table 2.3.5. Nitrogen (N) and phosphorus (P) from animal manure sources vs uptake by crops. The table reports the difference between nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil (excluding the share deriving from mineral fertilizers) and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			Phosphorus (kgP ha^{-1})		
NUTS2	**Name**	**N input excluding mineral**	**N uptake**	**N excess**	**P input excluding mineral**	**P uptake**	**P excess**
DE94	Weser-Ems	211	158	52.3	37.9	23.2	14.7
DEA3	Münster	192	151	41.0	33.5	24.6	8.86
DEA1	Düsseldorf	169	153	16.3	28.0	23.6	4.43
DE27	Schwaben	137	145	-8.64	23.1	20.8	2.35
DE14	Tübingen	119	129	-9.61	19.8	19.2	0.57
DEB2	Trier	114	125	-10.4	19.0	17.6	1.40
DE25	Mittelfranken	107	119	-12.0	17.4	18.3	-0.86
DEF	Schleswig-Holstein	117	130	-12.7	18.8	19.9	-1.10
DE23	Oberpfalz	116	129	-13.2	19.9	19.8	0.08
DEA5	Arnsberg	135	150	-15.7	22.6	22.9	-0.30
DE24	Oberfranken	98.8	115	-16.3	16.2	18.1	-1.93
DE11	Stuttgart	101	121	-20.1	16.6	19.1	-2.56
DEA4	Detmold	116	138	-22.1	18.5	22.3	-3.73
DE4	Brandenburg	74.8	101	-26.1	11.8	16.5	-4.74
DE21	Oberbayern	117	145	-28.4	19.2	20.9	-1.68
DE93	Lüneburg	123	152	-28.8	20.4	22.2	-1.82
DE13	Freiburg	92.0	122	-30.0	14.6	18.1	-3.54
DE22	Niederbayern	109	139	-30.0	17.8	21.3	-3.48

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DED	Sachsen	91.0	126	-34.9	15.0	20.8	-5.81
DEB3	Rheinhessen-Pfalz	54.0	93.0	-39.1	7.76	15.8	-8.03
DE12	Karlsruhe	74.8	114	-39.3	11.8	18.8	-7.03
DE26	Unterfranken	69.4	111	-41.3	10.4	18.3	-7.84
DE73	Kassel	94.4	138	-43.1	15.3	21.3	-6.03
DEC	Saarland	85.6	129	-43.2	13.4	18.8	-5.34
DEG	Thüringen	78.2	126	-47.7	12.1	20.7	-8.51
DEA2	Köln	104	152	-47.9	15.9	22.9	-7.00
DEB1	Koblenz	70.0	119	-49.2	10.3	18.6	-8.35
DE92	Hannover	95.5	146	-50.8	14.7	23.6	-8.87
DE72	Gießen	82.9	137	-54.4	12.7	20.6	-7.90
DE8	Mecklenburg-Vorpommern	71.6	129	-57.3	11.1	21.3	-10.2
DE71	Darmstadt	70.7	131	-60.6	10.7	20.6	-9.86
DEE3	Magdeburg	43.0	126	-82.9	4.69	20.9	-16.2
DEE2	Halle	41.6	126	-84.3	4.46	20.9	-16.4
DEE1	Dessau	40.5	126	-85.5	4.42	20.9	-16.5
DE91	Braunschweig	59.9	145	-85.6	8.46	23.8	-15.3
Mean ± SD		99.3 ± 38	131 ± 15	-32.0 ± 31	16.0 ± 7.3	20.5 ± 2.1	-4.53 ± 6.7

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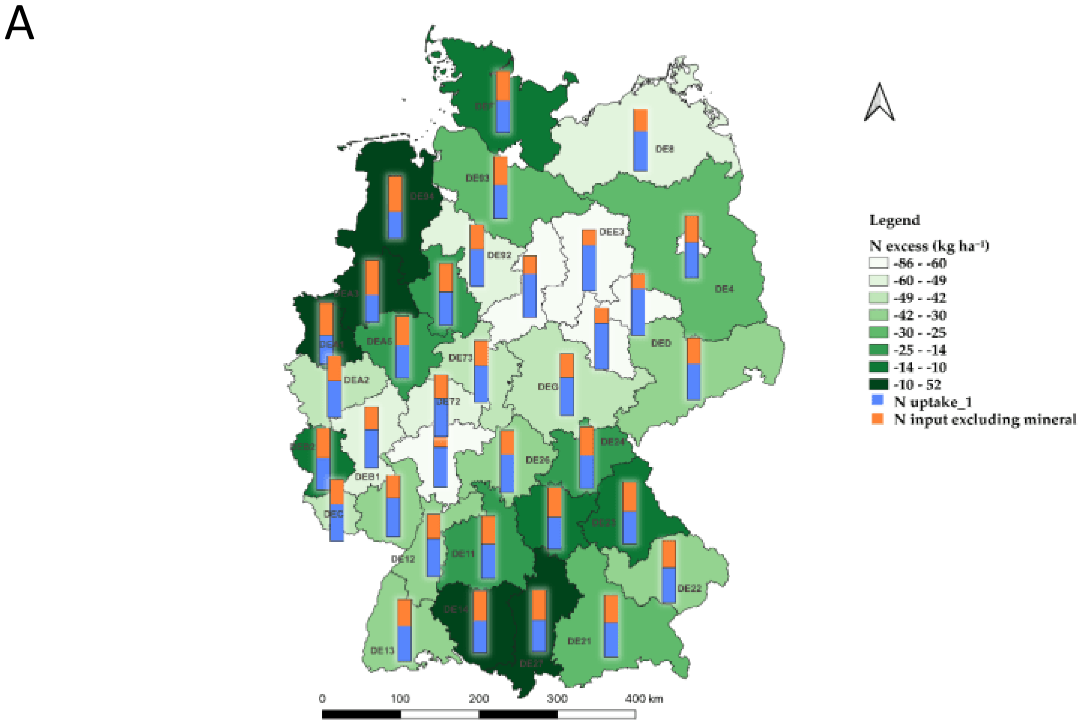
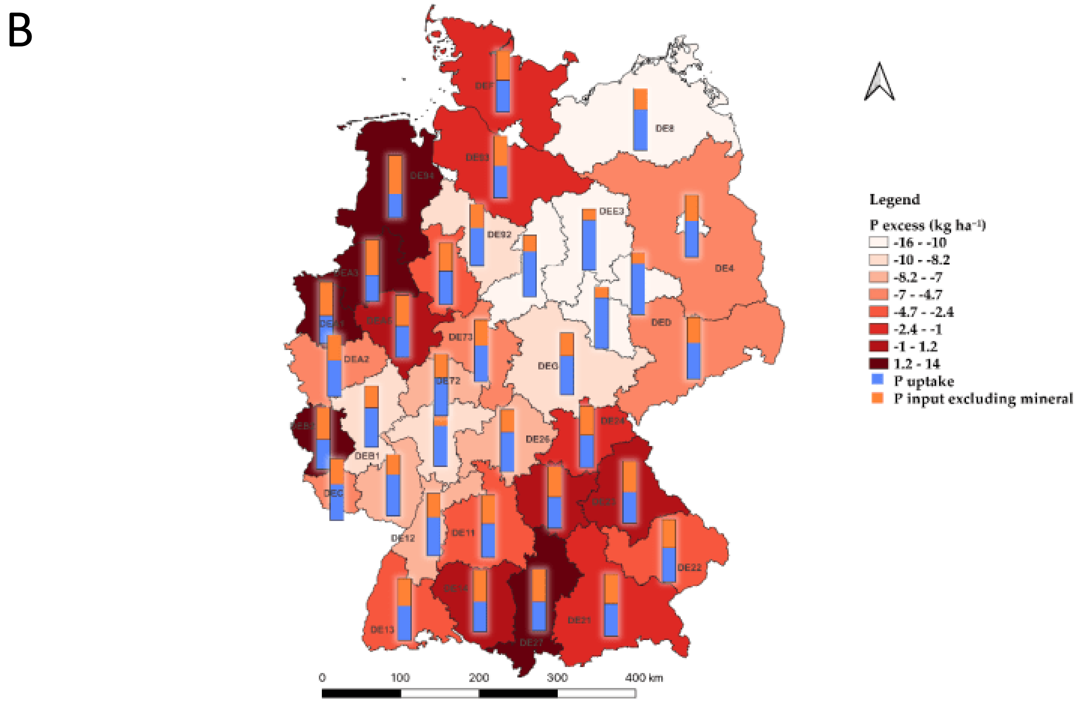


Germany: N Sustainability of animal manure sources



Germany: P Sustainability of animal manure sources

Figure 2.3.6. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources vs uptake by crops (kg ha^{-1}) in Germany.

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The nutrient balance shows that there is a gross excess of nitrogen and phosphorous in Germany but excluding the mineral fertilizers there would be a lack of nutrients to cover the yearly uptake in the agricultural lands. According to this data, despite of localized nutrient surplus, Germany still needs external nutrient sources to cover the overall nutrient needs in a sustainable way.

2.4. Belgium

The agricultural land use in Belgium is reported to be 1.35 million hectare (46% of the territory) which only accounts for 0.8% of the total European agricultural area. Since 2000, the Belgian agricultural area has decreased by 2.1% (Statbel, 2020). This decline is mainly due to the decrease in the area for forage (meadows and maize).

The Belgian agricultural sector is very heterogeneous, and all agricultural regions have typical outputs. Since different crops have different nutrient requirements, the reported nitrogen and phosphorus input is very different for every agricultural region. The regions with the highest percentages of livestock production are located in the Northern part of the country, even as the highest percentage of horticulture area is found in Flanders region. The situation is the opposite for cereal -and industrial crop production, which are common crops for the southern part. As livestock farming is responsible for the production of large quantities of manure rich in nitrogen and phosphorus, the agricultural fields of the northern part of Belgium are characterized by a higher input of nutrients from animal sources.

2.4.1. Nitrogen and phosphorus from animal manure sources

The average annual amount of nitrogen from manure supplied to Belgian soils is 136 ± 12 kgN ha^{-1} with 6 out of 10 provinces above average. All regions have a similar nitrogen supply by manure, which is illustrated by the low standard deviation. The region characterized with the lowest nitrogen supply form animal origin is Luxembourg (110 kgN ha^{-1}), an area located in the most southern part of the country. The soils that receive the maximum input of nitrogen from animal origin are those of province Branbant-Wallon. This region is particularly dedicated to farming and breeding. The average annual amount of phosphorus from animal origin distributed the Belgian soils equals 34.4 kgP ha^{-1}). The input of phosphorus from manure is also very similar for all Belgian provinces and is above the average for 6 out of 10 provinces. As for nitrogen, the province with the lowest P input from manure is Luxembourg, (27.7 kgP ha^{-1}), whereas Brabant-Wallon is characterized by the highest animal P input (38.3 kgP ha^{-1}).

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Table 2.4.1. Nitrogen (N) and phosphorus (P) from animal manure and mineral fertilizer sources. The table reports the total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input from animal manure and mineral fertilizer sources on soils for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N from manure (kgN ha^{-1})	Mineral N (kgN ha^{-1})	P from manure (kgP ha^{-1})	Mineral P (kgP ha^{-1})
BL31	Brabant Wallon	152	151	38.3	5.61
BL24	Vlaams-Brabant	148	142	37.3	7.34
BL22	Limburg	147	115	37.1	5.20
BL21	Antwerpen	138	105	34.9	3.42
BL23	Oost-Vlaanderen	138	139	34.8	7.40
BL35	Namur	137	132	34.6	5.18
BL25	West-Vlaanderen	136	142	34.3	7.25
BL32	Hainaut	132	151	33.3	6.93
BL33	Liège	124	138	31.3	6.82
BL34	Luxembourg	110	117	27.7	5.44
Mean ± SD		136 ± 12	133 ± 16	34.4 ± 3.1	6.06 ± 1.3

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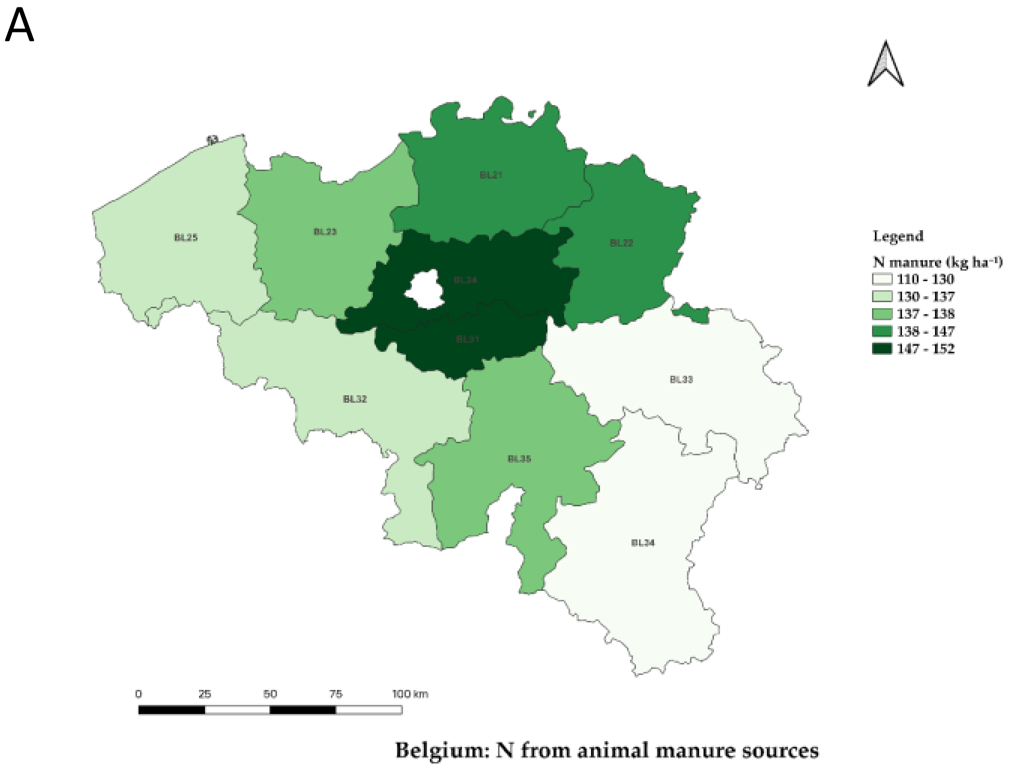

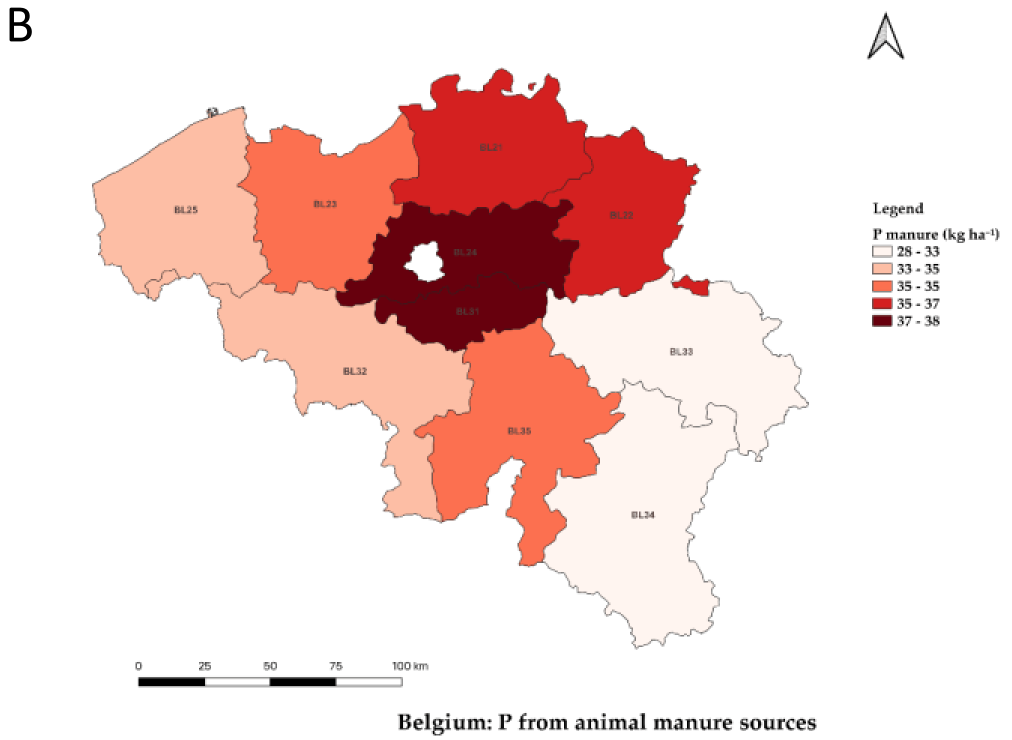

Figure 2.4.1. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources (kg ha^{-1}) in Belgium.

2.4.2. Nitrogen and phosphorus from mineral fertilizer sources

The average annual input of mineral nitrogen to the Belgian soils equals 133 ± 16 kgN ha^{-1} with 6 out of 10 provinces above the average. As for animal N, the standard deviation is low indicating on a similar mineral N supply of the Belgian provinces. The average amount of mineral N supplied to the Belgian soils is similar to the amount N supplied by manure. However, the share of nitrogen source is depending on the province. The region with the lowest annual mineral nitrogen input is Antwerpen, their soils only receive 105 kgN ha^{-1}. The soils that receive the highest annual input of mineral N are located in Brabant-Wallon and Hainaut. Both provinces are characterized by an average annual mineral N input of 151 kgN ha^{-1}.

As Belgian soils are already rich in phosphorus, the amount of mineral phosphorus applied to the soil is low in all provinces. The average annual mineral phosphorus input equals 6.06 ± 1.3 kgP ha^{-1}. As for mineral N, the lower mineral P input is found in the soils of Antwerpen, in the North of the country. The region with the highest mineral P input is Oost-Vlaanderen with 7.4 kgP ha^{-1}, immediately followed by Vlaams-Brabant and West-Vlaanderen with almost identical values (7.34 and 7.25 kg P ha^{-1}, respectively).

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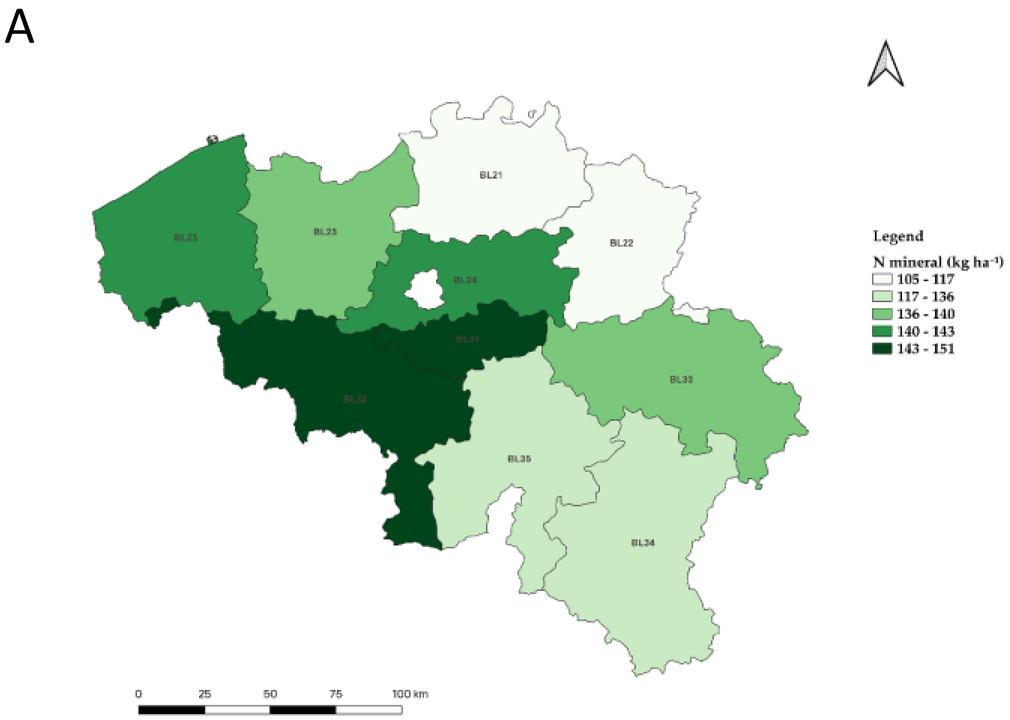
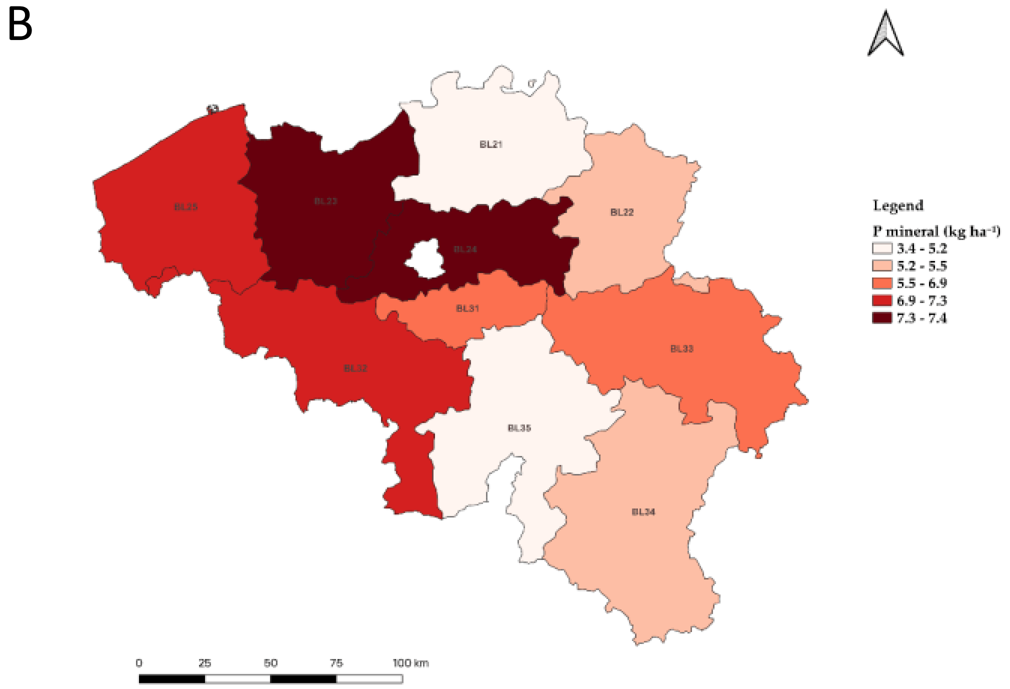


Belgium: N from mineral fertilizer sources



Belgium: P from mineral fertilizer sources

Figure 2.4.2. Thematic map for nitrogen (A) and phosphorus (B) from mineral fertilizer sources (kg ha^{-1}) in Belgium.

2.4.3. Nitrogen and phosphorus from other sources

The input of nitrogen and phosphorus from other sources (Table 2.4.2) includes that deriving from the use of sewage sludge as fertilizers, compost, nitrogen and phosphorus contained in the excreta of grazing animals and the share of nitrogen received by the soil from non-anthropogenic sources, such as atmospheric events or nitrogen bacterial fixation.

The majority of the nitrogen input from these four sources, excluding non-anthropogenic sources, is on average that deriving from pastures. The annual average nitrogen input from grazing animals equals 38.6 ± 14 kgN ha^{-1}, with 3 out of 10 provinces above the average. The two provinces characterized by the highest nitrogen input are Luxembourg and Antwerpen (59.7 and 59.4 kgN ha^{-1} respectively). The average annual input brought to the Belgian soils by the other two non-anthropogenic sources, namely sludge and compost, are very low (0.36 and 0.77 kg ha^{-1}, respectively). Instead, the input by non-anthropic processes (36.4 ± 5.1 kg ha^{-1}) almost equalled the input by grazing.

As for nitrogen, the majority of the phosphorus input from other sources originates from grazing animals, with a national average of 7.08 ± 2.1 kgP ha^{-1}. The province with the lower input of phosphorus from pastures is Brabant Wallon (2.83 kgP ha^{-1}), while the highest input of phosphorus from pastures is in Luxembourg and Anwerpen region (10 and 9.38 kgP ha^{-1}, respectively). Also in the case of phosphorus, the share of sewage sludge and compost is very low (0.57 and 0.16 kg ha^{-1}, respectively).

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Table 2.4.2. Nitrogen (N) and phosphorus (P) from other sources. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soils from sources other than animal manure and mineral for each region analysed. Non-anthropic considers both inorganic deposition and biological fixation. Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})				Phosphorus (kgP ha^{-1})		
NUTS 2	**Name**	**N from sludge**	**N from compost**	**N from grazing**	**Non-anthropic N**	**P from sludge**	**P from compost**	**P from grazing**
BL34	Luxembourg	0.18	0.36	59.7	29.3	0.27	0.07	10.0
BL21	Antwerpen	0.34	0.71	59.4	43.2	0.52	0.14	9.38
BL33	Liège	0.28	0.59	46.0	33.7	0.43	0.12	7.31
BL23	Oost-Vlaanderen	0.39	0.80	42.7	38.9	0.59	0.16	6.88
BL25	West-Vlaanderen	0.44	0.90	36.9	33.9	0.67	0.18	6.52
BL32	Hainaut	0.44	0.91	36.4	33.8	0.67	0.18	6.04
BL22	Limburg	0.44	0.90	32.9	44.8	0.67	0.18	5.26
BL35	Namur	0.31	0.65	32.4	31.1	0.48	0.13	5.39
BL24	Vlaams-Brabant	0.40	0.83	23.6	39.4	0.61	0.17	3.91
BL31	Brabant Wallon	0.51	1.04	16.1	36.3	0.77	0.21	2.83
Mean ± SD		0.37 ± 0.1	0.77 ± 0.2	38.6 ± 14	36.4 ± 5.1	0.57 ± 0.1	0.16 ± 0	7.08 ± 2.1

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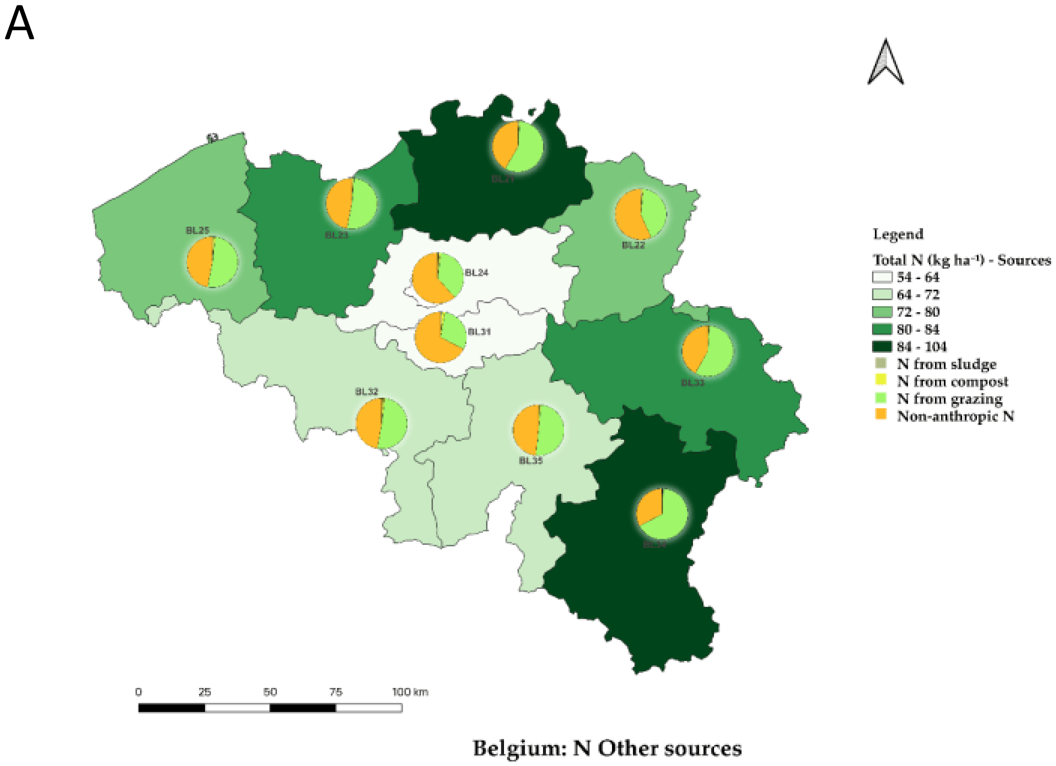

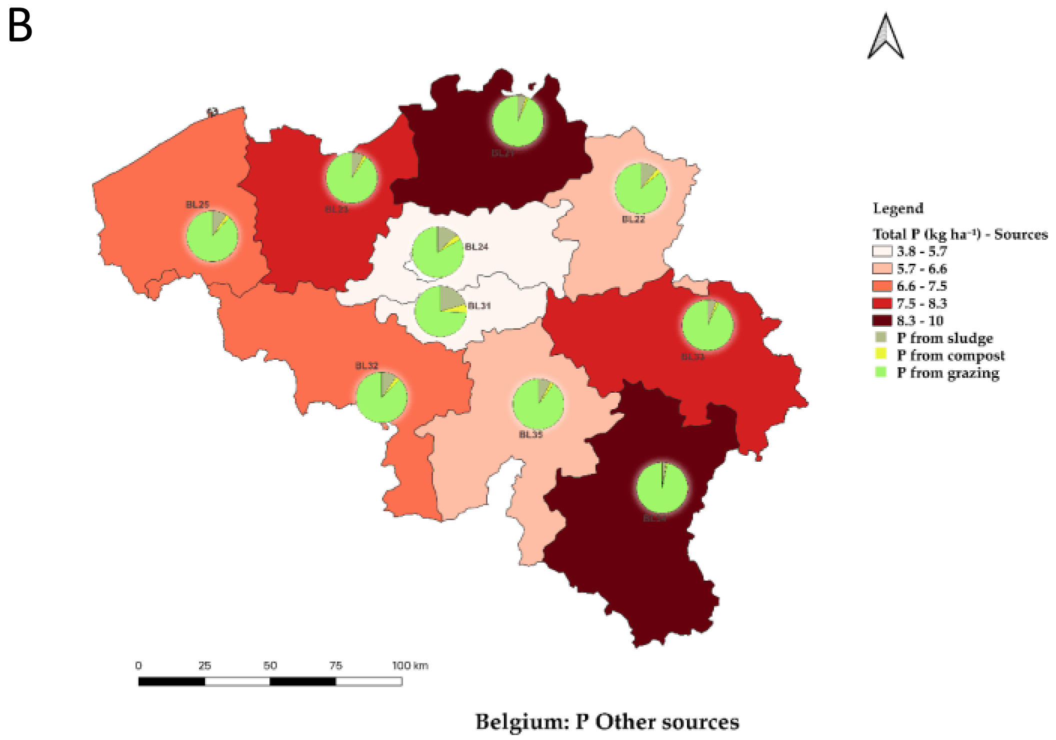

Figure 2.4.3. Thematic map for nitrogen (A) and phosphorus (B) from other sources (kg ha^{-1}) in Belgium.

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2.4.4. Nitrogen and phosphorus uptake by crops

The average annual nitrogen uptake from Belgian soils (Table 2.4.3) is 157 ± 6.4 kgN ha^{-1}, with 6 regions out of 10 above the average. The low standard deviation indicates that the nitrogen uptake is fairly uniform across the country, demonstrating that the agricultural sector is well spread across the provinces. The highest nitrogen uptake was found in province Oost-Vlaanderen (166 kg N ha^{-1}). Instead, the province with the lowest nitrogen uptake is Limburg (144 kg N ha^{-1}), located in the east of the country with a strong vocation for fruit crops.

The average annual phosphorus uptake from the Belgian soils is 23.6 ± 1.2 kg ha^{-1} and is also uniform across the country. The phosphorus uptake follows the same trend as the nitrogen uptake. The province that shows the lower phosphorus uptake is Luxembourg (21 kgP ha^{-1}), while the highest uptake is observed for the soils of the province of Oost-Vlaanderen (25.2 kgP ha^{-1}).

Table 2.4.3. Nitrogen (N) and phosphorus (P) uptake by crops. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual uptake by cultivated plants for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	**Name**	**N uptake (kgN ha^{-1})**	**P uptake (kgP ha^{-1})**
BL23	Oost-Vlaanderen	166	25.2
BL33	Liège	162	23.5
BL21	Antwerpen	160	23.5
BL24	Vlaams-Brabant	159	24.9
BL25	West-Vlaanderen	158	24.2
BL32	Hainaut	158	24.1
BL34	Luxembourg	157	21.2
BL35	Namur	157	23.2
BL31	Brabant Wallon	154	24.5
BL22	Limburg	142	22.2
Mean ± SD		157 ± 6.4	23.6 ± 1.2

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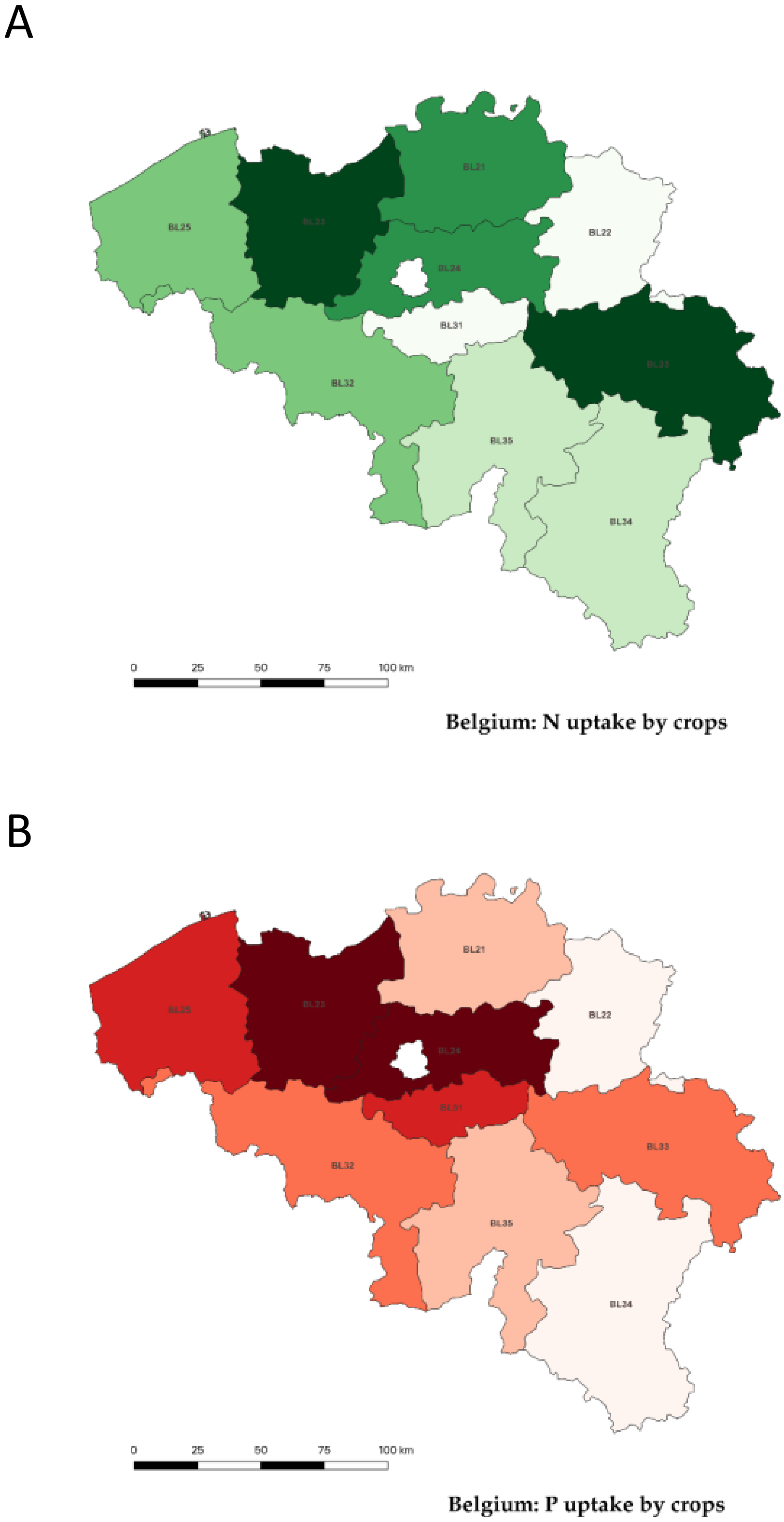

Figure 2.4.4. Thematic map for nitrogen (A) and phosphorus (B) uptake by crops (kg ha^{-1}) in Belgium.

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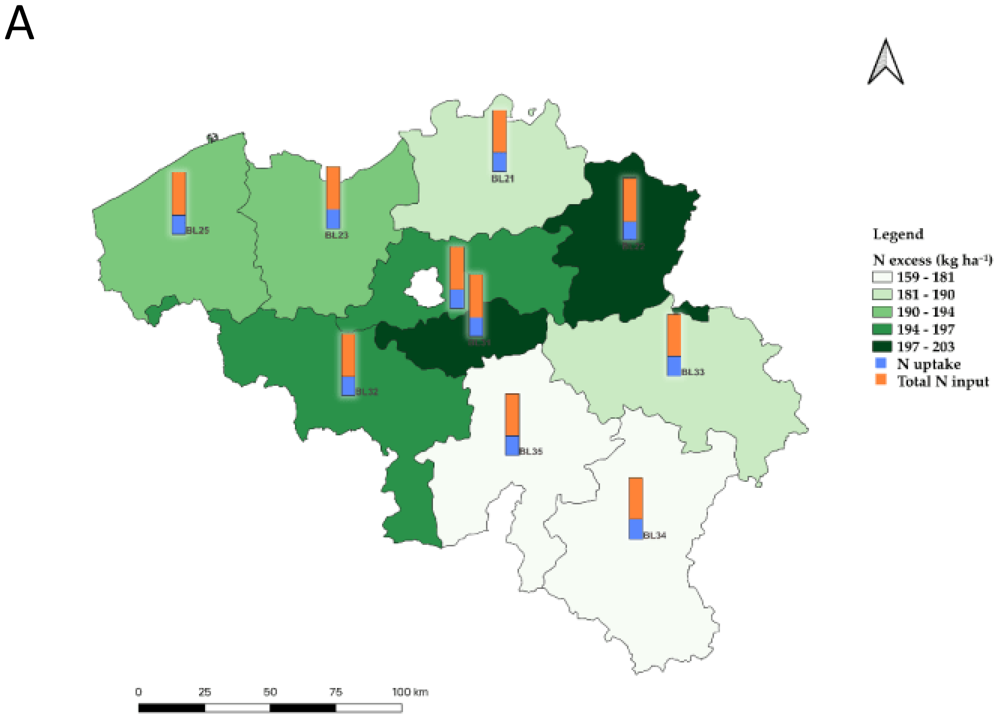
2.4.5. Nitrogen and phosphorus soil balances

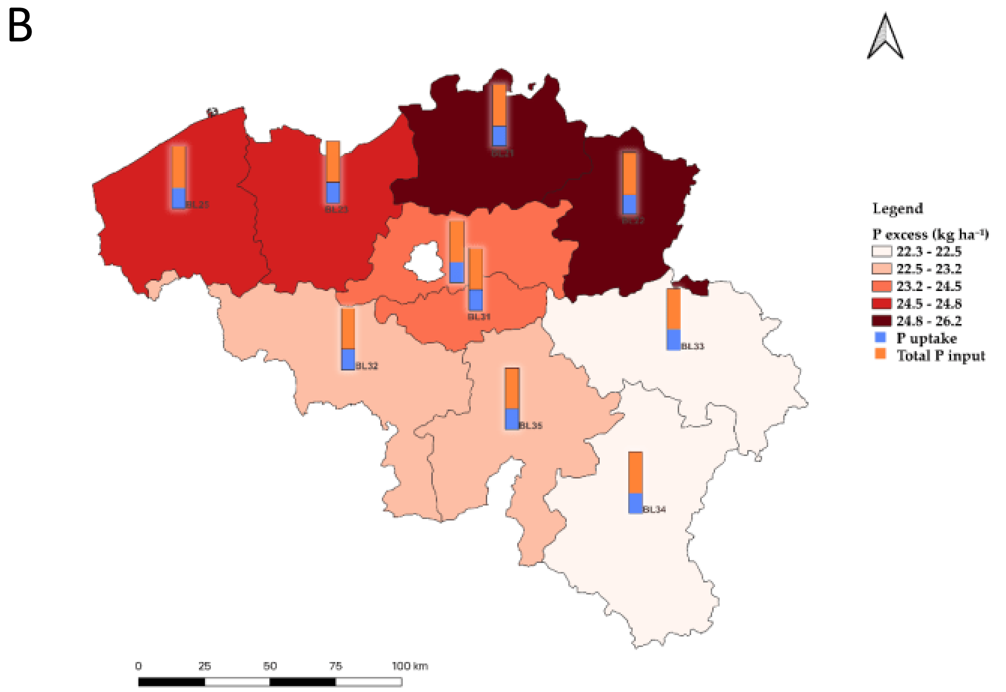
The annual soil nutrient balance (Table 2.4.4) indicates that there is a strong excess both for nitrogen and for phosphorus in all provinces. On average, Belgian soils have an annual nitrogen excess of 188 ± 13 kgN ha^{-1}, with province Brabant Wallon showing the highest surplus (203 kgN ha^{-1}), while the lowest annual nitrogen excess can be found in the soils of Luxembourg (159 kgN ha^{-1}).
The annual phosphorus excess on national level averages 23.8 ± 1.3 kgP ha^{-1}. The province that shows the highest surplus of phosphorus is Limburg, with 26.2kgP Ha^{-1}, while the lowest excess is found in the province of Luxembourg, with 22.3 kgP ha^{-1}.

Table 2.4.4. Nitrogen (N) and phosphorus (P) balances. The table reports the difference between total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**Total N input**	**N uptake**	**N excess**	**Total P input**	**P uptake**	**P excess**
BL31	Brabant Wallon	357	154	203	47.7	24.5	23.3
BL22	Limburg	341	142	199	48.4	22.2	26.2
BL32	Hainaut	354	158	196	47.1	24.1	23.0
BL24	Vlaams-Brabant	354	159	195	49.4	24.9	24.5
BL23	Oost-Vlaanderen	360	166	194	49.9	25.2	24.6
BL25	West-Vlaanderen	350	158	192	48.9	24.2	24.7
BL21	Antwerpen	347	160	187	48.3	23.5	24.9
BL33	Liège	343	162	181	45.9	23.5	22.4
BL35	Namur	334	157	177	45.8	23.2	22.6
BL34	Luxembourg	316	157	159	43.5	21.2	22.3
Mean ± SD		346 ± 13	157 ± 6.4	188 ± 13	47.5 ± 2	23.6 ± 1.2	23.8 ± 1.3



Belgium: N soil balance



Belgium: P soil balance

Figure 2.4.5. Thematic map for nitrogen (A) and phosphorus (B) balance (kg ha^{-1}) in Belgium.

2.4.6. Sustainability of animal manure sources

The data shown in Table 2.4.5 shows that, when the nitrogen input from mineral sources is eliminated, still all provinces have a surplus of nitrogen and phosphorus. However, the surplus with reduced values is less critical as the scenario which includes the use of mineral fertilisers. The average annual budget found for nitrogen in the case excluding mineral fertilisers is 55.2 ± 15kgN ha^{-1}.

The average annual balance for phosphorus in the case excluding mineral fertilisers is 17.8 ± 1.9 kgP ha^{-1}. This reduced balance is very similar to the one also including the mineral fertilisers, since the annual mineral phosphorus deposition to the soils of Belgium is very small.

Table 2.4.5. Nitrogen (N) and phosphorus (P) from animal manure sources vs uptake by crops. The table reports the difference between nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil (excluding the share deriving from mineral fertilizers) and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**N input excluding mineral**	**N uptake**	**N excess**	**P input excluding mineral**	**P uptake**	**P excess**
BL22	Limburg	226	142	84.2	43.2	22.2	21.0
BL21	Antwerpen	242	160	81.7	44.9	23.5	21.5
BL23	Oost-Vlaanderen	221	166	54.8	42.5	25.2	17.2
BL24	Vlaams-Brabant	212	159	53.2	42.0	24.9	17.1
BL25	West-Vlaanderen	208	158	50.4	41.7	24.2	17.5
BL31	Brabant Wallon	206	154	52.2	42.1	24.5	17.7
BL35	Namur	202	157	44.9	40.6	23.2	17.4
BL32	Hainaut	204	158	45.1	40.2	24.1	16.1
BL33	Liège	205	162	43.0	39.1	23.5	15.6
BL34	Luxembourg	199	157	42.0	38.0	21.2	16.8
Mean ± SD		212 ± 13	157 ± 6.4	55.2 ± 15	41.4 ± 2	23.6 ± 1.2	17.8 ± 1.9

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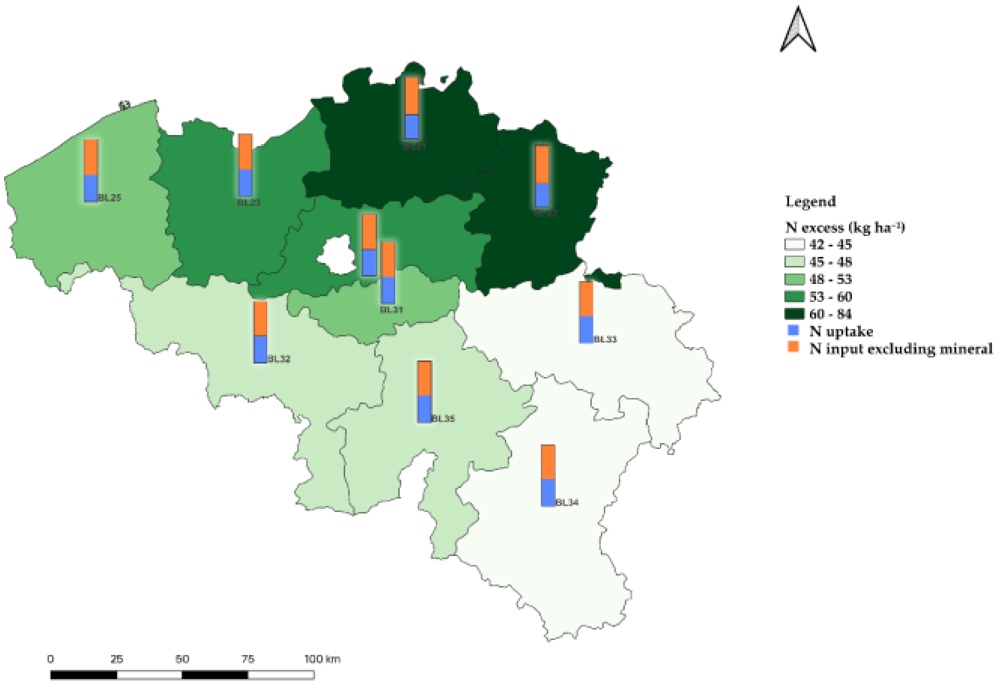
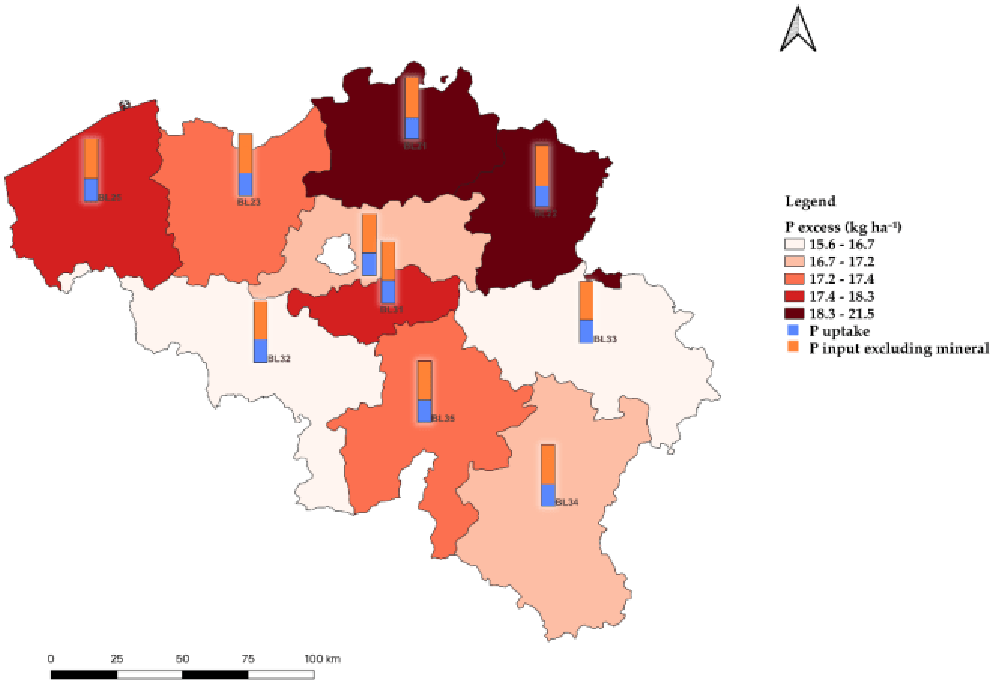
A



Belgium: N Sustainability of animal manure sources

B



Belgium: P Sustainability of animal manure sources

Figure 2.4.6. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources vs uptake by crops (kg ha^{-1}) in Belgium.

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2.5. France

In the NUTS codes of France, NUTS2 indicates 22 former regions (1982 - 2015) and five Overseas departments. From the 2015 regionalization law, some French regions merged: for example, Alsace, Champagne-Ardenne and Lorraine into Grand-Est. In this study we only considerate the 22 former regions.

2.5.1. Nitrogen and phosphorus from animal manure sources

The average annual supply of nitrogen from manure to French soils is 21.4 ± 13 kgN ha^{-1}. The high standard deviation indicates a high variability within regions. The regions that presents an annual supply from manure higher than the average are mainly livestock regions. Among them, the highest values are observed for Pays de Loire (36.4 kgN ha^{-1}) and Bretagne (68.5 kgN ha^{-1}), two intensive livestock farming regions. Bretagne is a major breeding region where more than 60% of the regional territory is devoted to agriculture. Mixed livestock farming is the main type of farming in Bretagne with dairy orientation dominating. It is the main French region for dairy cattle, pig and poultry production. Pays de Loire is the major French region for beef cattle and the second one for poultry and pig production.

The soils that receive the minimum amount of nitrogen from manure (Table 2.5.1) are those from Ile de France (5.28 kgN ha^{-1}), Centre (10.4 kgN ha^{-1}), Champagne-Ardenne (11.1 kgN ha^{-1}), Picardie (11.6 kgN ha^{-1}), Languedoc-Roussillon (11.9 kgN ha^{-1}) and Bourgogne (14.8 kgN ha^{-1}), the centre and northern area of the country (Figure 2.5.1). These regions are more devoted to cereal and oil crops production.

Compared to nitrogen, the input of phosphorus from manure is low and more uniform within regions, with 6 regions above the national average (6.07 ± 4.2 kgP ha^{-1}). The minimum input is observed for Champagne-Ardenne (1.21 kgP ha^{-1}). The maximum inputs are rather observed for the intensive livestock regions Pays de Loire (10.1 kgP ha^{-1}), Bretagne (16.8 kgP ha^{-1}) and for Corse (18.1 kgP ha^{-1}).

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Table 2.5.1. Nitrogen (N) and phosphorus (P) from animal manure and mineral fertilizer sources. The table reports the total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input from animal manure and mineral fertilizer sources on soils for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N from manure (kgN ha^{-1})	Mineral N (kgN ha^{-1})	P from manure (kgP ha^{-1})	Mineral P (kgP ha^{-1})
FR52	Bretagne	68.5	71.9	16.8	5.77
FR51	Pays de la Loire	36.4	79.0	10.1	6.95
FR25	Basse-Normandie	28.8	91.3	6.12	6.48
FR71	Rhône-Alpes	27.5	51.4	6.79	4.01
FR72	Auvergne	27.2	49.7	5.65	5.34
FR63	Limousin	25.4	58.0	7.20	3.01
FR43	Franche-Comté	24.4	67.6	8.00	3.64
FR3	Nord - Pas-de-Calais	23.2	113	5.94	8.48
FR61	Aquitaine	21.9	72.8	5.85	4.43
FR83	Corse	19.1	4.70	18.1	0.22
FR42	Alsace	18.5	97.0	5.72	6.27
FR41	Lorraine	18.2	88.1	2.75	9.10
FR62	Midi-Pyrénées	18.1	62.1	4.00	7.12
FR23	Haute-Normandie	17.2	114	4.64	7.79
FR82	Provence-Alpes-Côte d'Azur	16.0	14.4	3.00	2.15
FR53	Poitou-Charentes	15.3	84.6	3.70	7.32
FR26	Bourgogne	14.8	78.8	3.19	8.56
FR81	Languedoc-Roussillon	11.9	26.9	2.86	2.65
FR22	Picardie	11.6	130	4.30	10.4
FR21	Champagne-Ardenne	11.1	112	1.23	10.3
FR24	Centre	10.4	101	3.43	9.01
FR1	Île de France	5.28	130	4.14	8.32
Mean ± SD		21.4 ± 13	77.2 ± 34	6.07 ± 4.2	6.24 ± 2.8

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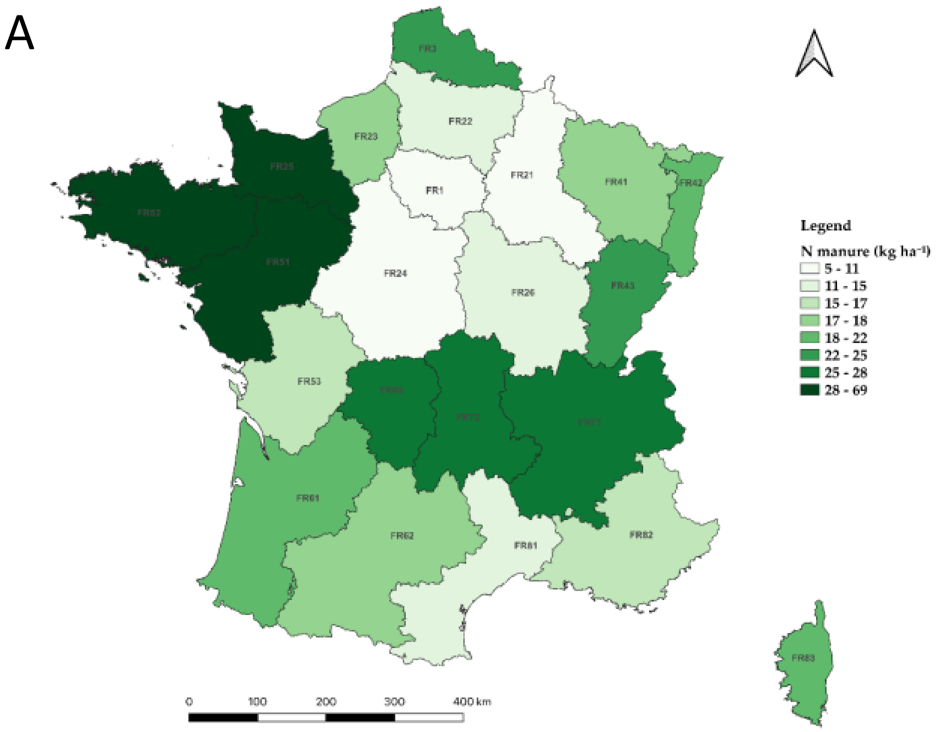
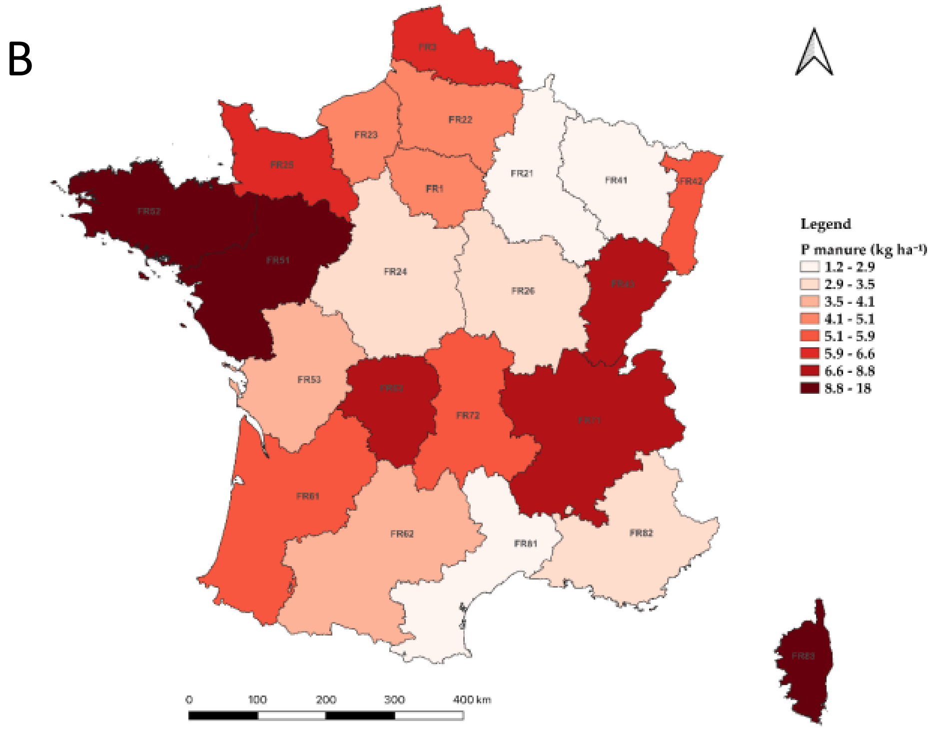


France: N from animal manure sources



France: P from animal manure sources

Figure 2.5.1. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources (kg ha^{-1}) in France.

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2.5.2. Nitrogen and phosphorus from mineral fertilizer sources

The average annual supply of mineral fertilizer nitrogen to French soils is 77.2 ± 34 kgN ha^{-1}, a higher amount than nitrogen from animal manure sources. The high standard deviation also indicates a high variability among regions. The regions that show an input of mineral fertilizer nitrogen to the soil equal to or higher than the national average are 12 out of 22.

The soils that receive a lower annual amount of mineral fertilizer nitrogen (Table 2.1.1) are those of Corse (4.7 kgN ha^{-1}), Provence-Alpes-Côte d'Azur (14.4 kgN ha^{-1}) and Languedoc-Roussillon (26.9 kgN ha^{-1}) (Figure 2.1.2), while the greatest input are received by the soils of Ile-de-France and Picardie (130 kgN ha-1), Haute-Normandie (114kgN ha^{-1}) and Nord-Pas-de-Calais (113 kgN ha^{-1}) – cereal and oil crops regions.

The amounts of mineral phosphorus exploited are extremely low and uniform (Table 2.1.1). The national average is in fact 6.24 ± 2.28 kgP ha^{-1}, the same order of magnitude than the amount of phosphorus from animal manure sources. The lower input is observed for the soils of Corse (0.22 kgP ha^{-1}). The soils that receive the higher input are those from Picardie (10.4 kgP ha^{-1}) in the north and those from Lorraine (9.1 kgP ha^{-1}) and Champagne-Ardennes (10.3 kgP ha^{-1}) in the north east (Figure 2.1.2).

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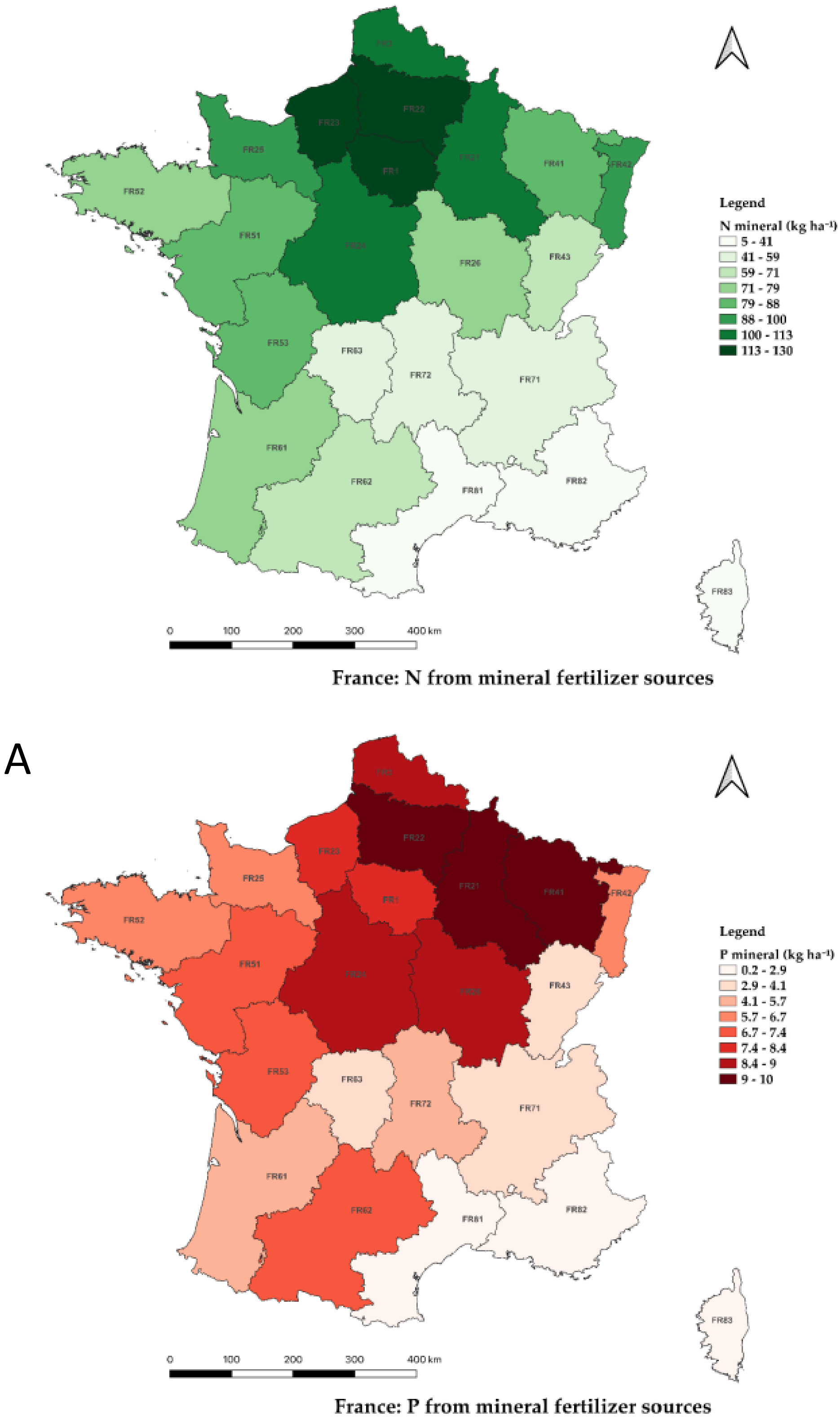

France: N from mineral fertilizer sources

France: P from mineral fertilizer sources

Figure 2.5.2. Thematic map for nitrogen (A) and phosphorus (B) from mineral fertilizer sources (kg ha^{-1}) in France.

B

2.5.3. Nitrogen and phosphorus from other sources

The input of nitrogen and phosphorus from other sources (Table 2.1.2) includes the ones deriving from the use of sewage sludge as fertilizers, compost, nitrogen and phosphorus contained in the excreta of grazing animals and nitrogen received by the soil from non-anthropogenic sources, such as atmospheric events or nitrogen bacterial fixation.

Of these four sources, the surely majority fraction is on average the source deriving from grazing animals. The national average for nitrogen input to the soil deriving from pastures is 32.3 ± 12 kgN ha^{-1}. The region that shows the lowest value is Ile-de-France (1.55 kgN ha^{-1}). Instead, the regions characterized by the highest nitrogen input from pastures are Auvergne (51.8 kgN ha^{-1}) and Limousin (56.8 kgN ha^{-1}), two extensive livestock farming regions. On the other hand, the nitrogen input from sewage sludge or compost is close to zero throughout the country.

Even in the case of the phosphorus input from other sources, the majority share is represented by the phosphorus from grazing animals, with a national average of 5.55 ± 3.1 kgP ha^{-1}. The region with the lower input of phosphorus from pastures is Lorraine (2.01 kgP ha^{-1}), while the highest input of phosphorus from pastures is in Franche-Comté region (16 kgP ha^{-1}). Finally, also in the case of phosphorus, the share of sewage sludge and compost phosphorus are extremely low.

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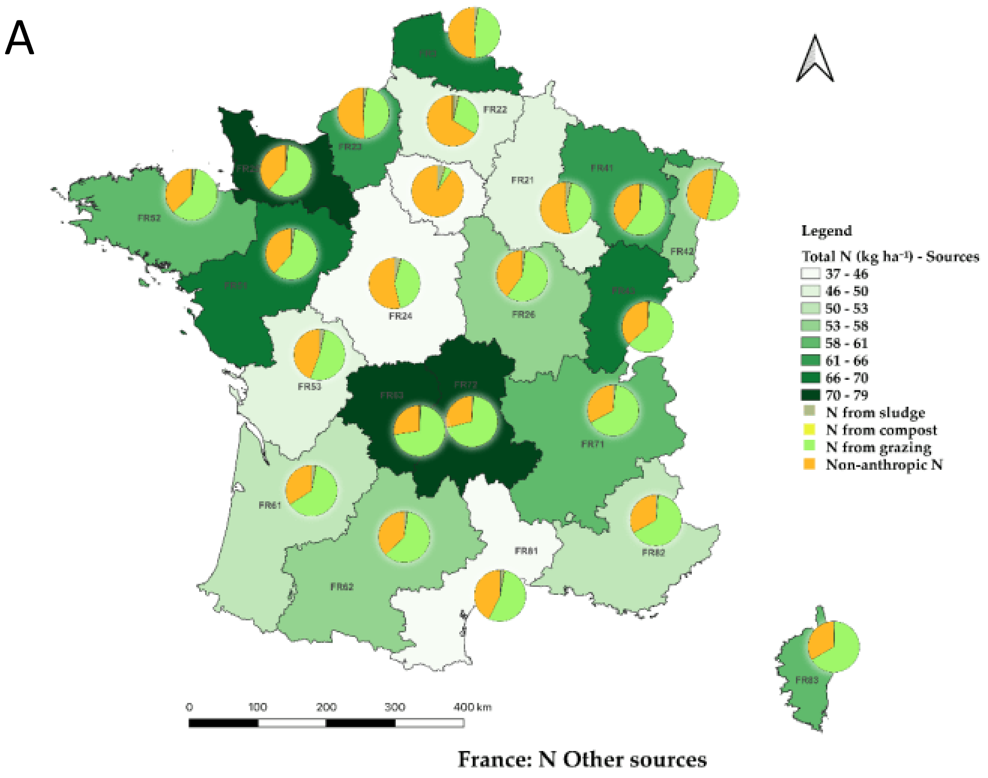
Table 2.5.2. Nitrogen (N) and phosphorus (P) from other sources. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soils from sources other than animal manure and mineral for each region analysed. Non-anthropic considers both inorganic deposition and biological fixation. Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})				**Phosphorus (kgP ha^{-1})**		
NUTS 2	**Name**	**N from sludge**	**N from compost**	**N from grazing**	**Non-anthropic N**	**P from sludge**	**P from compost**	**P from grazing**
FR63	Limousin	0.54	0.07	56.8	21.7	0.34	0.01	8.78
FR72	Auvergne	0.56	0.07	51.8	21.3	0.79	0.03	4.58
FR25	Basse-Normandie	0.82	0.11	44.0	28.3	0.61	0.02	7.30
FR43	Franche-Comté	0.64	0.08	41.8	24.6	0.30	0.01	16.0
FR51	Pays de la Loire	1.28	0.17	39.9	25.9	1.11	0.04	6.06
FR83	Corse	0.25	0.03	39.9	20.2	0.09	0	4.57
FR71	Rhône-Alpes	0.83	0.11	39.5	19.8	0.53	0.02	7.67
FR52	Bretagne	1.47	0.19	36.4	22.5	1.18	0.04	4.16
FR41	Lorraine	1.05	0.14	35.4	24.6	1.27	0.04	2.01
FR82	Provence-Alpes-Côte d'Azur	0.68	0.09	34.8	17.5	0.80	0.03	3.50
FR26	Bourgogne	1.05	0.14	32.9	22.6	1.17	0.04	3.79
FR62	Midi-Pyrénées	1.21	0.16	32.8	20.2	1.04	0.04	3.56
FR61	Aquitaine	1.44	0.19	32.4	17.6	0.77	0.03	7.30
FR3	Nord - Pas-de-Calais	1.45	0.19	31.6	34.1	0.84	0.03	5.33
FR23	Haute-Normandie	1.32	0.17	29.7	31.9	0.96	0.03	8.53
FR42	Alsace	1.50	0.20	27.2	24.7	0.53	0.02	6.25
FR53	Poitou-Charentes	1.56	0.20	25.3	21.4	1.17	0.04	4.01
FR81	Languedoc-Roussillon	1.15	0.15	23.1	18.2	0.89	0.03	3.63
FR21	Champagne-Ardenne	1.57	0.21	20.5	25.4	1.29	0.04	2.48
FR24	Centre	1.66	0.22	17.9	22.9	1.03	0.04	3.26
FR22	Picardie	1.71	0.22	14.8	32.9	1.17	0.04	2.75
FR1	Île de France	1.85	0.24	1.55	33.5	0.97	0.03	6.56
Mean ± SD		1.16 ± 0.4	0.15 ± 0.1	32.3 ± 12	24.2 ± 5.1	0.86 ± 0.3	0.03 ± 0	5.55 ± 3.1



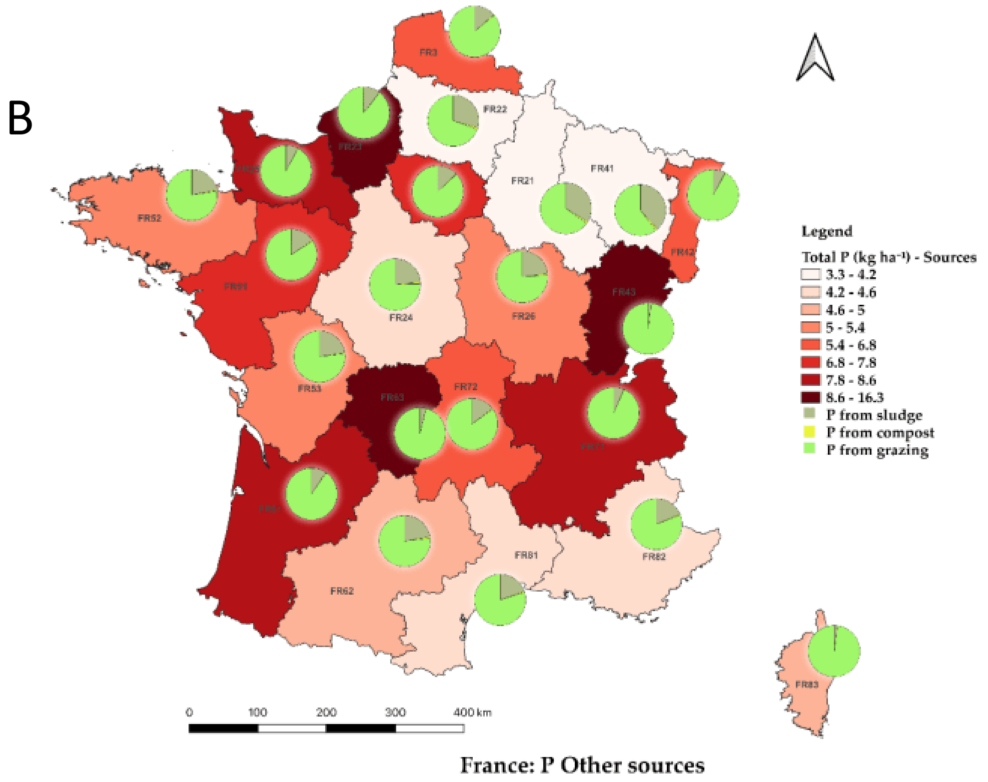


Figure 2.5.3. Thematic map for nitrogen (A) and phosphorus (B) from other sources (kg ha^{-1}) in France.

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2.5.4. Nitrogen and phosphorus uptake by crops

The uptake of nitrogen and phosphorus from the soils (Table 2.1.3) depend on many factors, including mainly how much area is left to pasture, how much is put into cultivation, the types of plants grown and the yield obtained, with can vary a lot each year.

The national average annual nitrogen uptake is 106 ± 36 kgN ha^{-1}. The region that shows the lowest nitrogen uptake is Corse (18 kgN ha^{-1}) with a high diversity of agricultural productions. The maximum annual nitrogen uptake detected is instead for the regions of the north: Picardie (147 kgN ha^{-1}), Haute-Normandie (147 kgN ha^{-1}), Nord-Pas-de-Calais (146 kgN ha^{-1}), Ile-de-France (138 kgN ha^{-1}), which is the northern area of the country devoted to cereals and oil crops and other crops like potatoes and beetroot.

Annual phosphorus uptake is proportionate to nitrogen uptake in almost all regions. The national average annual uptake for phosphorus is in fact 16.1 ± 5.2 kgP ha^{-1}. The region that shows the least phosphorus uptake is Provence-Alpes-Côte d’Azur (5.07 kgP ha^{-1}), while the highest uptake is observed for the soils of the province of Picardie (23.6 kgP ha^{-1}).

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Table 2.5.3. Nitrogen (N) and phosphorus (P) uptake by crops. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual uptake by cultivated plants for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	**Name**	**N uptake (kgN ha^{-1})**	**P uptake (kgP ha^{-1})**
FR22	Picardie	147	23.6
FR23	Haute-Normandie	147	19.9
FR3	Nord - Pas-de-Calais	146	20.9
FR25	Basse-Normandie	139	16.8
FR1	Île de France	138	21.3
FR21	Champagne-Ardenne	129	22.3
FR41	Lorraine	122	19.6
FR42	Alsace	122	16.5
FR51	Pays de la Loire	120	18.2
FR52	Bretagne	119	19.1
FR24	Centre	117	20.0
FR43	Franche-Comté	109	16.5
FR26	Bourgogne	108	19.3
FR53	Poitou-Charentes	106	17.0
FR63	Limousin	106	11.7
FR61	Aquitaine	98.2	13.1
FR72	Auvergne	94.5	12.0
FR62	Midi-Pyrénées	88.6	16.0
FR71	Rhône-Alpes	86.0	13.3
FR81	Languedoc-Roussillon	39.9	6.00
FR82	Provence-Alpes-Côte d'Azur	29.6	5.07
FR83	Corse	18.0	7.13
Mean ± SD		106 ± 36	16.1 ± 5.2

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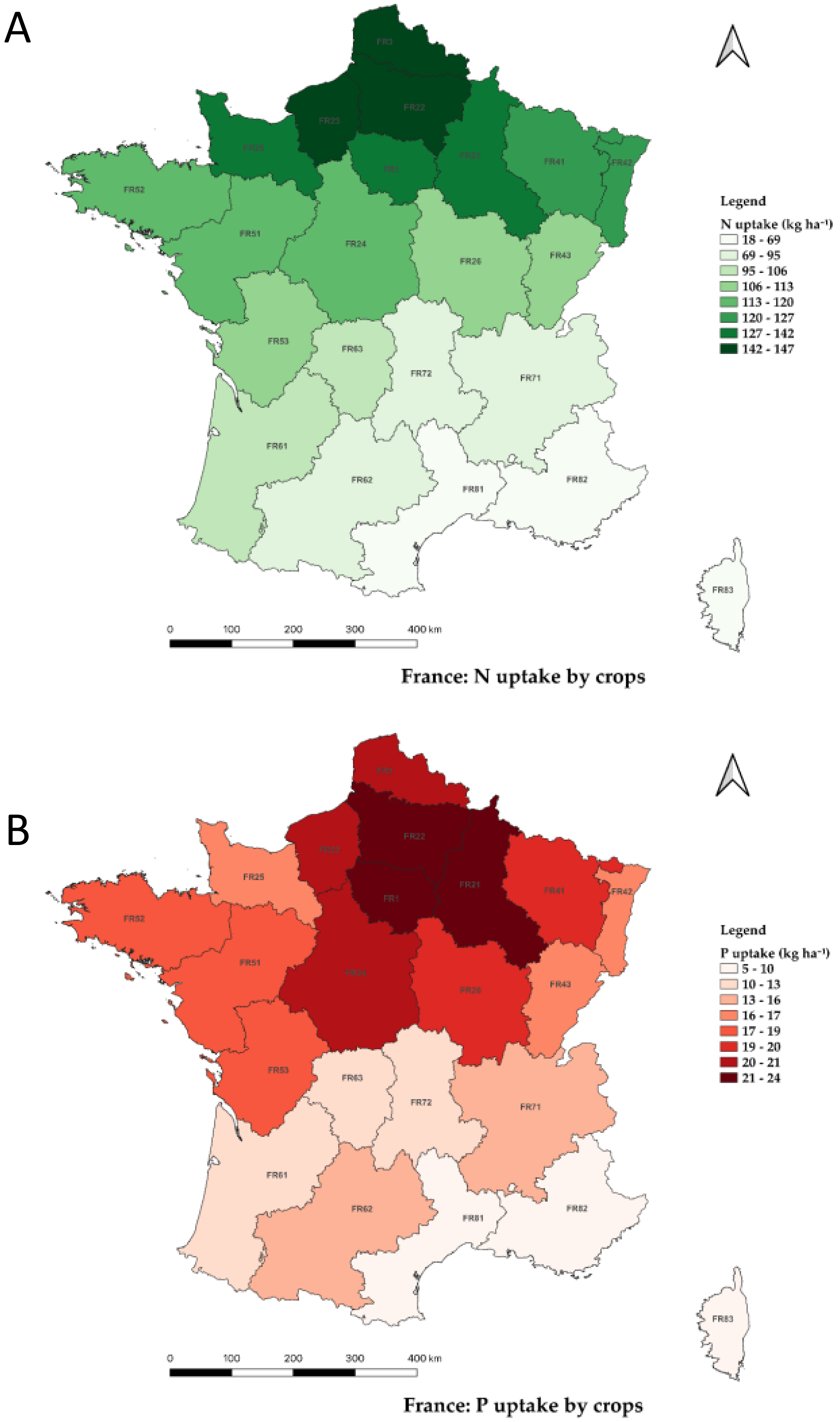

Figure 2.5.4. Thematic map for nitrogen (A) and phosphorus (B) uptake by crops (kg ha^{-1}) in France.

2.5.5. Nitrogen and phosphorus soil balances

The results obtained for the annual soil nutrient balance (Table 2.5.4) describe a general situation of excess for nitrogen. The country's average annual nitrogen balance is 50.5 ± 11 kgN ha^{-1}, with the region of Ile-de-France showing the lower value (34.3 kgN ha^{-1}), while the highest annual nitrogen excess is for the soil of Bretagne, with 82.2 kgN ha^{-1}. The intensive livestock farming regions are exposed to total N supplies from organic manure highest than crop/grassland uptakes. However, these values do not probably considerate i) exportations to N demanding neighbour regions and ii) manure treatments. These procedures are imposed to some farms in Bretagne when a threshold volume of manure production is exceeded.

The annual balance of phosphorus in soils is instead less critical with a national average of 2.59 ± 5.6 kgP ha^{-1}. Nine of the 22 regions are even in deficit of phosphorous. The decrease in phosphorous balance observed in France in the last 10 years is mainly due to the reduction of P inputs from mineral fertilizer sources. The highest observed excess is in Bretagne (8.84 kgP ha^{-1}), Franche-Comté (11.4 kgP ha^{-1}) and Corse (15.9 kgP ha^{-1}).

Table 2.5.4. Nitrogen (N) and phosphorus (P) balances. The table reports the difference between total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			Phosphorus (kgP ha^{-1})		
NUTS2	**Name**	**Total N input**	**N uptake**	**N excess**	**Total P input**	**P uptake**	**P excess**
FR52	Bretagne	201	119	82.2	27.9	19.1	8.84
FR83	Corse	84.1	18.0	66.1	23.0	7.13	15.9
FR51	Pays de la Loire	183	120	63.0	24.3	18.2	6.05
FR3	Nord - Pas-de-Calais	203	146	56.9	20.6	20.9	-0.23
FR63	Limousin	163	106	56.9	19.3	11.7	7.66
FR72	Auvergne	151	94.5	56.1	16.4	12.0	4.39
FR25	Basse-Normandie	193	139	54.5	20.5	16.8	3.77
FR82	Provence-Alpes-Côte d'Azur	83.5	29.6	53.8	9.47	5.07	4.41
FR71	Rhône-Alpes	139	86.0	53.2	19.0	13.3	5.72
FR43	Franche-Comté	159	109	49.7	27.9	16.5	11.4
FR61	Aquitaine	146	98.2	48.1	18.4	13.1	5.29
FR23	Haute-Normandie	194	147	47.7	21.9	19.9	1.99
FR42	Alsace	169	122	47.3	18.8	16.5	2.25
FR62	Midi-Pyrénées	135	88.6	46.0	15.8	16.0	-0.27
FR41	Lorraine	167	122	45.3	15.2	19.6	-4.41
FR22	Picardie	191	147	43.6	18.6	23.6	-4.94
FR53	Poitou-Charentes	148	106	42.2	16.2	17.0	-0.77
FR21	Champagne-Ardenne	171	129	42.1	15.3	22.3	-6.99
FR81	Languedoc-Roussillon	81.3	39.9	41.5	10.1	6.00	4.06
FR26	Bourgogne	150	108	42.0	16.7	19.3	-2.58
FR24	Centre	154	117	37.5	16.8	20.0	-3.19
FR1	Île de France	172	138	34.3	20.0	21.3	-1.29
Mean ± SD		156 ± 36	106 ± 36	50.5 ± 11	18.7 ± 4.6	16.1 ± 5.2	2.59 ± 5.6

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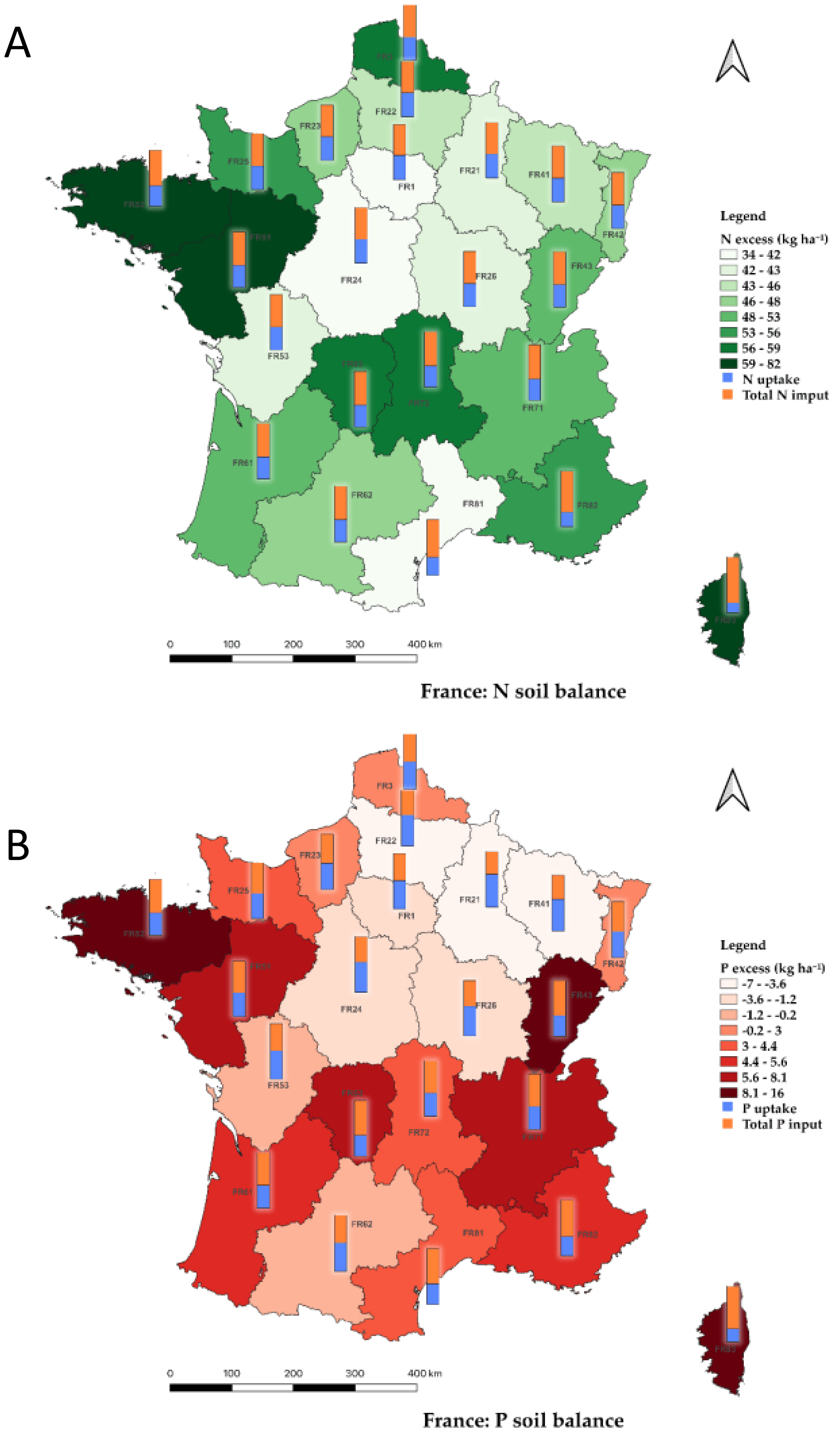

Figure 2.5.5. Thematic map for nitrogen (A) and phosphorus (B) balance (kg ha^{-1}) in France.

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2.5.6. Sustainability of animal manure sources

The exclusion of inputs from mineral fertilizer sources from the balance is particularly useful to understand if the need of nutrients for national agricultural production can be satisfied only with the recovery of nutrients deriving from manure and other organic sources. The balance on a NUTS2 scale also allows for the organization of a possible redistribution of recovered nutrients within the country.

The average annual balance obtained for nitrogen in this case is -26.7 ± 40 kgN ha^{-1}. The average annual balance for phosphorus in this case is -3.65 ± 8.1 kgP ha^{-1}. The high standards deviations indicates high differences among regions (

Table 2.1.5). Data show that, from the 22 regions, 16 are in deficit of nitrogen and 14 are in deficit of phosphorous. This indicates a dependence of nitrogen and phosphorous from mineral fertilizer sources for a great part of French regions.

Corse, Provence-Alpes-Côte d’Azur, Languedoc-Roussillon and Bretagne have the highest nitrogen balance, while Ile-de France, Picardie and Champagne-Ardennes are the poorest nitrogen regions (Figure 2.5.6).

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Corse, Franche-Comté, Limousin and Bretagne have the highest phosphorous balance, while Picardie and Champagne-Ardenne are the poorest phosphorous regions (Figure 2.5.6).

Table 2.5.5. Nitrogen (N) and phosphorus (P) from animal manure sources vs uptake by crops. The table reports the difference between nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil (excluding the share deriving from mineral fertilizers) and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			Phosphorus (kgP ha^{-1})		
NUTS2	**Name**	**N input excluding mineral**	**N uptake**	**N excess**	**P input excluding mineral**	**P uptake**	**P excess**
FR83	Corse	79.4	18.0	61.4	22.8	7.13	15.6
FR82	Provence-Alpes-Côte d'Azur	69.1	29.6	39.4	7.33	5.07	2.26
FR81	Languedoc-Roussillon	54.4	39.9	14.5	7.42	6.00	1.41
FR52	Bretagne	129	119	10.2	22.1	19.1	3.07
FR72	Auvergne	101	94.5	6.45	11.0	12.0	-0.95
FR71	Rhône-Alpes	87.7	86.0	1.76	15.0	13.3	1.70
FR63	Limousin	105	106	-1.11	16.3	11.7	4.65

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FR51	Pays de la Loire	104	120	-16.0	17.3	18.2	-0.90
FR62	Midi-Pyrénées	72.5	88.6	-16.1	8.63	16.0	-7.39
FR43	Franche-Comté	91.6	109	-17.9	24.3	16.5	7.76
FR61	Aquitaine	73.5	98.2	-24.7	13.9	13.1	0.87
FR25	Basse-Normandie	102	139	-36.8	14.0	16.8	-2.71
FR26	Bourgogne	71.4	108	-36.8	8.19	19.3	-11.1
FR53	Poitou-Charentes	63.8	106	-42.4	8.92	17.0	-8.09
FR41	Lorraine	79.4	122	-42.7	6.08	19.6	-13.5
FR42	Alsace	72.0	122	-49.6	12.5	16.5	-4.02
FR3	Nord - Pas-de-Calais	90.6	146	-55.7	12.1	20.9	-8.70
FR24	Centre	53.0	117	-63.8	7.76	20.0	-12.2
FR23	Haute-Normandie	80.3	147	-66.5	14.2	19.9	-5.79
FR21	Champagne-Ardenne	58.7	129	-69.9	5.05	22.3	-17.3
FR22	Picardie	61.2	147	-86.0	8.26	23.6	-15.3
FR1	Île de France	42.4	138	-95.4	11.7	21.3	-9.62
Mean ± SD		79.1 ± 21	106 ± 36	-26.7 ± 40	12.5 ± 5.5	16.1 ± 5.2	-3.65 ± 8.1

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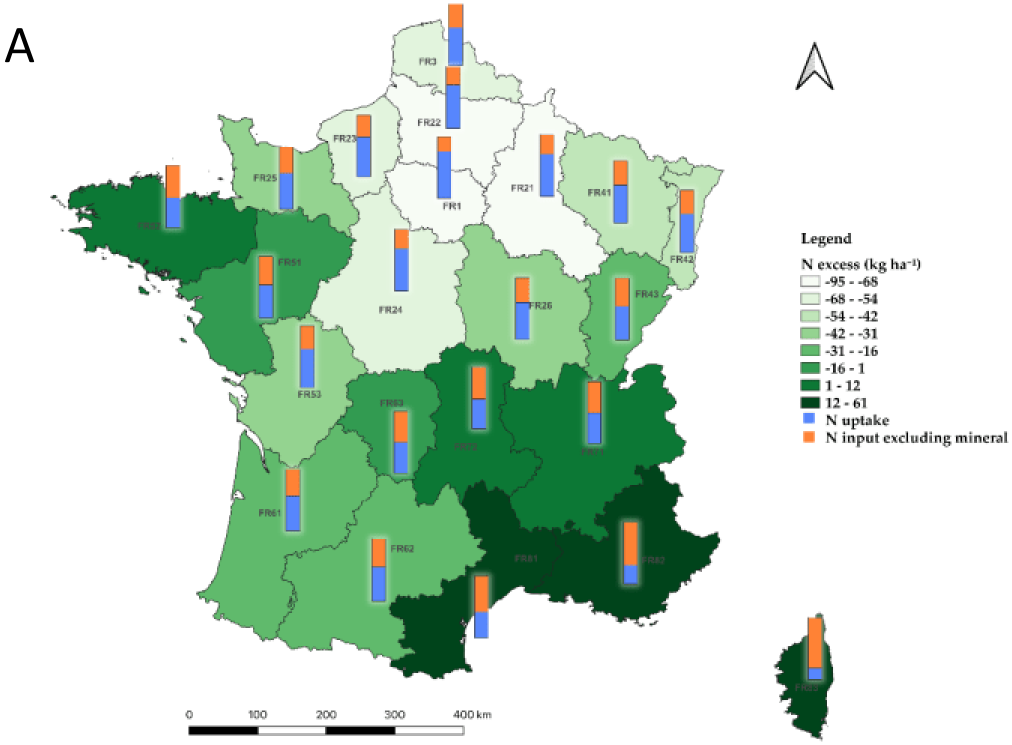
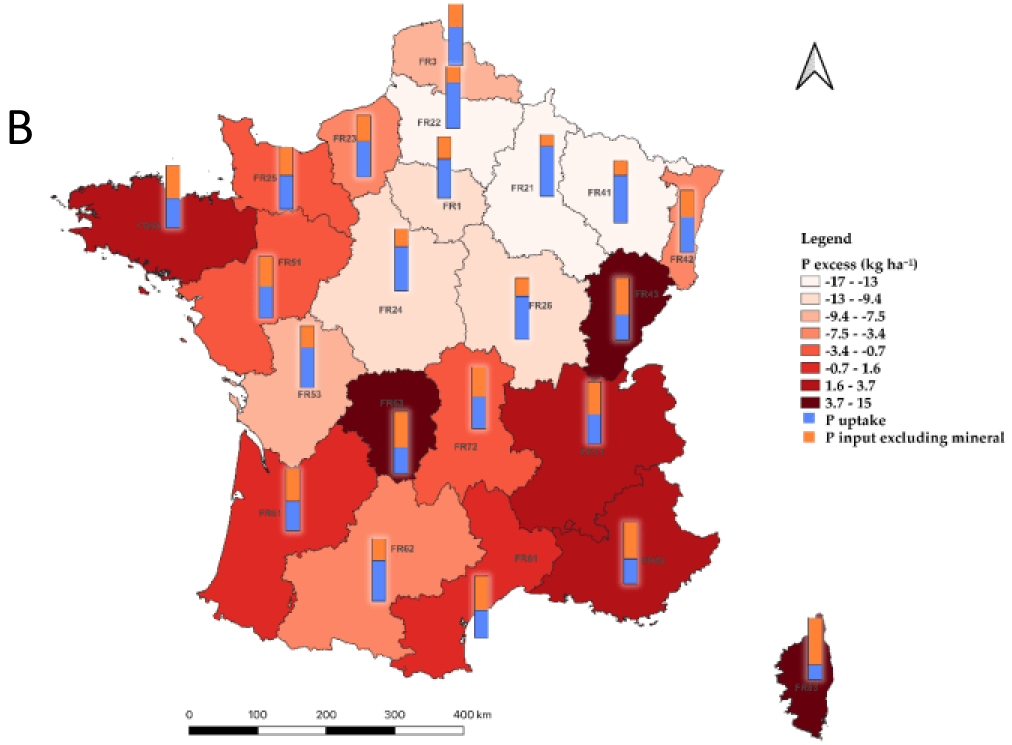


France: N Sustainablity of animal manure sources



France: P Sustainablity of animal manure sources

Figure 2.5.6. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources vs uptake by crops (kg ha^{-1}) in France.

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2.6. Italy

Italy is the third country in Europe by agricultural area (43% of the territory), although a decreasing trend has been observed in recent years (Eurostat data, 2013). Furthermore, the Italian agricultural production is very diversified, and many regions or areas have typical products. This obviously also affects the nitrogen and phosphorus inputs to the soil since different crops need different fertilization. In general, the regions with the highest percentage of cultivated area are those of central and southern Italy. The situation is instead the opposite for animal livestock, which is practiced largely in the northern regions. This distribution leads to some distortions in the amounts of nitrogen and phosphorus applied to the soil. Although in fact most of the crops are in the south, the soils of northern Italy are those characterized by the highest excesses of nutrients. On the one hand, in fact, the farms produce large quantities of manure rich in nitrogen and phosphorus, on the other the forage crops, widely grown in the Po Valley, typically have a great need for nutrients that are provided by mineral fertilization.

2.6.1. Nitrogen and phosphorus from animal manure sources

The average annual amount of nitrogen from animal origin distributed on Italian soils (
Table **2.6.1**) is 38.8 ± 30 kgN ha^{-1}, with six regions out of 20 above the average, all located in the north of the country. This indicates a strong polarization in the availability and application of animal N to the soil.

The region characterized by the minimum value of N animals applied to the soil is Toscana (14.9 kgN ha^{-1}), a region in the center of the country where olives and wine grapes are cultivated extensively, but also characterized by very little farming. The region characterized by the highest annual animal N input to the soil is Trentino-Alto Adige (128 kgN ha^{-1}), a partially mountainous region but still particularly dedicated to cattle breeding.

The average annual amount of animal phosphorus applied to Italian soils is instead of 10.9 ± 9.5 kgP ha^{-1}, with 7 regions above the average, also in this case all but one located in the north of the country.

As for nitrogen, the region characterized by the least input of animal P on the soil is Toscana (3.52 kgP ha^{-1}). On the contrary, the region with the greatest input of animal P on the soil is Liguria (28.6 kgP ha^{-1}).

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Table 2.6.1. Nitrogen (N) and phosphorus (P) from animal manure and mineral fertilizer sources. The table reports the total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input from animal manure and mineral fertilizer sources on soils for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	Name	N from manure (kgN ha^{-1})	Mineral N (kgN ha^{-1})	P from manure (kgP ha^{-1})	Mineral P (kgP ha^{-1})
IT31	Trentino alto Adige	128	8.85	33.8	0.31
IT2	Lombardia	105	61.9	22.8	8.14
IT32	Veneto	60.6	61.9	11.3	8.19
IT12	Valle d'Aosta	55.8	0.25	13.5	0.07
IT4	Emilia-Romagna	47.8	63.2	10.6	8.14
IT11	Piemonte	47.2	39.4	6.68	6.97
IT8	Campania	36.9	34.5	8.20	3.54
ITB	Sardegna	31.8	34.3	4.59	6.84
IT13	Liguria	33.2	7.49	36.5	0.07
IT33	Friuli-Venezia Giulia	31.3	42.1	13.2	4.23
IT52	Umbria	25.5	63.6	6.12	6.19
IT92	Basilicata	24.5	40.7	5.70	3.94
IT6	Lazio	24.1	52.2	5.24	6.92
IT72	Molise	23.4	31.2	11.8	2.64
IT53	Marche	18.4	64.8	5.90	6.29
IT71	Abruzzo	18.0	31.4	4.77	5.41
ITA	Sicilia	17.4	37.7	4.75	4.07
IT93	Calabria	17.1	48.3	6.34	4.31
IT91	Puglia	15.7	30.6	2.88	4.10
IT51	Toscana	14.9	50.6	3.52	6.99
Mean ± SD		38.8 ± 30	40.2 ± 19	10.9 ± 9.5	4.87 ± 2.6

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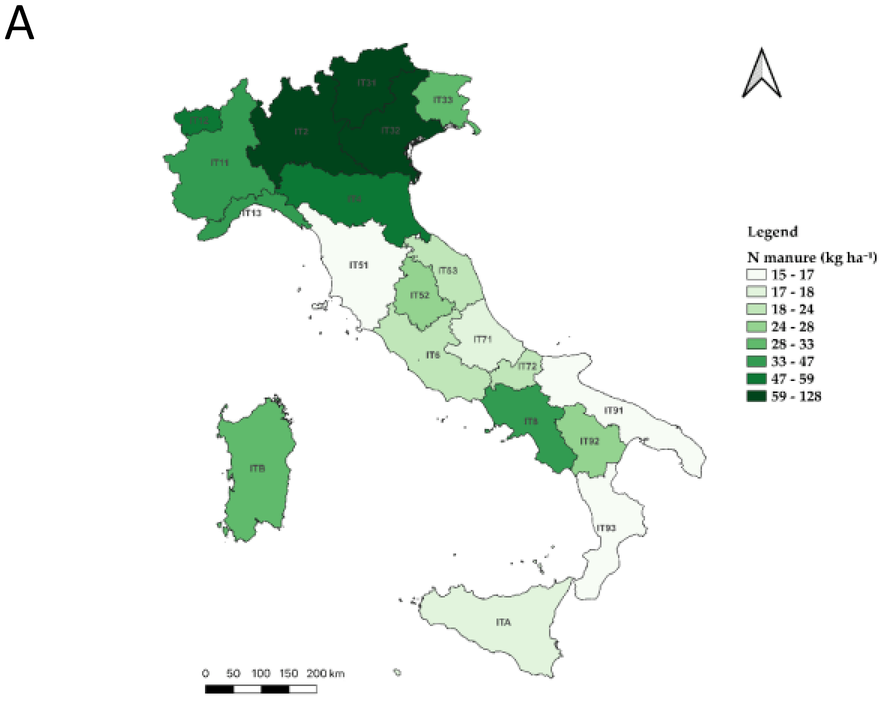
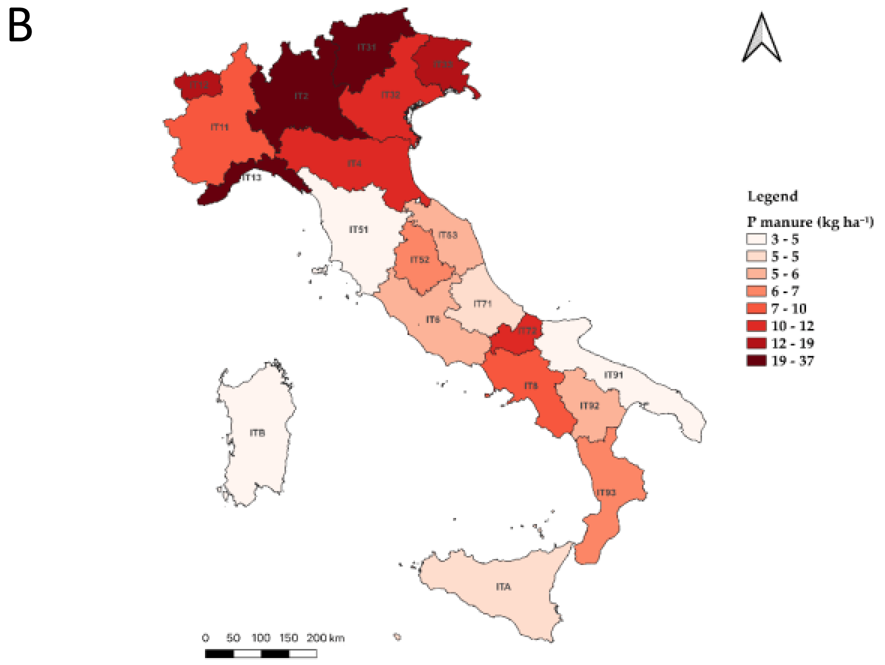


Italy: N from animal manure sources



Italy: P from animal manure sources

Figure 2.6.1. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources (kg ha^{-1}) in Italy.

2.6.2. Nitrogen and phosphorus from mineral fertilizer sources

The average annual input of mineral fertilizer nitrogen to Italian soils (

Table **2.6.1**) is 40.2 ± 19 kgN ha^{-1}, with 9 regions out of 20 above the national average. Observing the thematic map (Figure 2.6.1), it is also noted that almost all the regions with above average values are in the centre and north of the country, while the southern regions show lower values.

The region with the lowest annual N mineral input is Valle D'Aosta, which with only 0.25 kgN ha^{-1} is far below the national average. This region is characterized by an almost exclusively mountainous area, and the agricultural industry is mainly based on high altitude pastures. The region with the highest N mineral input is instead Marche, with 64.8 kgN ha^{-1}, immediately followed by nearby Umbria and Emilia Romagna, with very similar values (63.6 and 63.2 kgN ha^{-1} respectively).

The average annual input of mineral phosphorus to Italian soils is instead 4.87 ± 2.6 kgP ha^{-1}, with 10 regions out of 20 above the national average, also in this case mainly located in the centre and north of the country.

The regions characterized by the lowest mineral P input are the Valle d'Aosta and Liguria, both with 0.03 kgP ha^{-1}, an extremely low value. The region with the highest mineral P input is Veneto (8.14 kgP ha^{-1}), located in the north east of the country and largely included in the Po Valley.

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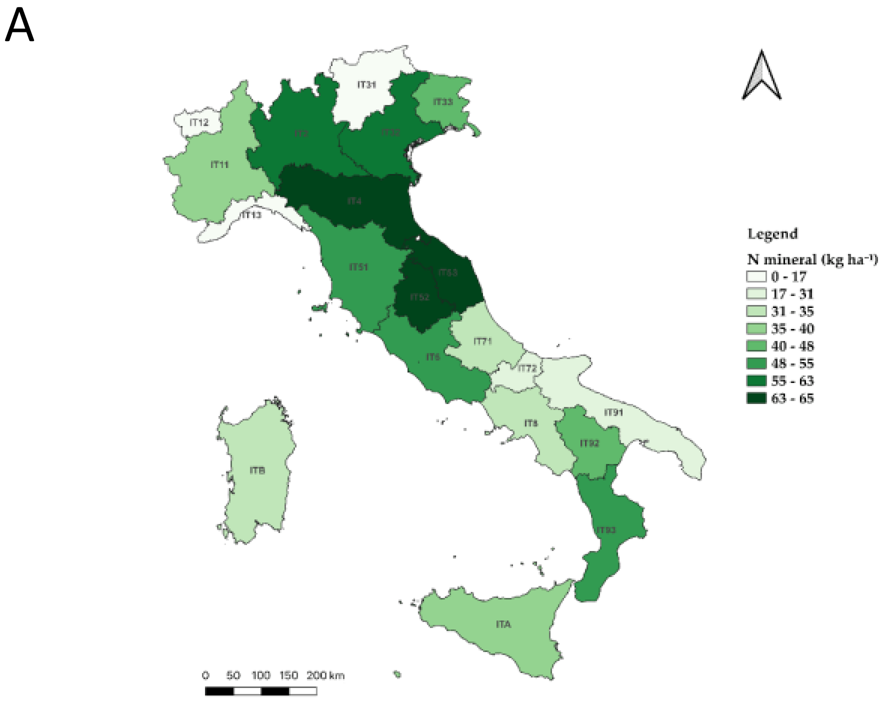
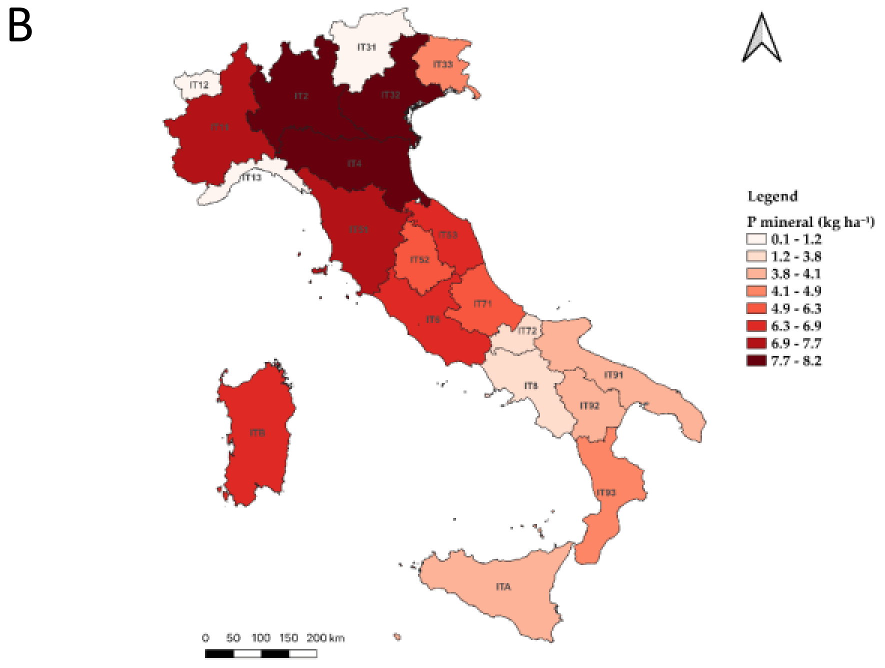


Italy: N from mineral fertilizer sources



Italy: P from mineral fertilizer sources

Figure 2.6.2. Thematic map for nitrogen (A) and phosphorus (B) from mineral fertilizer sources (kg ha^{-1}) in Italy.

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2.6.3. Nitrogen and phosphorus from other sources

The input of nitrogen and phosphorus from other sources (Table 2.6.2) includes that deriving from the use of sewage sludge as fertilizers, compost, nitrogen and phosphorus contained in the excreta of grazing animals and the share of nitrogen received by the soil from non-anthropogenic sources, such as atmospheric events or nitrogen bacterial fixation.

The average annual input of nitrogen brought to Italian soils by non-anthropic processes is 27.2 ± 15 kgN ha^{-1}, with 5 regions out of 20 above the average. In particular, the region showing the lowest value of non-anthropogenic N is Sardegna, with 15.8 kgN ha^{-1}, while the region with a greater share is Veneto, which with a value of 71.71 kgN ha^{-1} is well above the national average. Given the complexity and variety of natural processes that lead to nitrogen inputs into soils, it is very difficult to estimate the reason for the differences observed between Italian regions. However, most likely the types of soils and climates (both very variable elements between Italian regions) can play a significant role.

Excluding nitrogen from non-anthropic sources, the greatest input comes from grazing N. The national average in this case is 12.1 ± 13 kgN ha^{-1}, with 6 regions out of 20 above the average and a very high variability. The region with the lowest nitrogen input from pastures is Friuli-Venezia Giulia (2.72 kgN ha^{-1}), in the north east of the country. On the other hand, the region with the highest input, considerably above the average, is Sardegna (61.6 kgN ha^{-1}). This is in fact one of the Italian regions most dedicated to breeding.

Instead, the amounts of nitrogen from sludge and compost are minimal and almost irrelevant for all the Italian regions.

As for the input of phosphorus from other sources, the most significant input is represented by the P deriving from grazing, with a national average of 2.4 ± 1.8 kgP ha^{-1}, with 9 regions out of 20 above the average. Even in the case of P, the remaining inputs have much lower and almost irrelevant values.

The region that shows the lowest P input is Piemonte, with 0.08 kgP ha^{-1}. The region that shows the highest value is instead Valle D’Aosta, which with 6.81 kgP ha^{-1} far exceeds the national average. As already mentioned previously, in fact, Valle D’Aosta has a mainly mountainous territory, and the main agricultural activity consists of breeding on pastures.

Table 2.6.2. Nitrogen (N) and phosphorus (P) from other sources. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soils from sources other than animal manure and mineral for each region analysed. Non-anthropic considers both inorganic deposition and biological fixation. Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})				**Phosphorus (kgP ha^{-1})**		
NUTS 2	**Name**	**N from sludge**	**N from compost**	**N from grazing**	**Non-anthropic N**	**P from sludge**	**P from compost**	**P from grazing**
IT32	Veneto	0.75	0.34	3.92	71.7	0.34	0.07	0.17
IT33	Friuli-Venezia Giulia	0.42	0.19	2.72	58.2	0.16	0.03	1.76
IT2	Lombardia	0.60	0.27	6.41	41.4	0.38	0.08	0.42
IT4	Emilia-Romagna	0.70	0.32	3.12	38.5	0.37	0.07	1.42
IT11	Piemonte	0.52	0.24	5.72	28.3	0.39	0.08	0.08
IT12	Valle d’Aosta	0.05	0.02	7.06	26.1	0.06	0.01	6.81
IT31	Trentino alto Adige	0.29	0.13	18.5	25.0	0.09	0.02	3.83
IT13	Liguria	0.44	0.20	20.2	22.9	0.02	0.00	3.37
IT51	Toscana	0.69	0.31	12.9	22.3	0.37	0.07	1.01
IT53	Marche	0.68	0.31	5.56	21.9	0.27	0.05	3.38
IT71	Abruzzo	0.49	0.22	10.2	21.4	0.33	0.06	1.25
IT8	Campania	0.69	0.32	8.12	20.6	0.31	0.06	1.57
IT6	Lazio	0.60	0.27	15.2	19.8	0.31	0.06	1.16
IT52	Umbria	0.68	0.31	9.39	19.4	0.28	0.06	1.56
IT72	Molise	0.64	0.29	8.21	19.3	0.24	0.05	3.13
IT91	Puglia	0.76	0.35	4.11	18.3	0.40	0.08	1.03
ITA	Sicilia	0.69	0.31	9.51	18.3	0.29	0.06	6.00
IT92	Basilicata	0.76	0.35	18.6	18.1	0.31	0.06	2.91
IT93	Calabria	0.71	0.32	11.1	16.8	0.25	0.05	3.53
ITB	Sardegna	0.36	0.16	61.6	15.8	0.12	0.02	2.61
Mean ± SD		0.58 ± 0.2	0.26 ± 0.1	12.1 ± 13	27.2 ± 15	0.26 ± 0.1	0.05 ± 0	2.40 ± 1.8

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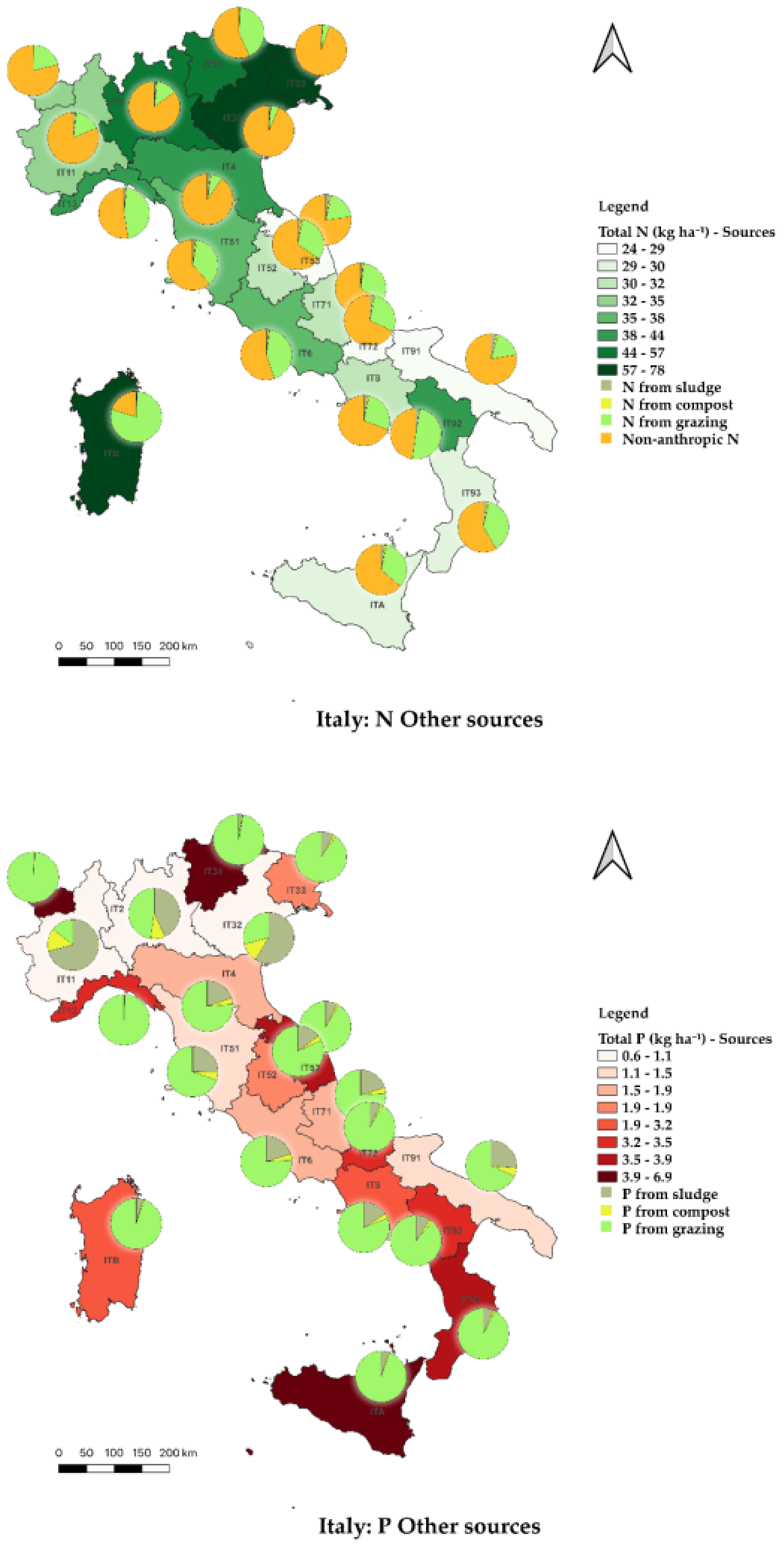

Italy: N Other sources

A

Italy: P Other sources

Figure 2.6.3. Thematic map for nitrogen (A) and phosphorus (B) from other sources (kg ha^{-1}) in Italy.

B

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2.6.4. Nitrogen and phosphorus uptake by crops

The average annual nitrogen uptake from Italian soils (Table 2.6.3) is 66 ± 27 kgN ha^{-1}, with 6 regions out of 20 above the average. Although the Italian regions most devoted to agricultural food production are those in the south of the country, the highest N uptake values are generally associated with regions of northern Italy. This is because the northern regions of the country, especially those located in correspondence with the Po Valley, are devoted to the cultivation of forage that typically has high nitrogen needs.

The region with the lowest N uptake value is Liguria (23.2 kgN ha^{-1}), a region particularly dedicated to the cultivation of flowers and potted plants, whose uptake of nutrients from the soil is consequently very low. The region that instead shows the highest value of N uptake is Lombardia (121 kgN ha^{-1}), located in the centre of the Po Valley and particularly dedicated to the breeding and cultivation of forage such as corn, soybeans and alfalfa.

The average value of P uptake for Italian soils is instead 10.5 ± 4.3 kgP ha^{-1}, with 9 regions out of 20 above the average, distributed in a similar way to what has already been observed for the average uptake of N.

The region that shows the lowest annual P uptake value is Valle d’Aosta (3.33 kgP ha^{-1}). The region showing the highest P uptake value is again Lombardia (21.5 kgP ha^{-1}).

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Table 2.6.3. Nitrogen (N) and phosphorus (P) uptake by crops. The table reports the nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual uptake by cultivated plants for each region analysed. Regions are indicated with both full names and NUTS2 codes of the areas.

NUTS2	**Name**	**N uptake (kgN ha^{-1})**	**P uptake (kgP ha^{-1})**
IT2	Lombardia	121	21.5
IT32	Veneto	113	18.0
IT4	Emilia-Romagna	95.7	15.7
IT33	Friuli-Venezia Giulia	80.6	12.0
IT53	Marche	79.7	10.5
IT52	Umbria	76.1	12.1
IT6	Lazio	63.5	10.6
IT51	Toscana	60.9	10.5
IT11	Piemonte	60.3	13.6
IT93	Calabria	54.1	6.68
IT92	Basilicata	50.9	7.53
IT8	Campania	50.6	6.85
ITB	Sardegna	45.7	9.81
ITA	Sicilia	45.2	6.76
IT71	Abruzzo	42.5	8.76
IT72	Molise	42.5	6.84
IT91	Puglia	37.2	6.65
IT31	Trentino alto Adige	31.9	10.7
IT12	Valle d'Aosta	25.8	3.33
IT13	Liguria	23.2	11.5
Mean ± SD		66.0 ± 27	10.5 ± 4.3

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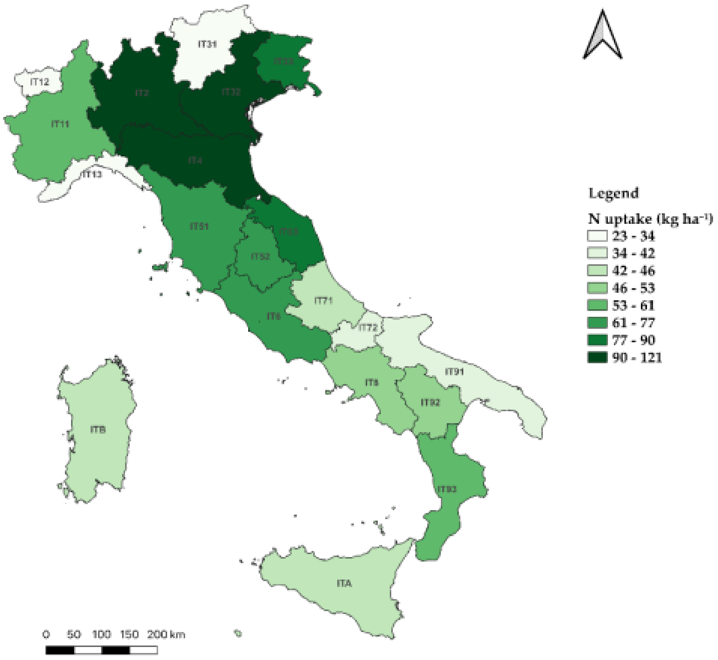
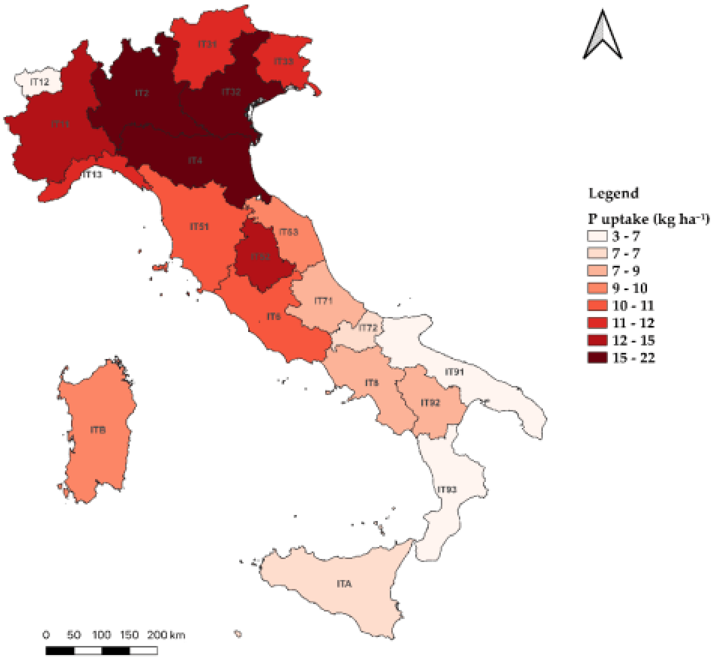
A



Italy: N uptake by crops

B



Italy: P uptake by crops

Figure 2.6.4. Thematic map for nitrogen (A) and phosphorus (B) uptake by crops (kg ha^{-1}) in Italy.

2.6.5. Nitrogen and phosphorus soil balances

The results of the balance, reported in Table 2.6.4, show that for both nitrogen and phosphorus, the annual balance is in excess in all Italian regions.

For nitrogen, the average of the annual regional balances is 59.2 ± 28 kgN ha^{-1}, which shows a situation of moderate nitrogen excess for Italian soils. Observing the thematic map (Figure 2.6.5), a north-south polarization in the N excess in soils is clear (except for Sardegna, for the reason discussed above), with the northern regions suffering more than those of the south, with lower N excesses. The region with the lowest annual nitrogen excess is Marche (32 kgN ha^{-1}), in the centre of the country. The region with the greatest nitrogen excess is instead Trentino Alto Adige (148 kgN ha^{-1}), characterized by a strong nitrogen input (mainly manure,

Table **2.6.1**), and a very low uptake.

Also as regards the excess of phosphorus, the thematic map (Figure 2.6.5), shows a north-south polarization, although less marked than that observed for nitrogen. The annual national average excess for phosphorus is 7.95 ± 7.9 kgP ha^{-1}. The region with the lowest phosphorus excess value is Piemonte, with a value very close to zero (0.56 kgP ha^{-1}). The region showing the highest level of phosphorus excess is instead Liguria (28.5 kgP ha^{-1}).

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Table 2.6.4. Nitrogen (N) and phosphorus (P) balances. The table reports the difference between total nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			Phosphorus (kgP ha^{-1})		
NUTS2	**Name**	**Total N input**	**N uptake**	**N excess**	**Total P input**	**P uptake**	**P excess**
IT31	Trentino alto Adige	180	31.9	148	38.0	10.7	27.4
ITB	Sardegna	144	45.7	98.4	14.2	9.81	4.37
IT2	Lombardia	215	121	94.5	31.8	21.5	10.3
IT32	Veneto	199	113	86.1	20.0	18.0	2.04
IT12	Valle d’Aosta	89.3	25.8	63.5	20.4	3.33	17.1
IT13	Liguria	84.4	23.2	61.2	40.0	11.5	28.5
IT11	Piemonte	121	60.3	61.0	14.2	13.6	0.56
IT4	Emilia-Romagna	154	95.7	57.9	20.6	15.7	4.92
IT33	Friuli-Venezia Giulia	135	80.6	54.3	19.4	12.0	7.45
IT92	Basilicata	103	50.9	51.9	12.9	7.53	5.40
IT8	Campania	101	50.6	50.4	13.7	6.85	6.84
IT6	Lazio	112	63.5	48.5	13.7	10.6	3.05
IT52	Umbria	119	76.1	42.7	14.2	12.1	2.12
IT51	Toscana	102	60.9	40.8	12.0	10.5	1.46
IT72	Molise	83.0	42.5	40.6	17.8	6.84	11.0
IT93	Calabria	94.4	54.1	40.3	14.5	6.68	7.81
IT71	Abruzzo	81.7	42.5	39.2	11.8	8.76	3.07
ITA	Sicilia	84.0	45.2	38.9	15.2	6.76	8.41
IT91	Puglia	69.9	37.2	32.7	8.49	6.65	1.83
IT53	Marche	112	79.7	32.0	15.9	10.5	5.42
Mean ± SD		119 ± 41	60.0 ± 27	59.2 ± 28	18.4 ± 8.5	10.5 ± 4.3	7.95 ± 7.9

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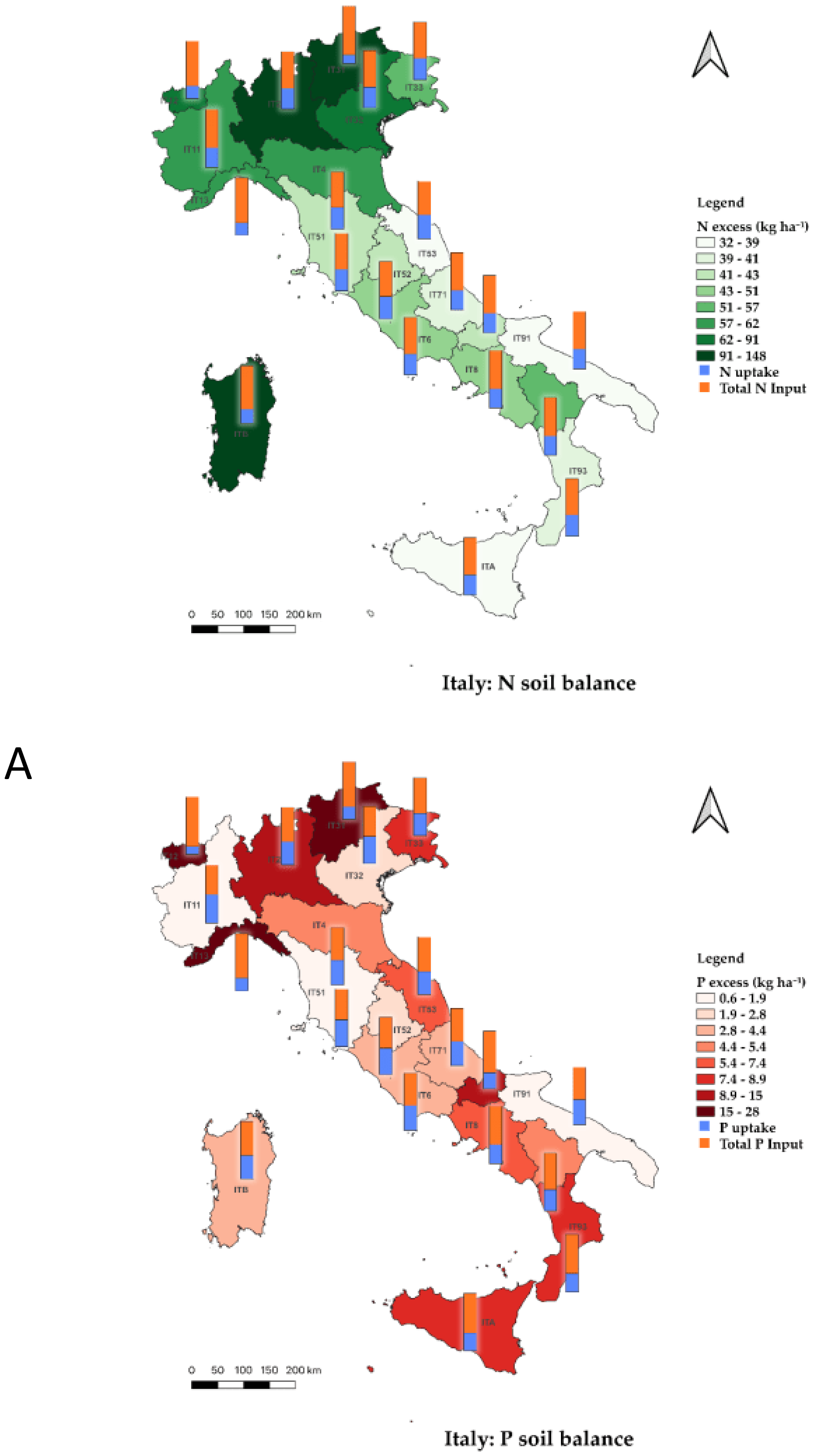

Italy: N soil balance

Italy: P soil balance

Figure 2.6.5. Thematic map for nitrogen (A) and phosphorus (B) balance (kg ha^{-1}) in Italy.

B

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2.6.6. Sustainability of animal manure sources

The data shown in Table 2.6.5 show that, by completely eliminating the nitrogen input from mineral fertilizer sources, only 6 out of 20 Italian regions have a negative balance. Almost all the regions with a negative balance are located in a compact cluster in the centre of the country.

The region with the largest nitrogen deficit in this case is Marche, with -32 kgN ha^{-1}, which is therefore very dependent on nitrogen-based mineral fertilizers. The region showing instead the greatest annual nitrogen excess excluding mineral N, is Trentino Alto Adige, with an excess of 140 kgN ha^{-1}. In fact, as previously observed, the soils of this region receive a strong annual input of nitrogen (almost all from manure), but are subjected to a very limited uptake.

As for phosphorus, 10 out of 20 regions show a negative balance. The region with the greatest non-mineral P deficit is Piemonte (-6.4 kgP ha^{-1}), located in the north east of the country. The region with the greatest P excess is instead Liguria (28.4 kgP ha^{-1}), also in the north east of the country.

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Table 2.6.5. Nitrogen (N) and phosphorus (P) from animal manure sources vs uptake by crops. The table reports the difference between nitrogen (kgN ha^{-1}) and phosphorus (kgP ha^{-1}) annual input on soil (excluding the share deriving from mineral fertilizers) and their annual uptake by cultivated plants per hectare, for each region analysed. The balances do not consider the losses due to volatilization (N) or leaching (N and P). Regions are indicated with both full names and NUTS2 codes of the areas.

		Nitrogen (kgN ha^{-1})			**Phosphorus (kgP ha^{-1})**		
NUTS2	**Name**	**N input excluding mineral**	**N uptake**	**N excess**	**P input excluding mineral**	**P uptake**	**P excess**
IT31	Trentino alto Adige	171	31.9	140	37.7	10.7	27.0
ITB	Sardegna	110	45.7	64.1	7.35	9.81	-2.47
IT12	Valle d’Aosta	89.1	25.8	63.3	20.3	3.33	17.0
IT13	Liguria	76.9	23.2	53.7	39.9	11.5	28.4
IT2	Lombardia	153	121	32.6	23.7	21.5	2.13
IT32	Veneto	137	113	24.2	11.9	18.0	-6.15
IT11	Piemonte	81.9	60.3	21.6	7.22	13.6	-6.42
IT8	Campania	66.6	50.6	16.0	10.2	6.85	3.30
IT33	Friuli-Venezia Giulia	92.8	80.6	12.2	15.2	12.0	3.22
IT92	Basilicata	62.2	50.9	11.3	8.99	7.53	1.46
IT72	Molise	51.8	42.5	9.35	15.2	6.84	8.34
IT71	Abruzzo	50.3	42.5	7.83	6.42	8.76	-2.34
ITA	Sicilia	46.3	45.2	1.13	11.1	6.76	4.34
IT91	Puglia	39.2	37.2	2.05	4.39	6.65	-2.27
IT6	Lazio	59.9	63.5	-3.68	6.76	10.6	-3.87
IT4	Emilia-Romagna	90.4	95.7	-5.30	12.5	15.7	-3.22
IT93	Calabria	46.0	54.1	-8.07	10.2	6.68	3.50
IT51	Toscana	51.1	60.9	-9.84	4.97	10.5	-5.53
IT52	Umbria	55.3	76.1	-20.9	8.01	12.1	-4.06
IT53	Marche	46.9	79.7	-32.8	9.61	10.5	-0.87
Mean ± SD		78.9 ± 38	60.0 ± 27	18.9 ± 38	13.6 ± 9.9	10.5 ± 4.3	3.08 ± 10

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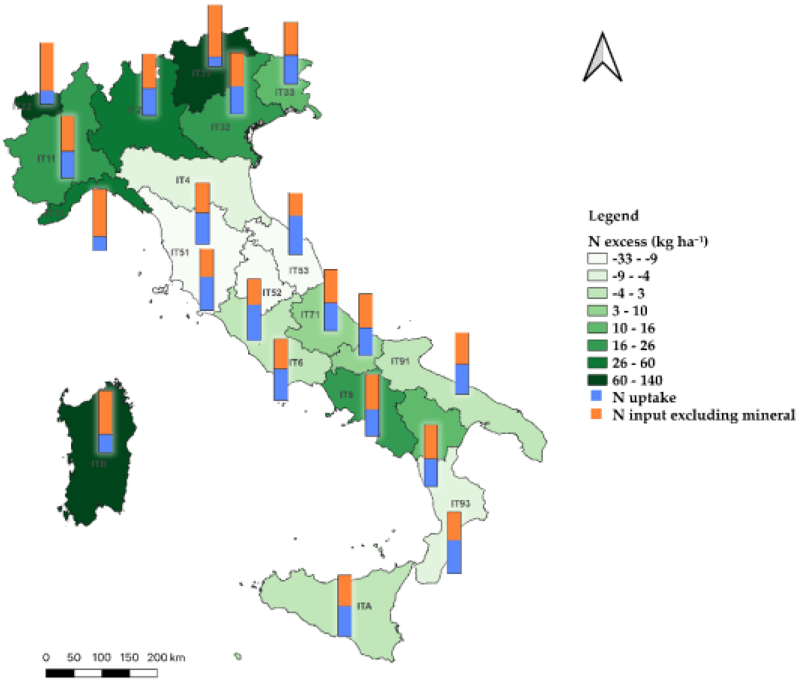
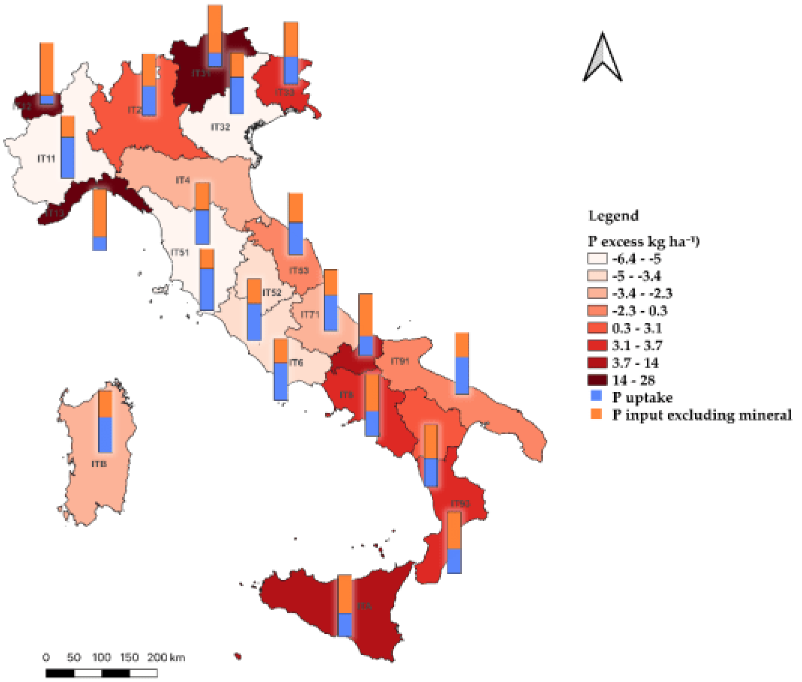


Italy: N Sustainability of animal manure sources

A



Italy: P Sustainability of animal manure sources

Figure 2.6.6. Thematic map for nitrogen (A) and phosphorus (B) from animal manure sources vs uptake by crops (kg ha^{-1}) in Italy.

B

The annual nitrogen and phosphorus balance for Italian soils, if mineral fertilizer sources are excluded, generally remains positive. Regions showing excess nutrients from non-mineral fertilizer sources account for most of the country's surface. Furthermore, the excesses recorded are also of considerable entity. This indicates that for almost all the Italian territory, the use of nutrients from organic sources can largely replace mineral fertilizers, greatly reducing their use.

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3. Comparison between NUTS2 (EUROSTAT) data and local data

Results reported in the previous chapter were obtained using data from the EUROSTAT database aggregated at NUTS2 level. Nevertheless, the European dataset does not take into account national legislation (e.g. max P application standards) but only the Nitrate Directive. From that point of view, the European dataset is probably limited. In the following paragraphs, a comparison between European data and national/regional data was carried out for countries where local data were available. The aim of this comparison was to highlight if significant differences between European and local data occur.

3.1 The Netherlands – The region Achterhoek case study

The pilot plant Arjan Prinsen Farm (APF) is located in the NUTS 3 region Achterhoek (Figure 3.1.1), a subregion of the NUTS2 region the province of Gelderland. For Gelderland data is presented in previous sections based on MITERRA model data at NUTS2 level (Velthof et al. 2009; Oenema et al., 2009). In this section agricultural nutrient balances are presented for the more specific NUTS3 region Achterhoek and its Agricultural Subareas. The pilot plant is situated in the subarea “Berkelland” (Figure 3.1.2).

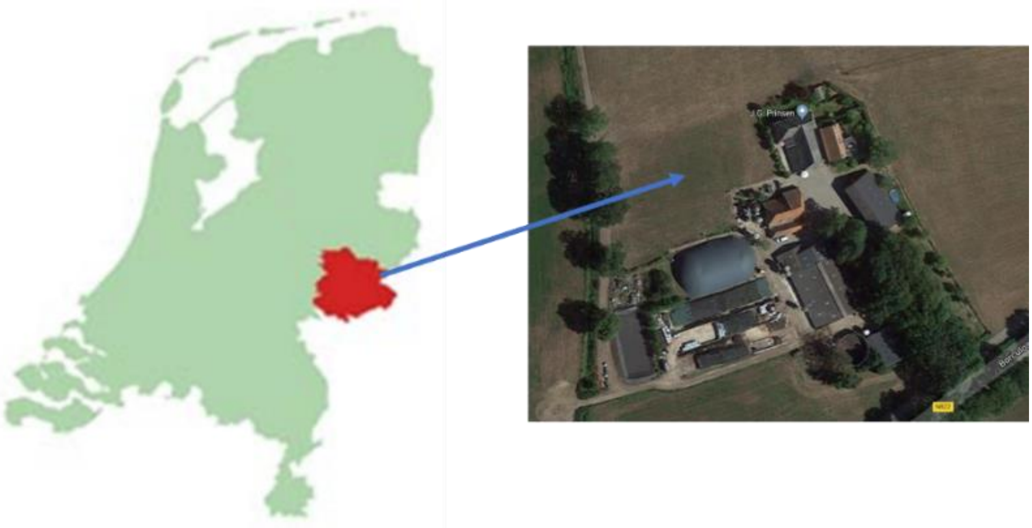

Figure 7: Dutch pilot plant in FERTIMANURE is Arjan Prinsen Farm (APF) located in the NUTS 3 region Achterhoek (red area).

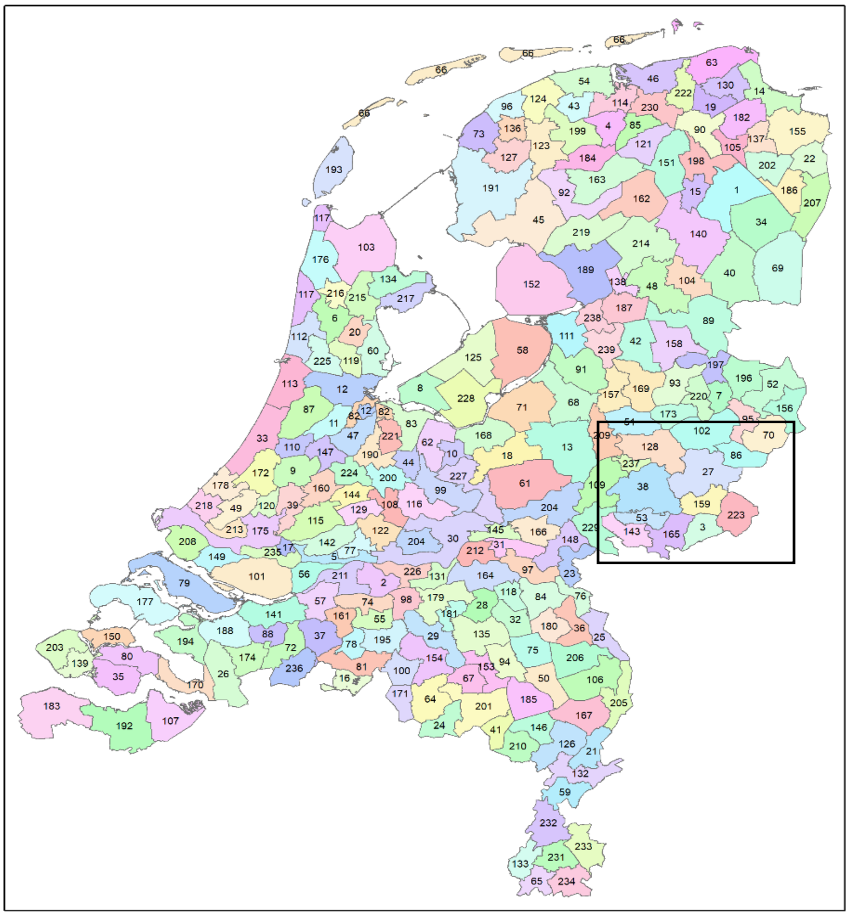

Figure 8: Level of detail of the Agricultural Subareas and their number codes used in the INITIATOR model, the pilot plant is situated in the sub-region Berkelland (number 27) within the NUTS3 region Achterhoek (black box) including the following subareas: Aalten (3), Berkelland (27), Bronckhorst (38), Doetinchem (53), Lochem (128), Montferland (143), Oost Gelre (159), Oude IJsselstreek (165), Winterswijk (223) and Zutphen (237). Source: Netherlands INITIATOR model.

The here presented information is based on more detailed data sourced from the INITATOR model (Kros et al. 2015; Vries and Kros, 2011; Kros et al., 2011) used in the Netherlands for national evaluations of the Fertiliser Act. It takes into account manure production, distribution of manure, maximum application standards for both N and P, actual application rates of N and P for different type of manure and fertilisers, N and P harvest by crops, soil processes and consequently nutrient balances and nutrient losses to the environment. Detailed national and regional data and factors are taken into account. But the most important differences is that the previous presented NUT2 calculations by the MITERRA model does not take into account specific national legislation. Especially for the Netherlands this is relevant, because the Netherlands has a strict P application

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standard which highly determine the manure distribution and actual application rates for P and N in terms of manure and fertilisers.

The agricultural nutrient balances in INITIATOR are calculated as the N and P inputs minus outputs for the year 2018. The inputs for N and P include mineral fertiliser, animal manure applied (minus losses in stables and during application), compost and sludge, deposition, and for nitrogen also fixation in the soil. The output includes the N and P offtake from the land by crop harvest.

The Achterhoek region has a surface area of 1475 km² and 389,682 inhabitants (2264 inhabitants km^{-2}). This region has about 89,222 ha of agricultural land in use, of which 68% of the area is used for grassland, 21% for fodder maize (silage maize) and 11% for other arable crop production. For the agricultural subarea Berkelland with 17,256 ha agricultural land, the percentages are respectively 70%, 22% and 7%. The arable farming land area in the Achterhoek is used for wheat (9%), other grains (40%), potatoes (37%), sugar beets (8%) and other crops (7%). The agricultural subarea Berkelland has relatively more potatoes with respectively 5%, 39%, 49%, 4% and 3% for these crops.

The nutrient balances in the Achterhoek region are positive for nitrogen and phosphorus for grass, maize and arable land, with the only exception of a negative balance for phosphorus for grassland with -6 kg P ha^{-1} year^{-1} (Figure 3.1.3).

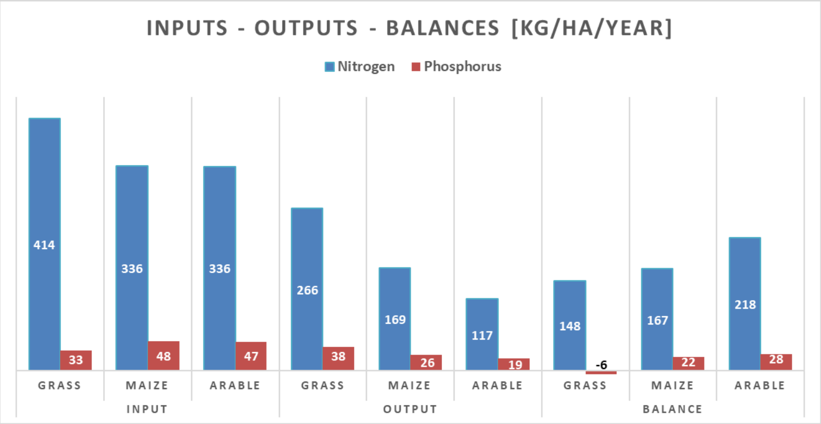

Figure 9: Nitrogen [kg N ha^{-1} year^{-1}] and phosphorus [kg P ha^{-1} year^{-1}] inputs, outputs and balances for grass, maize and arable land for the NUTS3 region Achterhoek in the Netherlands in 2018. Note: the outputs are presented as a positive value, but it is an outgoing flow from the system; for phosphorus for grass land there is a negative balance. Source: Netherlands INITIATOR model.

The surpluses in nitrogen are smallest for grass land (148 kg N ha^{-1} year^{-1}), followed by maize (167) and arable (218) land (Table 3.1.1). Among the agricultural subareas, the surpluses for all land uses (crop types) for nitrogen range between 124 and 228 kg N ha^{-1} year^{-1} and for phosphorus between -2 and 16 kg P ha^{-1} year^{-1}. The nitrogen surpluses per hectare per year among subareas and per land use range from 125-173 kg N for grass land, 82-442 kg N for maize land and 142-498 kg N for arable land. For phosphorus similar nutrient balances for grassland are negative ranging from -5.2 to -7.1 kg P and for maize and arable land positive ranging respectively from 6 to 65 kg P and from 11 to 75 kg P per hectare per year.

Table 6: Nitrogen [kg N ha^{-1} year^{-1}] and phosphorus [kg P ha^{-1} year^{-1}] agricultural inputs, outputs and balances [kg N ha^{-1} year^{-1}] for the agricultural subareas in the NUTS3 region Achterhoek in the Netherlands in 2018. Source: Netherlands INITIATOR model.

		Nitrogen [kg N ha^{-1} year^{-1}]								
		Input			**Output**			**Balance**		
Code	**Subarea**	**Grass**	**Maize**	**Arable**	**Grass**	**Maize**	**Arable**	**Grass**	**Maize**	**Arable**
3	Aalten	391	353	353	-266	-177	-130	125	176	223
27	Berkelland	409	375	365	-267	-177	-109	142	198	255
38	Bronckhorst	425	280	282	-266	-165	-129	159	114	153
53	Doetinchem	434	507	483	-269	-177	-116	165	330	367
128	Lochem	409	255	273	-272	-158	-119	138	98	155
143	Montferland	436	335	325	-263	-176	-106	173	159	219
159	Oost Gelre	389	619	600	-264	-177	-101	125	442	498
165	Oude IJsselstreek	429	280	280	-260	-165	-123	168	115	157
223	Winterswijk	404	238	258	-268	-155	-116	135	82	142
237	Zutphen	441	278	287	-270	-167	-115	171	111	172
	Total Achterhoek	**414**	**336**	**336**	**-266**	**-169**	**-117**	**148**	**167**	**218**
	Standard deviation	**± 17.9**	**± 115.9**	**± 104.3**	**± 3.3**	**± 8.1**	**± 8.8**	**± 18.2**	**± 110.2**	**± 109.3**

		Phosphorus [kg P ha^{-1} year^{-1}]								
		Input			**Output**			**Balance**		
Code	**Subarea**	**Grass**	**Maize**	**Arable**	**Grass**	**Maize**	**Arable**	**Grass**	**Maize**	**Arable**
3	Aalten	32	52	53	-38	-27	-21	-6	25	33
27	Berkelland	32	54	54	-38	-27	-18	-6	27	36
38	Bronckhorst	33	39	38	-38	-25	-21	-5	14	16
53	Doetinchem	33	79	78	-39	-27	-20	-5	51	58
128	Lochem	32	34	33	-39	-24	-19	-7	10	14
143	Montferland	34	50	48	-38	-27	-19	-4	23	29
159	Oost Gelre	32	92	91	-38	-27	-17	-6	65	75
165	Oude IJsselstreek	33	39	38	-38	-25	-21	-4	13	17
223	Winterswijk	32	30	29	-39	-24	-18	-6	6	11
237	Zutphen	34	37	36	-39	-26	-21	-5	12	15
	Total Achterhoek	**33**	**48**	**47**	**-38**	**-26**	**-19**	**-6**	**22**	**28**
	Standard deviation	**± 0.6**	**± 19.2**	**± 19.4**	**± 0.5**	**± 1.3**	**± 1.5**	**± 0.9**	**± 18.3**	**± 20.1**

Looking at the N and P agricultural balances per agricultural subareas (Figure 3.1.4), the inputs (e.g. application of manure and fertilisers) differ much more between subareas than the is output (crop uptake) of nutrients. The crop uptake for phosphorus is more similar across subareas than for nitrogen. For grassland the standard deviation among subareas is relatively small compared to maize and arable land for both N and P, especially for the inputs and overall balances (Table 3.1.1). The N and P agricultural balances per agricultural subareas are shown spatially and geographically in maps in Figure 3.1.5.

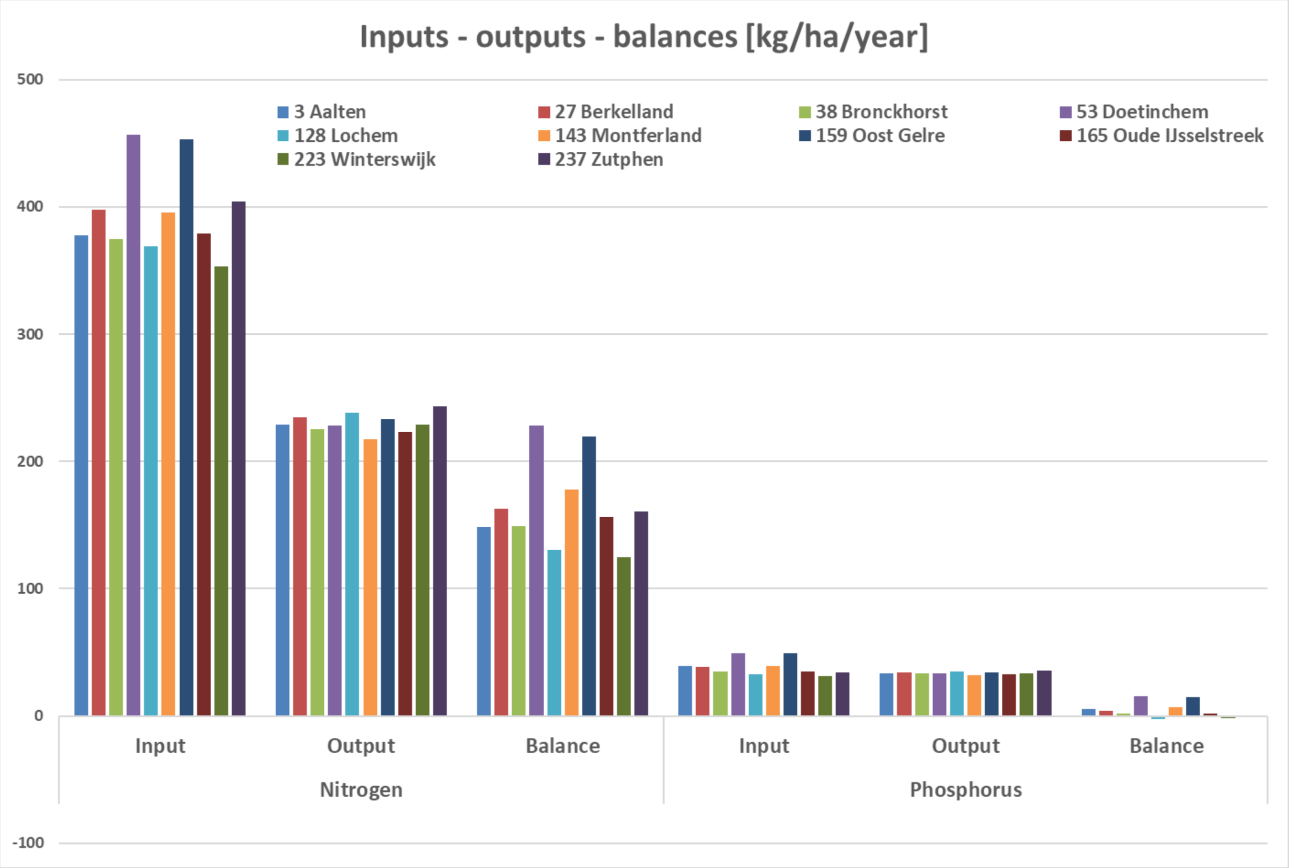

Figure 10: Nitrogen [kg N ha^{-1} year^{-1}] and phosphorus [kg P ha^{-1} year^{-1}] inputs, outputs and balances for all land use types (crop types) for the agricultural subareas of the NUTS3 region Achterhoek in the Netherlands in 2018. Note: the outputs are presented as a positive value, but represent an outgoing flow from the system; for phosphorus there are negative balances. Source: Netherlands INITIATOR model.

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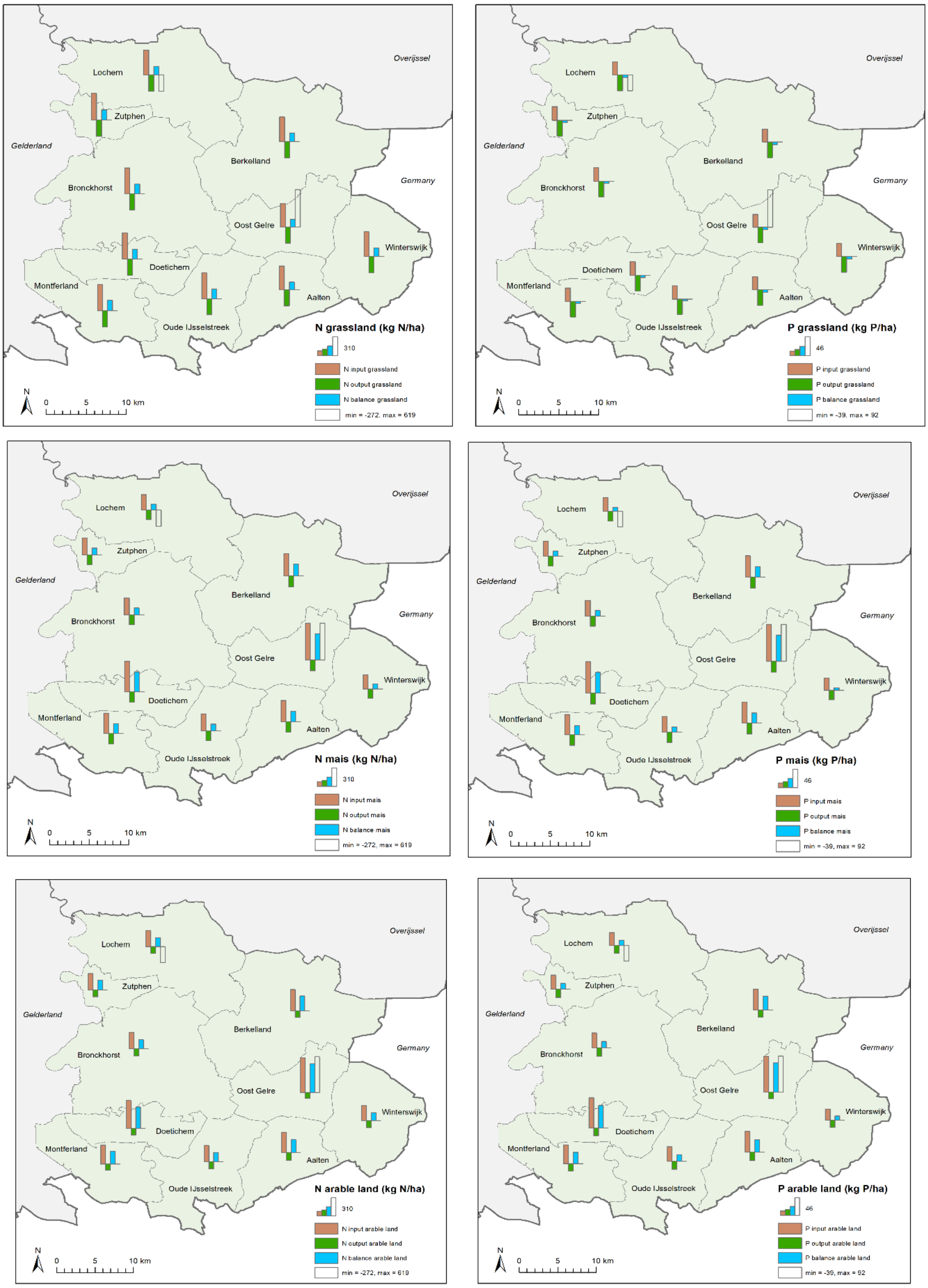

Figure 11: Nitrogen [kg N/ha/year] and phosphorus [kg P/ha/year] inputs, outputs and balances for the agricultural subareas in the NUTS3 region Achterhoek in the Netherlands in 2018; for grass land, maize land and arable land. Source: Netherlands INITIATOR model.

Comparing the data of the NUTS2 region province of Gelderland (previous sections) with the underlying NUTS3 region Achterhoek and its underlying agricultural subarea Berkelland presented here shows interesting differences. Gelderland (NUTS3) has higher N and P surpluses (234 kg N ha^{-1} year^{-1} and 17 kg P ha^{-1} year^{-1}) compared to Achterhoek (159 and 4) and Berkelland (163 and 4). On the one hand this can be explained by higher calculated inputs for Gelderland (413 kg N ha^{-1} year^{-1} and 45 kg P ha^{-1} year^{-1}) compared to Achterhoek (389 and 37) and Berkelland (398 and 39). On the other hand, lower outputs (crop harvest) are calculated for Gelderland (-179 kg N ha^{-1} year^{-1} and -27 kg P ha^{-1} year^{-1}) compared to Achterhoek (-230 and -34) and Berkelland (-235 and -34). Looking more closely at the inputs, the province of Gelderland has lower application of manure and higher application of mineral fertilisers compared to the subregion Achterhoek and its agricultural subarea Berkelland. The presented differences between the three spatial levels can be explained partly because the inputs, outputs and balances differ per spatial scale because of geographical differences, and partly because of differences in models used (MITERRA versus INITIATOR) with different input data, parameters and calculation methods. Most importantly the inclusion of national legislation on N and P application in INITIATOR makes the results it more detailed, complete and probably accurate.

3.2 Spain

The Spanish Inventory System (SEI) is responsible for calculating the total emissions of each of the pollutants related with greenhouse gas emissions and other atmospheric contaminants, such as methane, ammonia, nitrogen oxides and other non-methane volatile compounds, for each of the livestock categories and activities considered by international and EU regulations. These emissions should be estimated in accordance with guidelines established by the Intergovernmental Panel on Climate Change (IPCC) and the European Environmental Assessment and Control Programme (EMEP/EEA). In addition, the Ministry of Agriculture, Fisheries and Food must annually develop a "Balance of Nitrogen and Phosphorus in Spanish Agriculture" (BNAE) to respond to Eurostat's requirements.

The General Sub-Direction of Livestock Production, a focal point for certain aspects of livestock activities within the SEI, is responsible for the development of methodological guidelines for the determination of the nitrogen and phosphorus balance of the animal species that make up Spanish livestock, which provide complete and detailed information to meet the needs of the SEI and the BNAE. The methodology developed satisfies the requirements established in the latest editions of the IPCC (2006) and EMEP/EEA (2013) guidelines, allowing the estimation of NH_3, NO, NO_2, N_2O,

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CH_4, COVNM, as well as particulate matter with an advanced level of complexity (TIER II). For this reason, in Spain, there exist some differences between data reported in EUROSTAT (2016) and updated national data published on other sources like: **MAPA** (Ministry of Agriculture, Spain) (https://www.mapa.gob.es) or **ANFFE** (National Fertilisation Association) (http://www.anffe.com) due to the methodology used and some guidelines modifications. These new protocols are more precise because more factors (like N and P feed reductions or excretions) are introduced in the calculations and before these values were calculated using coefficients (TIER I).

While more detailed data is available for some Spanish governmental districts, there is no homogenization between all the autonomous regions, so it has been decided to use data from last set of data for the three year average 2016 – 2018 which was originally presented within the Nutri2Cyle project https://www.nutri2cycle.eu in this report.

3.3 Belgium

A legal protocol with the Flemish government is being setting up to acquire detailed information after which a detailed mass flow analysis for N, P along the Flemish Agro-food industry will be designed. These results will be ready in some months and are not ready for D1.4 at this stage.

Most obvious difference will be that EUROSTAT deals with national data, whereas the analysis that will be prepared focuses on more precise/finer data from the regional level. In Belgium agriculture and environmental are regional jurisdiction, meaning that the policies and databases are also arranged regionally.

So in essence that is an ongoing investigation of which the outcome is not expected to become immediately available. In this context, EUROSTAT data can be considered the only data available that works for Belgium.

3.4 France

Data at NUTS 2 level are quite different from data from regional sources. Whereas from some regions such as Grand Est no significant differences emerged between local and EUROSTAT data, for some regions the observed differences can change the final balance. For instance, for Bretagne, nitrogen crops uptake is 119 kgN ha^{-1} while the regional source indicates 157 kgN ha^{-1} (81 kgN ha^{-1} for crops and 76 kgN ha^{-1} for grasslands). Also non-anthropic nitrogen is 22.5 kgN ha^{-1} while the regional source indicates 6.9 kgN ha^{-1} for N fixation. N balance value is very different depending on the used source of data (82.2 kgN ha^{-1} for NUTS2 level to 29 kgN ha^{-1} for regional sources). When

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the inputs from mineral fertilizer sources are excluded, the nitrogen balance is -36 kgN ha^{-1} instead of 10.2, which means that in Bretagne despite the high production of livestock manure, farmers still depending on mineral nitrogen to fertilise some crops (mainly winter wheat and barley).

The differences between the different data sources are also observed for phosphorus. Phosphorus from grazing seems underestimated. In Bretagne, for instance, the regional data sources indicate an organic phosphorus of 64 kgP ha^{-1} while NUTS2 level data indicates 22.18 kgP ha^{-1} (P manure + P sludge + P compost + P grazing = 16.8+1.18+0.04+4.16). Also phosphorus crops uptake is 19.1 kgP ha^{-1} instead of 62 kgP ha^{-1} (40 kgP ha^{-1} for crops and 22 kgP ha^{-1} for grasslands). Despite this, phosphorus balance value is not affected.

3.5 Italy

Concerning Italy, local data are generally in accordance with EUROSTAT – NUTS2 database probably because Italian legislation for animal manure, sludge and compost application to the soil takes into account Nitrate directive. Consequently, data reported in the present deliverable can approximate well Italian nutrient balances.

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Overall conclusions

Deliverable 1.4 (*Report on the nutrient imbalances analysis*, deadline M13) reported the results of the nutrients imbalance analysis carried out in Task 1.4.

The results allow to predict where the nutrients recovered in FERTIMANURE can contribute in the long-term sustainability of agriculture. Generally, data reported in the present deliverable showed that animal manure sources can sustain nitrogen and phosphorous requirements in most of the studied countries (The Netherlands, Belgium and Italy). Whereas France and Spain data showed high differences within regions (northern regions need mineral fertilizers input to sustain plant uptake from soil), Germany is the only country that needs mineral fertilizers input in all the regions.

These results indicate that it is necessary to transform part of nitrogen and phosphorus from animal manure sources into bio-based fertilizers that can be distributed throughout different regions and countries, and thus reducing importation and usage of mineral sources. In this context, FERTIMANURE project can advance knowledge on nutrients recovery from animal manure, improving the sustainability of animal manure management and reuse. These can result in a reduction of mineral fertilizers usage, with positive effects for farmers and the environment.

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