WPT2, Activity 1, Deliverable 1.2

Exploring the demand for recycling-derived nutrients and organic matter in regions of Northwest Europe

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Summary

Crop farming in Northwest Europe highly depends on non-renewable nutrient sources such as imported rock-phosphate. Within the scope of a Circular Economy, nutrient recycling rates at the scale of Northwest Europe need to be increased. Farmers' requirements towards recycling-derived fertilisers (RDFs) are the focus of the Interreg NWE project ReNu2Farm. In this context the objective of this study is to quantify the requirement of N, P and K in various regions within the NWE territory and to formulate the desired properties of the RDFs, from an agronomic perspective.

The desk study is based on agricultural statistics as well as on expert knowledge from the participating institutions. The nutrient demand is quantified based on the area of crops grown per region, the yield levels, the fertiliser recommendations, the soil types (clay, silt, loam, sand), the soil quality (bioavailability of the nutrients in the soil), the current legislation and common fertiliser practice. Besides the demand, the regional availability of nutrients in animal manure and other organic fertilisers is also quantified. From the regional demand for nutrients on the one hand and the regional availability of manure nutrients on the other hand, the net potential demand for nutrients in RDFs is quantified and desired N-P-K ratios are calculated.

Results show that demand for nutrients from recycling exists everywhere, even in regions with high livestock density where animal manure is already largely used as a source for nutrients. However, the desired composition in terms of the three main plant nutrients, N, P and K as well as organic carbon differs largely between regions. Overall, it can be stated that a pure concentrated recycling-derived nitrogen fertiliser will find its use everywhere. It is common practice to apply a basis fertilisation in terms of N, P and K, often in the form of animal manure, but most crops receive an additional nitrogen supplement during the growing season. Such a concentrated nitrogen fertiliser will be demanded in grassland and cereal regions with high animal manure availability such as in the Netherlands or Flanders (Belgium). In Ireland on poor soils, an N-P-K fertiliser will be demanded. Root crop and vegetable regions with high availability of animal manure (the Netherlands and Flanders) are likely to demand an NK fertiliser whereas root crop as well as cereal regions with low availability of manure (Northeast France and Southwest Germany) are likely to demand an N-P-K fertiliser.

A demand for organic matter amendments additionally to regionally available manure can only be expected in regions with low availability of animal manure (e.g. locally in Germany and in France), especially if crops are grown which leave behind low amounts of organic matter with crop residues. In root crop and vegetable regions with animal manure input (the Netherlands and Flanders) a demand for a soil improver (high organic carbon content, low P content) can be expected.

Besides the aspect of nutrient composition as assessed with this report, a lot of other aspects such as ease of use, nutrient value, safety and knowledge and awareness of farmers towards this topic determine whether RDFs will be purchased and applied to fields by farmers in the future or not.

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Abbreviations

DM: Dry Matter

EOM: Effective Organic Matter

K: Potassium

N: Nitrogen

NWE: Northwest Europe

P: Phosphorous

RDF: Recycling-derived fertiliser

SOM: Soil organic matter

1. Introduction

Currently, farmers in countries of Northwest Europe (NWE) mainly use untreated animal manure and mineral fertilisers to fertilise their crops. However, several environmental and ecological problems are associated with this: emissions to the environment, high energy use for mineral nitrogen (N) fertiliser production, reliance on non-renewable mined and imported resources (phosphorous (P) and potassium (K)). At the same time, nutrients end up as waste and are not recycled back to food production: urban wastes such as sewage sludge, food and green waste. Therefore, the goal of the ReNu2Farm project is to increase the application of recycling-derived fertilisers (RDFs) on agricultural fields in NWE. This is in line with the Circular Economy Policy of the European Commission (European Commission, 2015).

Nutrient recovery technologies producing RDFs have been developed over the last number of decades. However, RDFs stay relatively unknown with little uptake by farmers. Part of the reason why farmers do not use RDFs is the perception that the properties of these innovative fertiliser products do not match with the demand criteria of the farmers. The aim of ReNu2Farm and in particular with this study is to change this perception By publishing this inventory of the nutrient and organic matter need at regional level it is expected that the desired composition of RDFs will be better known.

This report presents an estimation of the crop nutrient demand as well as the current nutrient availability in regions of the Interreg NWE program territory (see Figure 1). Maps are generated to give a visual representation of the nutrient requirement at regional level.

Figure 1: The territory of the Interreg NWE program covers Ireland, United Kingdom, Belgium, Luxembourg and parts of France, Germany and the Netherlands. Switzerland is associated but will not be covered in the context of ReNu2Farm; source: http://4b.nweurope.eu/

1.1. Objective of this study and target group

The objective of this study is to explore the potential demand for RDFs at regional scale within NWE and to characterize the desired properties of those fertilisers in various regions. Desired properties focus on the composition in terms of the plant macronutrients N, P, K as well as on soil organic matter (SOM). Besides identifying regions for potential uptake based on their regional nutrient balance, this report also provides information on the region-specific demand in terms of the required nutrient ratio for crop production. This will support a tailor-made production of RDFs by improving RDFs towards the nutrient composition that farmers require in specific regions.

This information is particularly relevant for producers of RDFs since it will assist them in directing their production towards a product that is likely to be demanded on the fertiliser market. Also, for developers and researchers in nutrient recovery technology it provides valuable information on the nutrient composition that technology development should target, to produce an RDF product with an enhanced chance for success on the fertiliser market.

1.2. Definition of recycling-derived fertiliser (RDF)

In the ReNu2Farm project, the term “recycling-derived fertiliser” (RDF) is used. “Recycling-Derived Fertilisers” is defined as a category that includes products from different origins such as animal manure, urban waste including household food waste, catering waste or green cuttings from recreational areas as well as human waste in the form of sewage sludge. It is important to note that this nutrient rich biomass in its raw form undergoes treatments such as: mechanical separation (of animal manure most commonly), composting, anaerobic digestion, incineration (resulting in ash products), pyrolysis (resulting in charcoal), evaporation and condensation and/or crystallization or precipitation processes as well as stripping/scrubbing, biological treatment and membrane filtration. Opposed to RDFs are mined mineral fertilisers such as rock phosphate (raw or derivates after treatment with sulfuric and phosphoric acids (such as triple super phosphate (TSP)) as well as mined potassium and mineral nitrogen which is energy intensive to produce.

2. Material and methods

The ReNu2Farm project and this report aim to identify the nutrient demand of the farming community to encourage farmers to replace mineral fertilisers with RDFs. To gain insight into the replacement potential a study of the current use and sources of nutrients in fertiliser is carried out. Currently, the nutrient demand of the crops which is necessary to obtain good crop yields, is mainly provided by two different types of fertilisers: mineral fertiliser and organic fertiliser typically in the form of animal manure, predominately from the farm holding or sourced regionally.

To calculate the potential demand for RDFs a balancing exercise must be undertaken to avail of the animal manure currently available regionally. This balancing exercise can be expressed as follows:

Crop nutrient demand – (less) nutrient available in animal manure and other organic fertilisers = potential demand for RDFs (this demand is currently satisfied by mineral fertilisers predominately) (see Figure 2).

To assess crop nutrient demand, a lot of factors play a role and were required to be estimated for this study: the crop type grown, the yield levels, the common fertiliser practice, including fertiliser recommendations, as well as the soil type (clay, silt, loam, sand), the soil quality (bioavailability of the nutrients in the soil), and the current legislation (see Table 3). Most fertiliser recommendation systems require soil and management related information to derive the recommended fertiliser dose and were consequently integrated in the assessment in this way (see Table 2).

Most of the required data was extracted from agricultural statistics, if available and detailed enough from the European database Eurostat, otherwise from National statistics (see Table 1). At European level statistical regions are defined at different resolution (NUTS1 to 3). In this report, a region is defined as a NUTS2 region which is thus the medium resolution of EU statistics and refers to political regions or provinces in a lot of countries. If possible, information about nutrient demand and supply was collected at this geographical/regional level.

In a 2nd step, to quantify the nutrient availability, the regional nutrient balance, the type of fertilisers which are currently fulfilling the crop nutrient demand was examined. In most cases this will mainly be animal manure (of which applied volumes were either directly available from statistics or estimated based on the livestock density and animal species composition). For France, data was also available on current volumes of compost and sewage sludge which are being used, for other countries these fertiliser types were of minor importance. Digestate from anaerobic digestion was also integrated in the current availability of organic fertilisers when data was available.

Legislation limiting the amount of animal manure or other organic fertilisers that may be applied to soil was also examined and considered in the assessment.

For some regions and countries (Wallonia in Belgium, Wales, Scotland and Northern Ireland in the UK, Luxembourg) another method was applied. Statistics on current mineral fertiliser sales and consumption were evaluated to estimate the replacement potential with RDFs.

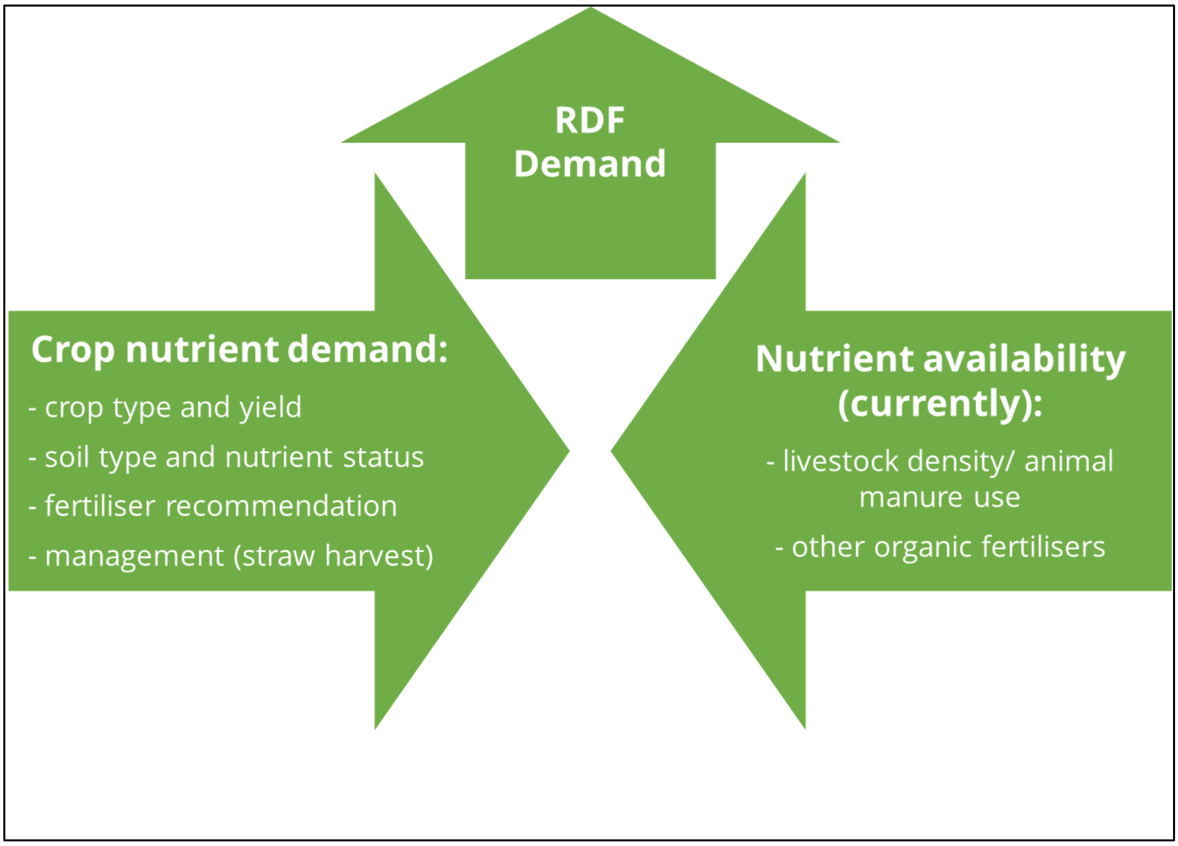

Figure 2: Balance methodology to determine the RDF demand on a regional basis.

Besides nutrients, SOM is also an important aspect of soil fertility and should be in balance, meaning that the amount of SOM that is being decomposed by soil organisms should be replaced with inputs of organic matter. For these inputs there are several options: crop residues, green manure or organic amendments such as animal manure, compost or other organic RDFs. Several countries have legislation established to assure a minimum level of SOM. This is the case in Germany for example (Landwirtschaftskammer Nordrhein-Westfalen, 2012). RDFs can also fulfil this function besides the nutrient delivery purpose and it should therefore be evaluated in which regions of NWE Europe there is demand for (additional) organic amendments and when possible be quantified. In this study a literature review was carried out to collect information from detailed assessments on the SOM status of soils in the regions of NWE and where available a quantification of the demand.

Table 1: Overview on datasets that provided the input data for the assessment of crop nutrient demand and current nutrient availability with animal manure and other organic fertilisers including the year that the data refers to.

		Netherlands	Belgium-Flanders	France	Germany	Ireland	Others
Crop Nutrient demand	**Cropping surfaces**	Eurostat 2018, situation in 2016				besides Eurostat for details Central Statistics Office, StatBank, situation in 2017	Eurostat 2018, situation in 2016
	Crop yield	*not required by recommendations*		Agreste, 2016-2018	average yield proposed by DueV 2017	*not required by recommendations*	UK and LUX: standard yields of recommendations
	soil type/ texture	Schils et al., 2015	Coopman, F (2019), personal communication	BDAT, 2010-2014	Geoviewer	*not required by recommendations*	UK: according to GGC and SNS of recommendations; LUX: not required by recommendations
	P content of soil	assumed as P rich according to Schils et al., 2015	Vandendriessche et al., 2016	BDAT, 2010-2014	average content assumed	Teagasc, Soil analysis and trends, 2017	UK: PAAG, 2019; LUX: medium “class C” assumed
	K content of soil	assumed as K rich according to Schils et al., 2015	*not required*	BDAT, 2010-2014	average content assumed	Teagasc, Soil analysis and trends, 2017	UK: PAAG, 2019; LUX: medium “class C” assumed
Current nutrient availability	**animal manure availability/ livestock density**	Statline referring to 2016	Mestrapport, 2018, situation in 2017	UNIFA (2011 & 2014) referring to 2008-2010 (N) and 2011-2013 (P, K)	Destatis, Fachserie 3 Reihe 2.2.2 referring to 2015	Central Statistics Office, StatBank, situation in 2017	Wallonia, BE: Godden & Luxen, situation in 2012; UK: Wales and Scotland: Defra, situation in 2017, Northern Ireland: Daera, situation in 2018, England: Farm Business Survey, situation in 2018/19
	other organic fertilisers	*not relevant*	*not relevant*	UNIFA (2011 & 2014) referring to 2008-2010 (N) and 2011 to 2013 (P, K)	*not relevant*	*not relevant*	*not relevant*

3. Crop nutrient demand

To characterize the demand in terms of volumes and properties for RDFs, this report aims to estimate as accurately as possible which doses of N-P-K farmers in Northwest Europe are likely to require, based on the crops they grow and on the soil conditions (type and nutrient status) that they cultivate on.

To determine fertiliser demand, fertiliser recommendations and limits are examined. These are then applied to the most important crops for a typical case (most common soil type, average P and K content). This is because farmers are obliged to respect limits and they are likely to follow recommendations, thus this gives a good estimation of the fertiliser rates that farmers will want to apply. In all countries of NWE fertiliser recommendations exist but they differ in concept and particularly when it comes to which factors (soil type, soil P content, etc.) are considered. Some countries in NWE also have exact limits on the fertiliser dose that is allowed to be applied at maximum. Table 2 gives an overview on fertiliser recommendation systems and the factors they take into account between the different countries. In principle, most fertiliser recommendation systems consider the crop type, the soil type and the soil nutrient status. Some systems are rather simple advising a certain dose for a crop and soil type combination (the Netherlands, Flanders) whereas other systems consider certain correction factors for N mineralization from the SOM for example (France, Germany). Table 3 gives an overview of the reference documents for fertiliser recommendations and limits as they have been used in this study.

Besides different recommendations, in all countries application of total N coming from animal manure (including animal manure derivatives such as manure based digestate) is limited to 170 kg $ha^{-1}yr^{-1}$ by the EU Nitrates Directive (91/676/EEC). In some EU countries (among those NL, DE, IRE, FL-BE) farmers can apply for a derogation allowing them to apply 230 to 250 kg N ha^{-1} coming from animal manure. For this, different conditions, mostly a high share of grassland surface, must be fulfilled.

Table 2: Overview on fertiliser limits and recommendation systems in countries of Northwest Europe

Country	Binding limit [yes/ no]			Factors taken in consideration		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Netherlands	yes	yes	no	crop and soil type (for limit)	grassland versus arable land and soil P status (for limit)	2 different systems and the higher one is advised: 1. Soil-dependent: crop type and expected yield leaching compensation on sandy soils; 2. crop-dependent: crop type, soil type and K_2O content of soil
Belgium-Flanders	yes	yes	no	crop and soil type (sand versus non-sand) (for limit)	grassland versus arable land and soil P status (for limit)	given by regional laboratories for soil analysis
Belgium-Wallonia	no	no	no	given by regional laboratories for soil analysis		
France	in Nitrate Vulnerable Zones N recommendations need to be respected	yes, in zones with low water quality	no	crop yield, soil type (via deductions), SOM (via spring Nmin, longterm organic amendment application, mineralization throughout season), crop rotation effects (pre-crop and catch crop)	crop type and yield, soil P_2O_5 content, soil type, region	same as P_2O_5
Germany	yes (crop and field specific N recommendation needs to be respected)	yes (crop and field specific P recommendation needs to be respected	no	crop yield, soil type (via deductions), SOM (via spring Nmin, longterm organic amendment application), crop rotation effects (pre-crop and catch crop)	crop type and yield, soil P content (class system), for cereals: straw harvest yes or no	same as P_2O_5

Ireland (grassland only)	yes	yes	no	arable versus grassland, type of grassland (pasture, hay, silage use), for pasture: stocking rate	Crop type and soil P content	Crop type and soil K content
Luxembourg	yes	yes	yes	crop type and yield	Crop type and yield, soil P content and soil type	Crop type and yield, soil K content and soil type
United Kingdom	yes	no	no	grassland: type of grassland use, management history, soil type, rainfall; arable crops: crop type, soil type, rainfall, previous crop, Nmin, mineralization potential	Crop type and yield and soil P content	Crop type and yield and soil K content

Table 3: Overview of documents and references regarding the fertiliser recommendations and limits that have been used in this study.

Country	Recommendation system/ limit for		
	N	**P_2O_5**	**K_2O**
Netherlands	limits: RVO, 2018b recommendations: Handboek Bodem en Bemesting, 2018	limits : RVO, 2018b	Handboek Bodem en Bemesting, 2018a and 2018c,
Belgium - Flanders	limit : VLM, 2018	VLM, 2018	Coopman, F. (2019), personal communication
France	Comifer, 2013, regional specification used here: Chambre d'Agriculture Hauts de France, 2015	Arvalis, 1995 and Comifer, 2007	
Germany	DueV, 2017	Hessen, 2018	Hessen, 2018
Ireland	Teagasc, 2018b	Teagasc, 2018b	Teagasc, 2018b
Luxembourg	Grand Duché de Luxembourg, 2019c	Grand Duché de Luxembourg, 2019a	
United Kingdom	AHDB, 2019		

3.1. Overview Northwest Europe

To present an overview of differences in crop nutrient demand between regions in Northwest Europe, general trends which are averaged over crops grown per region are presented. This is followed by crop specific details by region.

3.1.1. Most important crops grown

Different crop types have different needs in terms of N, P_2O_5 and K_2O. It is therefore crucial to look at which crops are most prominently grown in regions of NWE.

Farmland use in NWE can be distinguished into grassland, cereal and root crop regions (Figure 3). In Ireland, Northwest UK as well as regions in France, the Netherlands and Belgium grassland occupies the largest share of the utilized agricultural area. Cereals are dominating in Southeast UK and Germany as well as most regions in North and Central France. Regions with a high share of root crops, sugar beet and potatoes, can be found in Northern France, Flanders and in the Netherlands.

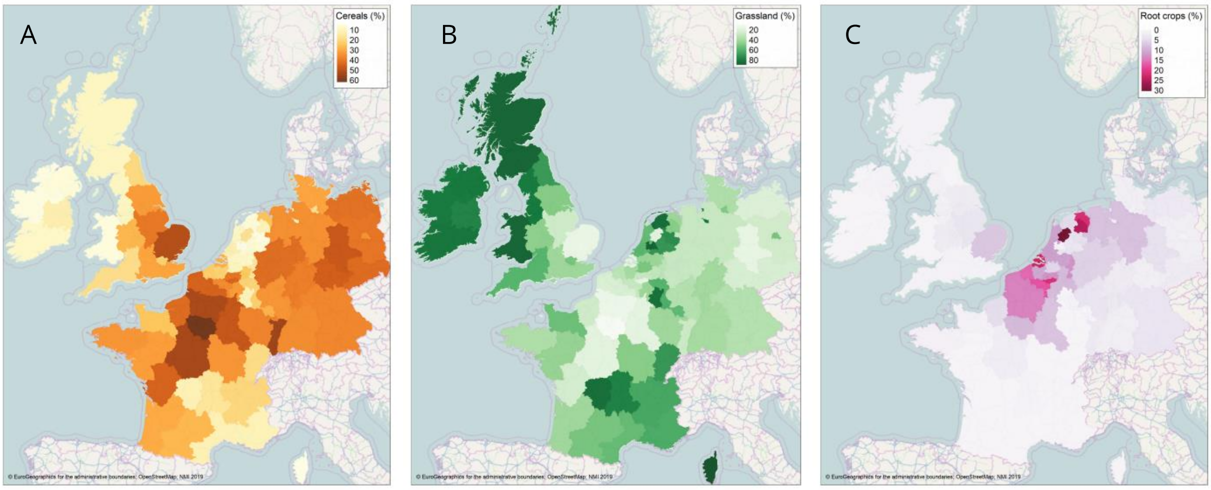

Figure 3: Share [%] of cereals (A), grassland (B) or root crops (sugar beet and potato) (C) of the total utilized agricultural area (UAA) as a NUTS2 region average in 2018; source: Eurostat, 2019

Once the land use has been identified, the fertiliser recommendations including necessary factors such as soil type and soil P and K status, will be applied for each of these main crops per region. The results are laid out in the following paragraph.

3.1.2. Crop nutrient demand

Despite differences in recommendation systems, a few principles relating to the nutrient requirement of various crop types are the same between countries and regions in NWE:

- all cereal crops, in particular if grown on a soil that is not nutrient deficient, do not require a lot of P_2O_5 and K_2O
- grass requires substantial amounts of K_2O (only Irish advice is for all the nutrients on a substantially lower level than in other countries)
- root crops require relatively high amounts of all the nutrients, N, P_2O_5 and K_2O

However, general trends can be observed when viewing Figure 3 and Figure 4 together, although factors such as different soil P and K status influence the picture. The general observed trends include:

- **Grassland regions** in Ireland, when compared to other parts of Europe, have a relatively low demand for all nutrients due to extensive management. This results in low level of fertiliser recommendations. However, soils are relatively low in P so that a moderate demand for P_2O_5 exists (see details in section 5.3.3).
- **Cereal regions** in Northern France require relatively low amounts of P_2O_5 and K_2O (one of the main reasons for this is the relatively high P and K content of soils). In Southwest Germany soils are less saturated than in France with P and K therefore P_2O_5 and K_2O demand is higher in Germany despite the large share of cereals.
- **Root crop regions** in the Netherlands have a high N, P_2O_5 and K_2O demand.

One of the results which warrants highlighting is that grassland in France has a particularly high K_2O recommendation level which leads to a relatively high regional average in regions with a significant area of land under grassland (Bretagne, Pays de la Loire, Basse Normandie and Franche-Comté).

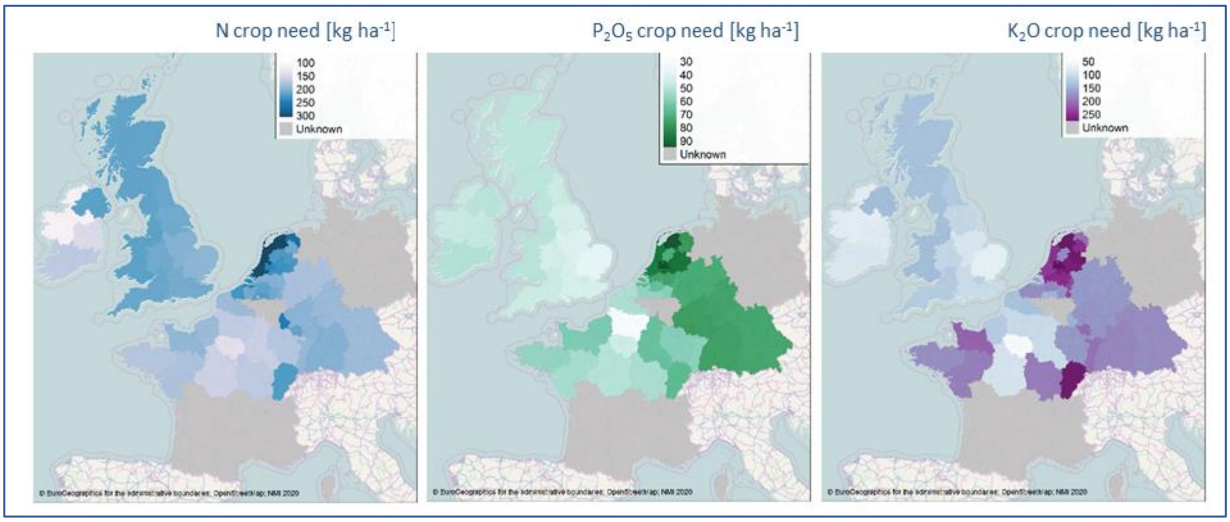

Figure 4: Regional average of crop nutrient demand for N, P_2O_5 and K_2O in NUTS2 regions in the Interreg NWE territory calculated based on most important crops and fertiliser recommendations.

3.1.3. Underlying assumptions and limitations

A number of assumptions had to be made to allow the estimation of regional average crop nutrient demand in the framework this study. Therefore, it has to be kept in mind that farming reality is somewhat more complex and that farmers can have individual circumstances that differ from the average assumptions.

The following assumptions have been made:

The Netherlands:

- In agreement with Schils et al., 2015, all soils were assumed to have a high P and K content.
- All grass was assumed to be grazed pasture.

Flanders (Belgium):

- In agreement with Vandendriessche et al., 2016, all soils were assumed to be in the highest P content class (class 4)
- Half of the grassland surface was assumed to be mowed and half grazed.
- Half of the vegetable surface was assumed to be leek and half cauliflower.

France:

- Crop yields, which have an important impact in the fertiliser dose calculation, were taken from national statistics (Agreste, 2018) as an average over the period 2016-2018.
- For grassland it was assumed that it is grown on a soil with good production potential and that the soil has an average P and K content. The assumed yield was 10 t DM ha^{-1}.
- Crop specific fertiliser recommendations were in detail applied for the regions: Champagne-Ardennes, Haute-Normandie, Lorraine, Nord-Pas-De-Calais and Picardie. Since fertilisation rates were found to be similar, an average dose was assumed for the other regions within the Interreg NWE territory.
- Average deductions in the N balance were applied (see details in Annex).

Germany:

- Soils are assumed to have an average P and K content falling into the German nutrient content index class of “C”.
- Crop yield levels are assumed to be the same as suggested as average yield by the fertiliser recommendation system. Average deductions have been applied (see Annex).
- Most national statistics are rather available at Bundesland resolution whereas European NUTS2 regions divide larger Bundeslaender into several NUTS2 regions. This report is working with Bundesland resolution for data availability reasons. This accounts also for the following assessment steps (e.g. animal manure application).

Ireland:

- In Ireland advise on nutrients are given as elemental P and K, therefore they must be converted to P_2O_5 and K_2O by multiplying by 2.291 and 1.205 respectively.
- For the Irish territory, Teagasc the national advisory body track the P and K content of Irish soils on a yearly basis. Therefore, in the various regions it is well known which fractions of the agricultural land fall into which P and K content class. Accordingly, the average P_2O_5 and K_2O dose was calculated as a weighted average for the region.

Luxembourg:

- For grassland in Luxembourg it was assumed that half of the grassland surface is grazed, and the other half used for silage production.
- For cereals cultivated in Luxembourg, straw harvest was assumed.

United Kingdom:

- Soil P and K index was based on results of the PPAG 2018-19 sampling campaign (reference!): grassland: P index of 2 and K index of 1; arable land: P index of 3 and K index of 2-.

- For grassland in the UK it was assumed that half of the grassland surface is grazed, and the other half used for silage production with 3 cuts.
- For cereals it was assumed that half from half of the surface straw was harvested, the other not.

3.2. Details assessed countries and crops

Some of the aspects observed above, e.g. the difference in nutrient demand between cereals and root crops and the different fertiliser recommendations between the various countries for grassland, are outlined in more detail in the following paragraphs.

3.2.1. Cereals versus root crops

The maps for crop demand above show substantially different average demand for cereal and root crop regions, as can be seen for example with a relatively low P and K demand in most regions of France and a high demand in most regions of the Netherlands. This has to do with the different N-P-K need of the different crop species, rather than with different recommendations or soil conditions. This is depicted in Figure 5: root crops have a higher P_2O_5 and K_2O fertiliser need than cereals, in particular compared to cereals on soils with relatively high P content such as in the Picardie region. Table 4 and Table 5 give an example of how N, P_2O_5 and K_2O demand is calculated according to French balancing methods. All cereal recommendations presented here are under the assumption that straw is not harvested.

Table 4: Example of the N balance approach applied for winter wheat in two different regions: Haute-Normandie and Picardie (both silty soils); besides crop yield and N content all in [kg ha^{-1}]

		Winter wheat	
		Haute Normandie	Picardie
	Crop yield objective [t ha^{-1}][a]	8.0	7.4
	N content in harvest good [kg t^{-1}][b]	3.1	3.1
N requirement	Crop N demand	247	230
	Residual N after harvest[b]	30	30
Deductions	N uptake until balance opening in spring[b]	15	15
	Mineral N spring[b]	40	40
	Soil mineralization[b]	40	40
	Catch crop N[b]	0	0
	Pre-crop effect[bc]	20	20
Balance		**162**	**145**

[a] Crop yield objectives according to Agreste, 2018 crop yield statistics average years 2016 to 2018
[b] Benchmark values according to method desccription (Chambre d'Agriculture Hauts de France, 2015)
[c] As pre-crop is assumed in Haute-Normandie rapeseed and in Picardie sugar beet or potato

Table 5: Example of the P_2O_5 and K_2O fertiliser recommendation system applied for winter wheat in two different regions: Haute-Normandie and Picardie (both silty soils); besides crop yield and P_2O_5 content all values in [kg ha^{-1}]

	Haute Normandie	**Picardie**
Crop yield objective [t ha^{-1}]	8.0	7.4
P_2O_5 content in harvest good [kg t^{-1}][a]	6.5	6.5
P_2O_5 removal	51.8	48.2
Correction factor[a]	1	0
P_2O_5 fertiliser dose	**52**	**0**
Crop yield objective [t ha^{-1}]	8.0	7.4
K_2O content in harvest good [kg t^{-1}][a]	5	5
K_2O removal	39.9	37.1
Correction factor[a]	0	0
K_2O fertiliser dose	**0**	**0**

[a] The correction factor and nutrient content in harvest good according to Arvalis, 1995. The correction factor is multiplied with the P_2O_5 or K_2O removal and depends on: the crop, the region, the soil type and the P or K content of the soil.

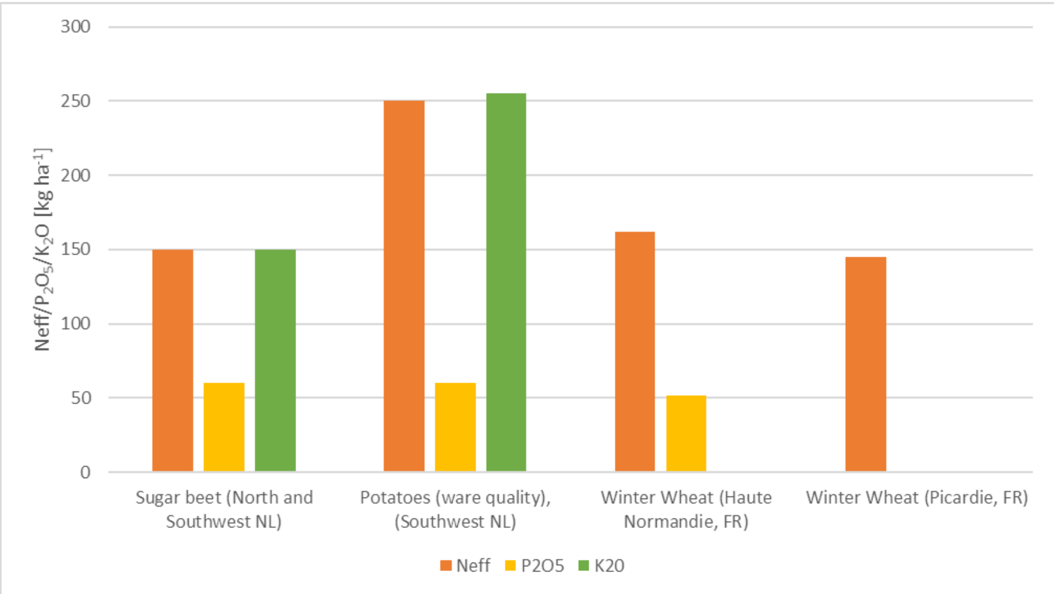

Figure 5 : Fertiliser recommendations for N, P_2O_5, K_2O for sugar beet and potatoes in the Netherlands and winter wheat in two different regions of France[1]

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[1] *For NL, N and P_2O_5 are limits (N soil type specific (RVO, 2018a) and P depends on soil P content (RVO, 2018b) and K_2O is the soil dependent recommendation with assumption of sugar beet: 60 t ha^{-1} with 2.5 kg K_2O t^{-1} and potato 50 t ha^{-1} with 5.1 kg K_2O t^{-1}; For FR see Table 4 and Table 5*

3.2.2. Different recommendations for grassland

Fertiliser recommendations for grassland differ substantially between different European countries. Nutrient management in Ireland is more extensive managed. Within the Irish recommendation system a difference is made between hay, silage and pasture land and with pasture it is further broken down to beef, dairy and sheep grazing. Whereas hay and silage land needs more P and K than pasture land. The relatively high recommendation in France for K explains why regions with a relatively high share of grassland show demand for K higher than cereal regions in France (Figure 4). Figure 6 highlights the recommended nutrient level in France, The Netherlands, Germany and Ireland.

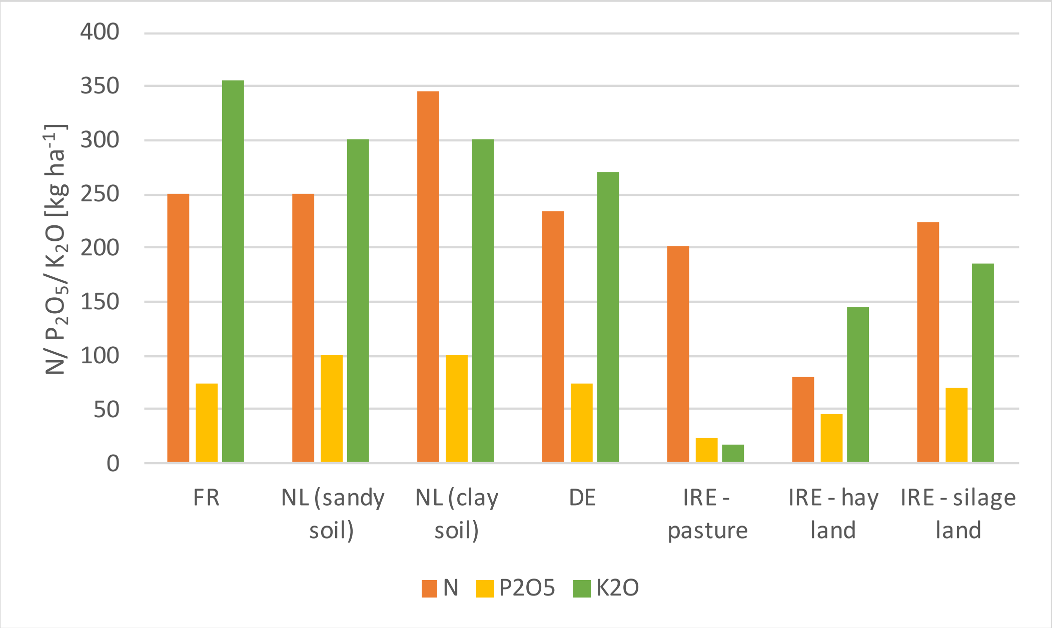

Figure 6: Fertiliser recommendations for grassland in France, the Netherlands, Germany and Ireland.[2]

[2] *The following assumptions apply: FR: good soil potential, average P and K content, 10 t DM/ha yield; NL: high soil P, under pasture; DE: silage grassland 4 cuts; IRE: a soil status with a soil P and K index of 3, silage is based on a two cut strategy and pasture is based on a stocking rate of 2 livestock units per hectare.*

4. Current use of animal manure and other organic fertilisers

Animal manure is the first most obvious fertiliser which is predominately applied by farmers due to good regional availability and low price. Therefore, nutrient volumes which are currently being applied with animal manure will not be replaced with other RDFs. However, as explained earlier the input of animal manure to soils is for environmental reasons (nutrient leaching) limited by EU legislation, mainly the Nitrates Directive and the Water Framework Directive. These Directives have been implemented in national laws, which differ by country. In this chapter the report examines how much animal manure nutrients are regionally applied. This data will be used when investigating the balance of how much nutrient need is left after animal manure application.

The estimation of regional average N, P_2O_5 and K_2O application to agricultural land was done based on national statistics (see Table 1). Most of this data was available as regional averages. For the Netherlands, total N and P_2O_5 application was directly available from the statistics. Only K_2O had to be estimated based on an average manure composition (average of cattle and pig slurry). In other countries either the total slurry volume (DE), or the livestock numbers and species composition (Ireland), or the total nutrient application per hectare and the division between different types of fertilisers (FR) was known, and used to estimate the regional average effective N, P_2O_5 and K_2O application to agricultural land with animal manure (in the case of France also other organic fertilisers). Where possible, national commonly used benchmark values where used for standard nutrient contents in manure and for N efficiency (see Annex). For Flanders and Wallonia in Belgium as well as for Wales, Scotland and Northern Ireland in the UK only an overall average was available, no data at more precise regional resolution.

4.1. Overview Northwest Europe

Manure nutrient input is highest in regions with high livestock density: the Netherlands, Flanders (BE) and Bretagne (France) (see Figure 7). For neighbouring regions to Bretagne and French regions close to the border with Belgium the current manure import is also taken into account based on data from UNIFA 2011 & 2014. In Germany, Ireland, Wallonia (BE) and in the UK the average composition of animal manure contains mainly cattle slurry which is higher in K compared to pig slurry that dominates in the Netherlands and in Flanders (BE). This has led to the situation that K_2O input to soils is on average higher relative to the P_2O_5 input in Ireland and Germany compared to the Netherlands and Belgium and also Bretagne.

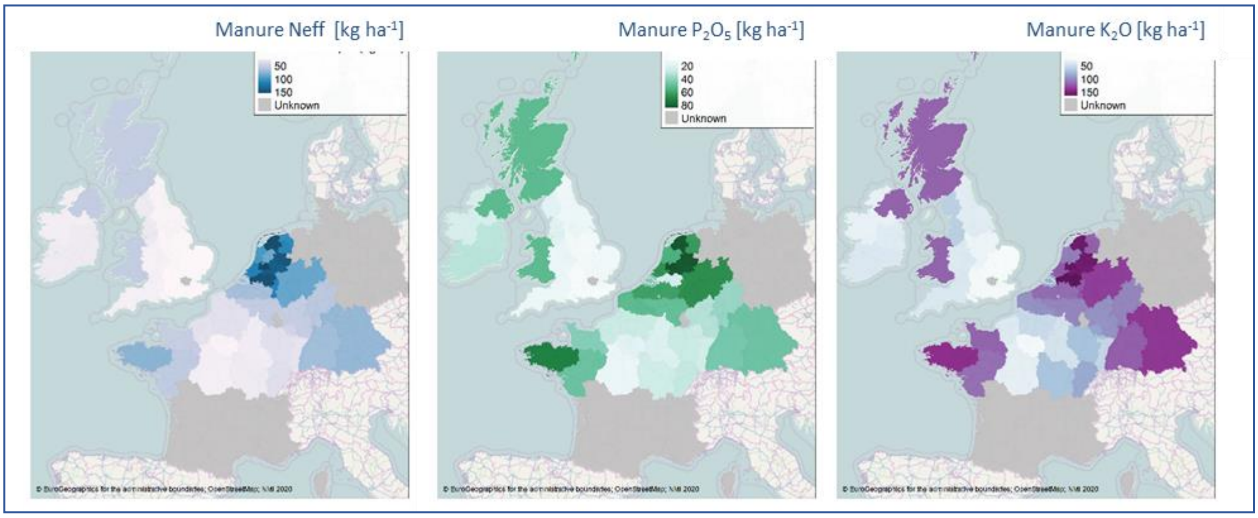

Figure 7: Regional average of nutrient input to agricultural land with animal manure (for France also incl. other organic fertilisers such as sewage sludge or compost or imported manure)[3]

[3] *based on national statistics and literature; N is indicated as effective N (Neff) using benchmark values for N efficiency as displayed in Annex; for Wales, Scotland and Northern Ireland in the UK, no data at region level was available, therefore the UK average is displayed; for Belgium averages for Wallonia and Flanders are displayed*

5. Balance: demand for N, P, K with recycling-derived fertilisers

To determine the potential demand of RDFs, a balance of the estimated crop nutrient demand minus the currently applied nutrients from organic fertilisers (mainly animal manure from the farm holding or other farms of the region) reflects the amount of nutrients that could potentially be replaced with RDFs in the future. Therefore, this report calculated this balance and assumes it to be the potential demand for RDFs.

Theoretically, this balance should be equal to current volumes of mineral fertiliser being purchased and applied by farmers. For some countries (Wallonia-BE, Luxemburg, Wales, Scotland and Northern Ireland in UK) where not all data necessary for the detailed assessment was readily available, the estimation of potential RDFs demand was done based on mineral fertiliser sales statistics (Wallonia: Etat de l'environnement Wallon, situation in 2017; Luxembourg: Grand-Duché de Luxembourg, situation in 2017 (Grand-Duché de Luxembourg, 2019b); UK: Defra, situation in 2017 and Northern Ireland: Daera, situation in 2018).

5.1. Overview Northwest Europe

RDFs will in most regions be used as a fertiliser supplement that will complement a base fertilisation with animal manure. However, in arable regions with a very low livestock density (parts of France and Germany), it could also represent the sole source of nutrients. Figure 8 and

Table *6* illustrate the findings of this report.

In **grassland** regions in general a (concentrated) N fertiliser is required in addition to animal manure (often cattle or sheep manure). However, soils in Ireland are relatively poor in P and K and therefore also require small quantities of P_2O_5. Since grass is grown as feed for animals it is assumed that grassland regions with low animal manure availability are unlikely. In France, recommendations for K_2O in grassland are high leading to a need for an NK fertiliser. However, since our calculations of the remaining demand assume that every hectare receives the average amount of slurry, it could well be that grassland receives a high volume of cattle slurry which is rich in K and consequently only a pure N fertiliser would be required as a supplement.

For Ireland the demand as presented in

Table *6* takes the weighted average for the region into account. In Ireland depending on the region between 60-66% of land have a soil P index of 1 or 2 and between 54-67% of land with a soil K index of 1 and 2. These levels of P and K in the soil mean the land will respond to the addition of P and K nutrients. Therefore, on good agricultural land only concentrated N is required but on poorer soils an RDF with NPK is required.

For **cereals** in regions with high manure availability, such as in the Netherlands and in Flanders, as well as in Nordrhein-Westfalen in Germany, a concentrated N fertiliser that will be used to complement a base fertilisation with animal manure will be demanded. The fertiliser must be as concentrated as possible in N as this reduces the volume and thereby also the costs for transport, storage and application. If in addition to this, it comes in granular form instead of liquid, it is easier to apply.

In cereal regions with low animal manure availability such as in North and Central France and in Southwest Germany as well as Southeast UK, an RDF containing all three nutrients N, P, K is likely to be required. Details and examples on desired nutrient ratios in these regions can be found in chapter 5.3.

In **root crop** regions with high animal manure availability, for example in the Netherlands and in Flanders-BE, RDFs containing N and K_2O but no to very little P_2O_5 (mainly applied with animal manure up to legal limit) are likely to be demanded. In root crop regions with low animal manure availability (North of France) an RDF containing all three nutrients, N, P_2O_5 and K_2O is likely to be demanded.

Mineral fertiliser sales for regions of Wales, Scotland and Northern Ireland show that mineral P_2O_5 is purchased in relatively high amounts especially in Scotland. For N and K_2O, the Southeast of England being cereal regions with relatively low livestock density, potentially require an NPK RDF.

In Luxembourg a substantial amount of mineral fertiliser N (104 kg N ha^{-1}) is consumed but almost no mineral fertiliser P and K. However, certain crops might receive mineral NPK fertiliser as displayed in Figure 8 that represents the average over the entire utilized agricultural area.

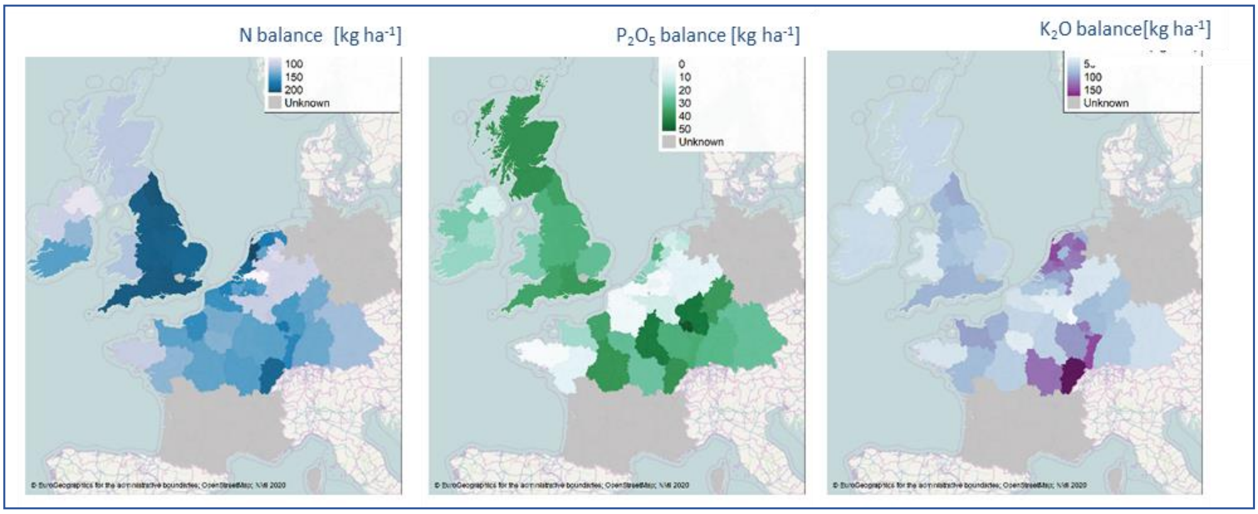

Figure 8: The estimated potential for RDFs after balancing the crop nutrient demand and the nutrient input with organic fertilisers for N, P_2O_5, and K_2O in NUTS regions of the Interreg NWE territory. For Wales, Scotland and Northern Ireland (UK) as well as, Wallonia (BE) and Luxembourg regional averages of mineral fertiliser sales are displayed because of a lack of data

Table 6: Clustering of demand regions for RDFs in dependence of the most important crop grown dominatingly in a region and the regional availability of animal manure.

	Grassland region	Cereal region	Root crop region
High availability manure	Concentrated N (Ireland N-P-K)	Concentrated N	NK
Low availability manure	/[a]	**N**-P-K	N-P-K

[a] The combination of grassland with low availability of manure is estimated as non-existing. Either, grassland in this case is unmanaged and unfertilised nature area or grassland is used for feed production for animals which will give manure back to the land.

5.2. RDF nutrient volumes required at regional level

To have an idea of the total nutrient demand in a region, the utilized agricultural area has to be taken into account. Figure 9, Figure 10 and Figure 11 indicate the total volumes of N, P_2O_5 and K_2O that will likely be demanded per region. This reflects amounts used as a supplement on top of animal manure which could potentially be RDFs to replace mineral fertiliser. Regions in Germany, Ireland, France and UK have a large agricultural surface which results in higher total demand. Despite of relatively high demand of N per hectare in regions of the Netherlands, the total regional demand for N is highest in Bayern in Germany, the Southern region of Ireland and the regions of Centre, Bourgogne and Pays de la Loire in France as well as in Scotland. P demand is highest in Bayern in Germany and in Champagne-Ardenne and Centre in France as well as in Scotland. Potassium demand is highest in Bourgogne and Pays de la Loire in France as well as in Scotland.

Based on these total sums of consumption, desired composition cannot be directly derived. As laid out earlier, several factors determine the required fertiliser dose of N, P, K: crop and soil type, P and K content of soil and fertiliser management. Consequently, nutrient demand can differ on the same farm for the same crop but on different parcels with different soil. It is therefore very difficult to give generalized advise on exact nutrient composition that will be required. However, general crop and regions specific trends can be observed and will be outlined in the following chapters.

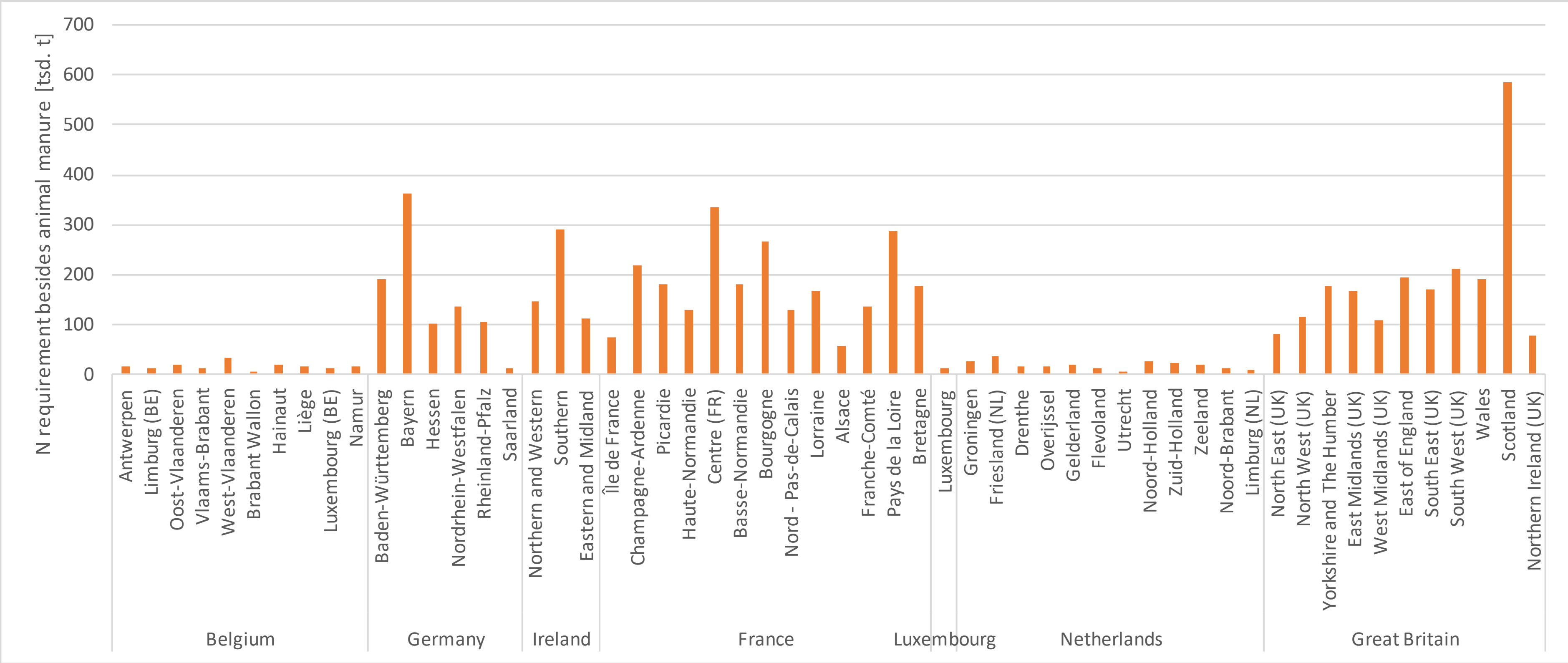

Figure 9 : Total requirement of effective N besides animal manure per NUTS 2 region of NWE (only those laying in Interreg NWE territory are included, excl. city regions such as Brussels); underlying data from Figure 8 multiplied with utilized agricultural surface (UAA) from Eurostat referring to 2016, for Ireland from Central Statistics Office, 2018a

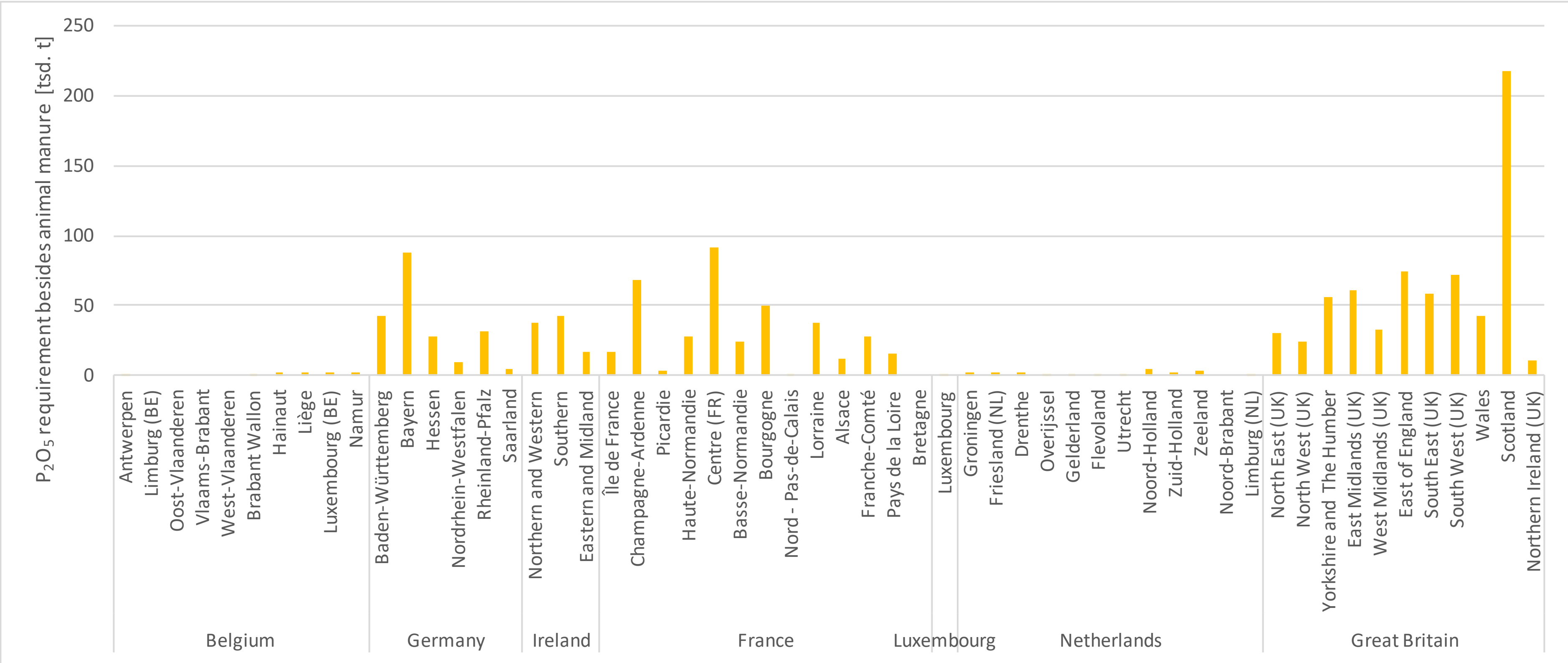

Figure 10: Total requirement of P_2O_5 besides animal manure per NUTS 2 region of NWE (only those laying in Interreg NWE territory are included, excl. city regions such as Brussels); underlying data from Figure 8 multiplied with utilized agricultural surface (UAA) from Eurostat referring to 2016, for Ireland from Central Statistics Office, 2018a

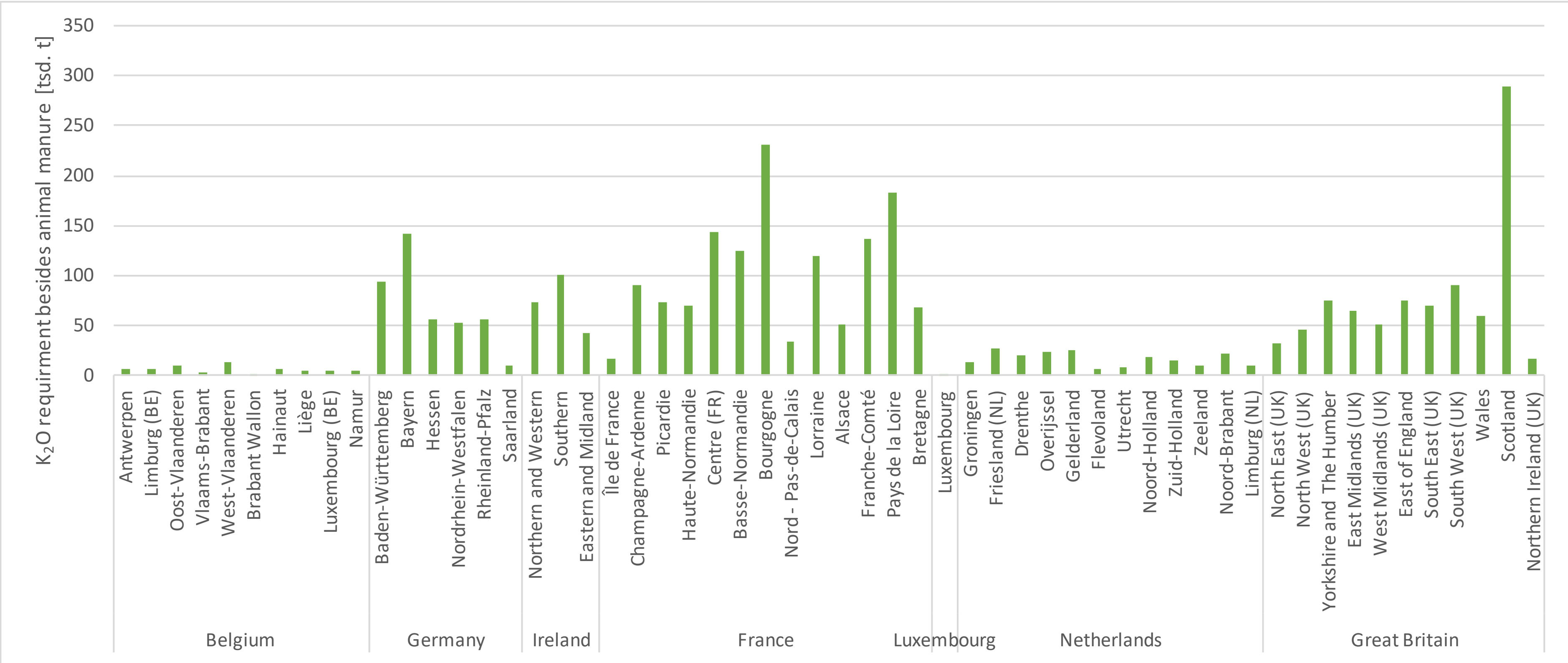

Figure 11: Total requirement of K_2O requirement besides animal manure per NUTS 2 region of NWE (only those laying in Interreg NWE territory are included, excl. city regions such as Brussels); underlying data from Figure 8 multiplied with utilized agricultural surface (UAA) from Eurostat referring to 2016, for Ireland from Central Statistics Office, 2018a

5.3. Details assessed countries

The information shown in the previous chapters is rather global, as it only indicates at regional level how much N, P and K are needed on average per hectare in addition to the organic fertilisers that are currently applied on average per hectare in that region. In this chapter, a closer look is taken at crop specific information from selected countries and regions. The following questions are relevant for this further elaboration:

- Which combinations of crop, soil type and soil quality occur in the various regions and what is the need for N, P, K and organic matter in the various situations?
- What is the current fertilisation for the various situations that occur in that region? This could include combinations of crop, soil type and soil quality;
- What does this mean for the potential use of RDF?

5.3.1. The Netherlands

As illustrated in Figure 8, the crop nutrient demand in the Netherlands is largely covered with animal manure, especially for P. However, demand for N and K still remains as animal manure does not provide the proper $N/P_2O_5/K_2O$ ratio that plants require. Consequently, fertilisation is done with animal manure as a base fertiliser and afterwards, for some crops in the course of the growing season, a supplement of N and/ -or K_2O is applied depending on the crop. This supplement is currently supplied with mineral fertiliser but in the future, it would be desirable to replace it with RDFs. Figure 12 illustrates the supplementary fertiliser needed for the most commonly grown crops and typical growing regions and their soil type. The assessment is based on the assumption that every crop and every hectare in a province receives an equal amount of animal manure (mix of different types of slurry as indicated by statistics, Statline, 2018) as data is based on the regional average manure input as depicted in Figure 7. Only for grassland an application of pure cattle slurry up to 250 kg N ha^{-1} is assumed. In farming practice, manure management will differ between crops, soil types, farmers and even parcels so that these figures can only give a broad indication. For example, on arable crops on clay soils, it may be difficult to apply animal manure in spring because of the risk of soil compaction and damaging soil structure. Also, in the Netherlands it is not allowed to apply manure in winter, in the period between September and February, to limit nitrate leaching risk.

However, some trends can be interpreted from Figure 12:

- There is no to very little demand for P in fertilisers to be applied besides animal manure.
- Cereals, such as winter wheat in Figure 12 require a fertiliser with concentrated N and no to very little P and K; the same applies to grassland (at least pasture when under derogation where slurry can be applied to 250 kg N ha^{-1}).
- Sugar beet and potatoes require a NK fertiliser; for sugar beet on sandy soils and ware potatoes on clay soils a N/K_2O ratio of 1:0.8 will probably be demanded and should not be exceeded as these crops are sensitive to an overfertilisation with K; starch potatoes on sandy soil require a $N:K_2O$ ratio of 1:1.4, seed potatoes on clay require a $N:K_2O$ ratio of 1:2.

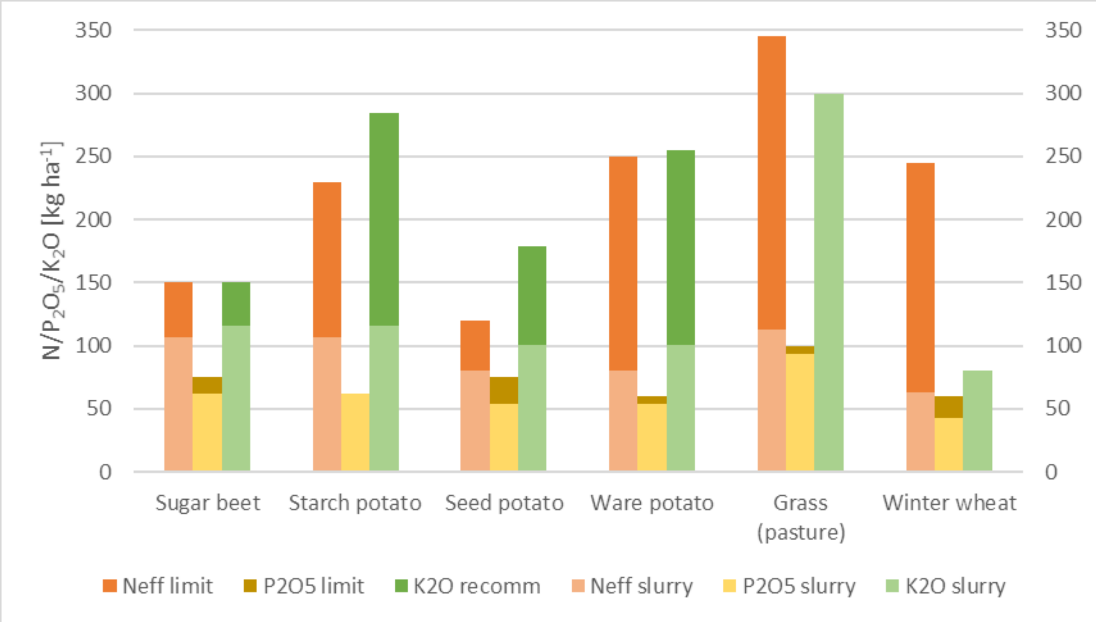

Figure 12: Fertiliser limits (effective N and P_2O_5) and recommendation (K_2O) as well as nutrient input with animal slurry (regional average, mix of different types, from Statline, 2018 as depicted in Figure 7). The difference between the two reflects the demand for additional fertiliser nutrients, mineral or RDFs.[4]

5.3.2. Belgium

Belgium is divided in its Flemish part, Flanders, and the French-speaking part, Wallonia. For this report data from Flanders was available in more detail. Fertiliser recommendations and consequently crop need could be derived NUTS2 region specific. However, nutrient input to land with animal manure was only available as average for Flanders and Wallonia separately. The following description focuses on Flanders.

The situation in Flanders is very similar to the Netherlands (see Figure 8): intensive crop management with a relatively high share of potatoes and vegetables in the crop rotation (in particular in the West Flanders region, see Figure 13). Animal manure is readily available and consequently there is an over-supply in P (Mestrapport, 2018). As pointed out for the Netherlands, individual nutrient management will differ between holdings and parcels and different conditions they farm in. However, as can be seen from Figure 14 some trends can be identified:

[4] *The assumption is that all crops within one region receive the same amount of slurry; depicted is a scenario for a sugar beet and a starch potato on a sandy soil in the Drenthe region, seed and ware potato on clay in the Flevoland region, grass pasture on clay soil in Friesland and winter wheat on clay in the Zeeland region; For grassland the cattle slurry input is assumed to be 250 kg total N ha^{-1} (maximum derogation limit) with an N efficiency of 45% (RVO 2018c).*

- There is no demand for P to be applied besides animal manure. The P_2O_5 limit is fulfilled with slurry.
- Cereals (as well as pasture, not displayed) require a concentrated N fertiliser with no P and K.
- Potato and leek (as well as other vegetables in general) are likely to require an NK fertiliser of the following ratio (as rough indication): 1:1.1 (potato) and 1:0.5 (leek) (expressed as $N:K_2O$).

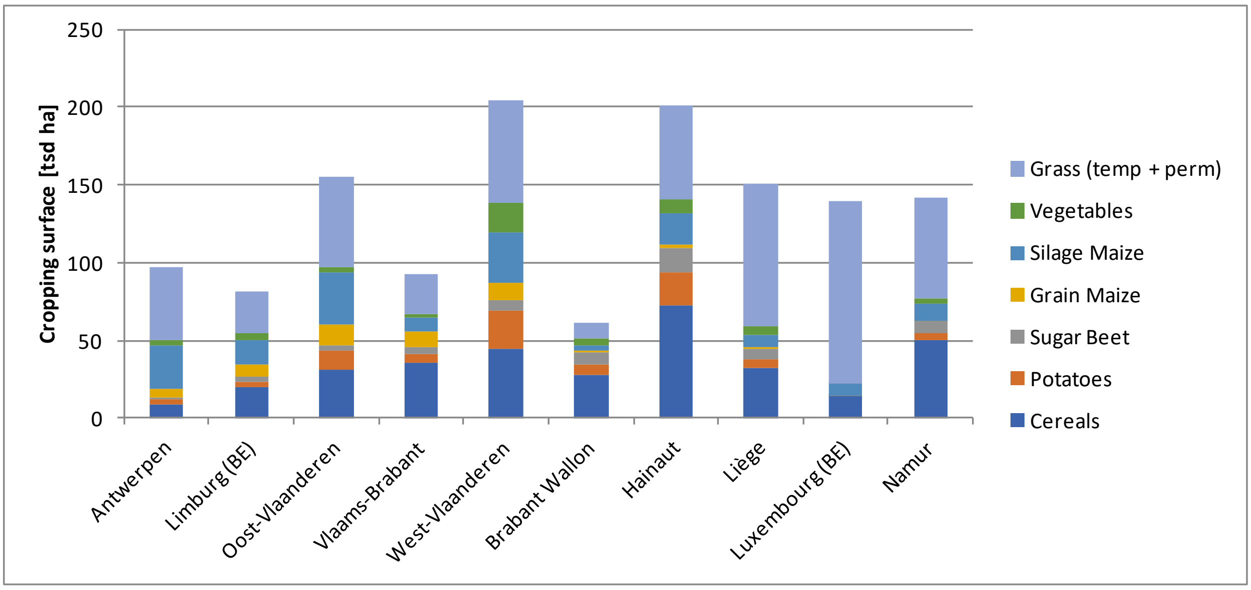

Figure 13: Cropping surface [in thousand hectares] of the most important crops in regions of Belgium. Source: Eurostat referring to 2016

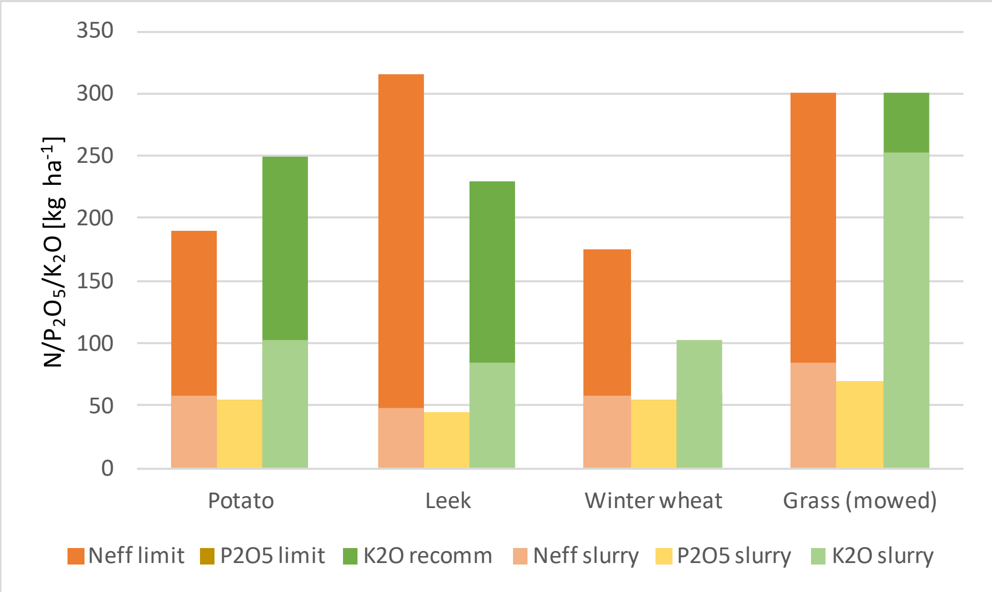

Figure 14 : Limits for N (effective) and P_2O_5 as well as K_2O recommendation in Flanders for the scenarios of potato and leek on a sandy soil in the West-Flanders region, winter wheat on a clay soil in the Flemish-Brabant region and mowed grassland on sandy soil in the Antwerp region as well as the slurry nutrient input.[5]

5.3.3. Ireland

Ireland is divided in three NUTS 2 regions which were regarded in this assessment: Northern and Western, Southern, and Eastern and Midlands region. In all of these regions, grassland occupies more than 75% of the agricultural land surface. The main three grassland usages: pasture, hay and grass silage are included in the assessment. Instead of investigating different crops as done for the other countries in the assessment, fertiliser recommendations and fertiliser management were assessed separately for these different grassland usages. In all three regions, pasture use is dominating (see Figure 15).

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[5] The P_2O_5 limit is defining the maximum slurry dose, for arable crops the average slurry composition as in Figure 7 is assumed, for grassland pure cattle slurry with nutrient contents according to Handboek Bodem en Bemesting, 2018 is assumed; average efficiency of 45% for N from slurry according to Mestrapport 2018 is assumed.

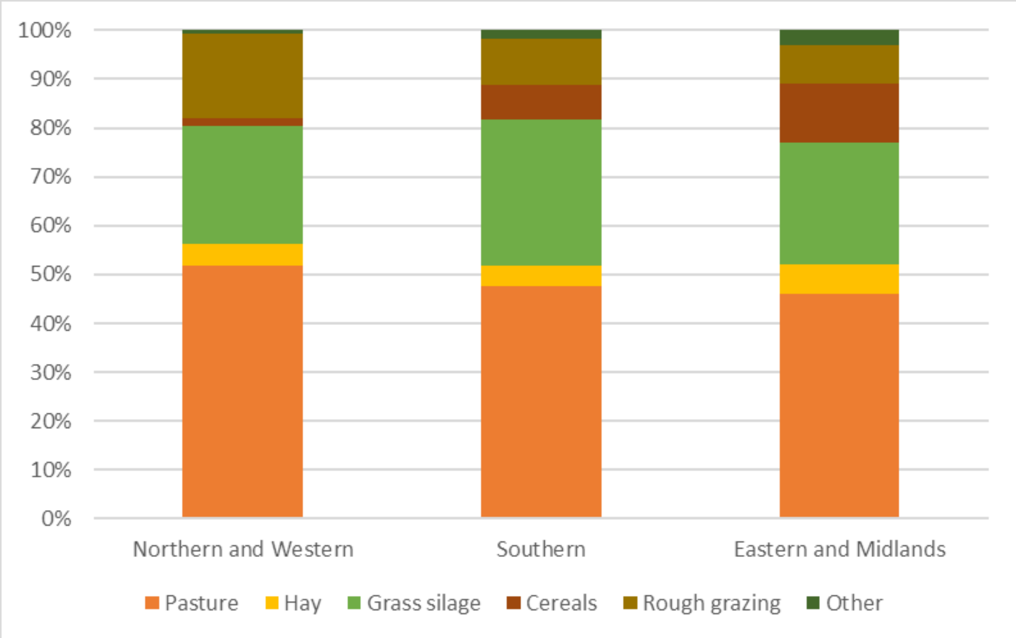


Figure 15: Overview of the agricultural surface in the three regions of Ireland; derived from data obtained from Central Statistics Office, 2018a

The fertiliser recommendation system for P and K in Ireland takes the soil P and K content into account. The system classifies soil according to the P and K content in 4 classes: Index 1 (lowest content) to Index 4 (highest content) (see Table 7). The target in fertilisation is to work towards Index 3. More than 60% of all soils are classified with P and K index 1 and 2. This holds true for all three regions (see Figure 16 and Figure 17). Consequently, it is advised to fertilise P and K to raise the P and K content in the soil.

Table 7: Soil Index System in Ireland; from:2018b

Soil Index	Index Description	Responste to Fertilisers
1	Very Low	Definite
2	Low	Likely
3	Medium	Unlikely/ Tenuous
4	Sufficient/ Excess	None

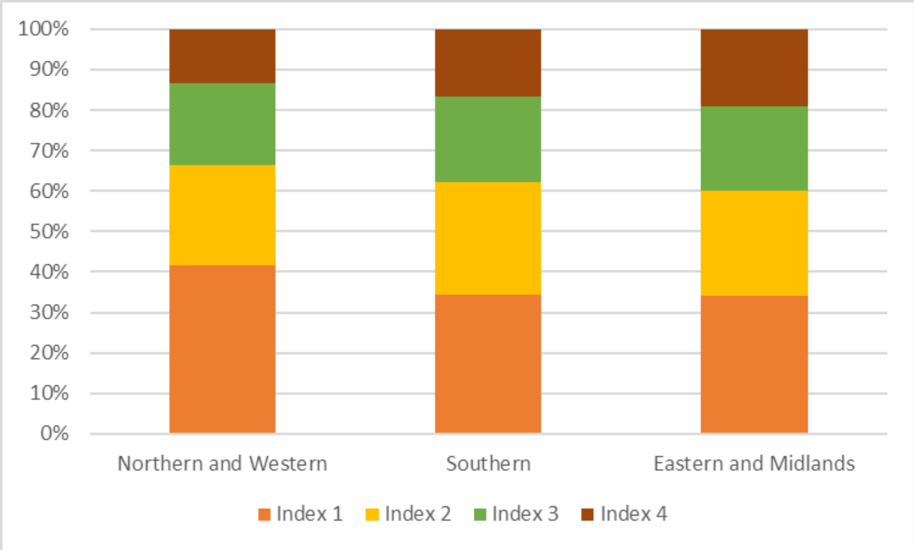


Figure 16: Breakdown of soil samples per region between the four P index classes; derived from data obtained from Teagasc 2018a and Central Statistics Office 2018b

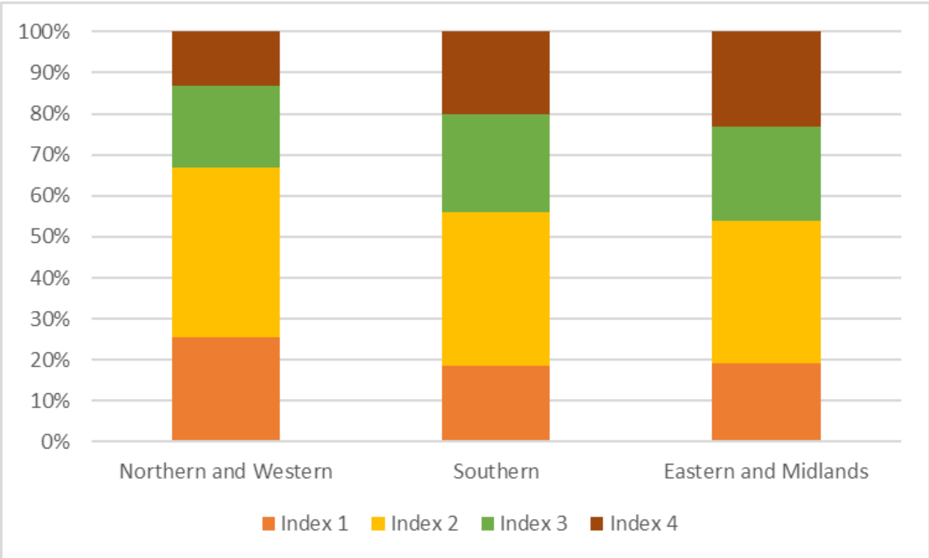
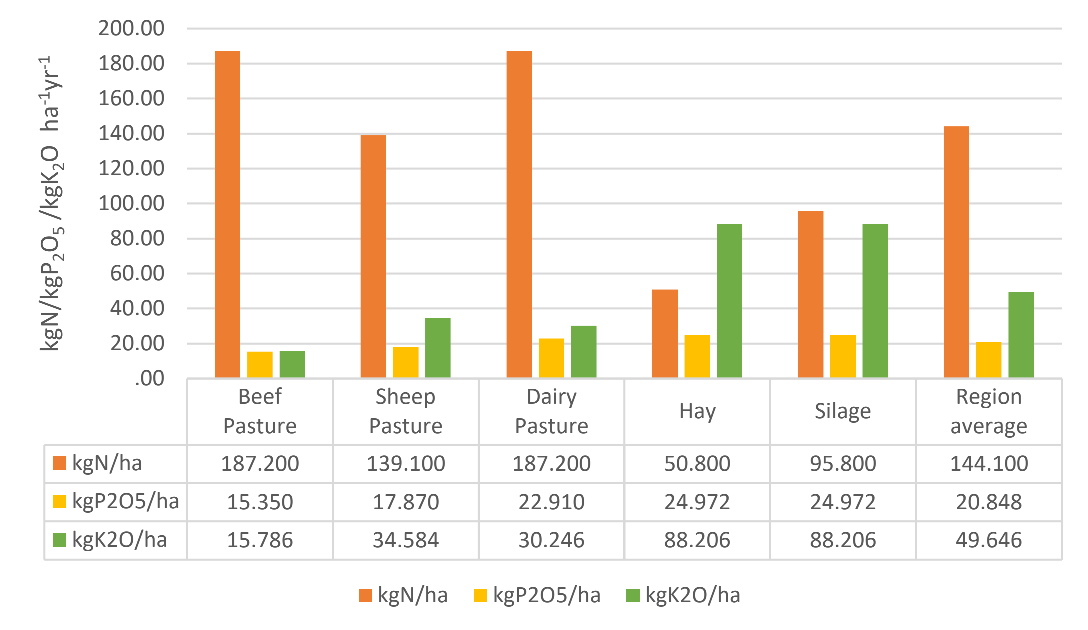


Figure 17: Breakdown of soil samples per region between the four K index classes; derived from data obtained from Teagasc 2018a and Central Statistics Office 2018b



	Beef Pasture	Sheep Pasture	Dairy Pasture	Hay	Silage	Region average
kgN/ha	187.200	139.100	187.200	50.800	95.800	144.100
kgP2O5/ha	15.350	17.870	22.910	24.972	24.972	20.848
kgK2O/ha	15.786	34.584	30.246	88.206	88.206	49.646

Figure 18: Additional nutrient requirement for grasslands in the Southern Region in terms of kg N, kg P_2O_5 and kg K_2O per hectare.

Figure 18 gives details on the nutrient requirement after animal manure has been applied to grassland. It represents the underlying data for the regional average for the Southern region also depicted in Figure 8. The Southern region has been selected as an example since differences between regions are not very large, in particular for hay and silage land. The fertiliser recommendation for pasture depends on the stocking rate: the higher stocking rate, the higher the advised nutrient dose. The Southern region has the highest stocking rate which results in the N advice being significantly lower in the other two regions: Northern and Western region: 100 kg N ha^{-1} and Eastern and Midlands region and 155 kg N ha^{-1} of additional nutrient requirement.

The additional nutrient requirement is very different between pasture and other grassland usages. The following indications hold true in all regions of Ireland.

- Pasture requires a concentrated N or NP fertiliser with high N/P_2O_5 ratio.
- Low levels of K_2O are required for beef pasture therefore a high N/K_2O is required ranging from 9.7-12.4.
- Hay requires: an NPK fertiliser with a N/P_2O_5 ratio around 2 and P_2O_5/K_2O of 1:3.5.
- Silage requires: an NPK fertiliser with a N/P_2O_5 ratio around 4 and P_2O_5/K_2O of around 1:3.5 (as hay).

5.3.4. North of France

For the North of France, the region of Picardie was chosen as an example to showcase. The situation is very similar to other regions of Northern France. The crop nutrient demand of the most important crops in the region, winter wheat, sugar beet, rapeseed and ware potatoes is displayed in Figure 19.

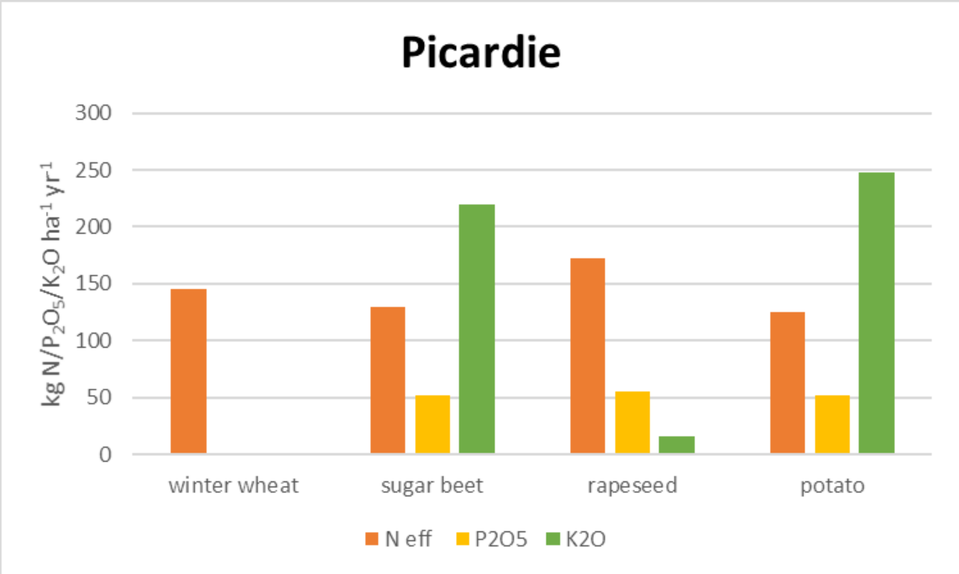


Figure 19: Fertiliser recommendation for Neff (efficient N), P_2O_5 and K_2O in Picardie on a silty soil. Displayed is the total demand which can be fulfilled partly with animal manure or other organic fertilisers.

This demand in Picardie, similar to other regions of France, to a large part is not fulfilled with animal manure or other organic fertilisers currently (see Figure 20). For Picardy (blue-marked region), it appears that most of the arable land area (approx. 2/3) does not receive organic fertiliser (Houot et al., 2014). This can be seen also in Figure 7 from the low N, P, K input with animal manure in Picardie.

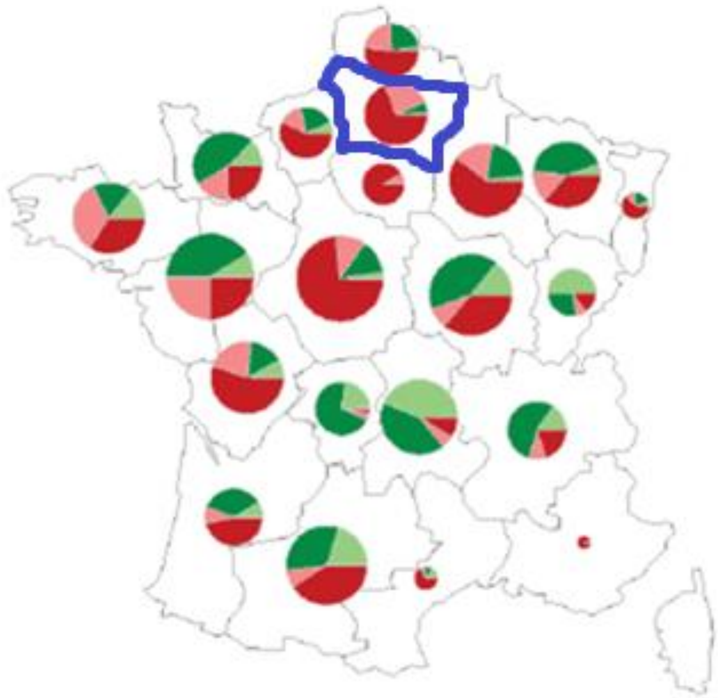


Figure 20 : Use of organic fertilisers on grassland (green) and arable land (red) by region in France (blue-marked is Picardie). The part that does not receive organic fertiliser is dark and the part that does receive organic fertiliser is light-coloured. Data from Agreste (2011), map from Houot et al., 2014.

Figure 21 shows the average use of organic and mineral fertilisers at crop level in France. This information is only available at national level.

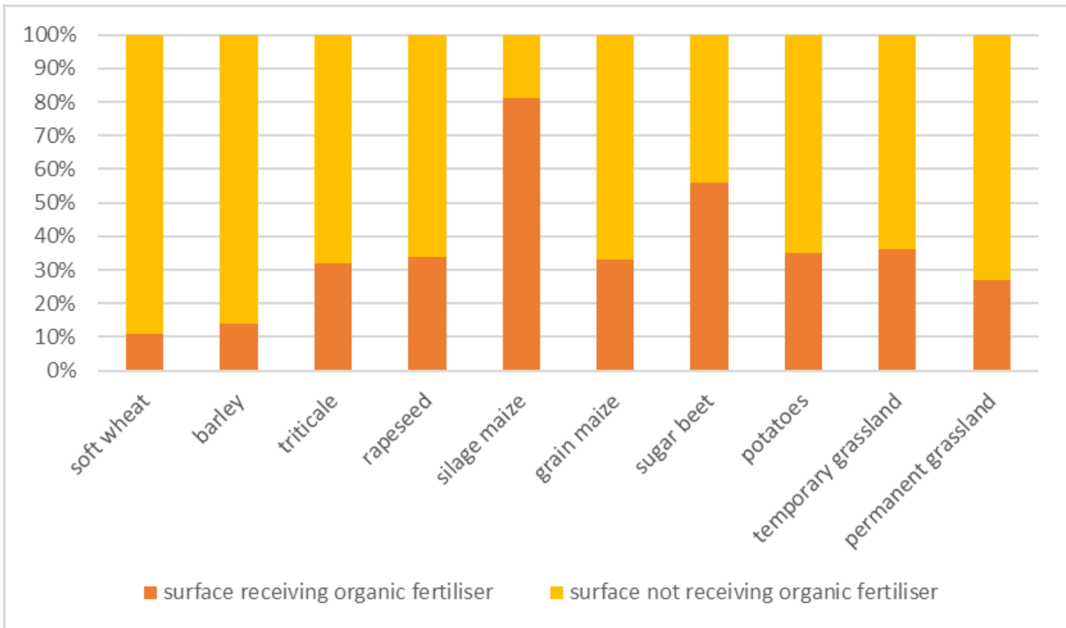


Figure 21: The share of cropping surface not receiving organic fertilisers and share of cropping surface that receives organic fertilisers for main crops in France. Data from Agreste (2011), modified from: Houot et al. (2014)

Figure 21 shows that in particular, silage maize uses a lot of organic fertiliser (81% of cropping surface) and that the lowest level of organic fertiliser used is for cereals (10 to 30%). The use of organic fertilisers is also still relatively low for potatoes, sugar beet and rapeseed (one third to half of the surface receiving organic fertiliser). From a market perspective of RDFs in Picardie and other regions of Northern France, this suggests the following:

For cereals (winter wheat) there is a need for an N-containing product, as the P and K requirement is low at the current P and K state of the soil. The same is true for other regions and countries. In the longer term, this may change if no P and K is applied via fertilisation for several years, while it is being extracted. This would result in negative P and K balances, which cannot be sustained in the long term. At that point there would be a need for an NPK fertiliser. It is also important whether the straw is structurally left behind or is removed from the field. In the case of structural straw removal, the K requirement will be considerably higher than if straw was left behind. In the case that straw is left in the field and soils have a moderate P and K status so that fertilisation compensating the P and K export with the harvest good is recommended, a fertiliser with a P_2O_5/K_2O ratio of around 1:0.8 will be required for cereals. The need for organic matter in cereal-rich cropping plans is also to a large extent determined by the fate of straw. If the straw is left behind, there will generally be a positive organic matter balance, as approximately 2600 kg of effective organic matter per ha will then remain, which in most cases will be sufficient to compensate for the decomposition of organic matter in the soil. Effective organic matter or organic carbon describes the amount of organic matter or carbon which is directly accessible to soil microorganisms for digestion and that remains in the soil one year after application of the organic amendment.

Effective organic carbon is the amount of carbon present in fresh organic matter that can directly be digested by soil micro-organisms estimated as organic carbon present one year after input into the soil.

For potatoes and sugar beet, an organic NPK-containing product with a P_2O_5/K_2O ratio of 1:4 or 1:5 may be well suited for basic fertilisation. The additional N requirement could be met by a separate product (N-containing fertiliser). For potatoes, the amount of organic matter left in the field with crop residues is limited, so that an additional organic matter input with an organic product would fit well. It should be noted that the organic matter balance is normally not considered at the level of the crop, but at the level of the crop plan or rotation (see section 8.4).

For rapeseed, an organic product containing NPK can also be used for basic fertilisation, but the desired P_2O_5/K_2O ratio of 3:1 is very different.

5.3.5. Southwest Germany

As shown in Figure 3, cereals and grassland dominate the crop cover in the regions of Southwest Germany. Silage maize, rapeseed, sugar beet and potato also play a minor role (see Figure 22). For Germany, no crop-specific information on manure management is available from statistics. However, as shown in Figure 8 crop nutrient demand is not completely fulfilled with animal manure and in particular for N there is a demand for additional nutrients. Also, only 20% (Rheinland-Pfalz) to 60% (Nordrhein-Westfalen) of the arable land receives animal slurry (see Figure 23).

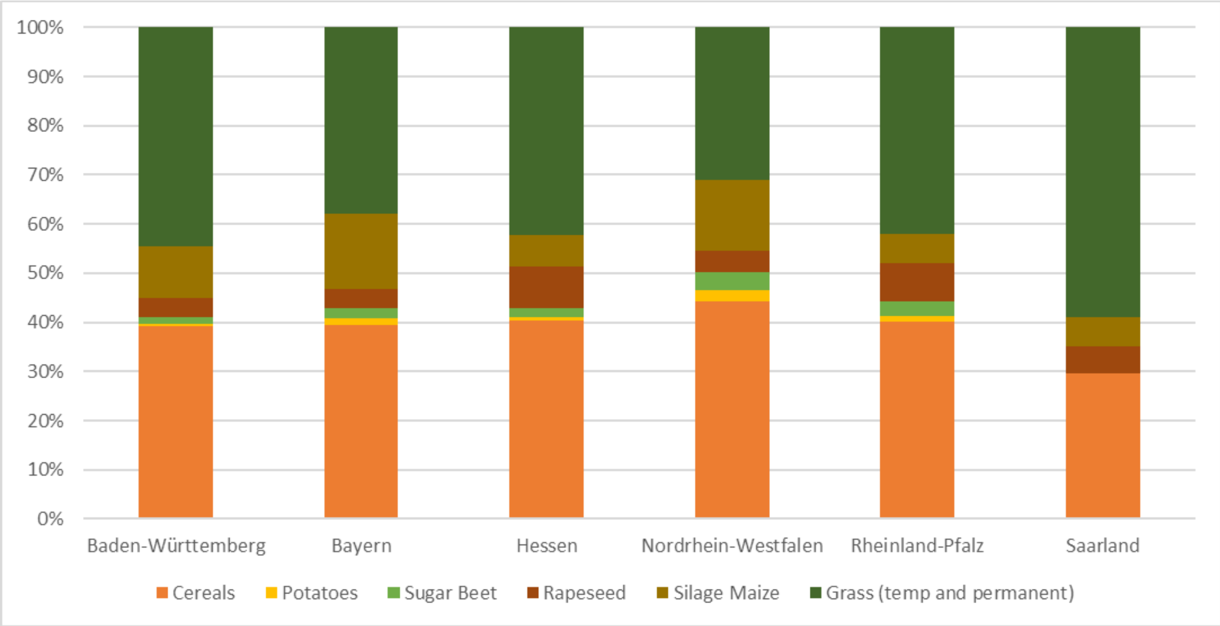


Figure 22: Contribution of different crops and crop groups to the total utilized agricultural area, data from Eurostat, 2018 referring to 2016

Statistics on mineral fertiliser sales at regional level give an indication of the amount and type of fertiliser being demanded and potentially replaced with RDFs in the future. Average doses of mineral fertiliser are, except for Nordrhein-Westfalen, way lower than what was calculated earlier by subtracting the average manure nutrient input from the average crop demand per hectare (see Table 8). This suggests, assuming that it was not highly underestimating the nutrient input to land with manure, that either fertiliser management in reality is way more extensive or that a large fraction of land is not at all fertilized. It could also be that this report slightly overestimated nutrient demand: for N because no deduction for long term manure application was applied; for P and K an overestimation can only be if significantly more straw is left in the field as opposed to the 50% of the cropping surface assumed, or if soil P and K status is higher than the average assumed. However, fertiliser sales statistics should therefore be interpreted as a minimal conservative estimate.

Table 8: Overview on the average dose of mineral fertiliser N, P_2O_5 and K_2O per ha and year if distributed equally over the entire utilized agricultural area (UAA); mineral fertiliser sales refer to the season 2017/2018; source: Destatis (2018)

	Average dose of mineral fertiliser [kg ha^{-1}]			**Balance (crop demand – animal manure) calculated (see Figure 8)**		
Bundesland	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Baden-Württemberg	71	16	13	136	30	66
Bayern	69	13	16	116	28	45
Hessen	121	6	44	134	37	72
Nordrhein-Westfalen	102	6	31	94	7	37
Rheinland-Pfalz	73	9	20	149	45	80
Saarland	42	4	4	172	51	120

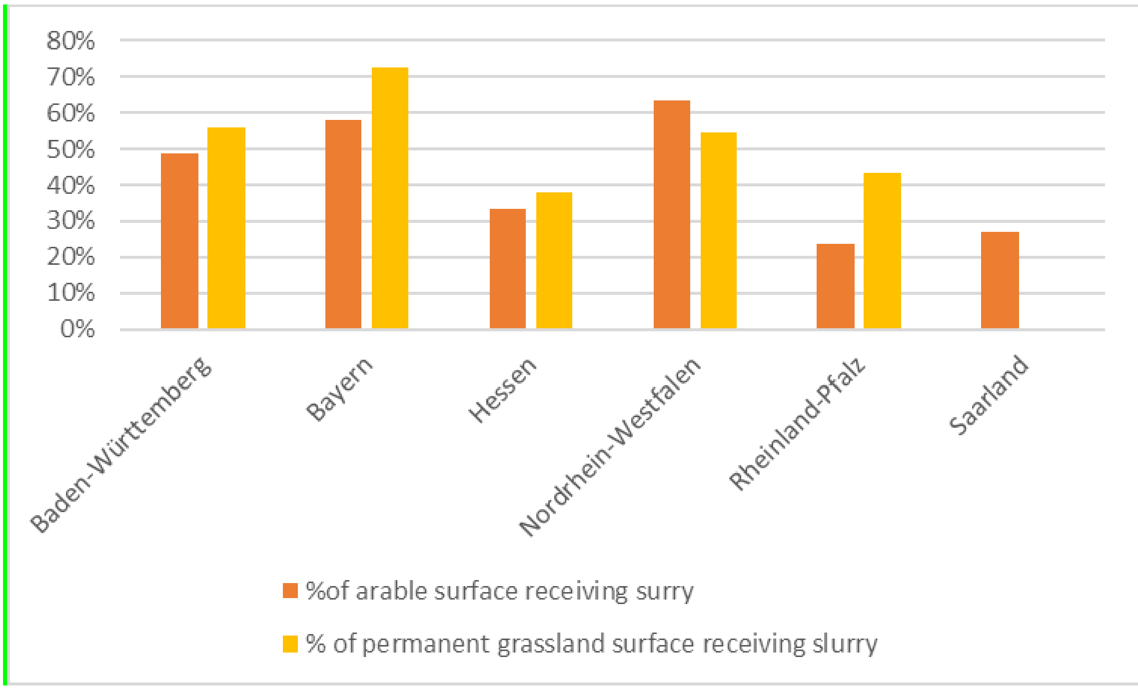


Figure 23: Proportion of the arable and the permanent grassland surface which is fertilised with liquid animal manure (slurry); data refers to 2011; source: Destatis, 2015

Mineral fertiliser sales statistics are available by type of fertiliser (see Figure 24 and Figure 25). With regard to mineral N fertilisers, it can be observed that most of the applied N is applied as a fertiliser containing only N, no P_2O_5 or K_2O (see Figure 24). Among the Bundeslaender being part of the Interreg NWE territory, this is even more pronounced in Hessen and Nordrhein-Westfalen where more than 90% of the applied mineral fertiliser N is in the form of an “N-only” fertiliser product. P_2O_5 in contrast to N and K_2O is almost never applied alone but mostly in combination with N or in the form of an NPK fertiliser (see Figure 25). In Rheinland-Pfalz and Saarland a lot more P is applied in the form of an NPK-fertiliser compared to the other Bundeslaender. This is in line with our assessment revealing a relatively higher K demand in these two regions compared to the others (see Figure 8).

Desired nutrient composition in RDFs for Southwest German regions are difficult to generalize since information on crop specific manure management is lacking and manure use is at a moderate level at the regional scale so that some farmers might use a substantial amount while others do not apply any animal manure. However, assuming the case of cereals where no slurry is applied and straw not harvested on a soil with average P and K content, following fertiliser recommendations, an NPK fertiliser with a P_2O_5:K_2O ratio of 1:0.8 would be required (same for most cereals). However, in winter wheat it is common practice to apply a 2nd and 3rd dose of N during the growing season. In that case, assuming an application of 90 kg N ha^{-1} with the first base fertilisation, a N:P_2O_5 ratio of 1:0.7 and a N:K_2O ratio of 1:0.5 will most probably be demanded.

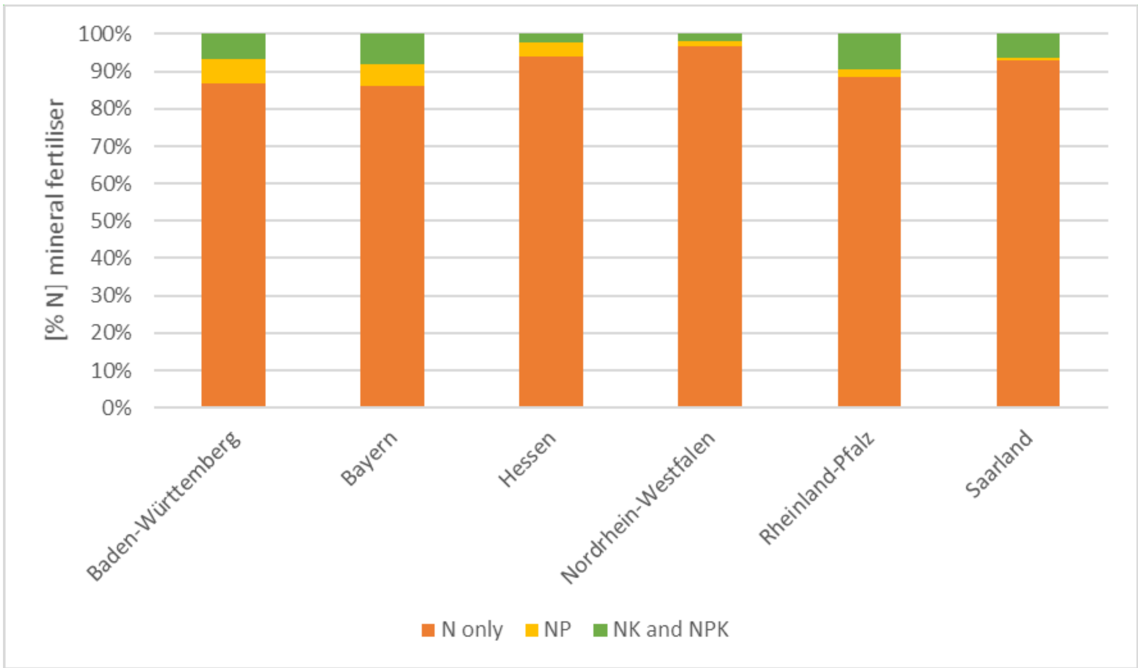


Figure 24: Breakdown of total amount of N applied with mineral fertiliser between pure N, NP and NK and NPK containing fertilisers for the six Bundeslaender in the Interreg NWE territory, situation in 2017/2018; source: Destatis (2018)

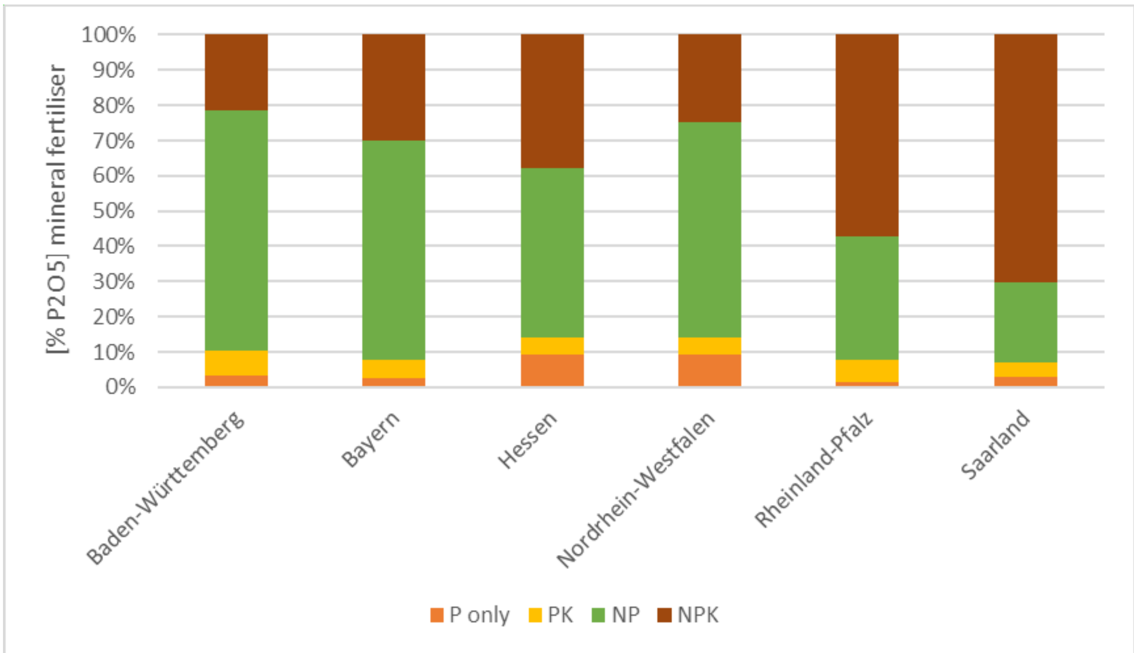


Figure 25: Breakdown of total amount of P_2O_5 applied with mineral fertiliser between pure P, PK, NP and NPK containing fertilisers for the six Bundeslaender in the Interreg NWE territory, situation in 2017/2018; source: Destatis, 2018.

6. Organic matter demand

Soil organic matter (SOM) is crucial for good soil quality. It is important for the natural supply of nutrients, for the stimulation of soil life, the soil structure and the retention of soil moisture. There are several options to maintain or to increase SOM content: grassland naturally maintains a good SOM content, cereals have a positive OM balance if straw is left in the field and incorporated into the soil, cover crops and green manure crops can be grown and their biomass incorporated in the soil and organic fertilisers such as animal manure or other organic matter containing RDFs such as compost or dry fraction of separated animal manure can be applied. The concept of an organic matter balance evaluates whether inputs of organic matter to soil (crop residues, animal manure and other organic amendments, cover crop and green manure biomass) compensate the natural decay of organic matter over time. This is a simplified approach since in reality, organic matter decay is influenced by many different factors: climate and soil type for example. In some West European countries there is legislation established to oblige farmers to keep a positive organic matter balance:

In Germany there are obligations to maintain the organic matter content. This is regulated by the Direktzahlungen-Verplichtungen-Verordnung (Landwirtschaftskammer Nordrhein-Westfalen, 2012). Under this regulation, a farmer must show that the organic matter content is maintained by means of an annual organic matter balance or soil analyses. The precondition is that the organic matter balance at farm level may vary between -75 and 125 kg C ha^{-1} $year^{-1}$, whereby the lower limit of -75 kg C ha^{-1} $year^{-1}$ may not be undercut. However, the recommended upper limit may be exceeded.

In Flanders (Belgium) farmers are obliged by law to have soil samples analysed for organic matter content every five years. An exception applies to grassland soils or others with permanent cover. The minimum limits where the farmers must take action (depending on type of soil), are displayed in Table 9. If soil samples show that the SOM content is below these limits, the farmer needs to apply organic matter amendments. The amount of organic carbon that needs to be applied in that case is not defined, advise needs to be followed.

Table 9: Limit of organic carbon content depending on soil texture that has been formulated in Flanders (Belgium) (Inagro, 2011)

Type of soil	Minimum organic carbon content [%]
Sand	<=1
Sandy loam	<=0.9
Loam	<=0.9
Clay	<=1.2

Regarding the aspect of which type of organic RDF might fit into different demand contexts (e.g. crop rotation, soil type, etc.), a proposal for classification of organic RDFs has been made by the EIP focus group on nutrient recycling at the European level (Veeken et al., 2018). The classification method suggests differing between organic fertilisers and organic soil improvers, based on the ratio between (effective) organic matter and the nutrients N and P. According to their definition, organic fertilisers are organic matter containing RDFs that contain readily available nutrients and have a rather short term, plant nourishing effect. In contrast, soil improvers are organic matter containing RDFs that have an indirect effect on crops by improving the physical and biological properties of the soil. Organic fertilisers are characterized by an Effective Organic Matter (EOM)/mineral N ratio of lower than 150 and an EOM/P_2O_5 ratio of lower than 35. Organic soil improvers are characterized by an EOM/mineral N ratio higher than 150 and an EOM/P_2O_5 ratio higher than 35 (Veeken et al., 2018).

The following paragraphs will reflect for the various regions in Northwest Europe whether organic matter amended with RDFs is likely to be required, and if yes, whether an organic fertiliser or a soil improver according to the above presented definition is more likely to be demanded on the market.

6.1. The Netherlands

Schröder & van Dijk (2017) calculated organic matter balances for various representative crop rotations in the most important arable regions of the Netherlands. They concluded that in most crop rotations, the organic matter input with crop residues was not high enough to compensate for the decomposition of soil organic matter (1800-2100 kg OM per ha per year). In situations where pig slurry was used as a base fertiliser, some additional organic matter was supplied, but even in that case, the total organic matter input was not sufficient to fully compensate for the decomposition. In situations where cattle slurry and/or compost (or a similar RDF) is used, the total organic matter input will be higher than the decomposition of SOM, which will lead to the maintenance of organic matter contents.

This is illustrated for a simplified crop rotation with 33% ware potatoes, 33% sugar beet and 33% winter wheat, where the straw is removed from the field (see Figure 26). This report distinguished three scenarios: one scenario without animal manure, one scenario with pig slurry and one scenario with cattle slurry. The assumption is that the application for P is 50 kg P_2O_5 per ha (which is determined by the P status of the soil) and that the P requirement at the level of the farm is fully supplied with animal manure (for the manure scenarios).

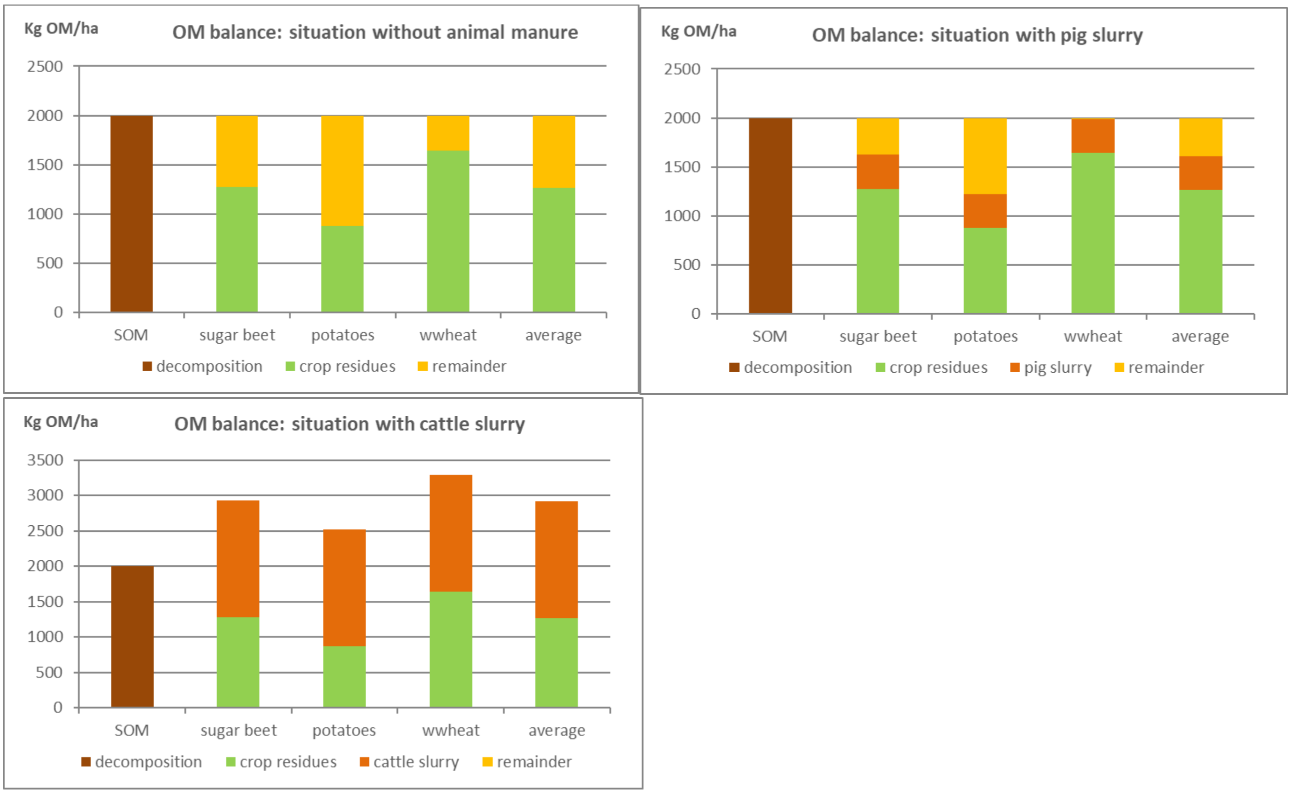


Figure 26 : Comparison of the decomposition of soil organic matter and the organic matter input with three scenarios: one scenario without animal manure (above, left), one scenario with pig slurry (above, right) and one scenario with cattle slurry (below, left). See text for details.

As presented earlier in this report, the majority of P_2O_5 farmers may apply within the legislative boundaries, is applied with animal manure. This is financially attractive, because arable farmers without animals, receive money for the acceptance of animal manure from intensive livestock farms that have to export manure from their farm. Organic matter always contains P. Therefore, farmers in the Netherlands where animal manure availability is high, have very limited possibilities to apply organic matter containing RDFs besides animal manure. The P limit does not allow them to, assumed that they apply all allowable P with manure.

Recently, the government has introduced new legislation, that supports the use of organic matter containing soil improvers with low nutrient contents. For soils with a high P content, the P limit is increased by 5 kg P_2O_5 ha^{-1}, if at minimum 20 kg P_2O_5 ha^{-1} is applied with soil improvers. To apply 20 kg P_2O_5 ha^{-1} about 5 t ha^{-1} of fresh compost (average of all soil improvers assessed by (Veeken et al., 2018) will need to be applied. This equals an organic matter amendment of around 1060 kg EOM ha^{-1} yr^{-1}(average of all soil improvers assessed by (Veeken et al., 2018). Seeing that as a rough universal target, an input to the soil of 2000 kg EOM ha^{-1} yr^{-1} is recommended, this represents a significant contribution. However, since the P_2O_5 limit is still limited in most cases to 55 kg P_2O_5 ha^{-1} (50 kg + 5 extra allowance thanks to compost application) farmers can then only apply animal manure at a dose of 35 kg P_2O_5 ha^{-1}. Seeing the good availability and low price for animal manure in the Netherlands it is doubtful whether farmers will apply soil improvers at the dose of 20 kg P_2O_5 ha^{-1}. This holds true in particular for regions with high livestock density which are in the Netherlands mostly sandy regions. Arable farms in clay regions with somewhat lower livestock density might have more interest in compost and other soil improvers. Also, specialized vegetable producers often do not use animal manure for sanitary reasons. These farmers might be interested in soil improver RDFs. Especially soil improvers with a high EOM/P_2O_5 ratio will be interesting from an organic matter amendment perspective. For a more detailed assessment a humus balance over the entire crop rotation would need to be calculated to gain insight on the organic matter input to the soil by crop residues and to determine the additional need for organic matter amendment. However, this is outside of the scope of this report. In reality, on a lot of farms the P_2O_5 limit will be fulfilled to about 100% with animal slurry. These farms will consequently not have a demand for RDF soil improvers such as compost.

6.2. Belgium

Figure 27 indicates that in all regions, with an exception of the region "high Ardenns" (region XIII in Figure 27), about half of the soils have a too low organic matter content. A demand for an organic matter amendment type of RDF can therefore be expected in Belgium. However, the situation, at least in the Flemish part, is comparable to the Netherlands: limits on N and P application do not allow for more application of readily available animal manure. Therefore, a demand for soil improver types of organic RDF can be expected.

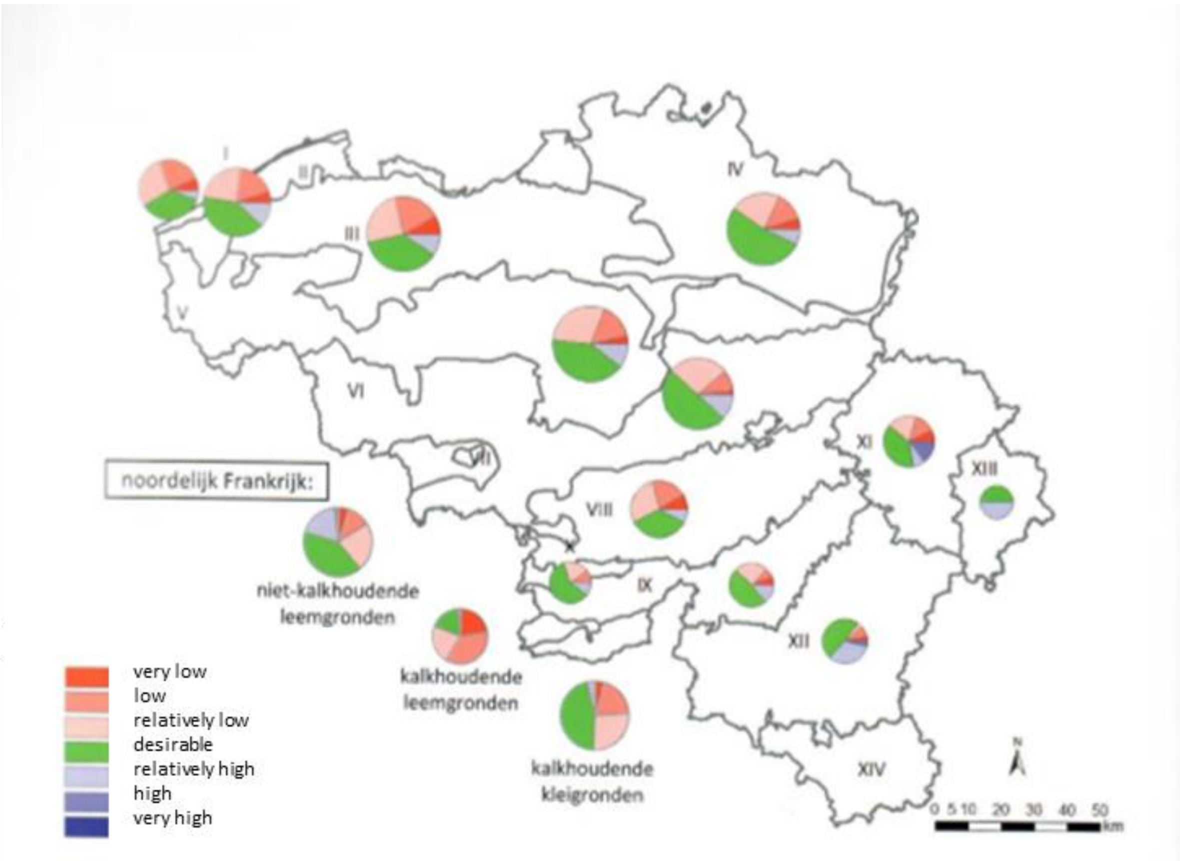


Figure 27: Percentage of distribution of arable land in 7 classes in Belgium for organic carbon; adapted from: Vandendriessche et al., 2016

6.3. Ireland

As shown earlier, Ireland is dominated by grassland. Grassland in general maintains good soil organic carbon content thanks to its large and fine root system and its high belowground biomass. Additionally, most grassland in Ireland is grazed by animals which leave behind their remnants and feed it back to the soil carbon pool immediately as well. Therefore, no demand for an organic matter containing RDF can be expected in Ireland. Also, with a look to soil organic carbon content in the soil, no soil with <2% soil organic carbon can be identified (see Figure 28).

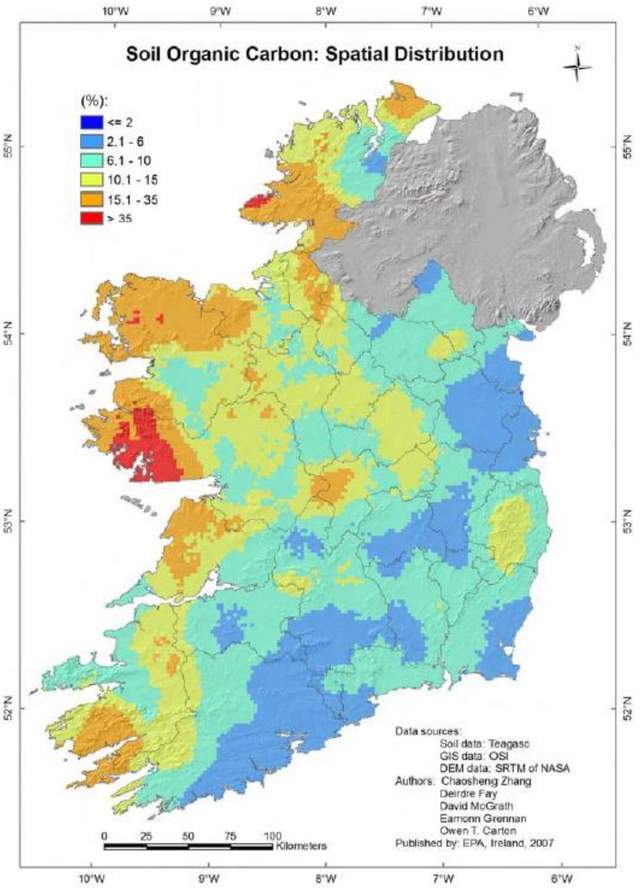


Figure 28: Soil organic carbon content in Ireland, from: Soil Geochemical Atlas of Ireland, 2007

6.4. North of France

In France there are no binding rules for farmers to maintain a positive humus balance but intensive monitoring of soil carbon content is taking place (Arrouyas et al., 2012). Based on carbon contents it is difficult to judge whether organic matter input to the soil is too low since this depends on a lot of factors, such as soil type and climate. However, from Figure 29 it can be seen that carbon contents in soil are lowest in the Northern-Central part of France and that they were also in decline in the period

1990 to 2004. More recent monitoring data confirmed this picture that carbon contents are lowest in the Northern Central part of France (see Figure 30). As shown earlier in crop maps (Figure 3) and manure input maps (Figure 7), these regions are root crop and cereal growing regions with a relatively low input of animal manure. A demand for a multi-nutrient and organic matter containing RDF product can therefore be expected. Since there is no strict P limit and P fertilisation is required, this RDF does not necessarily need to be a soil improver but can also be an organic fertiliser.

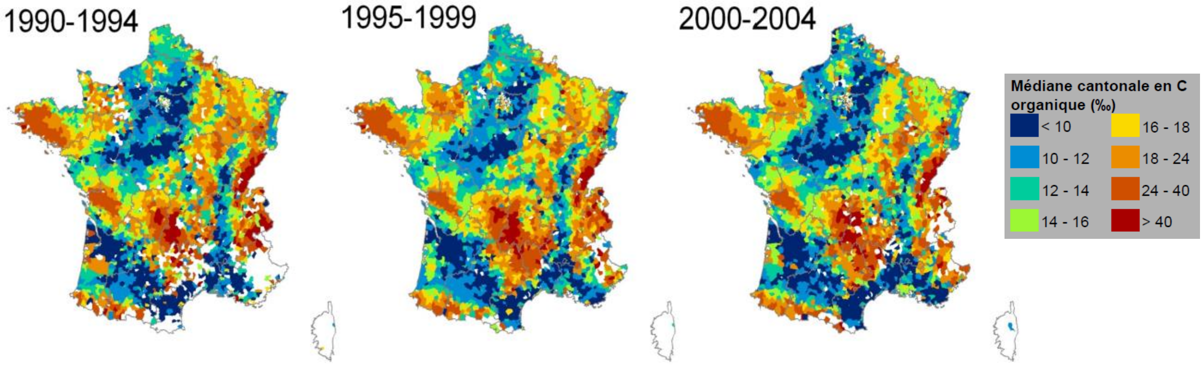


Figure 29: Development of organic matter contents in soils in France; from: Arrouyas et al., 2012; BDAT, 2014

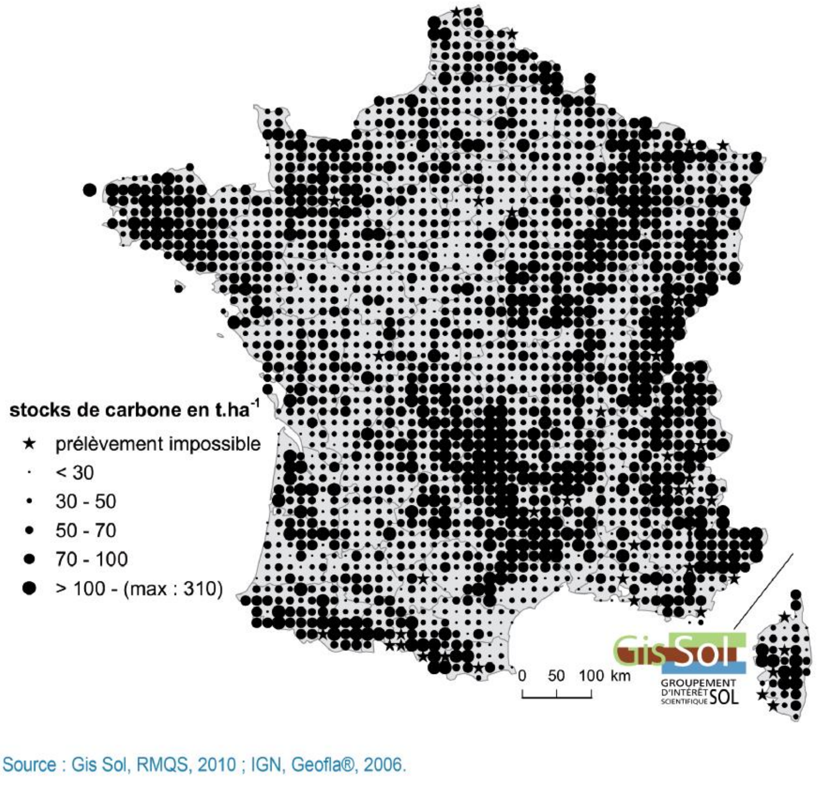


Figure 30: Sampling points for carbon stocks in the soil in France, indicated in t ha-1; from BDAT, 2014

6.5. Southwest Germany

The report focuses on regions in the Southwest of Germany. The organic matter balance is lower than in regions with a higher livestock density such as in Niedersachsen or Schleswig-Holstein (see Figure 32). Figure 31 shows the total balance at the county level in tonnes of organic carbon which is the outcome of a study made by Zeller et al., 2012. The authors applied three different balancing methods where the most left one (Figure 31) does not show negative balances in any of the counties. This is the case with the other two methods, also in some counties in Southwest Germany. The same study pointed out that in the Southwestern Bundeslaender 40 to 60% of humus reproduction is based on straw that is left in the field. Concerning the perspective of RDFs in the future it will therefore depend on the use of straw: if straw is used for other material or energy producing purposes, an import of RDF as for example solid fraction of manure from livestock intensive regions might become a viable scenario.

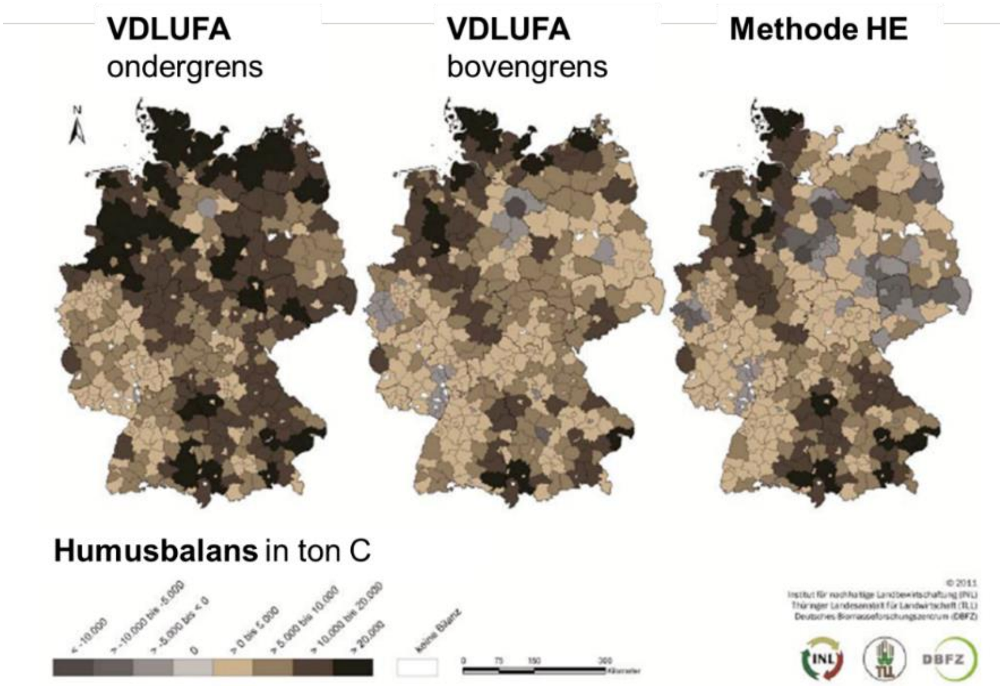


Figure 31 : Organic matter balance [t C], total per county assessed by three different methods (Zeller et al., 2012).

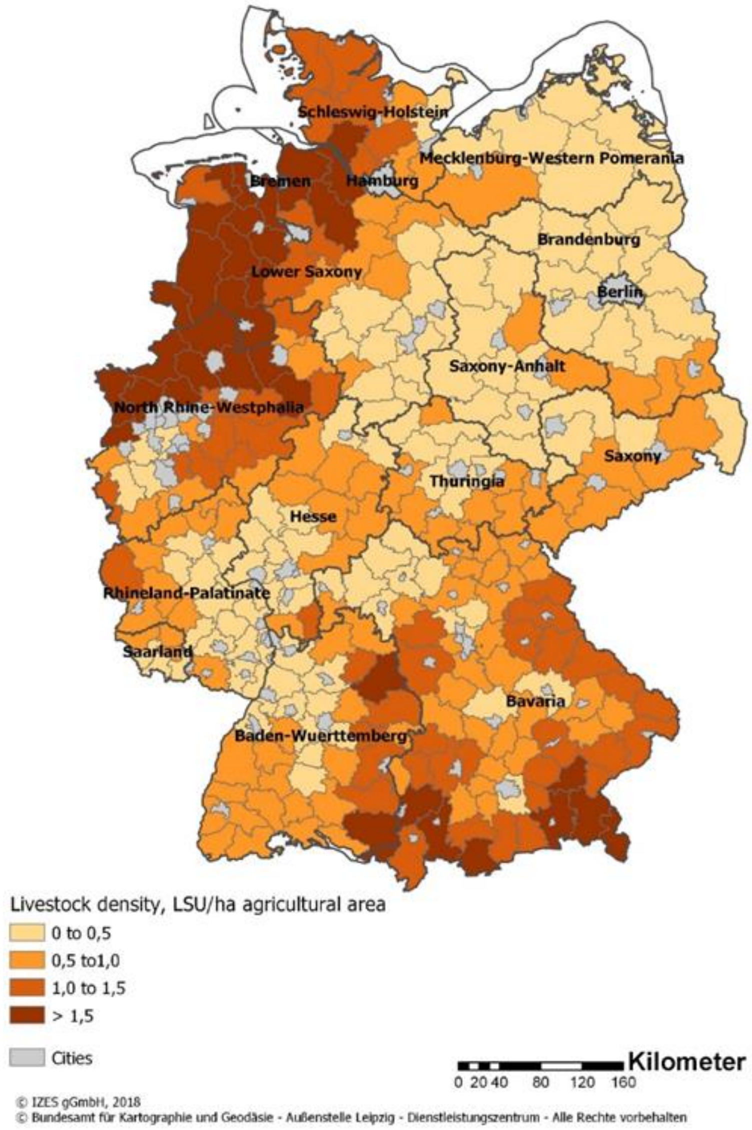


Figure 32: Livestock density in Germany at NUTS1 region level; from: IZES, 2018

A study from the German agricultural ministry confirms that at national level the humus balance is positive (see Table 10). Calculations for organic fertilisers do not include import of animal manure from other countries. Compost and sewage sludge contribute only minor carbon quantities to the German soil carbon balance.

Table 10: Nutrient and organic matter demand of the German agriculture in comparison to nutrient and organic matter supply (BMEL, 2015)

	humus equivalents (VD LUFA 2014 method)
Demand	5,860
Supply through:	
Organic fertilisers	3,086
Digestate (with slurry)	748
Compost	197
Sewage sludge	44
Animal by-products	N/A
Plant by-products	N/A
Crop residues	4,189
Humus enriching crops	444
Catch crops	112
Supply sum	8.820
Supply-demand	2.960

6.6. Summary organic matter demand

In summary, a demand for additional organic matter input can in general not be expected in grassland regions and in cereal regions where straw is not harvested.

However, potential demand for organic matter containing RDFs exists from an agronomic perspective:

- For RDFs of the type "organic fertiliser" (and also "soil improver"): in regions where P+K besides N are demanded, thus where there is room in the P and K balance, in the North of France namely.
- For RDFs of the type "soil improver": in the Netherlands and in Flanders in Belgium where P limits are strict and fulfilled with animal manure but additional carbon is required in intensive root crop or vegetable rotations
- In Germany, supposedly due to rules on the organic matter balance, a lot of straw is left in the field and the balance can at least be assumed to be positive. Demand for organic RDFs in the future will depend on resource pressure on using straw for other purposes (e.g. energy production).

7. Conclusions and recommendations

With the assessment of regional nutrient balances in fertilisation this report shows that demand for nutrients from recycling exists everywhere, even in regions with high livestock density where animal manure is already largely used as a source for nutrients. However, the desired composition in terms of the three main plant nutrients, N, P and K as well as organic carbon differs largely between regions. Main factors leading to these differences are: crops grown, soil types and nutrient status of soil, regional animal manure availability and fertiliser recommendations and legislation.

Overall, it can be stated that **a pure concentrated RDF nitrogen fertiliser will find its use everywhere**. This is because the ratio of N:P:K in animal manure does not exactly fit with crop needs: most crop species require more nitrogen than what is contained within any type of animal manure in relation to P and K. Also, it is common practice to apply a basis fertilisation in terms of N, P and K but for most crops to add one more or several doses of nitrogen during the growing season adjusted to crop needs.

The potential of RDFs lies in replacing volumes of mineral fertiliser which are used nowadays (rock phosphate and mined potassium, Haber-Bosch derived nitrogen fertiliser). Regionally available animal manure is and will be in the future the most obvious choice of fertiliser and from an agronomic point of view, if managed well, it is a good and locally available source of nutrients.

Despite the fact that fertiliser management, crop rotation, soil and climatic conditions can vary a lot between farmers of one region and even between different plots of one farm, this report identified several general trends for desired composition of RDFs in regions of NWE:

- An N (without P and K) RDF is demanded in all regions as a fertiliser used as a basis fertilisation with animal manure or to adjust crop N needs during the growing season. In particular, in regions where a P fertilisation limit exist and where this is almost to completely fulfilled with manure-P (the Netherlands and Flanders-BE). This type of fertiliser is demanded by cereal crops and in grassland. The more concentrated the N, the more interesting the fertiliser becomes for farmers as lower application volumes mean lower costs for transport, storage and application.
- In some regions (the Netherlands) root crops require an NK fertiliser that can be used besides animal manure. It should have an N:K_2O ratio of about 1: 0.8.
- In Ireland grazing is relatively extensive compared to other countries in continental Western Europe. Also, soil in Ireland are relatively poor in P. In consequence, pasture land in Ireland requires a NP fertiliser (no K) with a high N:P_2O_5 ratio. Hay and silage land in Ireland has different requirements. Here, an NPK fertiliser with a P_2O_5:K_2O ratio of about 1:3.5 is required.
- In the North of France animal manure availability is low. Therefore, root crops and rapeseed require a carbon containing NPK fertiliser. Expected is that a P_2O_5:K_2O ratio of 1:4-5 will be required by root crops and of 3:1 by rapeseed. However, soils are currently relatively high in P. This makes that cereals require only N. If the soil P content decreases in the future, it can be expected that cereals will require an NPK fertiliser with a P_2O_5:K_2O ratio of 1:0.8 (assuming straw not harvested).

- For Germany it is difficult to give a recommendation because animal manure is regionally moderately available. This results in a very mixed picture of some farms having large amounts of animal manure available, others not at all. Information on most common crop specific manure doses is not available from statistics. However, for cereal crops not receiving animal manure and under the assumption that straw is not harvested, cultivated on soil with an average P and K content, an NPK fertiliser with a P_2O_5:K_2O ratio of 1:0.8 is likely to be demanded.

The indicated composition which is likely to be required by farmers towards RDFs should be respected by producers, traders and vendors. In particular, respecting that RDFs in certain regions may not contain any P is crucial to succeed in replacing currently used mineral fertiliser volumes with RDFs. Only if RDFs meet the requirements of farmers, will the use of RDFs increase and the dependence on non-renewable resources in fertilisation will decrease.

This report focussed on the desired properties of RDFs in terms of nutrient composition. However, a lot of other aspects such as ease of use, nutrient value, safety and knowledge and awareness of farmers towards this topic determine whether they will be purchased and applied to fields by farmers in the future or not. These other aspects of end-user requirements have been researched with an online survey in the framework of ReNu2Farm and results will be published in separate communications. Despite having advantages within the scope of Circular Economy, recycled nutrients derived from waste streams also represent a potential safety and environmental risk. Therefore, it is important to properly assess these aspects. This is also part of ReNu2Farm where the impact on soil organism and ecotoxicological tests will be carried out. Results will be published in other communications of ReNu2Farm.

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Annex

Table A1: Overview on nitrogen efficiency coefficients [%] which have been used where statistics indicated total nitrogen applied with animal slurry or other organic fertilisers to transfer to efficient/ available nitrogen

	Animal Manure (slurry)[a]	**Other organic fertilisers[a]**
FR	60%	10%
NL	60%	n. r.
BE	45%	n.r.
DE	60%	n.r.
IRE	40% (cattle), 50% (pig+sheep)	n.r.

[a] For BE from Mestrapport, 2018; for FR, NL and DE Dutch benchmark values were applied from RVO, 2018c and for Ireland from European Union, 2014

Table A2: Overview on nutrient contents in animal slurry as applied in the assessment of nutrient input with animal manure; all values in kg t^{-1} fresh product

Country	**Type of manure**	**N**	**Nmin**	**P_2O_5**	**K_2O**	**Source**
FR		Nutrient input directly from UNIFA 2011 & 2014				
NL		Nutrient input directly available from Statline				
DE+BE	cattle slurry	4	1.9	1.5	5.4	Handboek Bodem en Bemesting, 2018
	pig slurry	7	3.7	3.9	4.7	Handboek Bodem en Bemesting, 2018
	digestate	3.9	0.4	1.1	3.5	Handboek Bodem en Bemesting, 2018
IRE	cattle slurry	5.0		1.8	4.2	Teagasc, 2016
	pig slurry	4.2		1.8	2.6	Teagasc, 2016
	sheep slurry	10.2		3.4	6.5	Teagasc, 2016

Table A3: Deductions in the German N balance of DueV, 2017, range in DueV and assumption applied in this study

Type of deduction	Range according to DueV [kg N ha^{-1}]	Assumption for this study
Catch Crop effect	0-40	20 (spring crops only)
Pre-Crop effect	0-20	10 (winter crops only)
Spring Nmin	own soil sample or yearly published values by regional extension service	30
N mineralization during growing season	20 (only if SOM >4%)	0
Grassland mineralization correction (SOC <8%)		10
Longterm organic amendment application	10% of total N applied in previous year with amendment	0

Table A4: Deductions in the French N balance as applied in this study; derived from: Chambre d'Agriculture Hauts de France, 2015

Type of deduction	Value [kg N ha^{-1}]
N uptake until balance opening in spring	0 (spring crops), 15 (winter cereals), 60 (rapeseed)
Spring Nmin	35 to 60 (depending on soil type)
N mineralization during growing season	35 to 85 (depending on soil type)
Catch crop effect	0 or 10 (spring crops)
Pre-crop effect	minus 20 to 20