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COMPARISON OF NITROGEN FERTILISER RECOMMENDATIONS IN DIFFERENT WEST EUROPEAN COUNTRIES

by

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SUMMARY.

Nitrogen (N) budget at farm level is influenced by the fertilisation rates applied by farmers. At larger scales, it is closely linked to multiple environmental concerns relating to air, water and biodiversity. In this study, we analysed the way the N fertilisation recommendations are calculated in ten West European countries, in order to detect innovative algorithms, original calculations and references that could be shared among countries having equivalent crop practices.

Our first result relates to published national official documents governing N fertilisation within each country. A detailed analysis of these documents reveals three categories of calculation methods: (i) 'N mass balance' (France, Italy, Spain), (ii) 'Corrected standard' (Germany, the Netherlands, Switzerland, Luxembourg), and (iii) 'Pre-parameterised calculation', relying on a soil N supply typology (United Kingdom, Ireland) or on a model parameterisation (Belgium).

Sixteen parameters were identified throughout the 10 national methods. The more complex algorithms use 10 parameters (Italy, France), while the simplest only rely on 3 (Luxembourg). The most common parameters considered include the direct effect of N concentration in manure, the total N uptake by crop and the N released by crop residues. At the opposite end, very few countries explicitly take N leaching, the residual mineral N in soil at harvest and atmospheric losses into consideration.

In addition to the previous theoretical approach, we have tested the extent to which the different methods converge or not when practically used. We therefore applied the ten national methods to two contrasting crop scenarios chosen in order to erase as much as possible the cultural and pedoclimatic specificities between the ten countries. The two case studies display large discrepancies in their recommendations, ranging from no fertilisation to 135 kg N/ha, and from 111 to 210 kg N/ha for a wheat crop fertilisation grown in a livestock and polyculture-farm scenario, respectively. The differences in the recommended rate are not accounted for by the complexity of the equations used. For the same conclusions, we identified differences in the consideration of manure's N availability, N uptake by crop (even for the same yield) and in the leaching of N calculation. The degree of regulatory status of the calculation methods was a more interesting parameter.

Two countries exhibit original tools that we consider worth highlighting: parallel to a simplified field N mass balance, Germany performs a second compulsory mass-balance at the farm scale considered to be a safeguard against risks of excess N budget. Another effective tool, implemented by Belgium, consists of controlling the residual soil mineral N at harvest in comparison to regional references.

CONTENTS

Keywords: nitrogen, fertilisation, recommendations, mass balance, innovative approaches, regulation, harmonisation.

1. INTRODUCTION.

1.1. Environmental concerns about nitrogen use in agriculture.

The spectacular increase in crop and animal production since the 1950s has been facilitated by a tremendous increase in agricultural nitrogen (N) fluxes, due to the generation of mineral N fertilisers derived from the Haber-Bosch process (Erisman *et al.,* 2008; Galloway *et al.,* 2013). However, the use of N by farmers is far from being 100% efficient. A recent European survey (EU-28, Eurostat, 2020) shows that only 61% of the N applied (organic + mineral) is used by plants, with great variations between countries. For example, the efficiency gap between Ireland and Luxembourg reaches 30%, with efficient N use estimated at 80% and 50%, respectively. As a result, the gross nitrogen balance for agricultural land exhibits an average excess of 50 kg N per ha per year, but with wide variation between countries and between farming systems (Eurostat, 2020).

Concurrently, N fluxes to waterbodies have doubled within the last century (Sutton and Billen, 2011), and emissions to the atmosphere have increased by a factor of four. Therefore, most parts of our environment have been facing excess N concentration, for decades (Steffen *et al.,* 2015). As a result, the nitrate concentrations in ground- and surface-waters have exceeded the standard for drinking water in several regions, and have contributed to the eutrophication of coastal areas. In addition, emissions of ammonia (NH_3) and nitrogen oxides (NOx and N_2O) to air are contributing to deteriorating air quality and biodiversity in natural ecosystems, and enhancing global warming (Sutton *et al.,* 2011).

At the scale of the European Union (EU-28), the annual nitrate mean concentrations for ground waters and rivers is around 20 mg $NO_3^-.L^{-1}$ and 2 mg $NO_3^-.L^{-1}$, respectively (Figure 1). The European statistics on water quality point out that those values have evolved without marked trends for the last 30 years (EEA, 2022). According to de Vries (2019), the risk of eutrophication of waterbodies is the most critical threat and necessitates a reduction in the N-leakages from fields by a factor of two.

Assessing the consequences of atmospheric N emissions to ecosystems and humans seems more complicated than assessing the consequences of high nitrate concentrations in water bodies. However, their effects should not be underestimated. For example, at the EU scale, the annual mortality linked to the fine particle matter in air ($PM_{2.5}$, caused in part by NH_3 and NOx emissions) is estimated at around 300,000. The contribution of nitrous oxide (N_2O), emitted by soils from fertiliser and manure use contributes 5% to the total greenhouse gas emissions in Europe (EEA, 2011).

Awareness of these concerns has led the European Union to develop environmental Directives, firstly targeted on water bodies (Nitrate Directive 1991/676/EEC, and the 2001 Water Framework Directive), and the atmosphere (Directive 2008/50/EC on ambient air quality and cleaner air for Europe). More recently, the 'Farm-to-Fork' strategy, standing for the

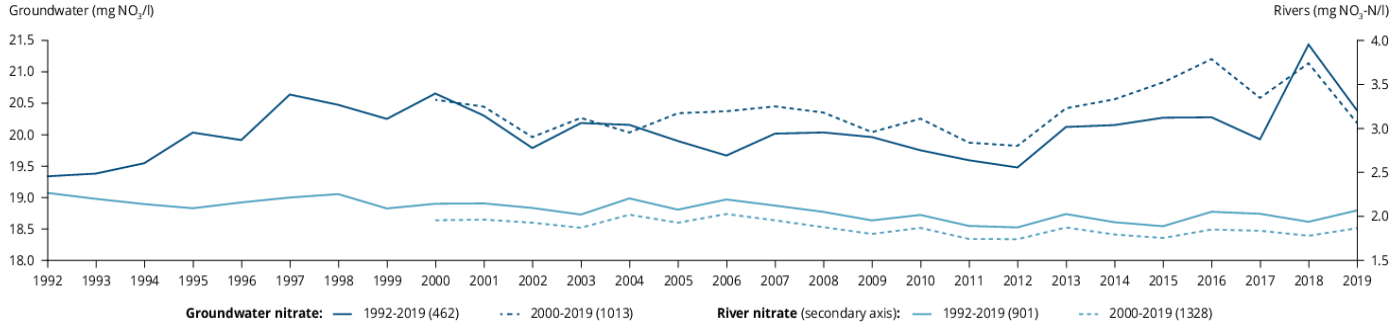


Figure 1: *Trends of nitrate concentration in European groundwater and rivers. The geographical coverage is the 38 EEA member countries plus the United Kingdom, but only complete time series are included in the analysis. Two time series are shown – a longer time series representing fewer water bodies and a shorter time series representing more water bodies (European Environment Agency, 2022).*

agricultural implementation of the 'Green Deal', is particularly focusing on nitrogen losses with the aim of a 50% reduction within the next ten years (European Commission, 2020). In this context, the N fertilisation recommendations for farmers (including organic products) stand for a potentially very powerful lever of action, as any excess of fertilisation for one given crop is potentially lost, therefore supplying water bodies, atmosphere and natural ecosystems with 'non-intended' fluxes.

1.2. Objective of this study: compare how European countries calculate the recommended fertilisation doses of nitrogen.

This study aims at gathering information on how the recommended N fertilisation doses for farmers are calculated among some West European countries. This information can be used to detect innovative algorithms, original calculations and references that could be shared among countries having equivalent crop practices, and, eventually, help to achieve a reduction in N losses by 50%, as expected by the 'Farm-to-fork' strategy.

Our analysis is mainly based on a theoretical approach (compilation from technical grey literature) with data from fertilisation practices from different countries, completed by a case study with two contrasting scenarios (farming systems). The study focusses on major arable crops at the scale of ten countries.

2. NITROGEN RECOMMENDATION SYSTEMS

2.1. Origin and geographic scales of information.

We focussed our survey on data from national or regional advisory services, which are providing advice to farmers, but also included data from scientists directly involved in the development of the calculation methods and N fertilisation recommendations in their specific countries. Data were obtained from the following countries: Belgium, Germany, Ireland, Italy, Luxembourg, the Netherlands, Spain, Switzerland and United Kingdom. Table 1 summarises the national and regional references, which gave information on the calculation rule for N recommendations.

2.2. Recommendation systems presented country by country.

The fertilisation calculation methods developed by every country rely on the use of a variable number of parameters that can be split into two groups: those providing mineral N (Nmin) to the crops (11 'Input' items), and those consisting in outputs of Nmin from the soil or unused stocks (4 'Output' items). Table 2 shows the parameters used by each country, ranked in decreasing order of number of parameters used. The same order was used in the following text to go through the ten investigated countries.

2.2.1. France.

In France, most of the fertilisation recommendations are based on an N-balance equation (also called 'balance-sheet method'). The generic equation is described in a reference guide edited in 2013 by the COMIFER (French Committee for the Study and Development of sustainable Fertilization, Table 1). Provided by at

least 20 parameters ('additive system'), the equation is inappropriate in this complete form, from a practical point of view. Therefore, it is accompanied by simplified forms, to cope with the lack of information, e.g. volatilisation and denitrification rates, leaching, etc. At the extreme level of simplicity, the equation can be reduced to a very few terms, the unknown variables being merged within an 'Apparent Use Coefficient' (AUC). MacKenzie and Taureau (1997) described the method in a former IFS conference. For secondary crops suffering from a lack of references, official recommendations rely on 'corrected standards' ('dose pivot', e.g. sunflower, soybean) or a maximum threshold ('plafond', e.g. vegetables, fruit trees, vineyards).

Table 1: *Names and origins of the national official documents governing the N fertilisation in some west European countries.*

Country	**References** (in their original language)	**Last update**	**Service**
Belgium (Wal.)	Prog. de Gestion Durable l'Azote en région wallonne Etablissement du conseil de fumure azotée en culture	2006	Walloon Government ASBL REQUASUD
France	Calcul de la fertilisation azotée. Guide méthodologique pour l'établissement des prescriptions locales	2013	COMIFER[1]
Germany	Verordnung über die Anwendung von Düngemitteln. Düngeverordnung - DüV	2020	German Ministry services
Ireland	Major & micro nutrient advice for productive agricultural crops, 5th Ed	2020	Teagasc, Johnstown Castle, Wexford
Italy	Linee guida nazionali di produzione integrata	2020	Ministry of agriculture and forestry
Luxembourg	Règlement grand-ducal concernant l'utilisation de fertilisants azotés dans l'agriculture	2014	Ministry of agriculture
Spain	Guia Practica de la fertilizacion racional de los cultivos en Espagna	2012	Ministries of Agric. and Environment
Switzerland	Principes de fertilisation des cultures agricoles en Suisse	2017	Agroscope, Swiss Confederation
The Netherlands	Handboek Bodem en Bemesting	2020	Arable Fertilisation Committee
United Kingdom	Nutrient Management Guide (RB209)	2020	AHDB[2], BBRO[3], PGRO[4]

[1] *COMIFER* *Comité français d'étude et de développement de la fertilisation raisonnée.*
[2] *AHDB* *Agriculture and Horticulture Development Board.*
[3] *BBRO* *British Beet Research Organisation.*
[4] *PGRO* *Processors and Growers Research Organisation.*

Table 2: *Variables taken into account in the calculation of the recommended rates of N fertilisation, ranked vertically by input/output to the soil-plant system, and horizontally by decreasing number taken into account in a given national method.*

S_{end} Soil mineral N remaining at harvest.

	Outputs (direct or through coefficient)					Inputs (or not needed to be brought)											Number of variables (except AUC)
	S_{end}	C_{end}	L	A	AUC	S_{start}	C_{start}	Hu	Past	CR	IC	Ir	M_1	M_{n-1}	Atm D	AdY	
	Soil end	Uptake	Leaching	Atmos. Loses	Apparent Use Coefficient	Soil start	Crop start	Humus min.	Pasture min	Crop residues	Interm. crops	Irrigation	Manure	Manure Year-1	Atmos. deposition	Adjust. of the yield	
France	■	■			■	■		■		■	■		■				10
Italy		■		■		■		■		■	■		■	■	■		10
Switzerland		■	■				(*)	■	■	■	■		■	■		■	9
Belgium (Wal.)		■				■	■	■	■	■	■		■	■			9
Germany		■				■		■		■	■		■	■		■	8
United Kingdom		■	■		■	■	■	■	■	■			■				8
Spain	■	■	■		■	■				■		■	■		■		8
The Netherlands	■	■				■	■	■		■			■			■	8
Ireland		■							■	■	■		■			■	6
Luxembourg		■											■			■	3

C_{end} Total N demand of the whole crop, including roots and annually adjusted to quality and variety criteria for cereals.

L Leaching.

A Atmospheric losses (denitrification, volatilisation).

AUC Apparent Use Coefficient, standing for the uptake efficiency of the mineral fertiliser provide.

S_{star} Soil mineral N at sowing (or starting point) generally directly measured in fields, but possibly computed for difficult sampling conditions.

C_{Start} N already taken up at the starting point (e.g. time of spring soil sampling), generally negligible except for winter rape.

Hu N net release from soil organic matter (humus mineralisation).

Past N net release from soil organic matter, following grasslands ploughing.

CR Effect of previous crop residues, depending on the type of residues.

IC Effect of catch crops or green manure.

Ir Nitrogen supplied by irrigation water.

M1 Nitrogen from the organic manure contribution, calculated from the inorganic fraction and an estimate of the organic release during the season.

M_{n-1} Nitrogen derived from the mineralisation of organic amendments brought the year before.

AdY Adjustment of the yield, when different to the standard values.

(*) The direct measurement of Nmin can be used as an alternative to the 'corrected standards' method.

Each of the twelve French regions are obliged to choose the equation that better suits their cropping systems and locally available parameters. For example, in the Nouvelle Aquitaine region, the equation used by farmers is a combination of the additive and the AUC system (Eqn 1). It is described at regional levels, with online information available derived from a Regional Nitrate Expertise Group ('GREN'):

$$N_{rate} = [(C_{end} + S_{end}) – (S_{start} + C_{Start} + Hu + Past + CR + IC + Ir) – M1] /AUC \quad \text{Eqn 1}$$

Explanation of symbols are given in Table 2. The specifics for France are:

- the crop N content at harvest (C_{end}) stands for the whole crop, including roots and is annually adjusted to quality and variety criteria for cereals; it is defined for every crop per yield unit;
- the soil mineral N at sowing (S_{start}) is generally directly measured in fields (but also estimated for difficult sampling conditions thanks to the fields reference network);
- the N already taken up at the starting point (C_{Start}) is generally negligible except for winter rape;
- the effect of intermediate crops (IC) destroyed before the starting date of balance calculation can be experimentally estimated by the 'MERCI' tool (Constantin *et al.,* 2023) from gross weighting at the destruction of the intermediate crops;
- ACU: Apparent Use Coefficient, standing for the uptake efficiency of the mineral fertiliser provided. Depends on the crop conditions (plant stage, climate, etc.) prevailing during at mineral spreading.

2.2.2. Italy.

The Italian N fertilisation approach is based on a mass balance at the field scale. The mass balance is entirely described in the national guide (National guidelines for integrated crop production, 2020), providing 'default values' unless Regional brochures are used. The approach is quite mechanistic, as most of the variables depend themselves on secondary factors, as shown below (Eqn 2). Several measurements are required, such as soil texture, organic matter content and C/N ratio.

$$N_{rate} = C_{end} + L + A – (S_{start} + Hu + CR + IC + M1 + Mn\text{-}1 - Atm\ D) \quad \text{Eqn 2}$$

Explanation of symbols are given in Table 2. The specifics for Italy are:

- The soil mineral nitrogen at sowing (Sstart) can be calculated from a combination of the soil texture and a measurement of the total N content;
- The N provided by humus mineralisation (Hu) is a combination between soil texture, C/N ratio and the organic matter content, and is proportional to the duration of the crop growing period;
- The N exported by leaching (L) can be either estimated by the cumulative winter rainfall between the 1st of October and the 31st of January (e.g. no leaching below 150 mm and no N left if rainfall greater than 250 mm) or can be deduced from the drainage facilities crossed with soil texture.

- The N lost by denitrification and volatilisation (A) is proportional to the soil N availability, defined as Hu + S_{start}. Proportionality coefficients vary from 20 to 40% according to the drainage facilities and the soil texture.
- The N derived from the use of manure depends on the frequency of their spreading (Table 3).

Table 3: *Percentage of annual recovery of the total amount of N applied in function of the frequency of manure spreading in Italy.*

Type of manure spread	Frequency of inputs		
	Every year	1 year out of 2	1 year out of 3
Solid manure	50	30	20
Liquid manure (dairy)	30	15	10
Liquid manure (pork & poultry)	15	10	5

2.2.3. Switzerland.

The Swiss method is described in the national brochure 'Principles of fertilisation of agricultural crops in Switzerland', edited by the AGROSCOPE research institute (Sinaj and Richner, 2017). The recommended rate of N fertilisation is based on the 'corrected standards' principle. This reference dose, also called standard fertilisation, corresponds, for a given crop, to the quantity of N that must be provided in a standard situation (soil normally provided with N) to obtain the average yield or reference yield observed in Switzerland for this crop. Fertilisation standards and yields reference result from experiments establishing the crop response curve to fertilisation N, farmers' experience and expert knowledge (Richner *et al.*, 2010, Maltas *et al.*, 2015). Therefore, the modified dose is calculated as follows:

$$N_{rate} = N_{rate\ std} + (AdY + Hu + CR + IC + M_{n-1} + L) \quad \text{Eqn 3}$$

Explanation of symbols are given in Table 2. Most of the corrected factors are quite similar to those developed in other countries. It is however worth noting that corrections due to the mineralisation potential are not only a function of clay and organic matter content (Table 4) but also vary according to the frequency of mechanical weeding, thus providing to the crop an addition of 10 to 20 kg N/ha.

Alternatively to the former method, it is also possible to calculate the N rate from measurements of the soil mineral N (Nmin). This method is based on a value reference (threshold) from which the Nmin measurement (standing for the stock of mineral N present in the soil before the first N input) is subtracted (Table 5). This reference value was established on the basis of field trials relating Nmin measurements to optimal N doses (Neeteson, 1990). Compared to the method of 'corrected standards', this approach has the advantage of measuring directly Nmin and avoids having to estimate it based on reference tables. Period and depth collection of Nmin depends on the crop.

Table 4: *Correction due to the mineralisation potential, function of clay and organic matter content (Sinaj and Richter, 2017).*

Potential of humus mineralisation	Organic Matter (%)			Corrections compared to standard mineralisation
	Clay < 15%	15 to 30% clay	Clay > 30%	
Weak	< 1.2	< 1.8	< 2.5	[0 ; +40]
Standard	[1.2 ; 2.9]	[1.8 ; 3.9]	[2.5 ; 5.9]	0
Favourable	[3.0 ; 6.9]	[4.0 ; 7.9]	[6.0 ; 9.9]	[0 ; -40]
High	[7.0 ; 19.9]	[8.0 ; 19.9]	[10.0 ; 19.9]	[-40 ; -80]
Very high	≥ 20	≥ 20	≥ 20	[-80 ; -120]

Table 5: *Nitrogen fertilisation of cereals based on the measurement of soil mineral nitrogen (Sinaj and Richter, 2017).*

Crop	1rst Input	2nd Input	3rd Input
	kg N/ha		
Wheat (winter)	120 - N_{min}	30	40
Wheat (spring)	110 - N_{min}	30	40
Barley (winter)	80 - N_{min}	30	40
Triticale (winter)	90 - N_{min}	30	40
Barley and Triticale (spring)	80 - N_{min}	30	40
Winter Rye (winter)	80 - N_{min}	30	30
Oats	100 - N_{min}	30	30

2.2.4. Belgium.

Belgian rules of N management are derived from two distinct documents. The first one consists of general advice on good agricultural practices, especially with the use of manure (e.g. Sustainable Programme of Nitrogen Management in the Walloon region, Table 1). The other one (ASBL REQUASUD) provides the fertilisation recommendation values. It is only available for the soil analysis laboratories; no public brochure exists. Values are calculated from a model inspired from the French mass balance method (Azobil, Abras *et al.*, 2012) and parameterised at the scale of each of the two Belgian areas. The model is considered to be particularly efficient in calculating the mineralisation of humus. In short, the recommendations are mainly based on soil types, crop uptake, mineral N at sowing, humus mineralisation, direct and long-term effect of manures, effect of intermediate crops, effect of residues of previous crops and uses spring soil analyses to determine the initial Nmin in the soil (Eqn. 4, Table 2):

$$N_{rate} = (C_{end} + S_{end}) - (C_{Start} + S_{start} + M1 + M_{n-1} + Hu + Past + CR + IC) \quad \text{Eqn 4}$$

Explanation of symbols are given in Table 2. The specifics for Belgium are:

- The soil mineral N at harvest (S_{end}) are generally equal to 20 kgN/ha.

- The soil mineral N at sowing (S_{start}), preferably measured on the whole soil profile.
- The mineral N released from ley ploughing (Past) includes alfalfa long term effects.

It is worth underlining that the measurement of mineral N at harvest is used by state authorities to control the potentially leaching quantity of N during winter, in comparison with regional references. Samples are collected between the 15th October and 30th November, to a depth of 0-90 cm for annual crops. It is therefore considered as an indicator of the fertilisation requirements at field scale.

2.2.5. Germany.

The German method (Table 1) relies on the 'corrected standards' approach, consisting of attributing to a given crop a standard recommended dose ($N_{rate\ std}$, Eqn 5), and then deducing some sources of N or reasons for a lesser uptake (or more occasionally a higher). There are detailed regional adaptations to account for climate and soil variations. The general approach can be presented as the following equation:

$$N_{rate} = N_{rate\ stdt} – (AdY + S_{start} + Hu + CR + IC + M1 + Mn\text{-}1) \quad \text{Eqn 5}$$

Explanation of symbols are given in Table 2. The specifics for Germany are:

- The optimum yield considered in the equation is 8 t/ha, 7 t/ha, 9 t/ha for wheat, barley and maize, taken as examples;
- 10% of the total N brought by farmyard manures is considered to provide an input to the crop the year following its spreading. So for a given year, in addition to the standard 'direct effect' corresponding to the N provided the year n, 10% of the farmyard manure of the previous year is to be accounted for (n-1).

In parallel to all calculations on permissible fertiliser dressings to their crops, farmers have to perform a second type of accounting: they have to report all purchases, imports and exports of nitrogen-containing goods to their farm including, for example, the N content of the feed for animals, which is absent from the field-scale approach. The current maximum of this large-scale balance is currently 170 kg N/ha and is planned to be lowered over the next years.

2.2.6. United Kingdom.

The calculation of N rate recommendations is accurately described in a national guide (Nutrient Management Guide, RB209, 2020) with two main brochures used in this study, the 'Section 1: Principles of nutrient management and fertiliser' and the 'Section 4: Arable crops'.

The UK system defines the crop nitrogen requirement as the amount of nitrogen that should be applied to give an on-farm economic optimum yield. Recommendations for cereals and oilseeds are calculated using a typical breakeven ratio to provide the best on-farm economic rate of N to apply. In addition to identifying crop nitrogen requirement, it is necessary to comply

with regulatory restrictions on the amount or timing of applications e.g. in Nitrate Vulnerable Zones. Fertilisation recommendations consider all supplies and losses of N and the efficiency of N use by the crop.

The basis of the rationale consists of evaluating the 'Soil Nitrogen Supply' (SNS) which defines the amount of N (kg N/ha) available for uptake from the soil, taking into account N losses but excluding external N applications. The SNS encompasses three additive separate components:

1) Soil Mineral nitrogen (S_{start}) within the normal maximum rooting depth of the crop.
2) Estimate of nitrogen already in the crop (C_{start}).
3) Estimate of mineralisable soil nitrogen, accounting for nitrogen which becomes available for crop uptake from mineralisation of soil organic matter (Hu) and crop residues (CR).

In most situations, the SNS Index will be identified using the Field Assessment Method, which is based on field-specific information for previous cropping, previous fertiliser and manure use, soil type and winter rainfall. The SNS Index, which is divided into six or seven categories, is read from tables and there is no requirement for soil sampling or analysis (Table 6). Alternatively, direct measurement (S_{start}, soil organic matter content) could be advised where organic manures have been used regularly in recent years. Whatever the method of estimating SNS, suggested values of doses are deduced from experimental datasets including over 1600 N response curves (Clarke *et al.,* 2016).

Table 6: *Nitrogen recommendations for wheat and triticale (RB209, 2021) before the application of the efficiency coefficient*.

Soil category	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand	180	150	120	90	60	[0;60]	[0;40]
Shallow	280	240	210	180	140	80	[0;40]
Medium	250	220	190	160	120	60	[0;40]
Deep clay	250	220	190	160	120	60	[0;40]
Deep silt	240	210	170	130	100	40	[0;40]
Organic	–	–	–	120	80	[40;80]	[0;40]
Peat	–	–	–	–	–	[0;40]	

Thereafter, the efficiency of uptake by both soil-derived N and fertiliser N is considered, taking into account soil type, crop disease, poor soil conditions, drought or other growth-inhibiting problems that will hamper the uptake efficiency of the soil mineral concentrations. Uptake efficiency (comparable to the Apparent Use Coefficient) ranges from 60 to 70%, for winter cereals fed

with ammonium nitrate. Eventually, an assessment of the marginal economic response is factored into the recommended rate.

2.2.7. Spain.

In the Spanish system, general recommendations are produced at the scale of the country ('Guide for rational fertilisation practices for crops in Spain', Table 1). The guide is split into two volumes: a first section with general rules and guide for nutrients, including N; the second one deals with specific crops (e.g. cereal, horticultural crops) and ends with a section on fertiliser legislation. However, the information provided is not precise enough to allow practical calculations. Therefore, each region publishes an application of these rules in the form of brochures or just on their website to fit with their specific conditions. A new decree promoting sustainable fertilisation is about to be published (2022) with local specific recommendations for regional governments.

The calculation of N recommended rates is based on a mass balance to be performed at the field scale. Recently, a decision support system was developed to help farmers and agronomists to calculate nutrients requirements for a crop rotation designed by the user by picking from 149 crops (Villalobos *et al.,* 2020). This application, called 'FertiliCalc', calculates the N rates for the selected crops and allows the user to choose among a combination of straight and complex mineral fertilisers and organic compounds. The general equation used (adapted from Villalobos *et al.,* 2020) can be written as:

$$N_{rate} = [(S_{end} + C_{end}) - (S_{start} + CR + A + L + Ir + M1)] / AUC \quad \text{Eqn 6}$$

Explanation of symbols are given in Table 2. The specifics for Spain are:

- The final soil inorganic N (residual N, S_{end}), assumes a fixed value of 10 kg N/ha;
- The initial soil inorganic N (S_{start}) is not introduced in the program but the user corrects by the value obtained from analysis or local information;
- The N provided by the previous crop residues is calculated very precisely, including root/shoot rations, proportion of residues left on the field, percentage of mineralisation (generally 0.9);
- The model assumes that the soil stable organic matter is in steady state, therefore Hu = 0 and the N supply by the soil corresponds to CR and depends on the crop rotation designed;
- Atmospheric inputs accounts for atmospheric deposition, estimated at 10 kg N/ha;
- The suggested Apparent Use Coefficient is 0.7. This relatively low value may be explained by the fact that the model does not calculate N losses mechanistically but applies coefficients based on scientific literature (Delgado *et al.,* 2008). It depends on management practices to estimate, first, N volatilisation, and then denitrification. Nitrate leaching is estimated by applying a coefficient to the remaining soil nitrate susceptible to be

leached. Losses might rise up to 60% of the applied fertiliser under non-favourable conditions for high N use efficiency (Quemada *et al.,* 2016a, b).

2.2.8. The Netherlands.

The N fertilisation recommendations in The Netherlands are based on numerous N fertilisation field experiments and are defined by committees consisting of scientists and representatives of farmers unions. These N fertilisation recommendation indicate the economic optimal N input (combination of N from animal manure and synthetic fertilisers, and corrected for the inputs from soil and crop residues). There are two committees, one for grassland and forage crops[1] and one for arable and vegetable crops[2]. Recommendations are explained in detail on the websites of the committees. Recommendations for grassland depend on soil type, the total N content in the top soil and on the frequency of grazing. Recommendations for arable and vegetable crops depend on crop type (and sometimes also variety), soil type, and the amount of soil mineral N in the top 30 to 60 cm of the soil (Table 7). Recommendations include advice on split application, described for several crops, providing proposals of inputs for the first, second and possible third application. Moreover, the use of N mass balances is advised. The analysis of mineral N in soils is not compulsory.

Table 7: *Summary of N fertilisation recommendations for some crops grown in the Netherlands. N_{min} stands for mineral Nitrogen (Source: https://www.handboekbodemenbemesting.nl).*

Crop	Soil type	Recommended amounts
Potato (consumption)	Clay / Loess	285 - 1.1 N_{min}(0-60cm)
Potato (consumption)	Sand	300 - 1.8 N_{min}(0-30)
Potato (starch)	Sand	275 - 1.8 N_{min}(0-30)
Wheat (winter)	Clay / Loess / Sand	140 - N_{min}(0-100)
Wheat (spring)	Clay / Loess / Sand	120 - N_{min}(0-60)
Barley (winter)	Clay / Sand	120 - N_{min}(0-100)
Barley (winter)	Loess	100 - N_{min}(0-100)
Barley (spring)	Clay / Loess	90- N_{min}(0-60)
Barley (spring)	Sand	120 - N_{min}(0-60)
Sugar beet	Clay / Loess / Sand	200- 1.7 N_{min}(0-60)

2.2.9. Ireland.

The Irish system is quite similar to the UK system due to the use of the 'Soil Nitrogen Index' (SNI) which is equivalent to a soil N supply. The SNI class (there are four classes in total) is calculated from the previous crop and soil

[1] https://www.bemestingsadvies.nl
[2] https://www.handboekbodemenbemesting.nl

type (Table 8). Account is also taken of previous applications of livestock manure N, the requirement of the crop and the likely crop yield. It is worth noting that, in the case of grasslands, for the purposes of checking compliance with the Nutrients Action Programme regulations, it is best to calculate both the advised N application and the maximum N allowance on a whole farm basis. In situations where the N advised exceeds the maximum amount of N allowed, it will be necessary to adjust the N application rates in order to comply with the regulations.

Table 8: *Recommended N rates for Ireland (as available fertiliser) for wheat (kg/ha) having moderate yields or where proof of higher yields is not available (Wall and Plunkett, 2020).*

Soil N Index	Wheat (winter)[1, 2] ≤ 9 t/ha	Wheat (spring)[1, 2] ≤ 7.5 t/ha
1	210	160
2	180	130
3	120	95
4	80	60

[1] Where proof of higher yields is available, an additional 20 kgN/ha may be applied for every 1 tonne above reference.
[2] An extra 30 kgN/ha may be applied for milling wheat.

2.2.10. Luxembourg.

The Luxembourg method is described in a decree ('Regulation concerning the use of nitrogenous fertilisers in agriculture, 24th Nov. 2000 with several updates, the last one on 28 February 2014). It states that 'The quantity of mineral N fertilisers spread per year and per hectare must not exceed the threshold quantities of N fertiliser, depending on the nature and yield of the crops and taking into account local specificities and agro-climatic conditions of the year'. Table 9 gives an overview of those maximum quantities. N fertilisation doses are calculated with a simplified approach of the 'corrected standard' method, applied in Germany:

$$N_{rate} = N_{rate\ stdt} - (AdY + M1) \qquad \text{Eqn 7}$$

Explanation of symbols are given in Table 2. The specifics for Luxembourg are:

- The total N brought by manures is limited to 170 kg N/ha (85 kg N/ha to legumes) and is considered only partially available to plants during the season;
- M1 is oscillating from 15% (compost) to 60% (slurry) depending on manure type, spreading season, and culture, and considered to have no effect after the year of spreading;
- It is compulsory to apply exactly the dose calculated by the guideline, on penalty of a fine.

Table 9: *Maximal amounts of N fertilisation permitted on crops (Annex of 11/24/2000 decree).*

Crop	Standard yield t/ha	$N_{rate\ stdt}$ kg N/ha.y	AdY kg N/δdt/ha
Grain	5	160	2.5
Rapeseed	3	180	5.0
Legumes	5	30 (start only)	--
Potatoes	35	170	4.0
Fodder beet	90	235	3.0
Maize	15 (DM)	190	1.4
Permanent grassland	9 (DM)	260	2.7
Temporary grassland	11 (DM)	300	3.0

AdY: adjustment for non-standard yield. DM: Dry Matter.

3. CASE STUDIES.

3.1. The chosen case studies for the simulations.

Previous country-specific methods of N-rate calculations were applied to two different crop situations. The objective was to test the extent to which the different methods converge or not when practically used. The comparison of the ten recommended rates of N fertilisation required erasing as much as possible the cultural and pedoclimatic specificities between the ten countries. For this comparison, common soil and production systems were chosen, e.g. a non-calcareous soil of deep silty-clay alluvium - one of the most widespread. In this general context, we tested two different farming systems (animal oriented farm vs pure crops) widespread in western Europe. The two cropping systems not only differ with the kind of fertilising material used, but also with the type of rotation, target yield, etc. (Table 10). The soil characteristics are given in Table 11.

Table 10: *Description of the two wheat crop scenarios for the calculation of the recommended N rate.*

Main crop	Polyculture	Crop, livestock
Main crop	Wheat	
Target Yield	7 t/ha	5 t/ha
Key-depths	Root depth: 60cm	Ploughing depth: 30cm
Key-dates	Sowing: 15th October	Harvest: 15th July
Rainfall (winter)	400 mm	
Straw management	Left on the field	Exported
Preceding crop	Rapeseed (4 t/ha) [1]	Grass ley (2 years), mown + grazed
Cover crop	Phacellia / Brassica [2]	
Manure		15 tonnes Farmyard Manure [3]

[1] fertilised with 140 kgN/ha. [2] mid-November destruction.

[3] 5.5 kgN/t of fresh weight spread in September, with a frequency of once every three years.

Table 11: *Soil characteristics of the wheat field.*

	Fraction >2mm	Clay	Fine silts	Coarse silts	Fine sands	Coarse sands	Total $CaCO_3$	Active $CaCO_3$
	‰							
0-30cm	0	194	215	324	196	52	0	0
30-60 cm	0	163	188	360	220	60	0	0

	OC °‰	OM ‰	Total N ‰	C/N	CEC Metson cmol/kg	Saturation of CEC	pH	Density
0-30cm	10.29	17.7	0.95	10.8	9.7	99	6.52	1.3
30-60 cm	4.19	7.2	-	-	5.4	86	4.65	1.4

OC: Organic carbon; OM: Organic matter; CEC: Cation exchange capacity

3.2. Results of the case studies.

In the polyculture farm scenario, i.e. without organic amendments, the amplitude of the recommended doses reaches 100 kg N/ha (Figure 2). Values range from 110 kg N/ha (Belgium, Wallonia) up to 210 kg N/ha (Luxembourg). The median value is around 150 kg N/ha. Three countries give the same amount (Germany, France and Italy), with 170 kg N/ha. In the farming system including animals, the gradient is slightly higher (from zero to 135 kg N/ha). The ranking of countries varies between both scenarios, although 'extremes' remain the same (Belgium and Luxembourg, for minimum and maximum N rates, respectively.

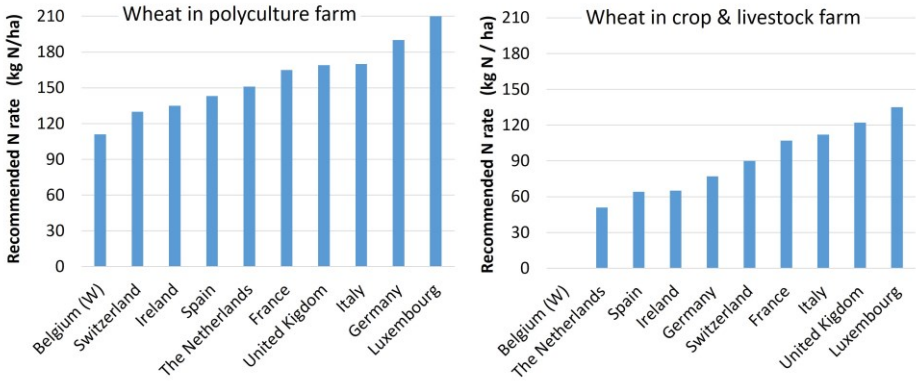


Figure 2: *Recommended nitrogen (N) fertilisation rates for ten west European countries, calculated from the official national methods, and applied on a theoretical study case consisting of a wheat crop grown under two farming systems.*

4. DISCUSSION ON METHODS AND RESULTS OF STUDY CASES.

4.1. Similarities between the different calculation methods.

The ten methods used to calculate N fertilisation rates can broadly be divided into three groups:

1. 'Nitrogen mass balance', used by France, Italy and Spain.
2. 'Corrected standard', used by Germany, the Netherlands, Switzerland, and Luxembourg, which are based on numerous N fertilisation field trials, and propose soil and crop specific maximum N inputs, which then have to be corrected for the amount of soil mineral N in spring (either measured or default quantities).
3. 'Pre-parameterised calculation', relying on a Soil Nitrogen Supply typology (United Kingdom, Ireland) or on a model parameterisation (Belgium).

In practice, such a typology is a bit artificial as every method relies on field parameterisation or could be presented as a mass balance writing, before being simplified.

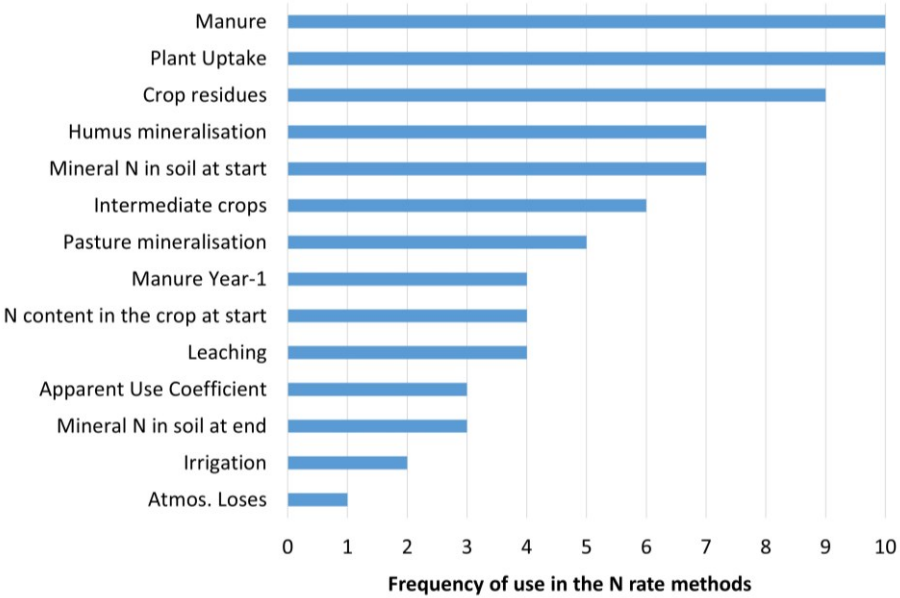
4.2. Variations in the ease of use of the different methods.

From a practical point of view, methods relying on mass balances are the more complicated to implement. The corrected standards methods are the easiest to apply in practice, because farmers can simply read the optimal N applications from published tables for each crop type (and variety) and soil type. The pre-parameterised calculation exhibits intermediate difficulties in practice. On average, methods relying on mass balances require the highest number of variables (e.g. France and Italy, 10 variables). Corrected standard and pre-parameterised methods include a range of 6 to 9 variables except for Luxembourg (3). Including a lower number of variables does not necessarily mean that some mechanisms are totally ignored or neglected. Sometimes, they are (e.g. atmospheric deposition in UK, N in irrigation in Ireland), but they may be integrated or pooled with other more integrative variables such as the long term N supply from fertilisers, which are accounted for by the measurement of soil mineral nitrogen at seeding in France. By the same logic, the quantities of N leached during winter are also indirectly included in the estimation or measurement of the residual soil mineral N after winter. It is also the role of the 'Apparent Use Coefficient' to synthesise the pooled effects of some N losses which are difficult to measure or even estimate (N leaching, atmospheric losses, etc.).

4.3. The most widely used variables.

The most widely used variables contributing to the calculation of the recommended nitrogen fertilisation rates are the N derived from manure, the N uptake by the crop, the N released by crop residues, the mineralisation of humus and the amount of mineral nitrogen already in the soil at seeding or at the start of the mass balance calculation (Figure 3). The least employed

variables are the N atmospheric losses, the N brought by irrigation water, the N brought by atmospheric depositions, the stock of mineral N at harvest, the N leached, the N in the crop at the start of the mass balance, and the apparent use coefficient. Taken all together, the combination of all the variables would account for the most complete equation, which is actually similar to the theoretical one suggested by the French method developed by COMIFER in its



extended version (COMIFER, 1993).

Figure 3: *Decreasing frequency of the variables used in the methods of calculation of the recommended nitrogen fertilisation rates.*

4.4. Case Studies: reasons for the differences between countries.

There are large discrepancies between the ten countries' recommended N fertilisation rates (study cases, Figure 2). Ideally, each dose should be accompanied by a margin of error, which was however impossible to estimate in the context of this exercise. For example, in France, preliminary results of an ongoing study by COMIFER give an initial estimate of uncertainties around 45 kg N/ha. In this context, the differences, analysed in the following chapter, can be accounted for by:

- the number of variables taken into account in the algorithms;
- the weight given to the N losses (in waters and atmosphere) in the algorithms,
- differences among the most shared variables, i.e. contribution of N from organic amendments and uptake of N from the crop;

- the regulatory status of the equation, i.e. if and how the fertiliser recommendation is used for legal enforcement of nutrient management.

4.4.1. The questionable benefits of using more variables.

The number of variables explicitly used by each country is not related to the recommended N fertilisation rate (Figure 2). The countries exhibiting the highest complexity (France, Italy) displayed intermediate N-rate values, which does not mean that they are the most accurate ones! Indeed, in this case study, the 'real value' will always remain unknown. With only three variables taken into account, Luxembourg calculations lead to the highest value.

4.4.2. The variable impact of using an explicit parameter for leaching.

We analysed the effect of the presence of the 'Leaching' variable in the equations on the final N recommendation rate (Spain, UK, Switzerland and Italy), with the hypothesis that calculating N leaching explicitly would result in a higher N fertilisation rate, on average. In reality, the opposite was found to be the case, at least for the UK and Switzerland (green spots, Figure 4). By comparison, when the equations neither refer to leaching nor use any apparent use coefficient (red spots, Figure 4), one could expect an underestimation of the outputs, which would in turn lead to recommend low values. Again, such a conclusion cannot be deduced from the results.

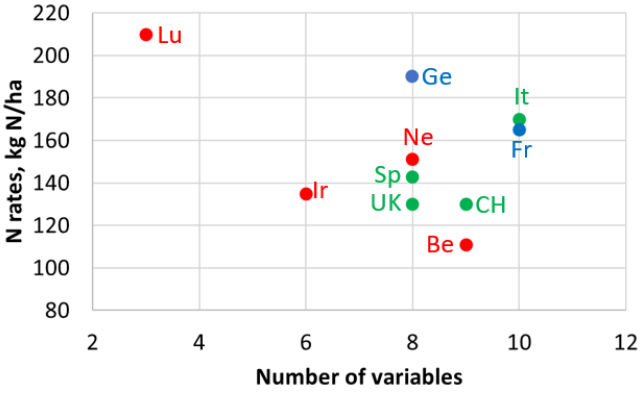


Figure 4: *Relationship between the recommended N fertilisation rates (polyculture scenario) and the number of variables explicitly present in the fertilisation calculation methods. Belgium (Be), Germany (Ge), Ireland (Ir), Italy (It), Luxembourg (Lu), the Netherlands (Ne), Spain (Sp), Switzerland (CH) and United Kingdom (UK). Red spots: countries that do not refer to N leaching, neither explicitly, nor with the Apparent Use Coefficient. Green spots: countries that explicitly take the N leaching into account in their equations. Blue: other cases.*

4.4.3. Manure does not provide the same amount of mineral nitrogen according to the countries.

All countries take into account the N brought by organic amendments (Figure 3), whether it is through their mineral N content or/and through the mineralisation immediately following the spreading. The quantity of N available for the crop is expressed as a percentage of the total N, which could be called 'mineral fertiliser equivalent' (Neq). This fraction varies from a 6-fold order of magnitude (Figure 5). For example, bringing a total of 83 kg of total N (the case study) will only supply the following wheat crop with 8 kg N/ha in UK, whereas this amount is considered to be 49 kg N/ha in Germany. However, this last value does not exactly match the given uniform scenario, as autumn spreading of manure to wheat is not allowed in Germany anymore. So the high percentage corresponds to storing the manure and applying it in spring with more favourable conditions.

These percentages are not linked to possible long-term release effects (Figure 5). On the other hand, they could be linked to local climate, with a lower mineralisation in colder and dryer climates. These differences in N supply from organic amendments explain why there are much greater differences in the recommended dose when fertilisation relies on organic rather than on mineral fertilisation (Figure 2).

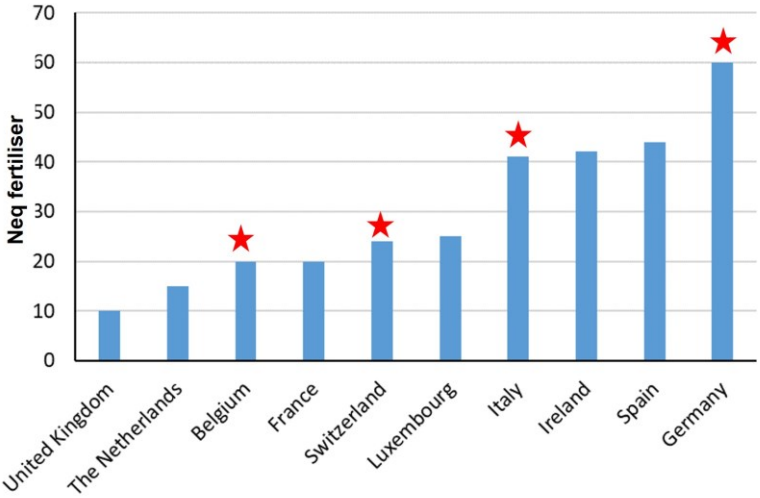
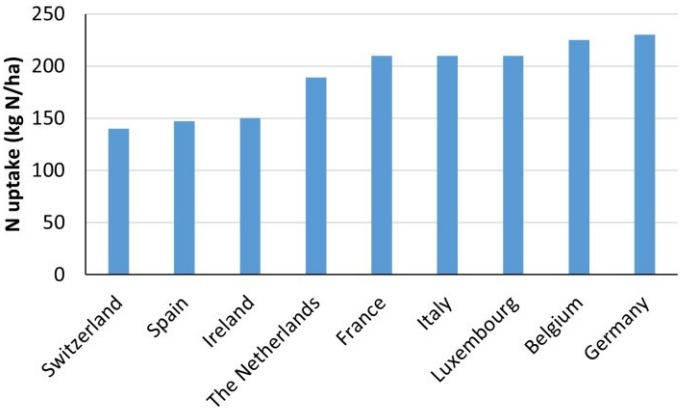


Figure 5: *Percentage of the total N content of the farmyard manure that is considered to be available for the crop following its spreading. Red stars indicate the countries that take into account a long time effect (> 1 year) of previous spreading on the soil N supply.*

4.4.4. Variations in the assumed level of nitrogen uptake by crops.

The estimate of crop N uptake (not only in grains but entire shoots) varies greatly from country to country, even with the same target yield (Figure 6). The 90 kg N/ha gap between Switzerland and Spain, on one side, and Germany and Belgium on the other side, is a supplementary cause of

heterogeneity of the N fertiliser recommendations underlined on the Figure 2. One explanation is that the N uptake may include more or less secondary factors (e.g. uptake efficiency) which are not explicit in the equations. The difference could hardly be accounted for by the food sector the wheat is dedicated to (animals feeding or flour mill), as varieties for animal feeding



may have a lower uptake equivalent to 5 kg N/t. The United Kingdom value could not be found as it is merged with other variables underlying the Soil Nitrogen Supply calculation (Figure 6).

Figure 6: *Amount of nitrogen (N) considered to be taken by the crop, for a 7 t/ha grain wheat yield.*

4.4.5. Regulatory status of the calculation methods.

According to the countries, the recommended doses of N fertilisation do not have the same level of integration into the legal enforcement of nutrient management. We analysed to what extent the fertilisation recommendations were serving as official references for regulatory controls towards the Nitrate Directive.

Belgium: the private laboratory REQUASUD system provides an agronomic-based referential and has no regulatory enforcement. In practice, the Walloon control systems is based on post-harvest soil mineral nitrogen concentrations, compared to regional references (results objective). Therefore, sanctions are taken according to a field indicator, and not based on the advice received by the farmer a few months before (means objectives).

France: For every region, the use of the mass balance equation or any equivalent calculation tool is mandatory, but not the dose itself. This is partly because the current equation cannot estimate the precision of the final value. So far, there is no threshold gap between the calculation performed by the assessor and the one made by the advisor or the farmer himself. The calculation tools that are officially used to perform the mass balance calculation receive the 'Prev'N' label.

Germany: The control is based on two complementary accountings, a field and a farm N mass balance. This two-steps control is particularly justified in regions with livestock, which may be concerned by high amounts of nitrogen-containing goods to their farm (e.g. Lower Saxony). This second approach may be more limiting to farmers than the field-scale crop approach.

Ireland: The recommendation rules provide maximum limits that are legally binding for farmers. The regulatory system is described in the National Action Programme (S.I. 114 of 2022).

Italy: the N doses applied have to fit with the fertilisation plan which describes the technical modalities (dose, time, spreading material, type of N fertiliser …) implemented by the farmers and based on the analytical calculation (mass balance). Alternatively, the control can focus on 'standard doses' for each crop established and approved at the national level. These standard forms can be adapted by regions and autonomous provinces according to specific territorial characteristics.

Luxembourg: Recommendations and current fertilisation amounts have to match, at the risk of sanctions.

Spain: The situation is similar to France. Farmers have to prove that the calculations are based on the recommended equations, but there is not an actual regulatory control.

Switzerland: The fertilisation recommendation rules are not mandatory for legal enforcement of nutrient management.

The Netherlands: The N fertilisation recommendations indicate the economic optimal N input. Concurrently, there are soil and crop-specific N application limits (including N from manure and fertilisers). These N application limits are derived from the economic optimal N fertilisation rates, but are corrected so as to guarantee that the nitrate concentration in the shallow groundwater does not exceed 50 mg NO_3^-/L. The N application limits are presented on the website of a governmental organisation (2022). Farmers have to comply with the N application limits, which are up to 20% below the economic optimal N application rates (depending on crop and region).

United Kingdom: In vulnerable zones, regulations are enforced in order to meet legal and environmental obligations, and place an N-max limit from manufactured fertiliser and organic manures that can be applied each year. In these circumstances, the N rates are generally capped at 170 kg N/ha/yr. Factors that determine the N-max limit include crop type, expected crop yields and time of year sown. In detail, whole-farm organic manure limits include up to 170 kg N/ha/yr per holding and 250 kg N/ha per any single field, provided farmers meet necessary criteria and conditions.

To conclude, the N fertilisation rates advised among the ten countries have varied legal enforcements, from methods providing direct support for regulatory controls (Luxembourg, Ireland, United Kingdom), to those only related to bio-physical criteria (Table 12). For those countries whose

calculation methods do not serve as direct references for legal enforcement, the N recommendation rates are generally capped at a fixed regulatory level (N-max), in order to facilitate the control procedures. Countries whose calculation methods exhibit a high level of legal enforcement (e.g. Luxembourg, Figure 7);.) have a tendency to require the highest rates of N, whereas where the dose is smaller, there is a weak legal enforcement (i.e. it can be practically overtaken).

Table 12: *Distribution of countries according to the regulatory status of their fertiliser recommendations. From green to red: decreasing gradient of legal enforcement. The distribution of the countries within the different categories is the result of a global approach which is currently under discussion.*

Integration of the fertiliser recommendations in legal enforcement			
Regulation tool ←-------→ No legal enforcement			
Ireland Luxembourg	**France Germany Italy**	**Spain United Kingdom**	**Belgium Netherlands Switzerland**

4.5. The best innovations among the ten investigated countries.

It is obvious that the different methods basically rely on the same concepts, i.e. estimations with more or fewer calculation steps of the N mass balance centred at crop and year scale. However, among the ten countries, two exhibit original tools that we consider (in our opinion) worth highlighting.

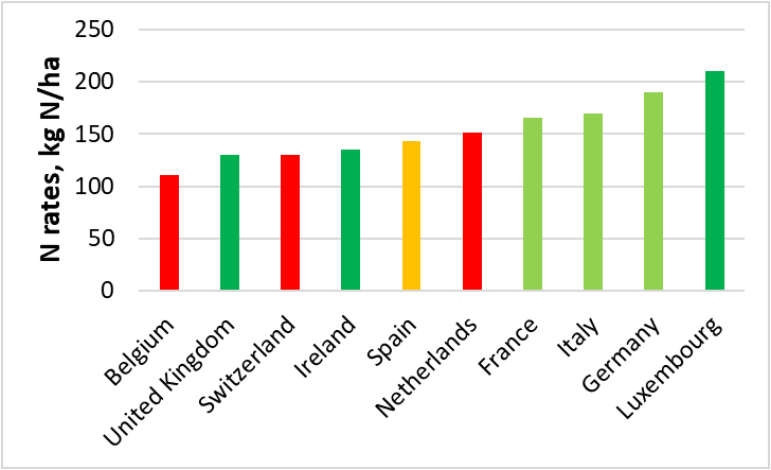


Figure 7: *Countries ranked by increasing sorting of their N-recommendation rates; the level of integration of the fertiliser recommendations in their legal enforcement*

is symbolised by the colour of the bars: from strong to weak enforcement (dark green, light green, orange, red).

In Germany, the supplementary mandatory mass balance performed at the farm level is a promising tool wherever massive imports of N-enriched feed is a potential threat to water and air quality. So far, the German regulation allows an excess of 170 kg N/ha/yr per holding; this amount will be lowered in the coming years. This farm-scale mass balance is considered to be a safeguard against risks of fraud or permissive field mass balance parameterisation. United Kingdom exhibits the same threshold at farm scale, but only for organic inputs.

Belgium is the only country implementing a control on the residual mineral N at harvest. Although the measurement of such an indicator probably exhibits methodological issues, its main quality is to be closely linked to the risk of leaching during the critical period of autumn and winter rainfalls. Residual Nmin measurements are already suggested to farmers in other countries (France, Luxembourg) for informative purpose and without any relation to control.

4.6. A detailed calculation method does not necessarily lead to higher NUE.

At the European scale, the mean level of the nitrogen use efficiency (NUE) was 63%, during the 2012-2014 period (Eurostat, 2020). There is a 30% gap between the most and the least efficient countries, among those investigated in the current study (Figure 8). In a first approach, and apart from Luxembourg, there are no correlations between the NUE calculated by Eurostat and the different factors analysed in this study; i.e. (a) type of method (mass balance, Corrected Standards, Pre-parameterised equations), (b) number of variables considered in each method, (c) N recommendation rates and (d) degree of legal enforcement.

Difficulties in relating the recommended calculation methods and the gross NUE are not surprising, since other parameters contribute to the N surplus at farm level and, hence, NUE. For example, farmers are not legally obliged to keep to the recommendations where the Nitrate Directive does not apply. Moreover, NUE is shown to be related to the specific crop-mix of every country: Zhang *et al.* (2015) particularly pointed out that countries dominated with crops (grasslands, wheat or winter cereals, rape, e.g. Ireland, France and Germany in Figure 8) exhibit a higher NUE than countries more concerned by horticultural and fruit crops (e.g. Italy, the Netherlands, Spain in Figure 8) since these latter countries rely on a large demand for N, although exporting very low amounts. Finally, Quemada *et al.* (2019) pointed out the very large influence of livestock farming systems and management (production intensity and breeding practices) on NUE at country levels, as well as difficulties in harmonising some calculation methods related to imported feed in the N budget of farms.

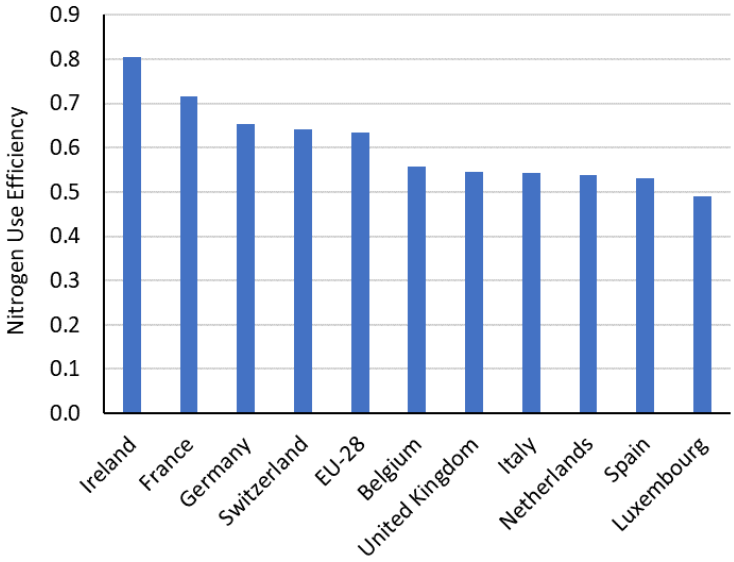


Figure 8: *Nitrogen Use Efficiency calculated on the 2012-2014 period at country scale (Eurostat, Agri-environmental indicator - gross nitrogen balance).*

5. CONCLUSIONS.

This study compared the methods used by ten West European countries to calculate the nitrogen fertilisation rates recommended for farmers. These quantities are of particular importance regarding the impact on the air and water environments of the reactive forms of nitrogen, and the relationship to the financial strength of farms in the current inflationary context. Our stocktake approach was particularly aimed at understanding the specificities of each method (i.e. type of equation), and, above all, at highlighting innovations, i.e. promising approaches that could increase the nitrogen use efficiency of fertilisers.

Our study suggests that the nitrogen mass balance approach should be used in every country, at the field scale; however, in some countries different parameters may be combined, giving the impression that some methods are 'simpler' than others. However, we underlined that there was no relationship between the number of parameters in an equation and the amount of fertiliser recommended, for a given cropping scenario.

According to the information provided by this study, we suggest that any attempt to standardise the fertilisation rules would meet the following limits:

a) there is great heterogeneity on variables that would a priori be considered to be robust (N uptake by plants, N released from farmyard manure);

b) some methods directly meet regulatory requirements, while others are centred on technical and economic issues;

c) the estimation of N losses, either by denitrification/volatilisation or by leaching, are generally addressed by 'security factors', hidden in integrative factors or apparently neglected. As they determine the gross nitrogen use efficiency, we suggest that the most exacting rule apply to all countries;

d) in spite of apparent homogeneity of calculation at the country scale, most of the countries exhibit regional adaptations to adapt these to local specifics; therefore, the real picture of heterogeneity is probably worse than the one depicted in this Proceedings.

Standardisation of the method should not be an end in itself; it should only serve to improve nitrogen use efficiency at the local and global scale. There is a real risk that efforts made by countries to adopt the same method would be counterproductive. To our opinion, we should rather try to spread what seems to be the more efficient initiatives (field + farm mass balances, soil mineral nitrogen measurement at harvest, fine soil organic matter mineralisation calculation) that we highlighted in this European stocktake study.

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