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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

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Glossary

Term or acronym	*Meaning or definition*
CAP	Common Agricultural Policy
CJEU	Court of Justice of the European Union
EU	European Union
GW	Groundwater
HD	Habitats Directive
MSFD	Marine Strategy Framework Directive
NAP	Nitrates Action Programme
ND	Nitrates Directive
NECD	National Emission reduction Commitments Directive
NRR	Nature Restoration Regulation
NVZ	Nitrate vulnerable zone
RPx	Reporting Period X
SW	Surface water
UN SDG	The United Nations Sustainable Development Goals
UWWTD	Urban Wastewater Treatment Directive
WFD	Water Framework Directive
IED	Industrial Emissions Directive
DWD	Drinking Water Directive

Terminology

“Nutrients” refers to Nitrogen (N) and phosphorus (P)

“Nitrate” (NO_3) is a form of nitrogen which is soluble in water

“Ammonia” (NH_3) is a form of nitrogen gas

“Phosphates” (PO_4) is a form of phosphorus soluble in water

“fertiliser” means any form of fertiliser (chemical fertiliser, organic fertiliser and manure)

“chemical fertiliser” refers to nitrogen fertilisers manufactured from natural gas

1. INTRODUCTION

1.1 Purpose and scope of the evaluation

The Nitrates Directive[1], adopted in 1991, aims to protect water quality across Europe by reducing and preventing pollution by nitrates from agriculture. The Directive was based on Article 130s of the Treaty establishing the European Economic Community. The evaluation of the Nitrates Directive was announced in the 2024 Commission work programme [1]. The evaluation covers all compulsory evaluation criteria set out in the Commission's better regulation guidelines to investigate effectiveness, efficiency, relevance, coherence and EU added value of the EU intervention.

The assessment of **effectiveness** will investigate to what extent the Directive's objectives are being achieved and to what extent it can continue to help reduce and prevent nutrient pollution from agriculture. It will consider how the Directive has been implemented, challenges that have arisen in applying the Directive, and any factors limiting its effectiveness. **Efficiency** will be considered by assessing whether the efforts and costs involved in implementing the Directive are proportionate for public administrations and farms, and whether the environmental and socio-economic benefits outweigh these costs. The assessment will also look at the potential for simplification, including in reporting and reducing the associated costs. In terms of **relevance**, the evaluation will assess the extent to which the objectives pursued by the Directive meet current societal needs, such as clean water and air and healthy soils, sustainable and resilient agriculture, and circularity. It will also assess whether the Directive is still in sync with the EU's environmental and climate commitments, the Water Resilience Strategy [2], and the Vision for Agriculture and Food [3]. The assessment of **coherence** will focus on the internal consistency of the Directive and its consistency with related EU legislation and policies, in particular on water, nature and agriculture. The evaluation of the Directive's **EU added value** will look at the extent to which an EU-level approach has improved on what could have been achieved by the Member States acting alone at national level. On 10 December 2025, the Commission adopted a **communication on the simplification of administrative burdens in environmental legislation** [4], in which it announced that it would complete the ongoing evaluations of the Nitrates Directive and take follow up measures, looking into how the objectives of the Directive could be achieved in the most effective and proportionate way[2].

1.2 Methodology

The evaluation is supported by several external studies (see **Annex I**) covering aspects such as: (i) changes in key input and results parameters at EU and Member State level; (ii) the effectiveness of measures under the Directive; (iii) the implementation of measures in the Member States; (iv) an analysis of historical nutrient flows; (v) implementation costs; (vi) the cost of nutrient pollution and the benefits of the Directive; (vii) impacts on competitiveness; (viii) case studies on Member State implementation of the Directive; (ix) coherence of the monitoring and reporting under the Nitrates Directive and other

[1] All references to legislation and regulations can be found at the back of this document.

[2] In line with the Commission's better regulation guidelines, Commission evaluation reports do not make any commitment for future action.

legislation; (x) overview of national implementation [5] and action programmes and (xi) an overview of case-law. The evaluation has also drawn on studies from the Commission's Joint Research Centre on the safe use of processed manure [6], on knowledge for Integrated nutrient management [7], and on the impact of the Nitrates Directive and the effectiveness of the manure limit [8].

To ensure that the public interest across the EU was properly reflected in the evaluation, consultation activities included an online public consultation[3], an implementation dialogue[4], three stakeholder events on specific topics, and interviews and questionnaires feeding into the support studies. Member State experts were consulted extensively in the Nitrates Expert Group[5]. Dedicated stakeholder events covered topics such as the objectives and scope of the Nitrates Directive, the costs and benefits of the Directive for farms and society, and opportunities for streamlining and simplification of monitoring and reporting under the Directive for public authorities. These topics were also covered by interviews and questionnaires, which were used to complement the information gathered through the literature review. The outcomes of the consultation activities are described in **Annex V –** *stakeholders' consultations: synopsis report* and in **Annex VI -** *outcome of consultations with the nitrate expert group***.**

The evaluation also relied on the implementation reports published by the Commission every four years [9] [10] [11] [12] [13] [14] [15] [16]. These reports cover changes in water quality and agriculture pressures in all Member States, based on the information formally reported by the national authorities. Data from these reports was a key source for the evaluation. Other sources of data from Eurostat, FAOSTAT and the European Environmental Agency (EEA) covering a longer time scale and external to the Nitrates Directive reporting complemented the data sources.

The evaluation covers the period since the Directive was adopted in 1991 until approximately 2023. It assesses how EU Member States have applied the Directive since it became applicable either pursuant to its Article 12 or under the accession treaties for the Member States that subsequently joined the EU. Where relevant data is available, the evaluation covers Member States in the period before they joined the EU. The last implementation report covering 2020-2023 is being drafted alongside this evaluation. Where possible, the assessment covers data received from Member States in connection with this report.

The Nitrates Directive is implemented differently in different Member States, reflecting the local environmental and agricultural situation. This evaluation focuses on how the Directive has worked overall and made a difference at EU level. Where relevant for the analysis, data has been disaggregated to take account of different approaches in the Member States or to highlight specific examples. The evaluation will analyse the practice of granting Member States specific implementing decisions (also known as derogations) adopted under the directive's Annex III.2.2 and Article 9(2), and the impact of those

[3] Protecting waters from pollution caused by nitrates from agricultural sources - Evaluation

[4] https://environment.ec.europa.eu/events/implementation-dialogue-environmental-legislation-2026-02-18_en

[5] The Nitrates Expert Group brings together experts from national administrations responsible for the implementation of the Nitrates Directive (https://ec.europa.eu/transparency/expert-groups-register/screen/home?lang=en GROUP E03023)

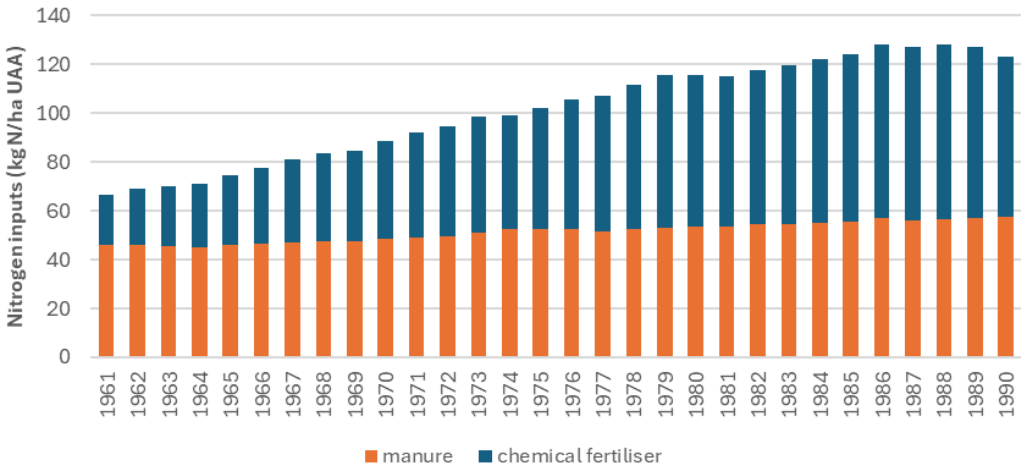
decisions on the Directive's implementation. A detailed explanation of the methodological aspects is provided in **Annex II** - *methodology and analytical models used*.

2. WHAT WAS THE EXPECTED OUTCOME OF THE INTERVENTION?

2.1 Description of the Nitrates Directive and its objectives (intervention logic)

The Nitrates Directive requires Member States to reduce and prevent the diffuse pollution of waters with nitrates from agriculture, as the spreading of livestock manure and chemical fertilisers results in losses to groundwater, rivers, lakes and coastal waters. Member States are required to promote good agricultural practices for the use of manure and other fertilisers for all farms and, in areas that are identified as polluted or at risk of pollution, enforce those practices for all farms in those areas through the implementation of action programmes with specific mandatory requirements to be implemented on farms. The societal objective is to protect drinking water resources and aquatic ecosystems. Its adoption in 1991 should be seen in the context of developments in European agriculture during the post-WWII years and the related environmental impacts of increasing fertiliser use. Figure 1 below shows the nitrogen[6] fertiliser inputs per hectare of agricultural land in EU12[7] since the early 1960s until the negotiation of the Nitrates Directive around 1990. Over this period, the use of chemical[8] nitrogen fertilisers increased by more than 300% and manure inputs rose by more than 20%. Total inputs almost doubled. This increase in nitrogen inputs was part of a global trend that resulted in an unprecedented increase in agricultural production. At the same time, however, it also brought about an increase in emissions of excess nitrogen with detrimental effects on the aquatic environment [17].

Figure 1[9] Nitrogen fertiliser inputs in the EU12, 1961 - 1990 (kg N/ha)



[6] Nitrogen (N) and phosphorus (P) are the two most important macronutrients besides potassium (Ka) that are applied in agriculture to promote crop growth. More importantly they are the main causes of negative environmental effects. Nitrate (NO_3) is a particular chemical form of nitrogen which is soluble in water and highly available for plants. Likewise, phosphates (PO_4) are soluble and highly plant available forms of phosphorus. Livestock manure includes both nitrogen and phosphorous in different forms and proportions depending on the type of livestock and production method.

[7] Member States when the directive was adopted in 1991: Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, Netherlands, Portugal, United Kingdom.

[8] For the sake of simplicity, the term "chemical" fertilisers is used in this document as it corresponds to the term used in the Nitrates Directive. Sources commonly refer to the term "inorganic" fertilisers.

[9] Source: European Commission based on FAOSTAT data.

The rise in nitrate concentrations in fresh ground and surface waters creates problems for their potential use as drinking water resources, as a high concentration of nitrates is toxic for humans and makes freshwaters unsuitable for human consumption. UN World Health Organisation guidance has for decades set a limit of 50 mg nitrates per litre as the maximum allowable concentration in potable water[10], a limit that had also been adopted in European directives on drinking water quality and protection of surface waters. Nitrate pollution therefore creates costs for treatment of drinking water and may cause risks to human health if not treated, e.g. in local rural wells. An excess supply of nitrogen and phosphorus leads to the over-fertilisation ("eutrophication") of surface waters, resulting in reduced biodiversity and resilience of aquatic ecosystems. In more extreme cases eutrophication can take the form of topic algae blooms or oxygen depletion events in lakes or coastal seas, killing fish and other aquatic life, sometimes over large areas[11]. While the Nitrates Directive does not explicitly mention phosphorus, livestock manure is a significant source of both nitrogen and phosphorus, especially in regions with large animal concentrations. The Nitrates Directive was adopted in parallel with the Urban Wastewater Treatment Directive, which aimed to address the nutrient pollution from urban wastewaters, recognised as the most important source of phosphorus to the aquatic environment at the time[12]. For more background and context on the adoption of the Nitrates Directive see **Annex VII**.

The **intervention logic** of the Nitrates Directive can be generally depicted as in Figure 2 below, setting out the needs, objectives, inputs/activities, outputs, results, and impacts, corresponding to the language and concepts currently used by the Commission's better regulation guidelines.

The **societal needs** that the Nitrates Directive was designed to address stand out clearly from the recitals of the directive, which note that the nitrate content of water in some Member States was increasing and was already high compared with standards laid down in existing legislation on waters intended for human consumption, and that there was a need for the protection of the North Sea and other waters in the Community. To protect human health, living resources and aquatic ecosystems and to safeguard other uses of water, it was therefore necessary to reduce water pollution caused or induced by nitrates from agricultural sources and to prevent further such pollution. On this background, the Fourth Environmental Action Programme [19] had indicated in 1987 that the Commission intended to present a proposal on the control and reduction of water pollution resulting from the spreading or discharge of livestock effluents and the excessive use of fertilisers[13].

[10] WHO guidelines for drinking water quality (GDWQ)

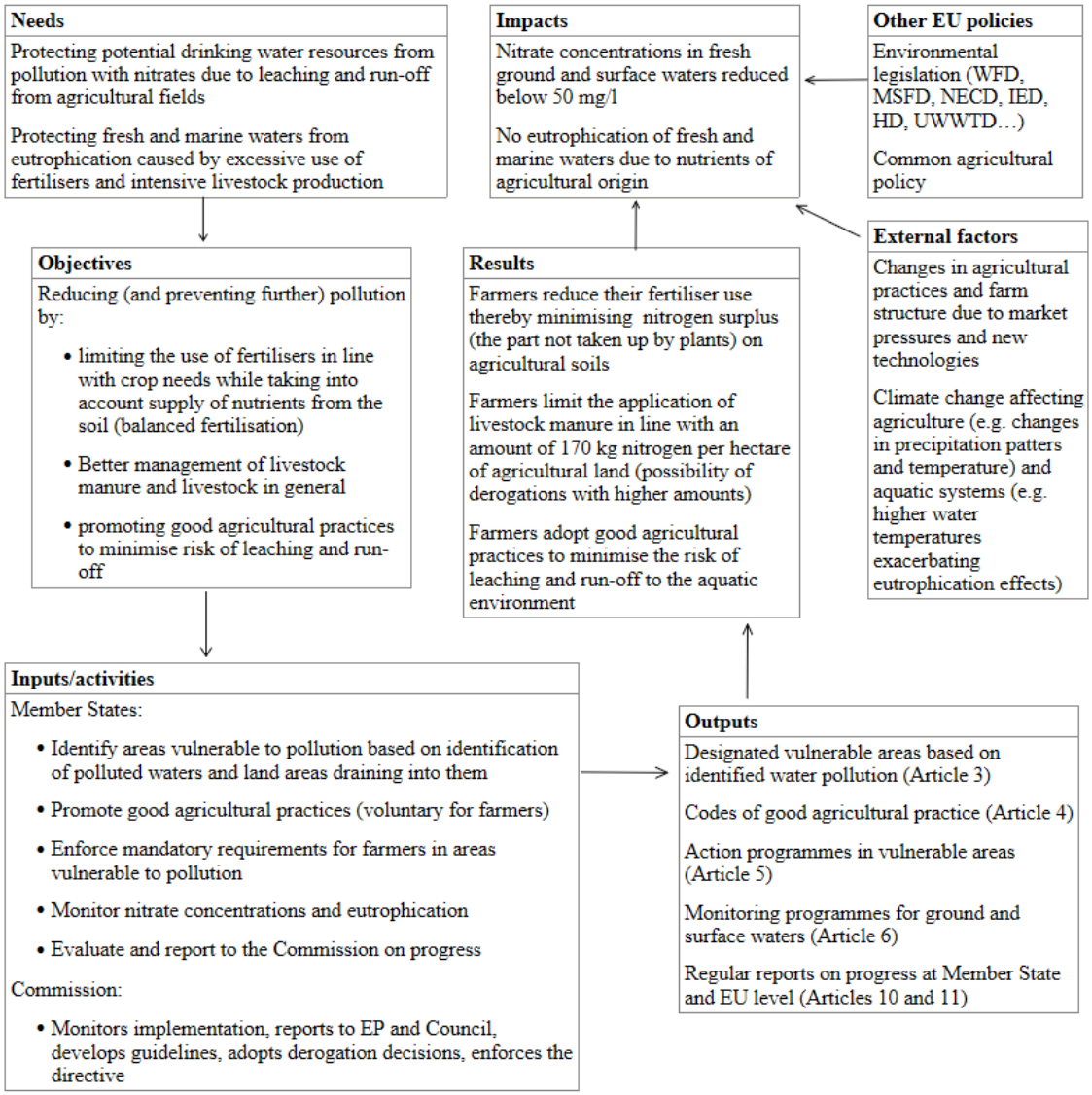
[11] While nitrogen tends to be the most important factor in the eutrophication of marine waters, phosphorus tends to be more important in freshwater systems. However, in practice the interplay between the two is complex and varies according to local circumstances.

[12] In 2001, based on the assessments by international sea conventions during the 1990s and on earlier literature and measurements since 1985, the EEA concluded "that eutrophication of marine waters caused by excess load with nitrogen and phosphorus nutrients from human activities is a major problem in many European coastal areas. [18]

[13] The Nitrates Directive contributes to the achievement of several UN Sustainable Development Goals (SDG). It contributes to achieving SDG 6 (Clean Water and Sanitation) and SDG 14 (Life below water) by preventing and reducing eutrophication and harm of aquatic life. The Directive also contributes to the achievement of SDG 12 (Responsible Consumption and Production) by encouraging the adoption of sustainable agriculture practices and to SDG 13 (Climate Action) by promoting more efficient use of nitrogen fertilizers. Finally, it

Article 1 of the Nitrates Directive defines its **objectives** in general terms as "reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution". Pollution is defined in terms of nitrate concentrations in fresh ground and surface waters exceeding the drinking water standard of 50 mg nitrates per litre or the eutrophication of surface waters (Annex I of the directive). Specific objectives include limiting fertiliser use ("balanced fertilisation"), limiting livestock manure application, and promoting good agricultural practices. The recitals of the directive refer to the need to address "excessive use of fertilisers" and to "control the problem arising from intensive livestock production", where high livestock numbers in some regions have made it difficult to dispose of the resulting livestock manure without a negative impact on the environment.

Figure 2 Intervention logic of the Nitrates Directive.



In operational terms, the directive envisages several **activities** to be carried out. Member States should put in place monitoring to identify waters affected by pollution. On this basis, they either designate the land areas contributing to the pollution as "nitrate vulnerable

can also help to the achievement of SDG 2 (Zero Hunger) by promoting sustainable food production via practices that reduce nitrate pollution and maintain soil fertility.

zones" (NVZ) and enforce mandatory measures for farms within these areas, or they decide to apply mandatory measures across their entire territory[14]. The directive leaves wide discretion to Member States to design the measures in line with local circumstances, setting out only the main types of measures to be included (for details, see box 1). A key measure is the application of "balanced fertilisation". This means that when applying fertilisers to a crop, account should be taken of the nitrogen needs of the crop as well as of other sources of nitrogen to the crop, such as the nitrogen available in the soil at the start of the growing season, nitrogen being made available from the mineralisation of organic nitrogen reserves in the soil, and the addition of nitrogen compounds from livestock manure. Compared to chemical fertilisers, livestock manure is associated with higher risks of nitrogen losses due to a more unpredictable release of nitrogen to the soil[15], a high risk of ammonia emissions[16], and as a result, lower overall ***nutrient use efficiency***[17]. The fact that livestock manure is continuously available and needs to be disposed of regardless of crop needs further increases the risks. Manure, as already mentioned, is also a major source of phosphorus. The directive therefore limits the application of livestock manure in vulnerable zones to the equivalent of 170 kg of nitrogen per hectare per year, broadly corresponding to a livestock density of 2 livestock units (LSU) per hectare[18]. The directive provides flexibility to set a higher amount where justified[19]. Apart from these quantitative limitations on the use of fertilisers and manure, the directive identifies good practices for the handling of fertilisers and manure on farms to minimise the risk of losses. A set of core practices should always be included in the national implementation. Others are indicated as optional.

Member States should also continue to monitor the state of their waters in terms of nitrate concentrations and eutrophication and report on progress every four years. The European Commission in turn is charged with ensuring overall implementation, reporting to the European Parliament and Council, developing guidance, adopting derogations from the livestock manure limit, and enforcing the directive through cooperation and dialogue with Member States and if needed infringement procedures.

[14] Member States are also required to promote good practices through training and information for farms.

[15] A large share of the nitrogen in manure comes in organic form and is released slowly over several years.

[16] Ammonia emissions to the air later result in the deposition of nitrogen from the air, which can provide a significant additional contribution to the nitrogen balance in agricultural soils. In natural areas, lakes and coastal seas this can result in the eutrophication of natural ecosystems.

[17] Nutrient use efficiency refers to the share of nutrient contained in a fertiliser that is taken up in the crop. This varies depending on crop, application method, fertiliser type and other factors. For the EU as a whole, overall nitrogen use efficiency has been estimated to around 60 % [20], meaning that around 40% of nitrogen is lost in the environment. The losses are higher for organic fertilisers such as manure. When planning the application of fertilisers, the use of organic fertilisers (such as manure) is typically counted based on their relative efficiency in comparison with mineral fertiliser, based on the share of nitrogen that is expected to be available to the crop in the course of the growing season. This fertiliser replacement value (or equivalency) can vary significantly, with examples of first year equivalencies ranging from around 20-40% for solid manures to 30-70% for slurries, translating into significantly higher losses than for mineral nitrogen fertilisers. Repeated applications over several years increases the long-term fertiliser replacement value of manure due to a build-up of organic nitrogen in the soil [21].

[18] The original Commission proposal referred to a requirement for Member States to ensure that the amount of livestock manure applied to the soil would not exceed the amount produced by 2 dairy cows or by the equivalent number of other animal types [22].

[19] For the first four-year action programme, Member States could decide to apply a limit of 210 kg, roughly corresponding to 2 ½ LSU/ha. After this first programming period, the directive requires any derogations to be approved by the Commission and the Member States via a comitology procedure.

Box 1: Annex II and III of the Nitrates Directive specify the types of measures that Member States should require farms to take in vulnerable zones. They are listed below with a brief explanation of how they reduce pollution risks. The measures are further discussed in section 4 and detailed explanations can be found in Annex XI.

The measures that Member States should always include in their action programmes concern:

- ***periods when the land application of different types of fertilisers is prohibited***: autumn and winter application of fertilisers (including manure) increases the risk of nitrate leaching, because crop nitrogen uptake during the autumn/winter period is generally low and there is sufficient over-winter rainfall to transport manure derived nitrate beyond crop rooting depth. Bare land also creates higher risks of runoff. The rules are set by national authorities, taking account of local climatic and other conditions.

- ***land application on water-saturated, flooded, frozen or snow-covered ground***: Soils that are frozen or covered in water or snow tend to have a high risk of overland flow and run-off. It is therefore a basic precaution to avoid spreading fertilisers or manure under such conditions. In the absence of rules, farmers may be tempted to spread manure on frozen soils in early spring, as these can better withstand heavy machinery, or they may be tempted to bring manures out on wet or snow-covered soils if their manure storages are full.

- ***the capacity of storage vessels for livestock manure, which must exceed that required for storage throughout the prohibition period***: storage in autumn and winter allows farms to valorise livestock manure as fertiliser in spring. This enhances overall nitrogen use efficiency on the farm, reduces the need for chemical fertilisers, and mitigates the risk of leaching and run-off. Insufficient storage capacity can lead to the untimely spreading of manure during winter or early spring. The capacity requirements are set by the national authorities.

- ***limitation of the land application of fertilisers based on a balance between the foreseeable nitrogen requirement of the crops and the nitrogen supply from all sources (balanced fertilisation)***: setting the right amount of fertiliser for the crop is one of the most important factors in limiting the leaching of excess nitrates. Leaching can be minimised through carefully estimating expected yields and available nitrogen in the soil and by taking into account soil characteristics and climate. Rules or limits are set by national authorities in line with local conditions and scientific evidence. The absence of rules or explicit limits can push farms to apply more than a precautionary approach would suggest.

- ***the amount of livestock manure that can be applied to the land each year (maximum 170 kg nitrogen per hectare, or higher amounts in the case of derogations)***: livestock manures are associated with specific risks, due to their organic nature and the need for farms to dispose of them regardless of crop needs. The 170 kg limit is a precautionary measure meant to mitigate these risks. Derogations can be granted to Member States via a comitology procedure where it can be justified that a higher amount would not undermine the objectives of the directive.

- ***land application on steeply sloping ground***: slopes increase the risk of soil erosion and run-off from agricultural fields, which can result in the concentration of nutrients in low-lying areas or in watercourses. The risks can be mitigated by the choice of crop and other agricultural practices, including restrictions on fertiliser use.

- ***the conditions for land application of fertiliser near water courses***: restricting the spreading of fertilisers within a buffer strip along watercourses can reduce the risk of runoff, leaching and direct deposition of fertiliser on the water. The width of the buffer strip needed can depend on a variety of factors including the type of fertiliser, slope of the land, cropping and tillage practices, the use of precision techniques and equipment, and whether the buffer has a permanent plant cover such as grasses, shrubs or trees.

Member States may also include additional measures, notably in relation to:

- ***land use management, including crop rotations and share of permanent crops***: agricultural crops have different risk profiles when it comes to nitrate leaching and run-off. Examples of risky crops are maize, potatoes and vegetables. Risks can be reduced by including a rest crops (grass, alfalfa) or set-aside requirement in the crop rotation. Grass is associated with lower risk due to a longer growing season. Derogations from the manure application limit are generally conditioned on having a minimum share of grassland on the farm.

- ***minimum vegetation cover during sensitive periods***: Cover/catch crops cover the soil between two main crops, catching the residual nitrate in the soil and retaining it during winter, releasing it again in spring. In this way, cover/catch crops reduce nitrate leaching and increase the transfer of nitrogen to the subsequent crop.

- ***fertiliser planning and record keeping***: this measure complements the balanced fertilisation requirement, as fertiliser planning is one of the steps contributing to this and record keeping can facilitate compliance checks by public authorities. Most Member States have implemented these requirements in some form or another.

- ***irrigation systems***: while increasing crop yield and nutrient uptake, irrigation also increases the water content in soils, increasing the risk of leaching and runoff. Good irrigation management can help manage these risks.

The concrete **outputs** of these activities are set out in the provisions of the directive. NVZ should be designated by the Member States based on the identification of polluted waters (Article 3). Codes of good agricultural practice should be established, implemented by farms on a voluntary basis, and promoted through training and information for farms (Article 4). Action programmes should be established and enforced in NVZ with mandatory measures applicable to farms in those areas (Article 5). Monitoring of waters should be established and implemented (Article 6). The Member States should prepare reports to the Commission every four years (Article 10) on the basis of which the Commission should report to the European Parliament and Council (Article 11).

The expected **results** of the intervention can be broadly defined in terms of addressing the three specific objectives set out. Fertiliser use in all Member States should be limited in line with crop needs and available nitrogen in the soil (balanced fertilisation). Management of livestock should be improved by limiting the application of livestock manure to 170 kg nitrogen per hectare per year on farm level (or the derogation amount) in NVZ. Agricultural practices should be put in place and be mandatory for farms in the NVZ minimising the risk of water pollution due to leaching and run-off from fields. A key result indicator is the so-called ***nitrogen balance***, which compares the inputs of nitrogen from fertilisers (including manure) and other sources (deposition from air, biological fixation in soil) with the removals in the form of nitrogen contained in the crop harvested[20]. The balance is an indicator of the degree to which farms have achieved the objective of balanced fertilisation. It is also a good indicator of the risk of nitrogen losses in the form of nitrate and ammonia emissions from the farm.

The expected **impacts** relate to the overall policy needs identified. Elevated nitrate concentrations in surface and groundwaters stemming from agricultural sources should eventually be reduced throughout the EU to ensure compliance with health standards for drinking water (50 mg/l) and address eutrophication of fresh and marine surface waters caused by agricultural nutrients. The causal links between fertiliser use and water quality are illustrated in Figure 3 and Figure 4 below. Figure 3 shows how the nitrogen in fertilisers and manure passes through different states in the soil as it is processed by plants and microorganisms. It ultimately leaves the soil through either harvesting of crops, gaseous emissions to air, soil erosion and runoff to surface waters, or leaching to groundwater. Figure 4 shows in schematic form how the increase in fertiliser use in the latter part of the 20th century was reflected over time in higher nitrate concentrations within shallow and deep groundwaters as well as in groundwater discharge to surface waters, illustrating the direct causal link between fertiliser use and nitrates concentrations in water.

Agriculture is the main contributor of nitrates to groundwaters and the main diffuse source of nitrates in surface waters. Deep groundwaters act as a long-term sink for nitrates, which can build up and stay for a very long time. Shallow groundwaters react more quickly to changes in the level of inputs over time. Surface waters (streams and lakes etc.) in turn react with different time-lags depending on the surrounding geohydrological conditions and the relative share of the water that is supplied through respectively overland flow and discharge from shallow or deeper groundwaters. Where discharge from deeper groundwater is more important, nitrate concentrations in surface water react more slowly.

[20] Glossary:Gross nitrogen balance - Statistics Explained - Eurostat

Nitrates – together with phosphates[21] - cause eutrophication in surface waters. The level of nutrients in surface water depends not only on agricultural contributions but also on background flows as well as discharge of wastewaters from urban areas, emissions from scattered housing not connected to the sewage network, deposition from the air etc. Nutrients also build up in sediments with the result that eutrophication effects can continue for a long time after the original source of the pollution has been reduced.

Figure 3 The flow of nitrogen from fertilisers and manure through the soil[22]

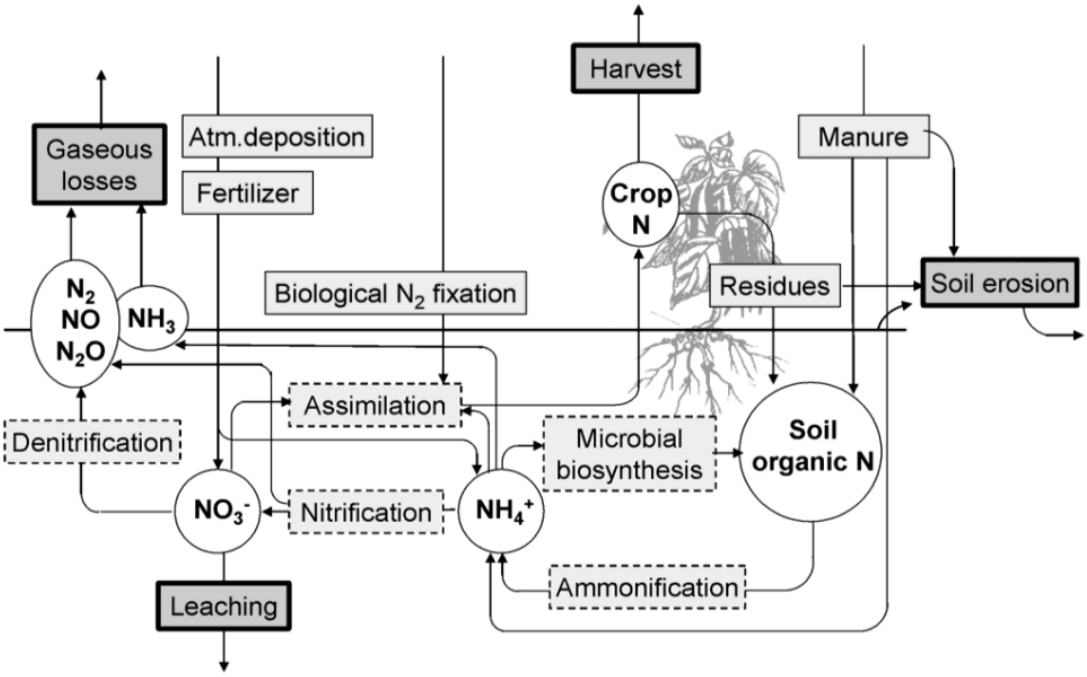
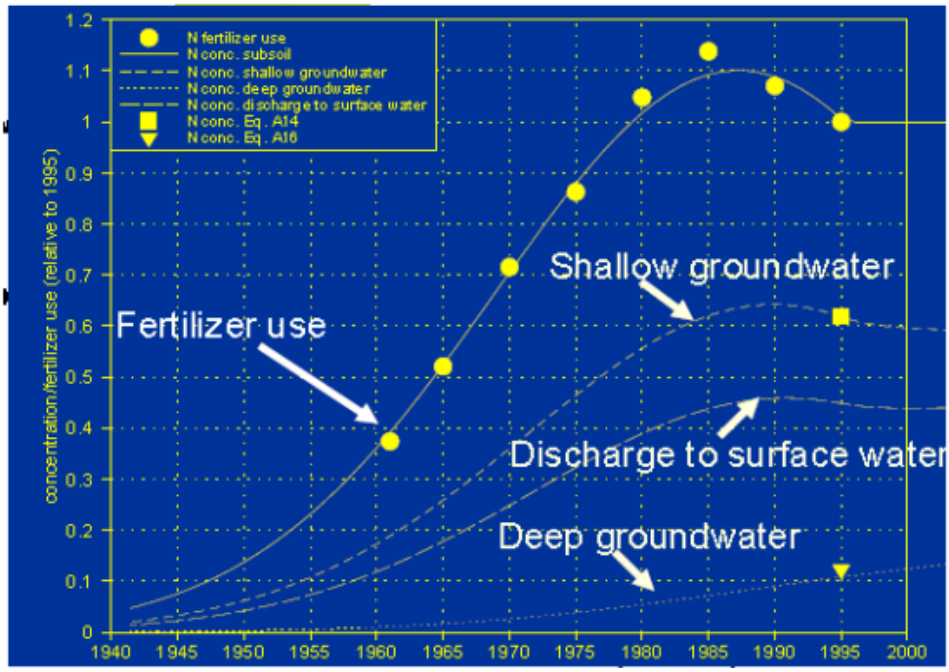


Figure 4 Evolution in fertiliser use and nitrate concentrations in groundwaters[23]



[21] Phosphorus is typically the limiting factor in rivers and lakes and nitrogen is important in coastal waters.
[22] Source: Recommendation for establishing action programmes PART C (2011), p. 22. [21]
[23] Source: Recommendation for establishing action programmes PART C (2011). p. 53. [21]

Box 2: eutrophication

The Nitrates Directive defines eutrophication as "the enrichment of water by nitrogen compounds, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned". In practice, eutrophication is the result of a complex interaction of both nitrogen (N) and phosphorus (P) in the aquatic environment. Both nutrients are necessary for plant growth. Their abundance varies across aquatic systems (rivers, lakes, estuaries, coastal and marine waters), and these systems have adapted to this (relative) abundance. Freshwater systems tend to be P limited whereas saline systems tend to be N limited.

An increase in the abundance of the limiting nutrient brings the system out of balance by accelerating plant growth beyond the normal level. The main causes of such an overabundance of nutrients include the leaching and runoff of nutrients from agriculture, urban and industrial wastewater discharges, and atmospheric deposition due to air pollution (especially for marine systems).

The concrete manifestations of eutrophication include the occurrence of harmful algal blooms (e.g. cyanobacteria), a general overabundance of algae and plant growth, lack of transparency in the water column, incidences of hypoxia (lack of oxygen) in bottom waters, resulting in dead zones and fish kills. Longer term effects include a reduction in biodiversity with the possible spread of opportunistic species at the detriment of more vulnerable species that are native to the ecosystem as well as a general impoverishment of the system.

The assessment of eutrophication is closely related to the assessment of ecological status under the Water Framework Directive (CIS Guidance Document No 23, EC 2009). The assessment is based on biological and physico-chemical criteria as set out in the table below. The assessment also includes supporting elements such as nutrient status, i.e. the relative abundance of N and/or P. Generally, water bodies are considered to be affected by eutrophication if they are in less than good status.

Ecological Status	WFD normative definition	Primary impacts (e.g. phytoplankton biomass)	Secondary impacts (e.g. O_2 deficiency)
High	Nearly undisturbed conditions	None	None
Good	Slight change in abundance, composition or biomass for relevant biological quality elements	Slight	None or only slight
Moderate	Moderate change in composition or biomass for relevant biological quality elements	Change in biomass, abundance and composition begins to be environmentally significant, i.e. pollution tolerant species more common.	Occasional impacts from increased biomass
Poor	Major change in biological communities	Pollution sensitive species no longer common. Persistent blooms of pollution tolerant species	Secondary impacts common and occasionally severe
Bad	Severe change in biological comm.	Totally dominated by pollution tolerant species	Severe impacts common

Eutrophication is a complex phenomenon, which is not always straight forward to measure with a high level of certainty. More importantly, some of its effects can be long-term and can interact with other factors, such as physical or chemical impacts. While nitrate concentrations provide a clear indicator of the potability of ground and surface waters, the eutrophication assessment cannot be pinned down to a single variable in the same way.

Various methodologies have been developed to estimate the nutrient threshold associated with conditions supporting good status in different types of water bodies. Once these thresholds are reached it is then assumed that the system may adjust over time and ultimately recover its good ecological status, but the process can take a very long time to fully play out. Once certain species have disappeared from an ecosystem, they take time to come back.

While reaching the necessary reduction in nutrient flows may already be a major challenge in and of itself, the challenge is further aggravated by the fact that nutrients can continue to linger in the environment for long periods after they have been released. This is particularly the case for phosphorus, which accumulates in soils and sediments, from where it can be released slowly over time. Nitrogen is less persistent, as it can be released to the atmosphere through denitrification, but it can also stay around for an extended period embedded in organic material. As a result, once nutrient flows have been reduced, it will take time for nutrient levels to adjust downwards as well.

2.2 Points of comparison

When the Nitrates Directive was adopted in 1991 it did not undergo a formal impact assessment. It is therefore not possible to compare with the original scenario of how the achievement of the directive's objectives was intended to play out. It is evident that the aim of the directive was to satisfy the quality standards for waters corresponding to the **impact indicators** in the intervention logic above: reducing concentrations in freshwaters below 50 mg nitrate per litre and addressing agriculture's contribution to the eutrophication of fresh and marine surface waters. However, the directive does not define a timeline for the attainment of its objectives[24]. The recitals to the directive explicitly recognise that the hydrogeology in certain Member States is such that it may be many years before measures lead to improvements in water quality. Indeed, groundwater aquifers and natural ecosystems may respond to a reduction in inputs over the course of many years, even decades in some cases, before fully reflecting the lower input. For groundwaters, this is due to the residence time of groundwater in different parts of the soil profile. For eutrophication, long lag times can be due to retention of organic material in bottom sediments of rivers, lakes and coastal seas and the retention of phosphorus in riparian soils, meaning that initial inputs from agriculture can continue to have residual impacts over several decades. In addition to this comes the complex dynamics of ecosystems, which may take a long time to recover from significant disturbances. The directive is based on a clear recognition of the long-term nature of the challenges to be addressed. The directive therefore does not require that Member States ensure immediate compliance with the water quality standards set out in the directive, which would indeed be impossible, but that they put in place effective measures to prevent further deterioration and to reduce the pollution already accumulated, which would allow waters to reach quality standards within a reasonable timeframe. As a result, the impact indicators may take a long time to properly reflect improvements resulting from the intervention under the Nitrates Directive. For this reason, it is also relevant to look at the evolution of intermediate indicators for agricultural inputs, corresponding to the **result indicators** in the intervention logic: manure and fertiliser inputs, nitrogen balances and the implementation of good agricultural practices. These variables should provide an idea of how the directive has been able to reduce the agricultural pressures ultimately affecting the level of pollution.

It should also be recognised that the Nitrates Directive is not alone in addressing nutrient pollution of waters and that various **other EU policies as well as external factors** have played a role in affecting outcomes. Relevant EU policies include the broader water acquis, which has evolved significantly since the adoption of the Nitrates Directive. The Urban Wastewater Treatment Directive (UWWTD)[25], also originally adopted in 1991, can be regarded as a sister directive to the Nitrates Directive, addressing nitrogen and phosphorus in effluents from urban wastewater discharge, the main source of eutrophication of surface waters besides agriculture. In 2000 the Water Framework Directive (WFD) introduced an overarching legal framework for water policy in the EU, with comprehensive water quality objectives and deadlines, significantly changing the policy context for the Nitrates Directive's implementation. In particular, the WFD set a deadline by the end of 2027 for Member States to ensure that all ground and surface water bodies in the EU reach at least 'good' status in line with certain conditions. In 2008 the Marine Strategy Framework

[24] Article 1 rather sets an open-ended objective to "reduce" and "prevent" pollution.

[25] References to all EU legislation cited in this evaluation can be found at the back of this document.

Directive (MSFD) set out a general framework to improve the state of marine waters, including on eutrophication. Relevant EU legislation also includes the National Emission reduction Commitments Directive (NECD), which aims to reduce emissions of certain air pollutants including ammonia, and the Industrial Emissions Directive (IED), introducing requirements for industrial permitting for large pig and poultry farms to reduce their environmental impacts. Finally, the Common Agricultural Policy (CAP) plays a key role in defining the framework conditions and public interventions for the agricultural sector in the EU, and the successive CAP reforms have played an important role in the implementation of the Nitrates Directive. Apart from policy interventions, other external factors also have had an impact on outcomes, such as global and regional markets within which the agricultural sector functions, the evolution of agricultural practices and technologies, consolidation and specialisation of farms. Climate change also affects outcomes by making the management of nutrient losses on farms more challenging, and by directly impacting the response of the aquatic environment to nutrients, exacerbating eutrophication. The analysis below will cover these factors more thoroughly.

All in all, the context is a complex one and it is not always straightforward to fully separate the impacts of the Nitrates Directive from those of the various other factors.

Section 3 will provide data on the evolution in the various indicators, including water quality, fertiliser and manure inputs, as well as nitrogen balances. Section 3 will also highlight the external factors that have had an impact on the evolution of these indicators. See Annex II for a further discussion of the methodological approach to this aspect.

3. HAS THE SITUATION EVOLVED OVER THE EVALUATION PERIOD?

3.1 Implementation of the Nitrates Directive

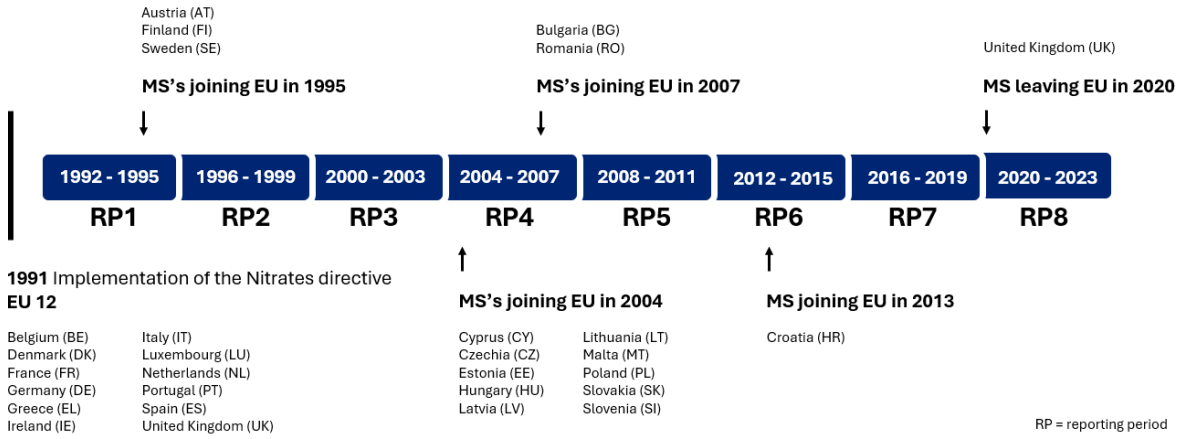
The Nitrates Directive is based on a four-year implementation cycle (Figure 5). Based on reports received from the Member States, the Commission presents an overview of progress in an implementation report to the European Parliament and the Council every four years[26]. Each reporting period (RP) comprises a cycle of obligations to be implemented under the Nitrates Directive, as Member States are required to monitor waters and identify polluted waters, review their NVZ and action programmes every four years, and to revise them where needed. In this way, the directive set out a coherent policy cycle to be reiterated every four years up until today (Figure 6). The transposition and implementation of the Nitrates Directive since 1991 is described further in Annex VIII.

Figure 5 Implementation cycle of the Nitrates Directive



[26] Nitrates - European Commission

Figure 6 Graphic representation of implementation cycles and enlargements



In the majority of Member States, the responsibility for the implementation of the Directive is coordinated through several ministries, primarily ministries responsible for water protection and agriculture.

The initial transposition and implementation in the Member States showed significant delays and transposition issues. The 2012 Fitness Check of EU Freshwater Policy [23] found that the implementation of the Nitrates Directive had been slow overall and that problems persisted, mainly in relation to insufficient designation of NVZ and non-conformity of action programmes. During the next cycles, Member States kept reviewing their action programmes and designation of NVZ, with the Commission promoting full implementation of the various obligations under the Directive, with the development of guidelines, exchanges of good practices and through infringement procedures (see Annex VIII).

The overall cycle of the Nitrates Directive is now well established, with Member States making use of their flexibility in approaching the review and revision of NVZ and action programmes. Experience shows that a four-year implementation cycle can be tight, as updating NVZ and reviewing action programmes, including assessments and consultation requirements, takes time. The implementation of the Nitrates Directive in the Member States has seen an increasing involvement of stakeholders in the various steps of the process. In 2012, the CJEU confirmed that the SEA Directive also applies to the adoption of nitrates action programmes, including an obligation of public consultation. Many Member States have established working groups with farm organisations to consult on the design of their action programmes. Some Member States have involved civil society (nature organisations) or drinking water companies in these groups.

3.1.1 Establishing water monitoring networks and identifying polluted waters

The establishment of a comprehensive water monitoring framework using a network of stations is critical for the effective implementation of the Nitrates Directive, to identify polluted waters and designate Nitrate Vulnerable Zones (NVZs). Although initial development was slow, informal guidelines from the Nitrates Committee and the adoption of the Water Framework Directive (WFD) in 2000 significantly boosted the development of the monitoring networks, as the Member States increased the density of monitoring points in subsequent reporting periods (see Annex VIII for additional details).

With the establishment of the comprehensive networks, there was steady progress in the nitrate concentration monitoring and reporting. However, the complexity of assessing the trophic status of surface waters due to varied methodologies and lack of explicit thresholds for nitrates and phosphorus concerning eutrophication delayed its effective monitoring. Guidance in 2009 [24] aimed to address these challenges, yet subsequent Commission implementation reports still highlighted difficulties in evaluating trophic status.

Since 2016, the Commission has encouraged methodologies developed by the ECOSTAT working group and to use the corresponding assessments of ecological status under the WFD. Whereas an increasing number of Member states are using the WFD assessments, the recent RP7 and RP8 reports reveal ongoing variability in approaches among Member States. (Additional information on monitoring networks is included in Annex VIII and on interactions between the monitoring under the Nitrates Directive and the WFD in Annex XV).

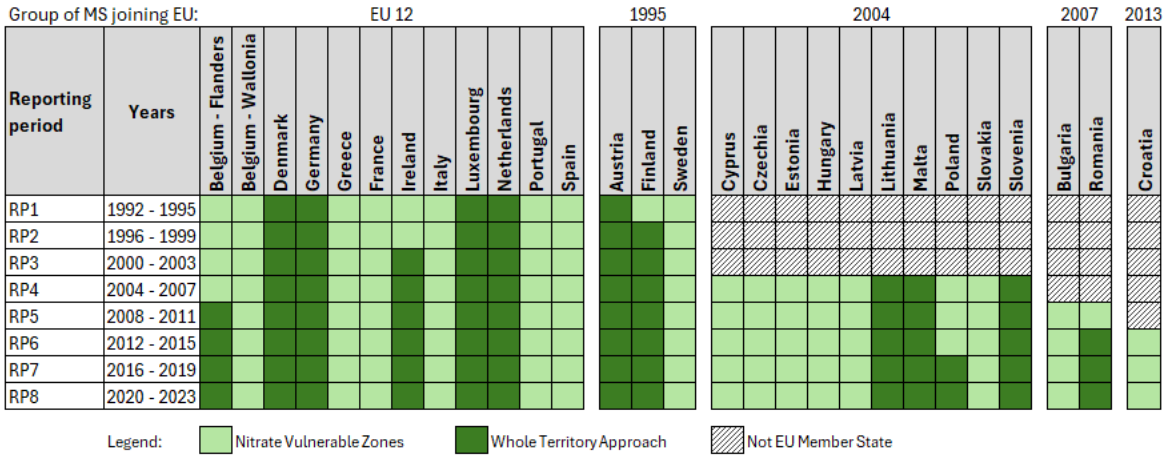
3.1.2 Designating nitrate vulnerable zones (NVZ)

Once polluted waters have been identified, Member States designate the land areas draining into these waters as NVZ, unless they implement an action programme throughout their entire national territory (whole territory approach). The designation of NVZ was initially slow. In the first three reporting cycles, the Commission noted that the designation was insufficient or that some Member States had failed to fulfil this obligation. Factors for the slow designation included the insufficiency of monitoring networks, difficulties in identifying the origin of the pollution (agriculture or urban wastewater) as well as the sensitivity of imposing mandatory measures on farms. Over the years the Commission has opened infringement proceedings due to failure to designate areas where water is polluted or at risk of being polluted or which drain into marine waters. (see Annex IX on the enforcement by the European Commission and national courts).

The whole territory approach gives Member States flexibility to dispense with the designation of NVZ, which can be complex and politically sensitive. It also gives a more equal treatment of farms across the entire country and a stronger preventive impact by enforcing good practices everywhere. It does not prevent a targeted approach, as it leaves flexibility for Member States to vary requirements geographically in line with the nitrate pollution or eutrophication challenges in different regions[27]. Figure 7 shows the use of the whole territory approach over time.

[27] Such approaches have been introduced in several Member States, including Germany, Denmark, Belgium and the Netherlands.

Figure 7 Approach adopted by Member States on designation of NVZ



The geographic extent of NVZ and Member States applying the whole territory approach in 2024 is shown in Figure 8, based on the latest reporting by Member States and covers more than two thirds of agricultural land in the EU.

Figure 8 Nitrate vulnerable zones and whole territory approaches (2024)



3.1.3 Establishing nitrates action programmes

For NVZ or in the whole territory approach, the Nitrates Directive lists the types of measures to be included in the nitrates action programmes in annexes II and III to the

Directive (see box 1). The measures aim to enforce good agricultural practices for the application of fertilisers and livestock manure to reduce the risks of pollution[28]. It is the responsibility of Member States to adapt the design of the measures according to local conditions and to the level of pollution. In several Member States, there are regional nitrates action programmes, sometimes complementing a common national programme.

In 1997, the RP1 implementation report [9] noted that few Member States had adopted an action programme. Whereas some Member States already had measures in place before the adoption of the directive, reflecting national policies, most had to develop their programmes. By the time of the RP2 implementation report [10], most Member States had adopted nitrates action programme, but the Commission concluded that several Member States still failed to implement all the required measures. After several implementation cycles the action programmes were successively strengthened, partly spurred on by infringement proceedings (See Annex IX). Cross-compliance, linking CAP payments to basic environmental requirements, introduced as part of the 2003 reform of the CAP (see Annex XVI), further strengthened the enforcement of action programmes. The RP7 implementation report [15] found that the measures listed in Annex II and Annex III of the Directive were implemented in all Member States.

As mentioned, the directive's annexes outline the type of measures that national action programs (NAPs) should include, but Member States have scope to tailor and build upon these to account for national and regional circumstances. This flexibility is crucial for tailoring measures to local circumstances such as climate, soil characteristics, and farming practices to optimize pollution reduction effectiveness. Consequently, there is a very high variability in the 76 different NAPs identified, on how the mandatory measures are implemented. Yet, the assessment of the compiled information on NAPs confirms that mandatory requirements from Annexes II and III are implemented in all MS and voluntary requirements from Annex II B in nearly all of them. There are many additional measures beyond the main requirements with variable presence in the national or regional implementations (e.g. soil sampling, design guidance for manure storage, conditions for field manure heaps). Thus, the degree of flexibility provided by the directive has not impeded the application of mandatory measures, nor the implementation of additional and stricter ones depending on the local circumstances. The directive set up a minimal common denominator on the basis of the type of measures that are valid and required in all relevant areas. Member States have also implemented additional voluntary measures under the WFD and CAP to address agricultural phosphorus loss. The measures in Annex II B of the directive are optional for the Member States, including requirements on fertiliser planning and record keeping, minimum soil cover, and crop rotation, but are widely included in the NAPs. Almost all Member States require fertiliser planning and record keeping, as it seen as facilitating implementation and control of the balanced fertilisation requirement. Moreover, most Member States applying the NVZ approach have also implemented at least some mandatory measures outside NVZ[29], further contributing to a general trend in the direction of extending mandatory measures to address pollution effectively (see also section 3.1.2 above). Annex XII of this report provides an extensive analysis of the existing

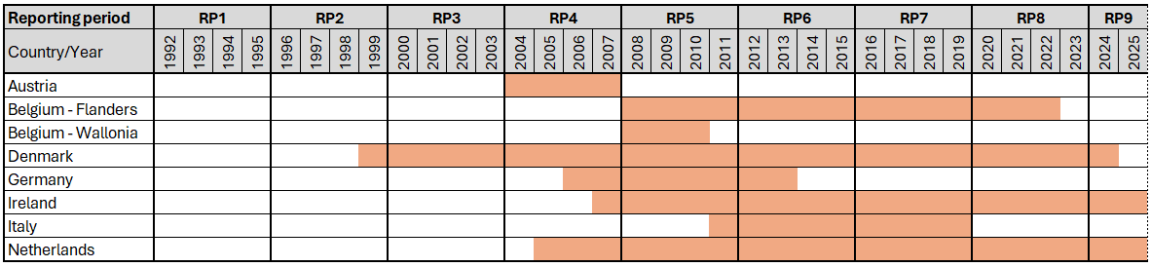
[28] Section 4 will look further into the effectiveness of the measures.

[29] Member state experts also pointed out that outside NVZs they implement measures such as buffer strips, crop rotation and minimum soil cover as part of the GAECs under the CAP.

measures across NAPs, assesses their variation and effectiveness, and provides examples of specific measures assessments.

The obligation to limit the manure application on farms inside the NVZ to 170 kg of nitrogen per hectare, is the most specifically defined measure in the directive. The limit aims to address the specific risks associated with livestock manure due to its organic nature and need for the farm to dispose of it all year round regardless of crop needs, which increases the risk of leaching and run-off. During the legislative procedure, a provision was included for derogations allowing Member States to fix different limits above 170 kg, provided these amounts are fixed so as not to prejudice the achievement of the objectives of the directive and are justified on the basis of objective criteria (e.g. long growing seasons, crops with high nitrogen uptake, high precipitation and soils with exceptional denitrification capacity etc.)[30]. While derogation requests began to be submitted already in the mid- 1990s, these were controversial with other Member States in the Nitrates Committee, and the first decision was adopted only in 2002. Figure 9 shows the evolution of derogations, reaching a peak between 2008 and 2013, where 6 Member States had derogations. In recent years, several derogations were phased out due to infringement proceedings and concerns over water quality.

Figure 9 Overview of derogations granted to Member States[31]



3.1.4 Enforcement action by the European Commission and national courts

Over the years, the Commission has taken enforcement action to ensure the correct implementation of key obligations under the directive and to ensure the effectiveness of national measures. It has included dialogue with Member States, investigation procedures[32], and where solutions could not be found at this stage, infringement cases were opened, some of them leading to rulings at the CJEU. The four-yearly implementation reports have been an important tool to keep track of progress in the Member States.

Most infringement cases that have dealt with issues related to non-conformity transposition of the directive into the Member States' national laws took place in the initial reporting periods or soon after the accession of candidate countries into the EU. Later cases dealt primarily with insufficient designation of NVZ, and more recently cases addressed the need of additional measures or reinforced actions to address water pollution identified (articles 3, 4 and 5, and Annexes II and III of the directive) (see Annex IX for an assessment on the different infringement procedures that have taken place at EU level, as well as the

[30] Also, during the first four-year action programme, a transitional limit of 210 kg was allowed, so that Member States with high livestock density and manure production had a transition period.

[31] The graph shows the currently approved derogations. Both the Irish and the Dutch derogations expire at the end of 2025.

[32] As of 2008 also through the EU Pilot mechanism.

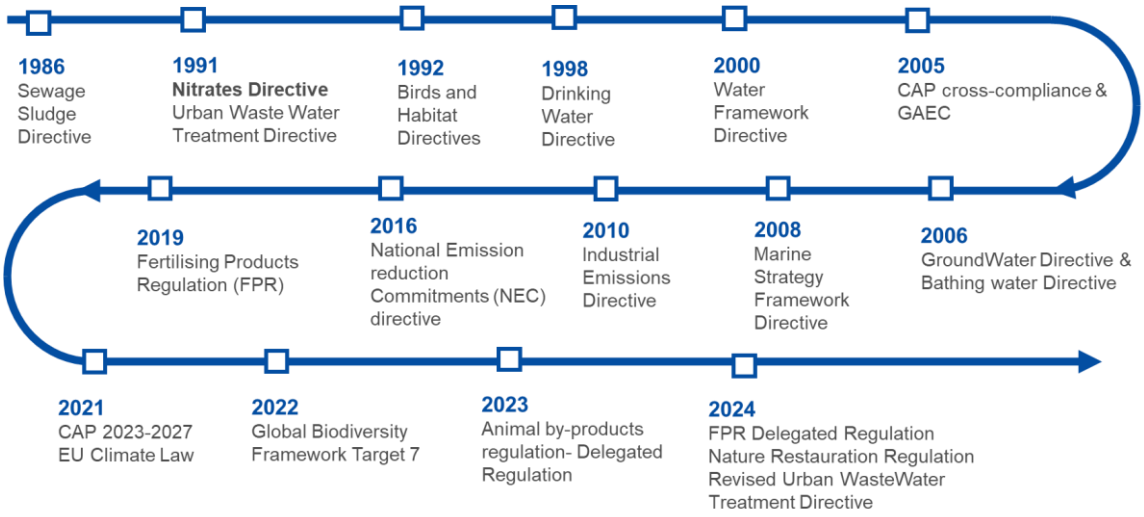
resulting court rulings). In the period 1998 to 2024 the Court issued more than 20 rulings on infringement cases brought by the Commission [26].

The enforcement actions have been essential to improve and strengthen the national implementation. Some of the rulings of the Court, also in cases referred by national courts, have provided important interpretations for the implementation of the directive and of the directive's relationship with other environmental legislation. More details on the history of legal enforcement and jurisprudence around the directive is included in Annex IX.

3.1.5 Evolution of the legal context.

The development of the EU legal framework on water, nutrients and agriculture since the adoption of the Nitrates Directive in 1991 has had a major impact on the policy context of the Nitrates Directive and on its implementation at EU and national level. Figure 10 illustrates this development. An overview of the evolution of legal context is included in **Annex X** and the interaction with other legislation is further explored in sections 3.2, 3,3 on results and impacts, and section 4 on coherence.

Figure 10 Evolution of EU legal context for the Nitrates Directive



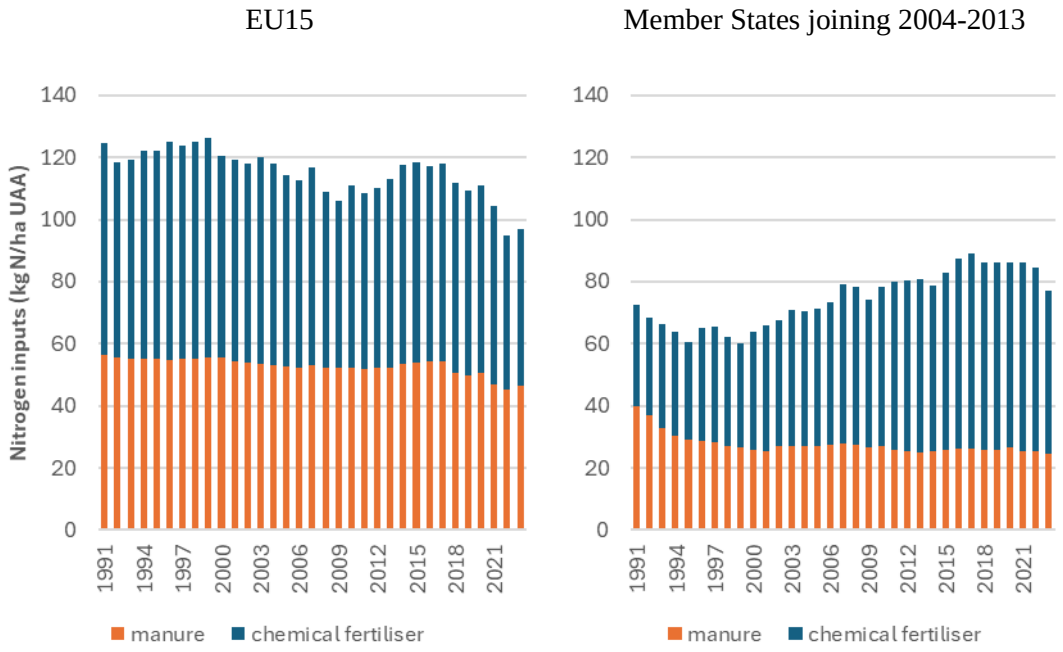
3.2 Results: Evolution in fertiliser use, livestock manure and nitrogen balances

3.2.1 Fertilisers and livestock manure

It is important to note how the use of fertilisers has evolved in the EU compared to other regions worldwide. Over the recent decades, as global food production and fertiliser use have grown, the EU's environmental laws have curtailed the use of fertilizers on farms but without affecting production. Before these regulations, chemical fertiliser use surged in the former EU28 from 1961 to the 1980s, but the increase slowed around the 1990s, stabilizing until the 2010s. During this period, farms began using nitrogen more efficiently, boosting yields and reducing nitrogen waste. Research indicates that many Member States maintained or increased crop yield while using less fertiliser, thanks to EU regulations like the Nitrates Directive that ensure balanced fertilization. Unlike Europe, countries like the USA, China, India and Brazil continued increasing their nitrogen fertiliser use. (See Annex XII section 4.1 on the implementation of measures with specific graphs on trends in nitrogen use efficiency of world cropping systems.)

Figure 1 in section 2 above showed how the nitrogen fertiliser inputs per hectare of agricultural land in the EU12 increased significantly in the decades before the adoption of the Nitrates Directive. Figure 11 below shows the evolution of nitrogen fertiliser inputs after the adoption of the Nitrates Directive for Member States that had joined by the mid-1990s and for Member States joining from 2004 onwards.

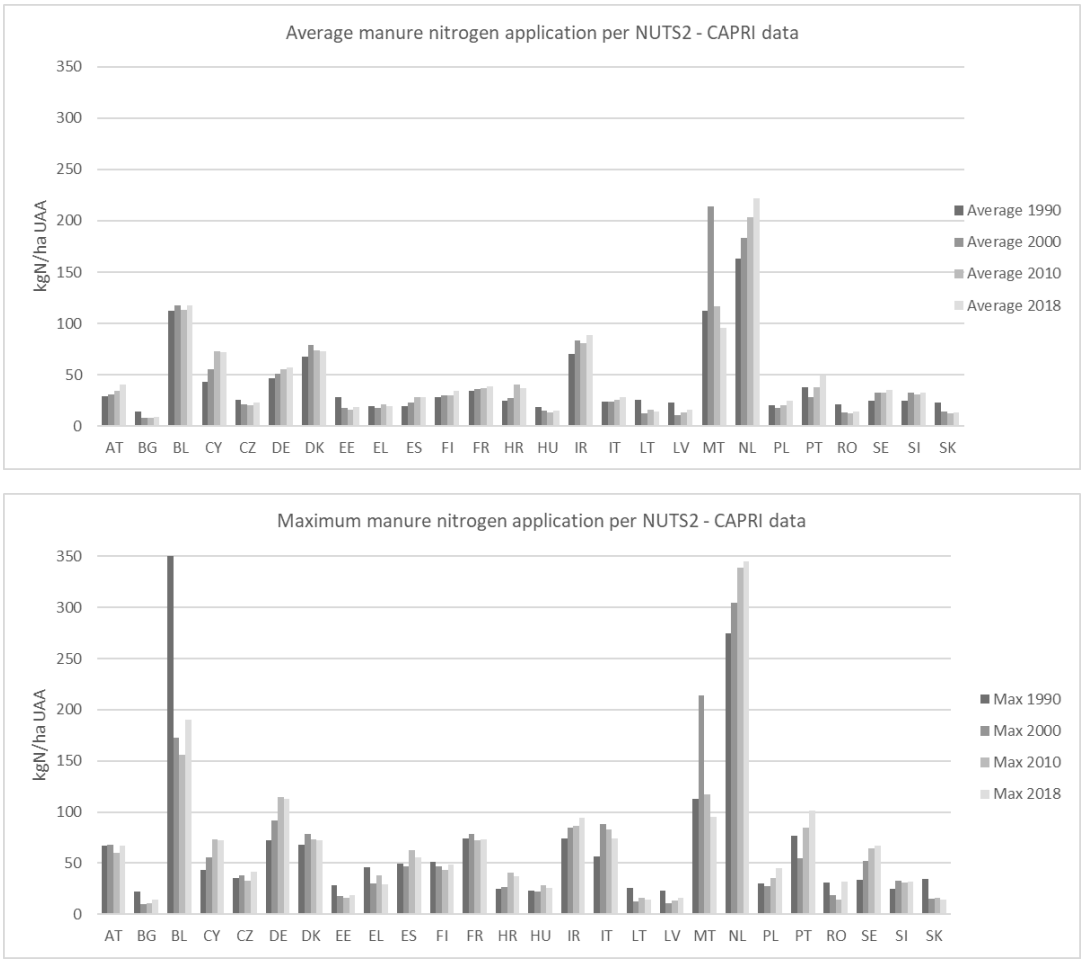
Figure 11 Nitrogen fertiliser inputs in the period 1991-2023 (kg N/ha)[33]



The graph shows a 15% reduction in the EU15[34] between 1991 and 2009, followed by a temporary increase in the 2010s after which the inputs level off again, [35]. The aggregate data for Member States joining the EU since 2004 show a drop in inputs in the early 1990s due to the reduction in the use of manure[36] followed by sustained increases of chemical inputs since the 1990s, with total inputs remaining below those in the EU15[37]. For all Member States, the main driver of short-term fluctuations over time is the input from chemical fertilisers. Manure input, dependent on livestock production levels, has generally been more stable but with a downward trend, except for a temporary spike in the mid-2010s in the older Member States followed by a renewed reduction in recent years. The level of manure input per hectare differs significantly between Member States and between individual regions within Member States. Figure 12 depicts the evolution in average nitrogen inputs from manure per hectare in EU Member States since 1990 for each Member State as a whole and for the NUTS2 regions with the highest manure application rate in each Member State. Annex XII provides further data on the temporal evolution of manure production.

[33] Based on FAOSTAT data.
[34] The EU12 plus Finland, Sweden and Austria who joined in 1995.
[35] The additional drop in 2022 and 2023 should be seen in the context of the Ukraine war and the related spike in fertiliser prices.
[36] This likely reflects the disruption connected with the economic transition of Central and Eastern European countries in the 1990s.
[37] Again, the reduction for chemical fertilisers in 2022 and 2023 is likely due to the extraordinary increase in fertiliser prices those years.

Figure 12 Manure nitrogen application rates per hectare of utilised agricultural area in EU27, according to CAPRI model data: average rates (top) and maximum rates (bottom) by NUTS2 region. *BL: BE and LU. (*Source: JRC* [8])



The Nitrates Directive does not set limits to the application of phosphorus in fertilisers [38]. In practice, however, the limit on livestock manure expressed in relation to nitrogen plays an important role in this respect, as livestock manure is a significant source of phosphorus in regions with high livestock concentrations. The phosphorus content varies depending on the animal type, but generally the 170 kg limit for nitrogen tends to result in an amount of phosphorus that exceeds crop needs in most cases, especially in regions with high legacy phosphorus content in agricultural soils. Due to the role of phosphorus in eutrophication, more than half of the Member States set specific limits for the amount of phosphorus applied to agricultural land[39] and have specific fertiliser rules on it. Some also put limits on animal production based on the phosphorus content in the livestock manure produced[40]. Annex XII provides further detail on existing measures on phosphorus across the Member States.

[38] Phosphorus inputs differ significantly cross the EU and many areas continue to have significant annual surpluses as well as phosphorus built up over many years in soils [8]

[39] In the Member States around the Baltic Sea such limits are for example promoted by HELCOM under which guidance exists that livestock manure application should be limited to 170 kg nitrogen and 25 kg phosphorus per hectare per year (Helsinki Convention, Annex III, point 8).

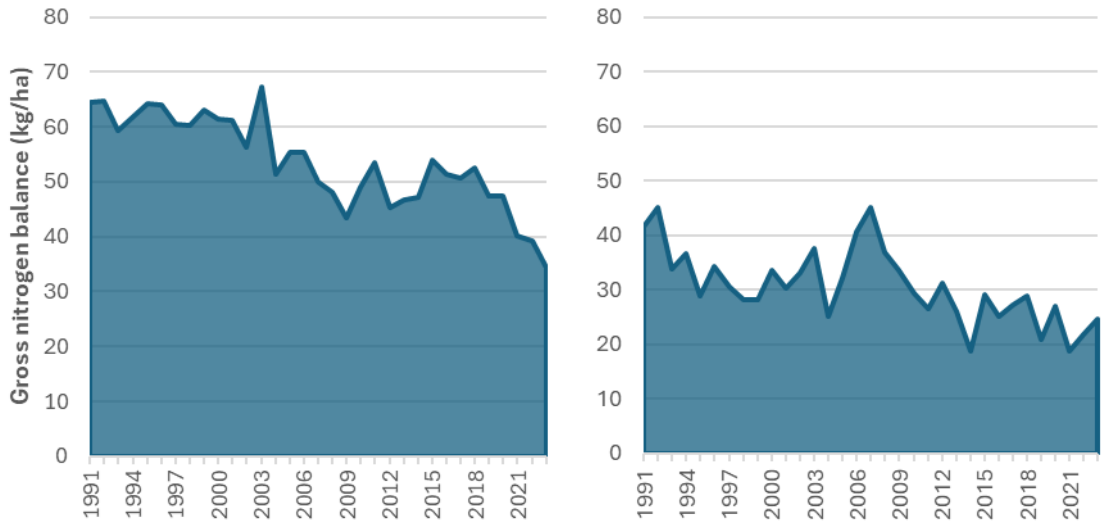
[40] For example, the Netherlands.

3.2.2 Nitrogen balances

The nitrogen balance per hectare of agricultural land is a key indicator of the success that farms have had in implementing balanced fertilisation, in reducing the resulting nutrient pressure from agriculture, and in reducing the risk of nitrogen losses to water and air[41]. Eurostat keeps a data series of balances going back to the 1980s based on data reported by Member States[42]. Figure 13 shows the evolution 1991-2023 in Member States for which data are available for the whole period[43]. The graph on the left shows the evolution in seven Member States that were members already in the 1990s. It shows a significant reduction of the average between 1991 and 2009, after which there was a temporary increase, followed by a renewed reduction. This is coherent with the evolution of inputs shown in Figure 11. The graph on the right shows the evolution for seven Member Stats that joined since 2004. Here there has been a downward trend since the early 1990s[44]. The evolution in balances for each Member State since the start of the Nitrates Directive implementation is shown in Figure 14 below. It shows a general downward trend in most of the Member States, but with significant variations in the overall amounts and the temporal evolution. Understandably, the decrease is less pronounced in Member States with low nitrogen balance from the start.

Figure 13 Evolution of the gross nitrogen balance since 1991 (based on Eurostat data)

7 Member States since the 1990s (EU15)[45] 7 Member States joining since 2004[46]



[41] It has been estimated that on average near 40% of nitrogen added to agricultural soils is lost, mainly in the form of ammonia emissions, nitrogen runoff and nitrate leaching. See [20].

[42] The gross nitrogen balance, see Statistics | Eurostat. The coverage varies among the Member States with significant data gaps over the years, including after 2014. DG ESTAT launched a voluntary exercise with Member States to fill in data gaps on nutrient balances with improved comparability. The collection of data on nutrients balances will become mandatory as of 2026 under regulation EU/2022/2379.

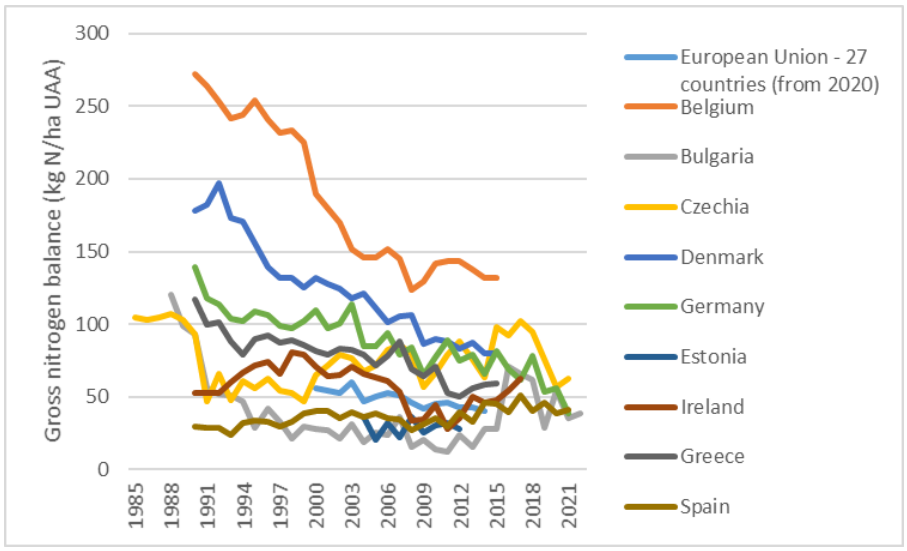
[43] These Member States cover the large majority of agriculture in the EU, even if some significant producer countries are missing (e.g. Belgium and Denmark are not included due to incomplete data).

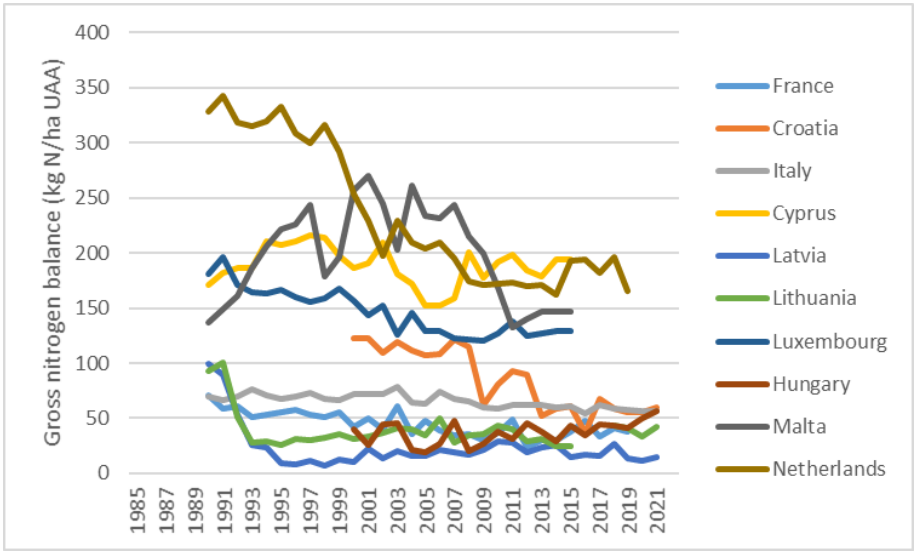
[44] The parallel increase in inputs and reduction in the balance is likely explained by an increase in agricultural productivity in these Member States, with most of the added inputs being reflected in higher yields, which was possible due to relatively low agricultural productivity at the start of the period.

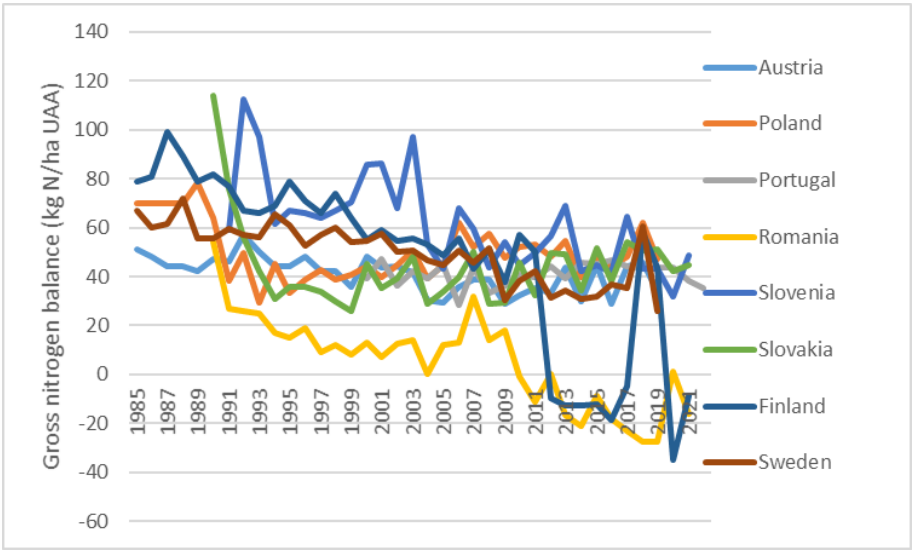
[45] Germany, Spain, France, Italy, Netherlands, Austria, Finland. Note that there were no data for 2020-2021 for Netherlands and Austria, so an average value of 2019 and 2022 used to bridge the gap.

[46] Bulgaria, Czechia, Latvia, Poland, Romania, Slovenia and Slovakia

Figure 14 Evolution of gross nitrogen balance per hectare of utilised agricultural area (UAA) between 1985 and 2021 in EU27 countries [note different scales]. (*Source: JRC* [8])

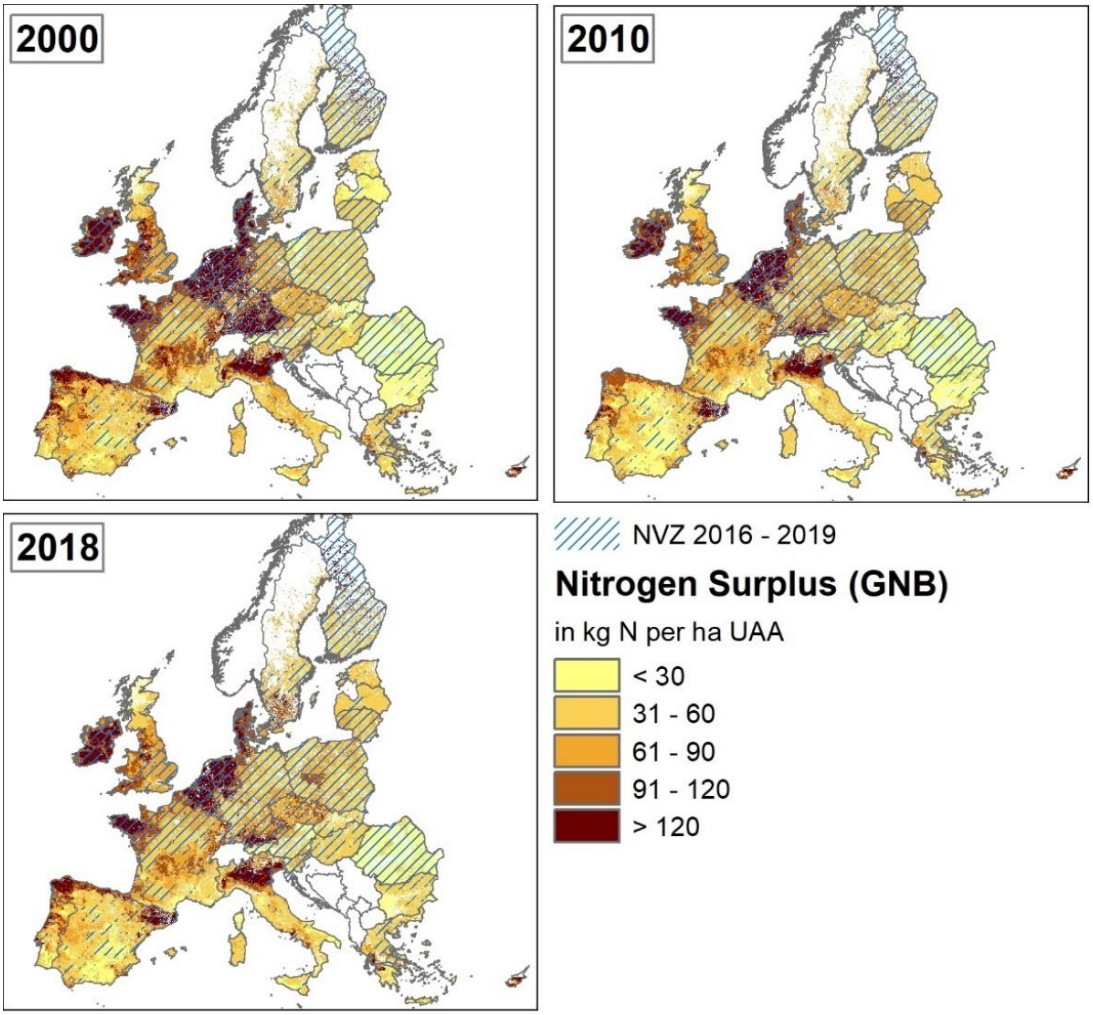






The graphs indicate that since 1991 the nitrogen balances have fallen significantly in Belgium, Denmark, Germany, Greece, Luxemburg, Netherlands and Romania. For other Member States, the evolution appears more even. Most of the decrease took place between 1990 and 2010 and in some Member States the surpluses remain significantly above the mean[47]. Figure **15** shows maps for the spatial distribution of gross nutrient balances across the EU in 2000, 2010 and 2018 based on disaggregated data from the CAPRI model [8]. From the maps it can be seen that the nitrogen surplus has decreased in large areas between 2000 and 2010 but has remained more stable in most areas since 2010, with significant remaining surpluses in hotspot regions with high livestock density (see section 3.2.4).

Figure 15 Gross Nitrogen Balance 2000, 2010 and 2018 (source: JRC, [8])



3.2.3 CAP influence on the Nitrates Directive implementation

The Common Agricultural Policy (CAP) and the Nitrates Directive are closely interconnected, and several elements of the CAP have influenced the implementation of the directive.

[47] Note that this graph does not cover 2022 and 2023 where balanced reduced further. However, this additional reduction was to a large extent the result of high fertiliser prices.

Through major reforms since the adoption of the Nitrates Directive, the CAP has decoupled payments from production and fostered synergies and cross-compliance by requiring farms to adhere to environmental standards, including those of the Nitrates Directive, to receive financial support. CAP's evolving frameworks have shaped how Member States and farmers address nutrient management, with recent reforms further strengthening environmental commitments, advisory services and strategic planning.

The 1992 MacSharry Reform led to a major change in the CAP as the policy shifted from a market support system to direct income support for farmers. It has gradually reduced the incentive for increased production and thereby opened the way for a more balanced use of fertilisers promoted by the Nitrates Directive as it aligned with the economic interests of the farmers. With direct support on the number of livestock maintained, there was however little incentive to reduce manure production which but continued to increase in most of EU15 Member States after 1992.

The introduction of cross-compliance in 2003 linked CAP payments to adherence to environmental, health and animal welfare legislation, bringing environmental objectives to the agricultural policy. Compliance with the Nitrates Directive was one of obligations and it led to major improvements in the implementation as it promoted compliance at farm level. Cross-compliance was extended to all CAP payments in 2007. The subsequent greening of CAP in 2013 further strengthened the focus on environmental objectives of the subsidies, both in the first and second pillar. Cross-compliance with the WFD on phosphorus measures was introduced in the CAP regulation from 2014. While positive effects from these reforms are evident, challenges remain, particularly regarding livestock intensity and concentration and market pressures that often conflict with environmental goals. The abolition of the Milk Quota in 2015 brought additional challenges by allowing for an increase in dairy production in some Member States, with larger dairy herds being stocked at the same place resulting in an increased spatial nutrient concentration and regional nutrient imbalances.

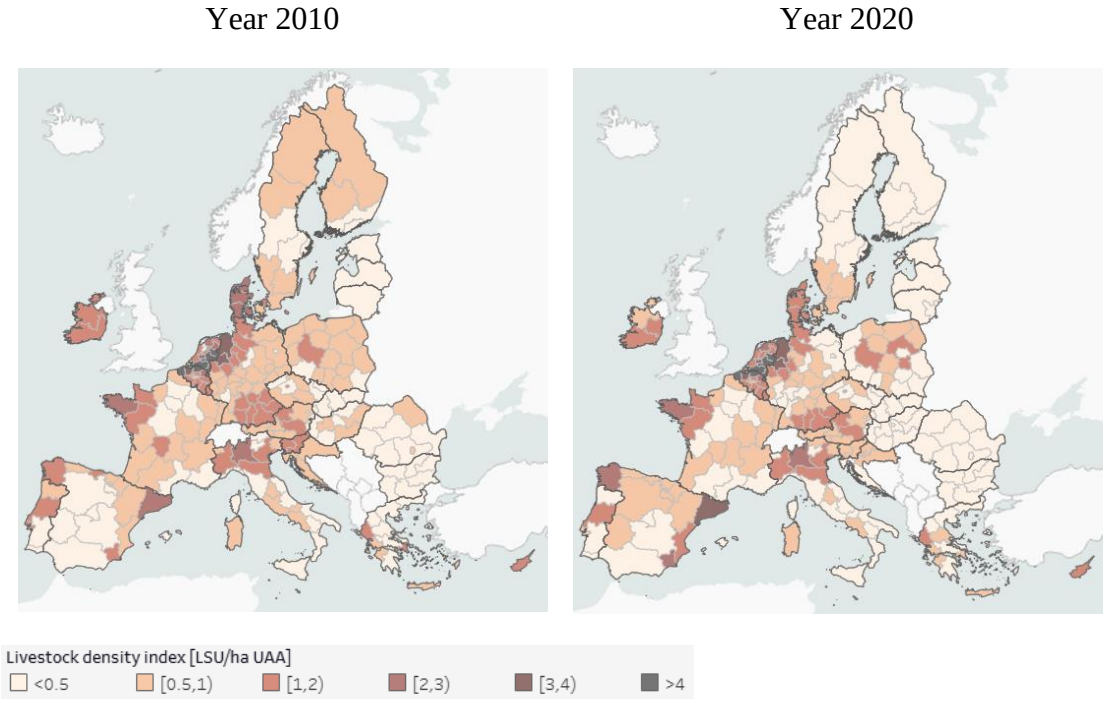
The 2023 CAP reform introduced a new delivery model based on national CAP strategic plans incorporating stricter environmental criteria and objectives, maintaining conditionality and emphasising nutrient loss reduction, water protection, and soil preservation and increased attention to farm advisory or digital support services. Various studies have highlighted how, despite occasional overlaps and varying commitments, the CAP as a policy continues to support progress in nutrient management and water quality improvement and to increase awareness and cooperation between countries, thereby supporting the Nitrates Directive and influencing its implementation.

As a result of the successive reforms, the integration and synergy between the CAP Regulation and the Nitrates Directive have grown over time. Today these two legal instruments are intricately linked, supporting each other in the achievement of their respective objectives, highlighting their mutual dependability in implementing good agriculture practices for sustainable farming and environmental protection throughout the EU. (Annex XVI further analyses the interlinkages between the Nitrates Directive and the CAP Regulation and describes in detail how the different CAP reforms have influenced the Nitrates Directive implementation).

3.2.4 Agriculture intensification and markets

Agricultural market pressures mediated by policy changes, increasing population and global competition have had an impact on the implementation of the Nitrates Directive**,** driving fertiliser use and livestock production. Figure 16 shows the livestock density in terms of livestock units per hectare (LSU/ha UAA) at NUTS 2 level in 2010 and 2020, indicating that intensive livestock production persisted in several regions over the last decade.[48] When the manure production is higher than the amounts that can be put on land in the region within the limits of the Nitrates Directive, the compliance with the directive and other environmental legislation becomes more complicated, as it is difficult to dispose of the excess livestock manure without a negative impact on the environment. Data show a clear geographic correlation between livestock density and nitrogen surpluses, both at the level of Member States and in specific regions.

Figure 16 Livestock density index LSU/ha UAA at NUTS2 level

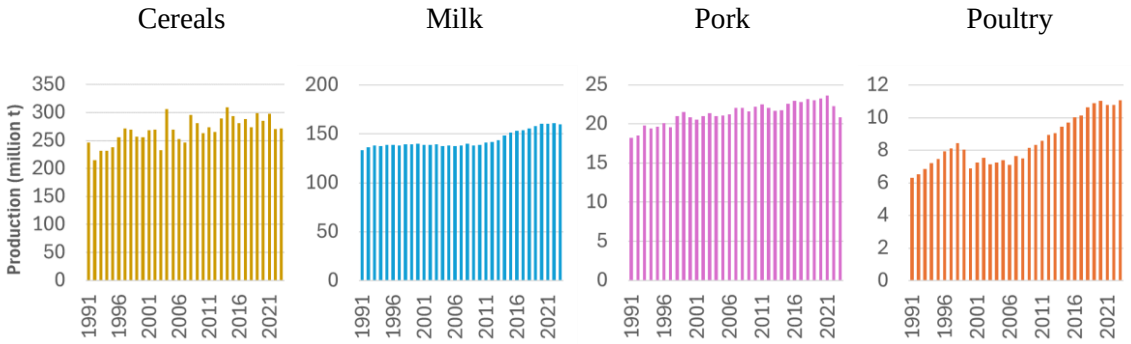


Source: EC based on Eurostat data

The continuous pressure to increase the intensity of agricultural production is further shown in Figure 17 illustrating the evolution of production in the EU27 since 1990 for cereals, milk, poultry and pork meat. While the trend has levelled off somewhat compared to the earlier decades after the Second-World War, the graphs show that production has continued to increase over the last three decades. Note the temporary interruption of this trend for poultry meat following first major outbreaks of bird flu in the late 1990s and the relative stability of milk production until the abolition of the milk quotas in the mid-2010s.

[48] Latest data (up to 2025) from Eurostat indicate reductions of herd numbers in many Member States. See also upcoming report on the implementation of the Nitrates Directive.

Figure 17 Evolution in production in the EU27 between 1991 – 2023 (million tonnes)



Source: Estimation based on FAOSTAT data.

There are many possible factors behind the increase in production since 1991, but it underlines the steady pressure from the market for agricultural intensification. Fertiliser use for maximizing yields leads to a higher risk of nitrogen losses and an increase in meat production is associated with increased manure production. As explained in Annex XI on balanced fertilisation, the take-up of nitrogen by crops is not linear, there are also strong annual and regional variations, and the fertiliser application standard will have a direct effect on the amount of leaching. The application standards are ideally based on a dose response curve. The economically optimal rate is strongly dependent on the economic situation (including the market prices of fertilisers and crops), can be highly variable, is not known at the beginning of the season, and does not necessarily coincide with agriculturally optimal dose. When fertilisers are cheap there is little incentive to use less fertilisers and increase nitrogen use efficiency so as to coincide with the agricultural optimal dose. As long as fertiliser prices remain low and the market price for the crop is sustained, the economic optimum for the farm will tend to be equal or higher than the agronomic optimum, as the economic losses due to over-fertilisation in one year would be compensated by high yields in another. However, high application standards based on unrealistically high yield figures will result in nutrient losses and have a negative effect on the environment. On the other hand, when fertilisers are expensive, there is a strong incentive to adjust the standard to the agriculturally optimal dose (higher nitrogen use efficiency). Very high fertiliser prices can also reduce fertiliser application and in some cases it can have undesirable effects on production volumes and quality. On the other hand, the last thirty years also saw the development of sustainable farming practices aiming at reconciling farming and environmental limits. The Organic Farming Regulation, providing a framework for organic farming throughout the EU, reproduces some of the key requirements from the Nitrates Directive, facilitating compliance with the measures of the Nitrates Directive. While Organic farming is supported by the CAP, and the organically farmed area made up 10.5 % of total EU agricultural land in 2022 compared to 5.9 % in 2012 [28], the increase remains slow in many Member States.

3.3 Impacts: Evolution in water quality

3.3.1 Nitrates pollution in groundwaters

Nitrates pollution in groundwaters was a major and increasing issue when the directive was adopted. The situation can be illustrated by data on nitrate concentrations in groundwater from the Nitrates Directive monitoring network in the early 1990s. Figure 18 shows the situation in the six EU Member States that had reported data for the first monitoring period (1992-1995). The data show that 572 monitoring stations corresponding to 15.8% of the total at the time reported concentrations above the pollution threshold (50 mg/l). Of these, 139 stations or 3.8% of the total reported concentrations above 100 mg/l. Figure 19 shows the evolution over the subsequent monitoring periods up until today. Since Reporting Period 4 (RP4), where the monitoring networks have been relatively more stable[49], less than 15% of monitoring points have reported nitrate concentrations of 50 mg/l or higher, with RP6 to RP8 showing a rate slightly above 13%. While the data indicate an overall stabilisation in nitrate concentrations across the EU, pollution remains significant many places, and the averages hide many geographic differences (see Annex XIII on the distribution of nitrates concentrations and trophic status of waters in Member States from 1992 to 2023).

Figure 18 Distribution of nitrates concentrations in groundwater 1992 – 1995 from 6 Member States[50]

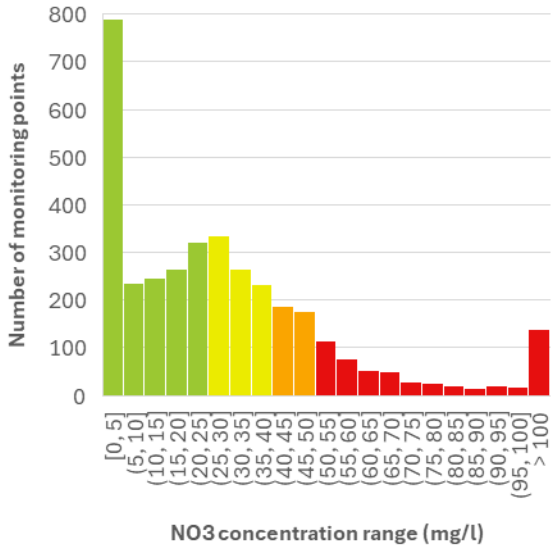
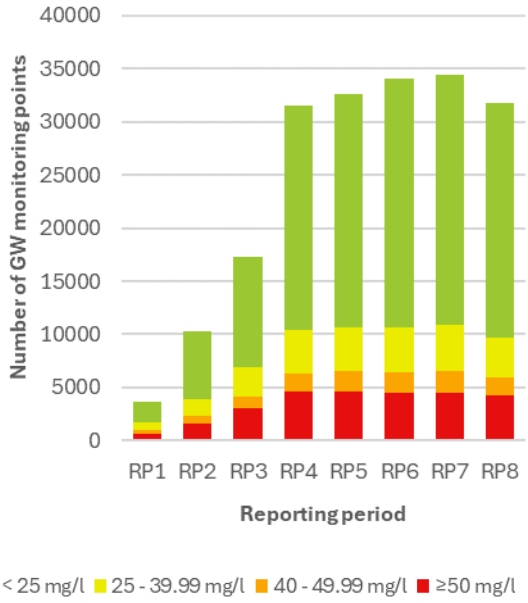


Figure 19 Evolution in nitrate concentration classes 1992 – 2023 (number of Member States covered depends on RP)



[49] Overall, it remains difficult to directly compare the distribution of the average nitrate concentrations across different reporting periods (RPs). The groundwater monitoring network matured through the initial reporting periods and subsequently stabilised in total numbers in the EU, showing relative stability since Reporting Period 4 (RP4), but changes continued within national monitoring networks.

[50] Belgium, Denmark, Finland, France, Netherlands, Portugal

Figure 20 Annual average nitrate concentrations in groundwater at the NUTS2 level for the reporting period 2020-2023

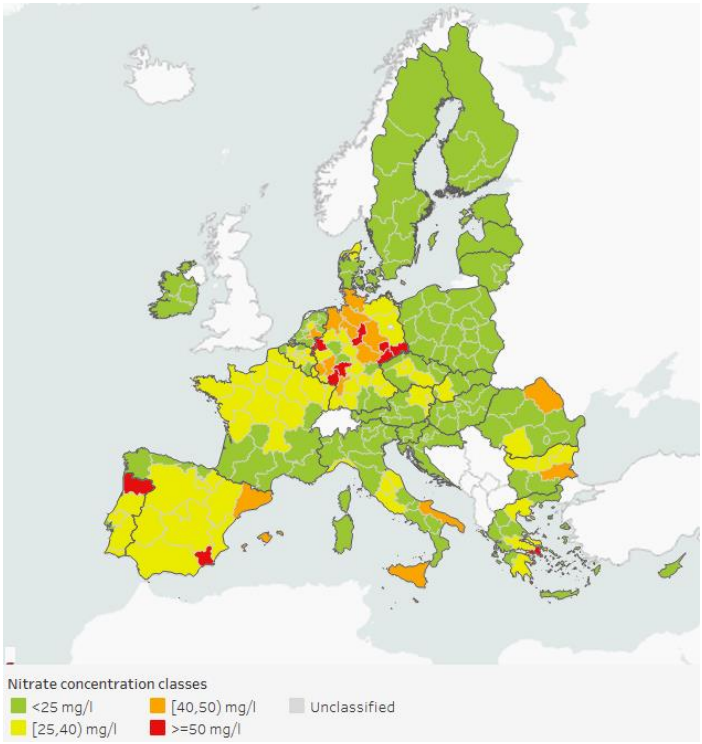
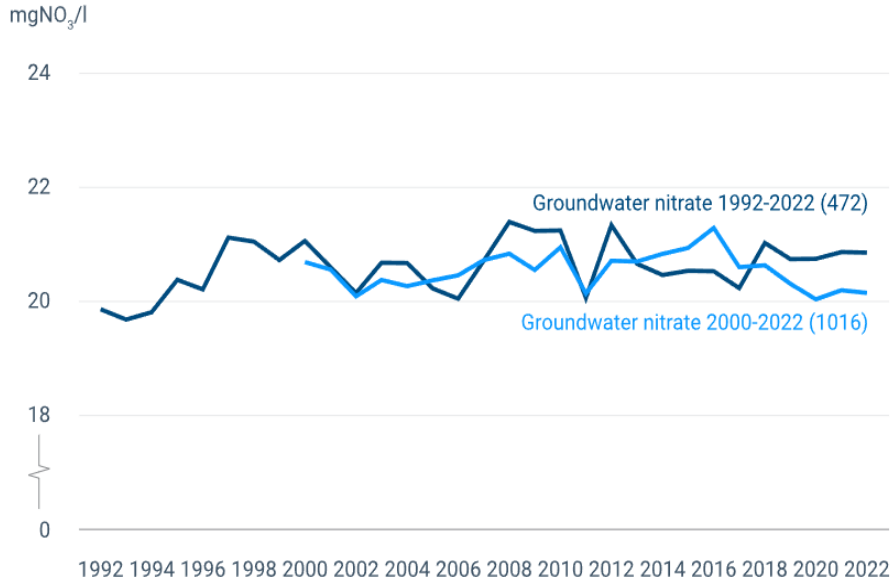


Figure 21 shows data from the European Environmental Agency (EEA) [29] which has followed the evolution in selected monitoring stations across EU since the early 1990s. In 2000, a slightly more extensive data sample was introduced. These samples are more limited than what we get from the national networks under the Nitrates Directive[51]. On the other hand, the advantage is that they have remained stable over a longer period of time.

Figure 21 Average nitrate concentration in groundwater (source EEA)



[51] In effect, this is a small sample of monitoring stations to give an indication of the evolution at EU level. It cannot reflect the different situations at Member State and local levels.

The data from the sample going back to 1992 indicates a stabilisation of the average nitrate concentrations around 21 mg/l across Europe from the mid-1990s and onwards. The more extensive data series established in 2000 seems to indicate an increasing trend until the mid-2010s after which a reversal may have taken place, resulting in a decreasing trend in the most recent years, with average nitrate concentrations around 20 mg/l across Europe.

The overall stabilisation of the groundwater nitrate concentrations shows the effects of the preventive measures under the Nitrates Directive. As regards the reduction of pollution already accumulated, an important factor to consider is that there is generally a variable time lag between the changes in agricultural practices and how this shows up in the nitrate concentrations of groundwaters. The lag can be very different depending on the groundwaters concerned ranging from a few years to several decades, depending on a number of factors including geology, hydrology, presence of oxygen and other factors relevant for denitrification, as well as depth of the groundwaters. Pollution can also be very localised so that broad averages do not necessary tell the whole story. Therefore, the pace of reduction of nitrate pollution in groundwater will vary considerably from one Member State or even one region to another. Nevertheless, the monitoring networks under the Nitrates Directive have been set up to monitor progress and should in principle be responsive to broad changes in agricultural practices over time[52].

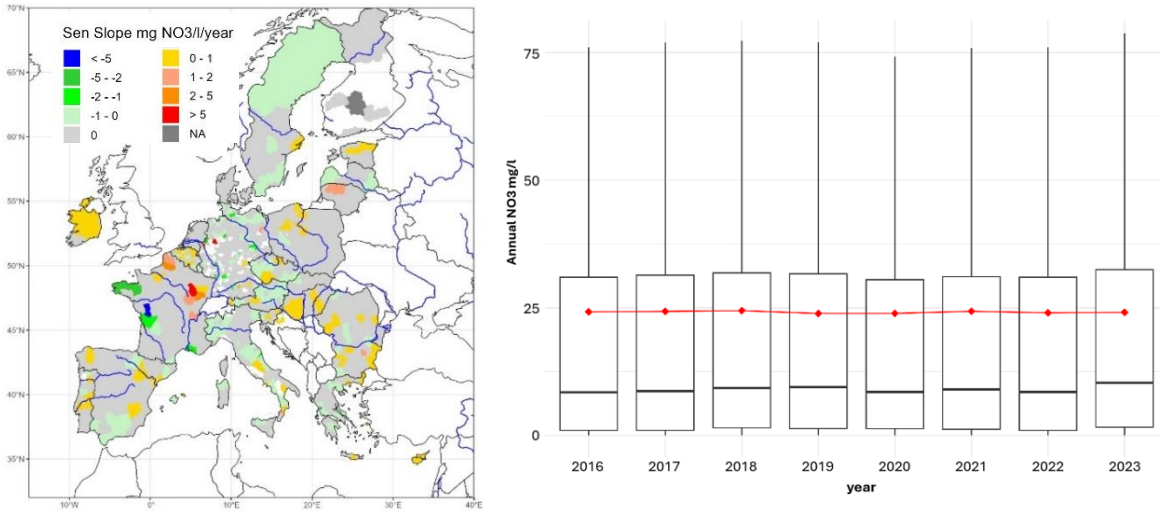
Analysis from Member States show clearly how the level of pollution in groundwater responds to fertiliser inputs. Annex XIV illustrates this with relevant examples in several Member States, notably the parallel evolution of nitrogen balance and nitrate concentrations over a long time period and the effect of measures taken under the directive in terms of the evolution of nitrates concentrations in the root zone and upper groundwater layer over the whole period of implementation of the directive.

Finally, Figure 22 presents some data on the most recent evolution in groundwater nitrate concentrations, based on the monitoring points under the Nitrates Directive where Member States have provided data in both RP7 and RP8[53]. The map on the left shows NUTS3 regions where significant trends can be identified over the eight years 2016-2023. The graph on the right shows the evolution in the average concentration across the entire sample (red line) as well as box plots with the median and quartile values in the sample. The data indicate that while significant trends can be seen in various regions across the EU with differences between Member States, the aggregate picture shows a stable situation over the period. Despite the overall average stagnation of results at EU level from 2016 to 2023, Annex XIV shows examples in Member States with continued reduction of nitrates concentrations in the most polluted monitoring points between 2008 and 2023, illustrating a continued response of pollution in groundwater to the measures of the Nitrates Directive.

[52] Some Member States have also set up dedicated networks, with more detailed monitoring of nitrate concentrations in leaching waters from selected agricultural fields to monitor the effect of changing practices.

[53] While this is based on a sub-set of all monitoring points, the total number of monitoring points is significantly higher than the EEA sample presented above and should therefore be rather more representative. Moreover, since only common points are included, the results are not affected by changes in the monitoring networks. See also Annex XIII.

Figure 22 Spatial distribution of trends in EU between 2016-2023 (left) and box plot of EU annual nitrates concentrations in groundwater (right) (Source: JRC [8])



3.3.2 Nitrates pollution in surface waters

When the Directive was adopted, nitrates pollution in surface waters was an important and increasing problem in many Member States, including in coastal and marine waters, but the availability of data at EU level was limited. Overall nitrates concentrations tend to be lower in surface waters than in groundwaters because there is less accumulation in flowing freshwaters, however nitrates will converge to the seas.[54]

Figure 23 shows the nitrates concentration values in surface water monitoring stations under the Nitrates Directive in the period 1992-1995 from 6 Member States that had reported data for the first monitoring period. 58 monitoring stations (2.8%) show values above the drinking water threshold of 50 mg/l and a large majority of reporting values not compatible with good trophic status[55]. Figure 24 shows the data since 2004 for all Member States that reported in each period[56]. There are still some surface waters showing nitrate concentrations above the drinking water limit of 50 mg/l, and a percentage of waters with concentrations high enough to contribute to eutrophication of lakes, coastal and marine waters. Importantly, the aggregated EU view hides the national variations, including positive evolutions shown in many regions and Member States (see Annex XIII on the distribution of nitrates concentrations and trophic status of waters in Member States from 1992 to 2023).

[54] The Nitrates Directive requires Member States to monitor nitrates concentrations in surface waters. Also here, the drinking water limit of 50 mg/l is used for the identification of polluted waters. However, another aspect considered under the directive is eutrophication, which can be caused by much lower concentrations of nitrates. In fresh and brackish waters phosphorous also plays a key role.

[55] The thresholds for nitrate concentrations compatible with good ecological status depend on the water bodies concerned and differ across the Member States but annual average nitrate concentrations above 10 mg/l will generally have exceeded the relevant thresholds in many cases.

[56] The percentage of stations reporting nitrogen concentrations above 50 mg/l has remained below 2.7% since RP4 (2004-2007). The drop in RP8 reflects the exit of the United Kingdom of the EU. When comparing only EU27 countries there is almost no difference between RP7 and RP8.

Figure 23 Distribution of average nitrate concentrations in surface waters 1992-1995 for 6 Member States[57]

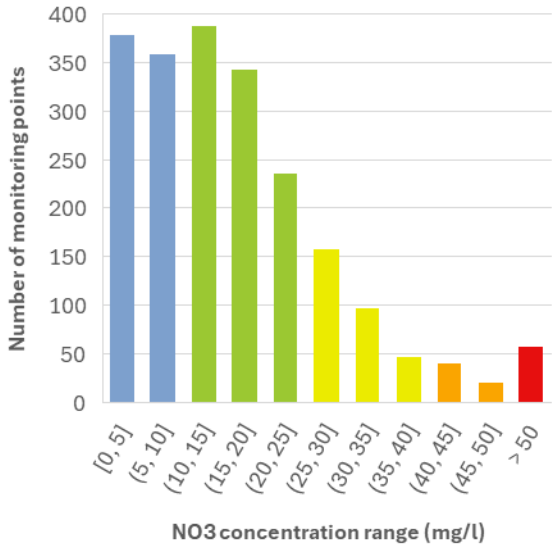
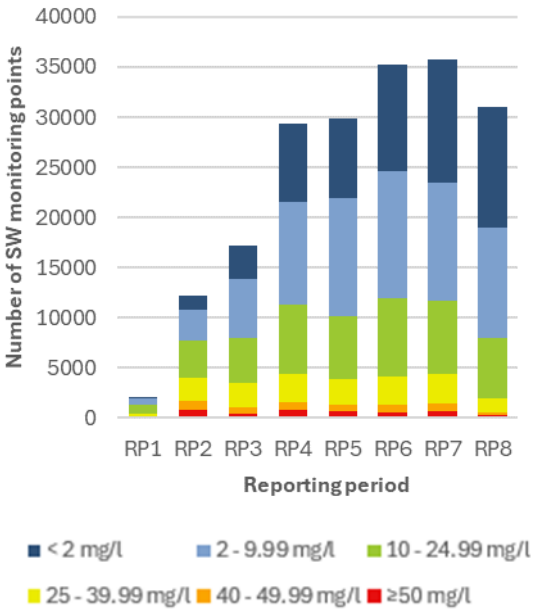


Figure 24 Evolution of distribution of average nitrate concentrations in surface waters (1992 – 2023)



The EEA has followed average nitrate concentrations in surface water monitoring stations since the early 1990s, just like they have done for groundwaters. Figure 25 shows the evolution of the average nitrate concentration in European rivers using the EEA data. In this case, both samples show average nitrate concentrations decreasing significantly during the period up until the late 2010s. In the most recent years, the data seem to indicate a certain stagnation or even a possible reversal of this downward trend[58].

Nitrate concentrations in surface waters generally tend to reflect the changes of agricultural practices more quickly than for groundwaters, with a time lag of only a few years. The data on surface waters therefore generally tend to reflect more promptly the effects of nitrates directive measures than data on groundwaters. The temporal evolution of surface water nitrate concentration at EU level therefore clearly shows not only the preventive effect but also the reduction of nitrate pollution since the start of the implementation of the directive. Annex XIV further shows relevant examples in several Member States on the effects of the measures on the reduction of nitrates concentrations in surface water and the lag times[59].

[57] Belgium, Finland, France, Ireland, Netherlands, Portugal

[58] The same caveats apply as for the EEA's groundwater network with respect to the limited extent of the network compared to the networks established under the Nitrates Directive.

[59] See e.g. the support study prepared by the JRC [8] for analysis showing estimated response times in French river nitrate concentrations ranging from 1-10 years, with the highest correlation around 6-7 years following the reduction in agricultural inputs.

Figure 25 Nitrate concentration in European rivers (EEA)

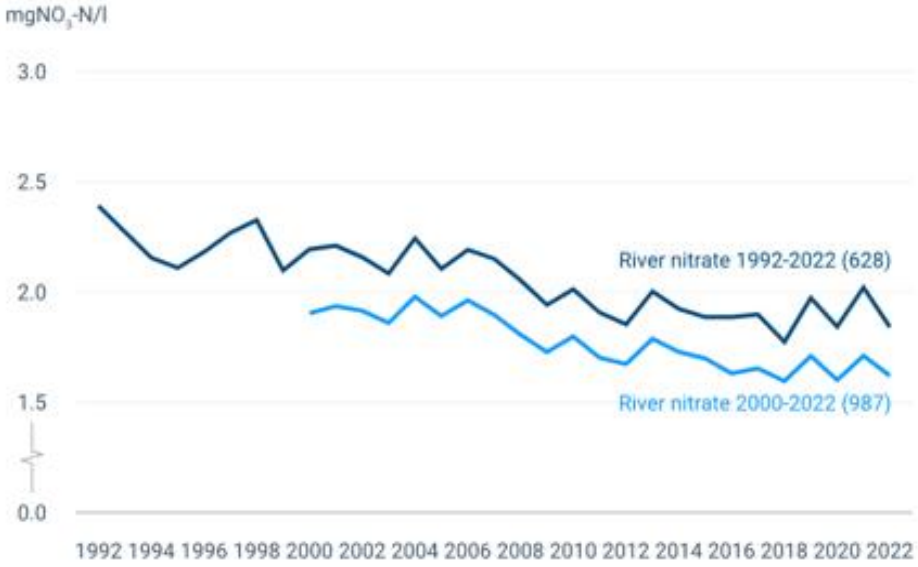


Figure 26 below indicates the geographic distribution of nitrate trends in surface waters during 2016-2023 based on data reported by Member States under the Nitrates Directive[60]. As for the groundwaters, we are also here presenting data on the most recent evolution in surface water nitrate concentrations, based on the monitoring points where Member States have provided data in both RP7 and RP8. Again, the map on the left shows NUTS3 regions where significant trends can be identified over the eight years 2016-2023.

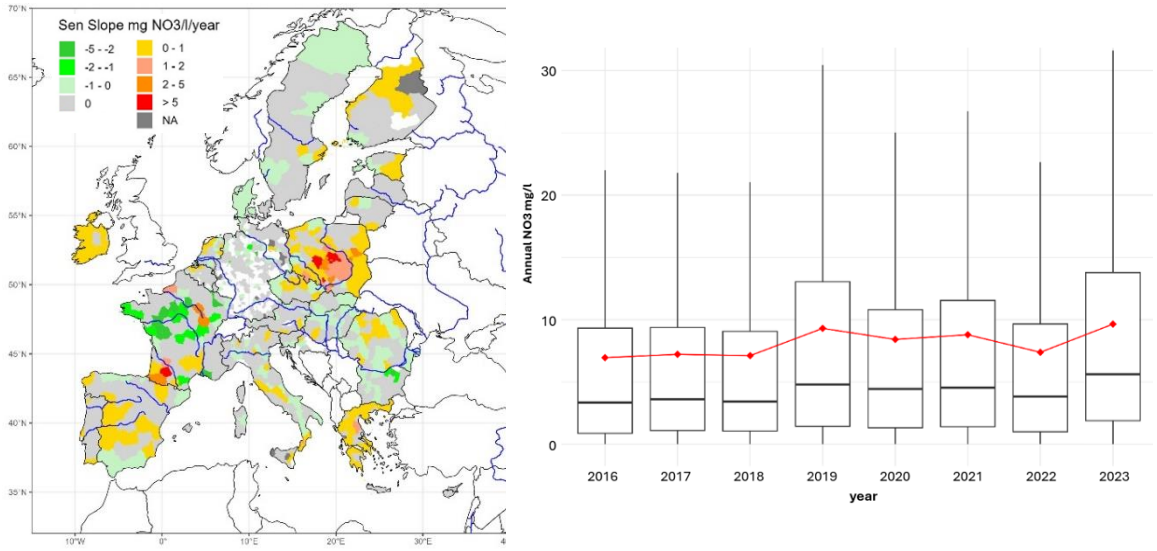
The graph on the right shows the evolution in the average concentration across the entire sample (red line) as well as box plots with the median and quartile values in the sample. In the case of surface waters, the data clearly show an upward movement in concentrations over the period, indicating that the direction of travel in recent years has been contrary to the overall objective of the Nitrates Directive[61]. Some of this may be due to climatic factors (exceptional droughts may have increased nitrate concentrations) but some part is also likely to reflect the increases in fertiliser inputs and surpluses in the mid-2010s shown earlier, which would be reflected in surface waters with a few years of delay.

It should be noted again that these are overall aggregate trends at EU level, whereas developments differ at national, regional and local level. Annex XIV shows examples in Member States with continued reduction of nitrates concentrations in the most polluted monitoring points between 2008 and 2023, illustrating a continued response of pollution in surface waters to the measures of the Nitrates Directive. The overall and continued reduction of surface water nitrate concentrations below 50 mg/l is also a key factor of progress in addressing eutrophication, as the nitrate concentration thresholds for eutrophication are significantly lower.

[60] Annual nitrate concentration in surface water was reported for 34430 stations in the RP7 and for 30828 stations in the RP8. Matching between the RP7 and RP8 monitoring networks resulted in 21918 common stations. Each station was assigned to its corresponding NUTS3 region and a regional Mann-Kendall test was used for calculating the trend in each NUTS3 region [8]. See also Annex XIII.

[61] As for groundwaters, this picture masks important differences between Member States and regions, where there were also continued improvement in many places (see examples in annex XIV).

Figure 26 Spatial distribution of trends in EU NUTS3 regions between 2016-2023 (left) and box plot of EU annual nitrates concentrations in surface waters (right) (Source: JRC [8])



3.3.3 Eutrophication

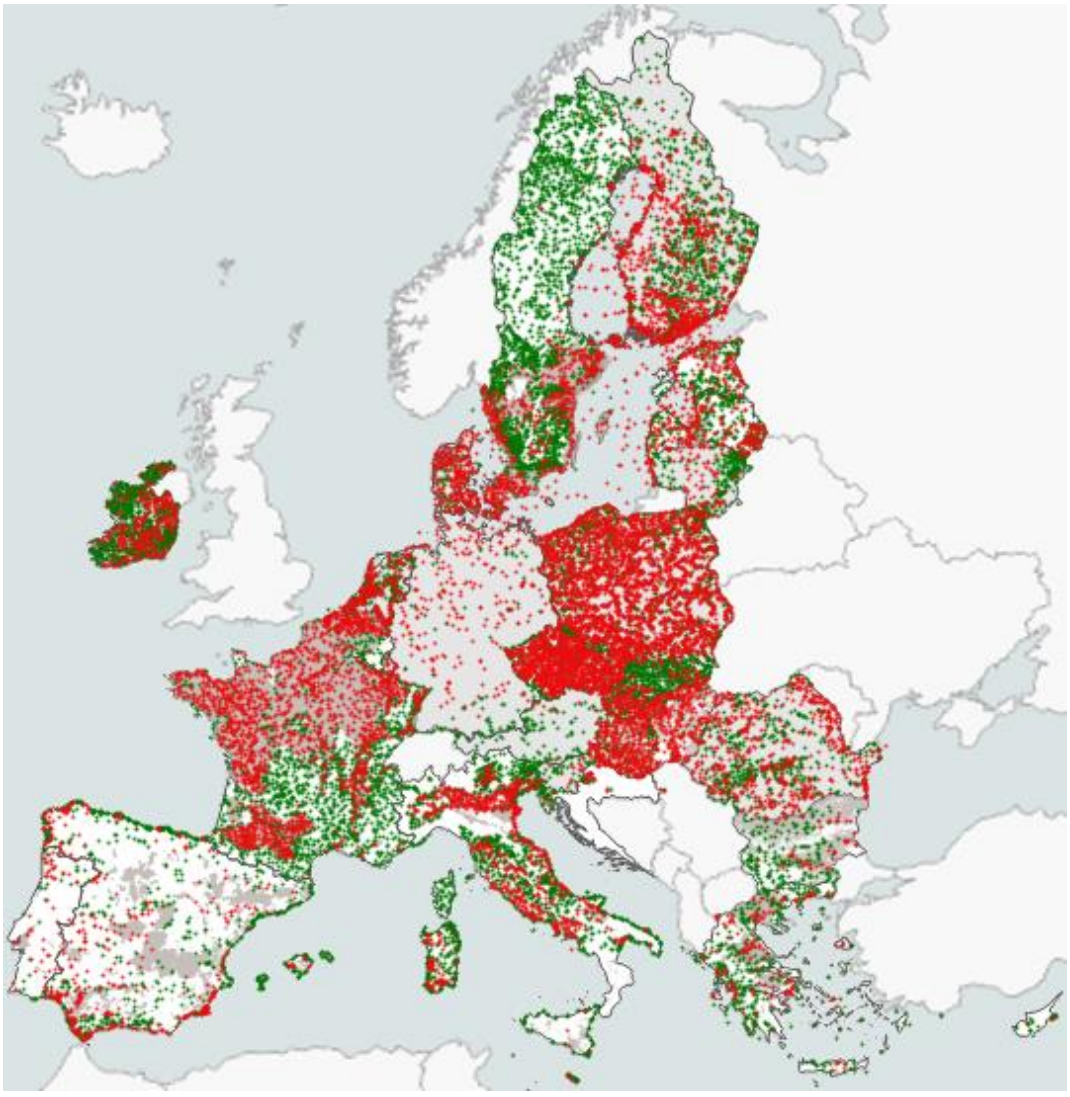
As mentioned in section 2, eutrophication was found to be a major issue when the Directive was adopted. In the period 1985 to 2000 extensive eutrophication had been reported in the Baltic Sea and the North Sea, and to a lesser extent in the Mediterranean Sea. Data reported under the Nitrates Directive has shown that eutrophication remains a major problem for all types of surface waters, including inland, transitional, coastal and marine water. In the implementation report for 2016-2019 [15], 36% of rivers and 32% of lakes, 31% of coastal and 32% of transitional water and 81% of marine waters were reported as eutrophic. This picture is also confirmed by a recent assessment under the WFD [30], which concludes that, although considerable improvements have been observed compared to the 1990s and most Member States and farms have made significant efforts to reduce nutrient losses in waters, current measures are still not sufficient to reach the water quality objectives. For more eutrophication data for individual Member States under the Nitrates Directive, see Annex XIII.

Box 2: The Mar Menor lagoon in Spain has suffered in the latest years the consequences of excess of nutrients from intensive agriculture and other sources. After decades of nutrient inputs, mainly nitrogen, the oligotrophic status of this lagoon changed to eutrophic status. In 2016, an algal bloom had severe effects on macroalgae and marine plants in the lagoon. In 2019 and 2021, hypoxia conditions resulted in the mortality of marine fauna. In a ruling from 2024, the CJEU considered that Spain had failed to fulfil its obligations, inter alia by failing to take the additional measures or reinforced actions required with regard to nitrate pollution in several regions, including the region of Murcia, where the Mar Menor lagoon is located. While the Spanish authorities have started taking measures, the lagoon still shows eutrophication in the 2020-2023 period.

The Baltic Sea is the marine region with the highest proportion of coastal waters where nutrient conditions is a problem. Eutrophication also occurs in the southern North Sea, along the north-western coast of France and near riverine outflows in the Mediterranean Sea. Widespread oxygen-depletion can be regularly observed in the Baltic Sea and the Black Sea, caused by eutrophication in combination with natural conditions and higher water temperatures due to climate change. A recent assessment under the MSFD [31] also

highlights continued challenges in European Sea basins. There have also been areas of progress when seen over a longer time perspective. Notably, with regard to the North Sea, assessments from OSPAR since the 1990s show a gradual decrease in the surface areas that do not achieve "Good" status[62]. In the Baltic Sea, the situation remains more serious. However, input loads of both nitrogen and phosphorus have been reduced significantly since the 1980s and the situation would likely have been much worse without these reductions [32]. Figure 27 shows the geographic distribution of eutrophic monitoring points as reported under the Nitrates Directive in RP8 [16]. Note that the density of the monitoring network differs across the Member States, which should be taken into account when interpreting the map. The continued challenges in the Baltic Sea clearly stand out. Eutrophication remains a challenge across the EU, but this does not mean that no progress was achieved. As shown in the previous sections, the measures of the Nitrates Directive have contributed to the reduction of nitrogen loads to surface water and to the steady reduction of nitrate concentrations throughout the EU, which are necessary steps to reduce eutrophication and achieve good ecological status (as defined under the WFD).

Figure 27 Monitoring points under the Nitrates Directive reported as eutrophic/may become eutrophic (red) and as non-eutrophic (green) in RP8



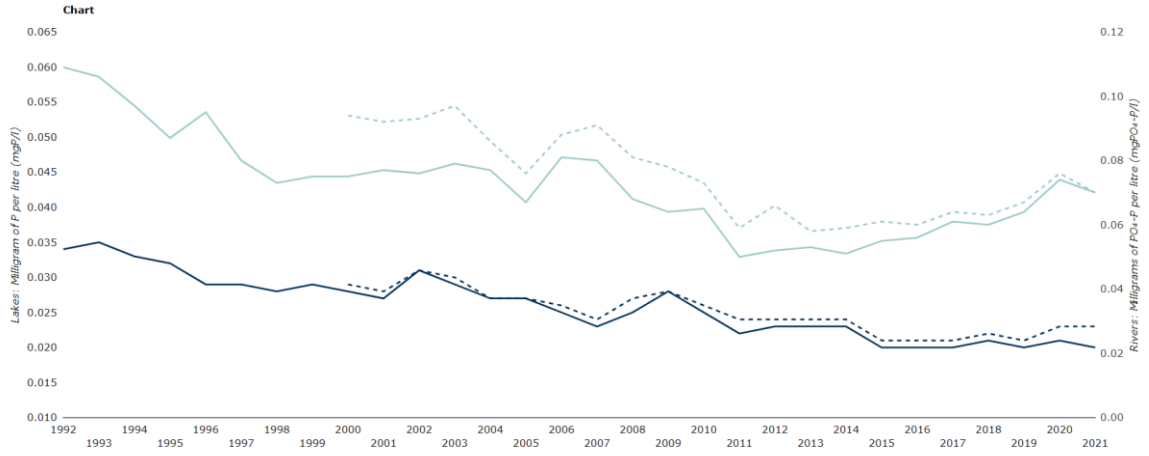
[62] OSPAR eutrophication thematic assessment, see here.

3.3.4 Urban wastewater treatment

When looking at the impact of the Nitrates Directive on nitrate concentrations in surface waters and on eutrophication, it is important to keep in mind other factors that affect these outcomes. Urban wastewaters are a key factor in this regard – and by extension the Urban Waste Water Treatment Directive, which over the years has contributed to a significant reduction in point source emissions to rivers and coastal waters. Although less important than agriculture overall[63], urban wastewater contributes significantly to nitrogen concentrations in the aquatic environment. More importantly, it is a major contributor of phosphorus emissions[64], even if it has diminished over the years.

Figure 28 below shows the evolution of phosphorus concentrations in a sample of monitoring stations in EU rivers (light blue) and lakes (dark blue) that has been monitored by the EEA since the early 1990. The overall reduction in phosphorus concentrations likely reflects the implementation of the Urban Wastewater Treatment Directive to a large extent, in addition to a change to phosphate-free detergents. It is notable that concentrations in rivers have started increasing again since the early 2010s. A contributor in this regard could be agricultural soils, where erosion, runoff and leaching into water courses from fields reflects the overall level of phosphorus accumulation in the soils as well as ongoing manure spreading. Annex XIV illustrates the interplay between the Nitrates Directive and the UWWTD in the Danube River between 1996 and 2021. It shows the rapid improvements resulting from the UWWTD implementation especially in P reductions, and the effects, albeit slower and less significant, of the Nitrates Directive in continuous reduction of nitrate concentrations.

Figure 28 Evolution in phosphate concentrations in EU rivers and lakes (EEA[65])



3.3.5 Water Framework Directive

The Water Framework Directive (WFD) adopted in 2000 provides a comprehensive legal and scientific framework for achieving water quality objectives in the EU by 2027. It has profoundly changed the approach to water management across the EU and, by incorporating the Nitrates Directive as a fundamental part of its Programmes of Measures

[63] Wastewater discharges can have significant local effects, even if their overall contribution is lower than that of agriculture.

[64] See **Annex II** for more details on the relative inputs of nitrogen and phosphorus from different sources.

[65] Phosphorus in lakes and rivers - Nutrients in European water bodies | European Environment Agency's home page

to reduce nutrient pollution from agriculture, it has significantly influenced the implementation of the Nitrates Directive. By setting broader water protection goals, the WFD supports the Nitrates Directive's specific objective of mitigating nutrient pollution, particularly from agricultural sources, thereby helping to meet environmental targets for both surface and groundwater quality. The impact of the WFD on the Nitrates Directive's implementation and results can be understood through several dimensions such as integrated approach, synergies in monitoring and environmental objectives, enhanced stakeholder engagement, reinforced legal and institutional framework as well as focus on achieving good status and its deadlines.

The WFD promotes an integrated approach to water management across entire river basins, which has enhanced the implementation of the Nitrates Directive by ensuring that agricultural nutrient pollution is considered within the broader context of water management. This holistic approach encourages coordination among different policy measures and stakeholders and should lead to more effective planning and targeted actions. This complementary role is crucial in overcoming challenges like eutrophication, as several sectors can contribute to the pollution.

The WFD has introduced comprehensive monitoring and assessment requirements, which have improved the monitoring networks, data collection and analysis related to water quality, including nitrate levels and eutrophication. This enhanced understanding has helped in identifying pollution sources more accurately and in evaluating the effectiveness of measures taken under the Nitrates Directive. The development of scientific criteria for eutrophication under the WFD in 2009 [24] has been a major progress for the monitoring of eutrophication under the Nitrates Directive. By encouraging the integration of various environmental policies, the WFD has helped align the objectives of the ND with other environmental goals, such as those related to biodiversity and ecosystem health. This alignment has led to more cohesive strategies that address multiple environmental challenges simultaneously.

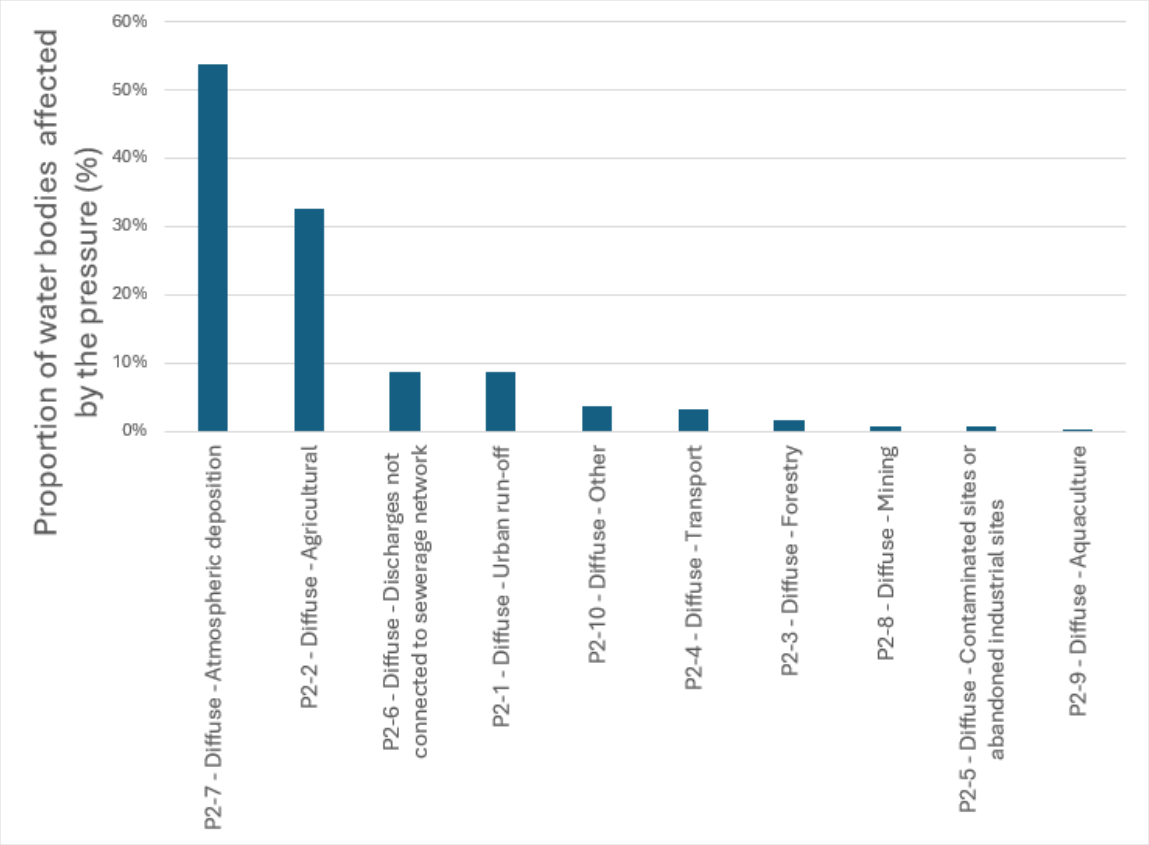
Moreover, the WFD emphasises public participation and stakeholder involvement, which has led to greater awareness and cooperation among stakeholders regarding nitrate pollution. This increased engagement is essential for the successful implementation of measures. The WFD has also reinforced the legal and institutional framework for water protection in the EU, providing additional support for the implementation of the Nitrates Directive. This has included more stringent reporting and compliance mechanisms, which have further encouraged Member States to effectively implement action programs to control nitrate pollution from agriculture. In addition, the WFD’s goal of achieving good status for all waters has provided a clear water quality objective and target that complements the Nitrates Directive’s aim of reducing water pollution from nitrates and eutrophication, but under the ND, there are no specific deadlines as in the WFD. The WFD's aim was to achieve the water quality objectives by 2015. Extensions were allowed up to **2027** under certain conditions, including technical feasibility, disproportionate costs, or natural conditions that require more time for recovery after all the relevant measures had been taken. This is the deadline set by the directive for all EU water bodies to achieve good ecological and chemical status[66]. Therefore, when designing their nitrates action

[66] The only possibility of extending the WFD deadline beyond 2027 is in the case where natural conditions still require additional time for recovery after all relevant measures have been taken

programmes Member States must also consider the objectives of the WFD, thus ensuring a cohesive approach to managing nutrient pollution. Annex XV describes in detail the interlinks between the Nitrates Directive and the WFD.

The role of the Nitrates Directive in achieving WFD objectives is critical. In the 7th WFD Implementation report [30], the Commission pointed out that diffuse pollution from agriculture is one of the main pollution pressures on EU water bodies identified by all reporting Member States in almost all river basin districts and affects both surface and groundwater bodies. This is illustrated in Figure 29 below as the reporting data under the WFD allows to have a broader picture on the different pressures impacting water bodies and the sources of diffuse pollution. Furthermore, the same report states, that nitrates are the biggest pollutant in groundwater bodies, and they also cause surface water bodies to become eutrophic. This is consistent with the findings on the nutrient loads across EU marine regions that show that for all regions, except the Black Sea, the largest source of nitrogen in the sea comes from agriculture.

Figure 29 Proportion of surface water bodies in the EU affected by diffuse pollution pressures. Data reported by Members Sates under the third River Basin Management Plans.



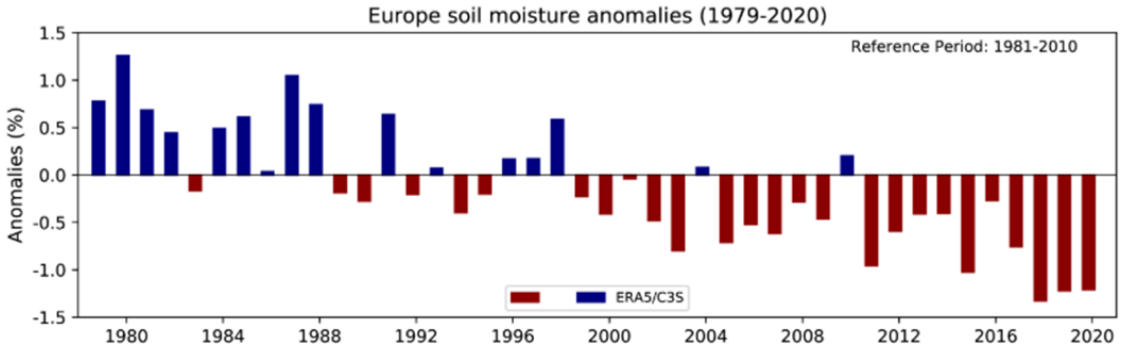
Source: WISE dashboards, 2024.

3.3.6 Climate change.

Another external factor with increasing impact on the implementation of the Nitrates Directive has been climate change. Meteorological factors affect yields, as precipitation

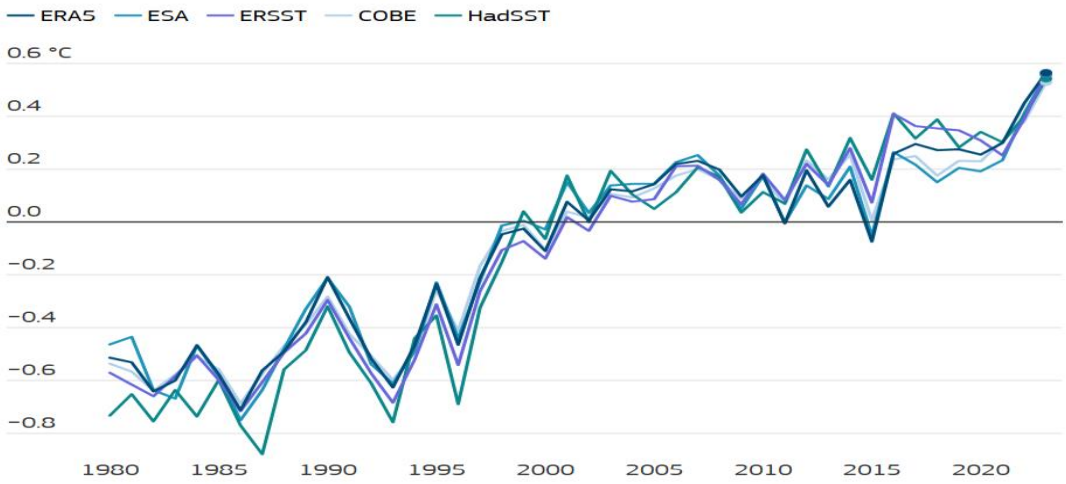
and temperature can induce water and heat stress in crops. The increased weather variability, especially heat and droughts, reduces crop productivity and, thus, nutrient use efficiency, leading to greater nutrient losses than what would have been the case with climatic conditions thirty years ago. As noted in the 2021 RP7 implementation report [15], the unexpected dry conditions across Europe in 2018 resulted in reduced crop yields and increased nitrogen pollution. There have also been severe droughts in 2022 and 2023. Figure 30 shows a more general worsening trend in soil moisture since the 1970s.

Figure 30 Annual European soil moisture anomalies (%) from 1979 to 2020 relative to the annual average for the 1981–2010 reference period [33]



Higher water temperatures also exacerbate the effects of eutrophication due to nitrogen or phosphorus, as warm waters spur additional algae growth, resulting in an increased occurrence of hypoxic events. Figure 31 shows the evolution in average sea surface temperatures in the seas around the EU since 1900.

Figure 31 Annual average sea surface temperature anomalies (°C), relative to the average for the 1991–2020 reference period, for the European ocean domain [34]



The effects of climate change on nutrient pollution are increasingly visible, with unexpected dry conditions affecting crops and increasing nutrient pollution and higher temperatures in worsening eutrophication effects in European rivers and seas. Without additional measures to reduce nutrient losses to water, there is an important risk that climate change offsets the improvements in water quality achieved in the last 30 years.

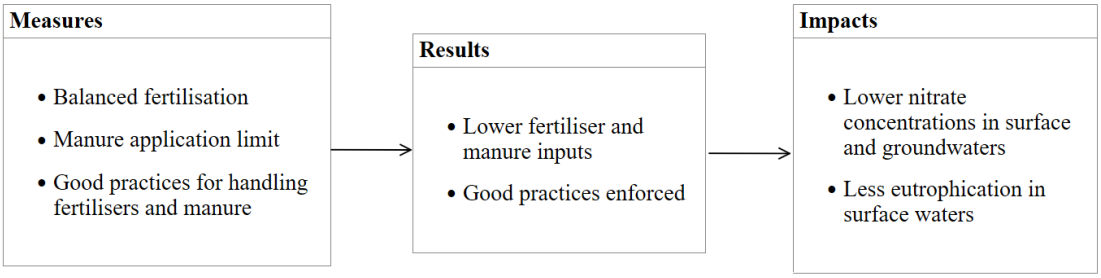
4. EVALUATION FINDINGS

4.1 To what extent has the Nitrates Directive been successful and why?

4.1.1 Effectiveness

This section asks whether the Nitrates Directive has been effective in reaching its objectives. The effectiveness is examined from three perspectives: (1) whether Member States and farms have implemented the measures and how effective the implementation is (2) how the main result indicators related to agricultural pressures (use of fertilisers and manure, nutrient balances) have evolved, and (3) how the main impact indicators related to the quality of waters (nitrates concentrations in surface and groundwaters, eutrophication of aquatic ecosystems) have evolved. Section 3 above has presented the temporal evolution of the implementation of the directive to date, with a focus on ***result indicators*** related to agricultural pressures (use of fertilisers and manure, nutrient balances) and ***impact indicators*** related to the quality of waters (nitrates concentrations in surface and groundwaters, eutrophication of aquatic ecosystems). Figure 32 below shows the basic causal chain of the Nitrates Directive (based on the intervention logic in section 2).

Figure 32 ND causal chain from measures over results to impacts



Looking first at the result indicators, the 1990s saw a clear reversal of the previous, increasing trend in fertiliser inputs that had characterised the 1960s-1980s[67], reflecting the increased acceptance and awareness of the concept of balanced fertilisation. The reduction was not uniform but the trend over the next two decades after the start of the implementation of the Nitrates Directive was generally in a downward direction, except in the Member States joining from 2004 where there was a process of convergence towards the level of chemical fertiliser use in the old Member States, although still at a lower level. The application of livestock manure has also seen a downward trend. The mid-2010s saw a stagnation in these positive trends and even a partial reversal, with fertiliser and manure inputs increasing for a few years in the old Member States, although below the earlier levels of the 1990s, before resuming a downward trend (Figure 11). The reduction in fertiliser inputs in the early years resulted in an improvement in the average nitrogen balances across the EU with lower surpluses up until the late 2000s. Later, the temporary increase in inputs in the 2010s was reflected in a temporary increase in the overall nitrogen balance, followed by a renewed reduction (Figure 13). To summarise, the overall picture appears to be one of significant progress until around 2010, followed by a temporary setback in the 2010s, and a return to improving trends in the most recent years.

[67] See section 2 and 3. It should be noted that the averages disguise significant variations among the Member States, but they produce a basis for assessing overall trends.

High fertiliser prices resulting from the Ukraine war had a significant impact on chemical fertiliser inputs and the overall balance in 2022 and 2023. It is too early to tell how much of this effect will be permanent.

As regards the enforcement of good practices, more than two-thirds of the utilised agricultural area of the EU is now designated as NVZ or under a whole territory approach and thereby covered by mandatory measures under the Nitrates Directive. Over the years, moreover, an increasing number of Member States have implemented whole territory approaches, as described in section 3. Furthermore, a significant number of the Member States apply at least some mandatory measures outside the designed vulnerable zones, even though the directive does not require it. It should also be remembered that the directive requires Member States to define and promote good agricultural practices through training and information across their territory, both inside and outside vulnerable zones. As described in section 2, the measures enforced under the Nitrates Directive in NVZ include a set good agricultural practices including the balanced fertilisation requirement and the manure application limit, designed to reduce the risks inherent to the use of fertilisers and spreading of manure on farms. The effectiveness of the measures is discussed further below.

In terms of impact indicators, aggregate data at EU level show a stabilisation of nitrate pollution in groundwaters, after years of increasing pollution until the 1990s. As shown in section 3, the share of monitoring points with nitrate concentrations above the drinking water standard (50 mg/l) has remained around 13-15 % since 2012 (see Figure 19). These are aggregate figures at EU level, but more detailed Member State data presented in Annex XIII shows clearer pictures of reduction of nitrate concentrations in many Member States. The prevention of further increases in pollution is an important result of the implementation of the directive. The fact that pollution overall has not been increasing since the 1990s, following years of steady increase, shows the effectiveness of the directive in its objective of preventing pollution. Member State's analysis and scientific studies referred to in Section 3 and in annex XIV show clear evidence of the impact of the directive's measures on reducing nitrate concentrations. It should also be noted that groundwater concentrations can be subject to long lag times with renewal of groundwater reservoirs taking place over years to decades, depending on the hydrogeological conditions. Even if concentrations diminish at a regular pace, it may take time for concentrations in a polluted location to reach the 50 mg/l limit value, as sometimes the starting point can be very high. As already mentioned in section 2, the directive therefore does not require that Member States ensure immediate compliance with the water quality standards set out in the directive, but that they put in place effective measures to prevent further deterioration and to reduce the pollution already accumulated, ensuring eventual compliance with the water quality standards. Data on the evolution in groundwater nitrate concentrations in the most recent years do not yet show a clear downward trend at the aggregate level (Figure 22). Nevertheless, more detailed analysis in the Member States has confirmed the positive impact of reduced fertiliser inputs on groundwater concentrations over time (see Annex XIV for concrete examples). Persistent policy implementation and enforcement over a longer period will be required to eventually reach the objectives. In this context, it is also important to point out, as already mentioned, that the directive not only aims to reduce existing pollution but also to prevent further pollution.

As regards surface waters, aggregate data at EU level shown in section 3 show an overall downward trend in nitrates concentrations starting in the 1990s. Nitrate concentrations in surface waters generally tend to reflect the changes of agricultural practices and the effect of the Nitrates Directive more quickly than for groundwaters, with a time lag of only a few years. The reduction of nitrate pollution at EU level since the start of the implementation of the directive in figures 24 and 25 in Section 3 clearly shows the effectiveness of the directive. Annex XIV further shows relevant examples in several Member States on the effects of the directive's measures on the reduction of nitrates concentrations in surface water and the lag times[68]. However, progress has stagnated after 2010 and concentrations appear to be increasing in recent years. Trends over the most recent years seem to confirm that concentrations are increasing again (Figure 26), which is likely to reflect a combination of higher fertiliser inputs and nitrogen surpluses in the mid-2010s (see above) and the intensifying impact of climatic extremes (droughts, heavy rains) resulting in higher losses to surface waters. It is possible that more recent reductions in the overall nitrogen balance observed after 2020 could revert this deteriorating trend in the coming years (with a few years of delay), although the impact of climate change is likely to only get worse over time. It should be noted again that these are overall aggregate trends at EU level, whereas developments differ at national, regional and local level. Annex XIV shows examples in Member States with continued reduction of nitrates concentrations in the most polluted monitoring points between 2008 and 2023, illustrating a continued response of pollution in surface waters to the measures of the Nitrates Directive.

The measures under the directive provide a sustainable approach to the protection of drinking water resources from nitrate pollution. The fact that nitrate concentrations remain well below the 50 mg/l drinking water threshold in a large part of the EU ground and surface waters is reassuring as regards the protection of drinking water resources. The enforcement of mandatory measures under the Nitrates Directive in more than two thirds of the agricultural land in the EU plays a key role and ensures a continued and long-term protection, necessary for water resilience. In some parts of Germany and France, drinking water companies pay farmers for implementing good practices and reducing fertiliser use near drinking water extraction points. Nevertheless, it is notable that more than 30 years after the adoption of the directive, nitrates concentrations exceeding the standard for drinking water can still be found in more than 10% of groundwaters and in a small share of surface water monitoring stations across the EU (Figure 24) and that occurrences of excess nitrate in drinking water, making it improper for human consumption, have continued to take place in recent years, showing examples where prevention has failed.[69]

Measures under the directive have contributed to reducing and preventing eutrophication but it is not sufficient. Section 2 explained how to assess success in addressing eutrophication and section 3 has shown relevant data and provided references to reports showing how and where the directive has contributed. In particular, the significant reductions in both nitrogen and phosphorus loads to the aquatic environment as

[68] See e.g. the support study prepared by the JRC [8] for analysis showing estimated response times in French river nitrate concentrations ranging from 1-10 years, with the highest correlation around 6-7 years following the reduction in agricultural inputs.

[69] An EU infringement procedure is on-going against France since 2024 because the drinking water in seven regions of France exceed the norms for nitrate concentration. 107 water supply zones do not comply with the norms. Problems with drinking water polluted by nitrates affecting several thousands of people have been reported in Spain in 2024 and 2026.

well as the stabilisation and continued reduction of surface and groundwater nitrate concentrations including in the ranges below 50 mg/l are key factors that have contributed to progress in addressing eutrophication. Section 3 further highlighted areas of progress such as in the North Sea, and in other places the situation could have been worse without a clear policy and mandatory measures to reduce nutrient emissions from agriculture. Nevertheless, eutrophication remains a widespread and serious issue. In the assessments under the WFD and the MSFD, eutrophication due to nutrients from agriculture is among the main challenges for reaching good ecological status for river, lake, transitional and coastal water bodies and good environmental status for marine waters.

Continued widespread eutrophication of surface waters reflects the complexity of aquatic ecosystems and the pressures affecting them, and the Nitrates Directive only acts on part of it. Eutrophication is an end-of-pipe phenomenon, and agriculture is not the only pressure, although it is the dominant pressure overall and it therefore remains essential to continue reducing nutrient loads from agriculture in the aquatic environment. It is also the case that the effects of eutrophication may persist for a long time, depending on physio-chemical factors and the fact that ecosystems can take a long time to recover from severe disturbances [35]. The quality of waters needs to improve over large areas by decreasing the excess nutrients causing eutrophication. Nutrients can also accumulate in groundwaters as well as in sediments of rivers, lakes and coastal water bodies with the result that effects of past pollution can continue to be felt over many decades. Phosphorus, the legacy of many years of wastewater discharge as well as the contribution from agricultural soils, tends in particular to stay in sediments for a long time. And finally, biological systems take time to reestablish themselves once severely disturbed. Another more practical issue is that the Nitrates Directive does not set out a specific methodology or thresholds to be applied for the eutrophication assessment[70], which may have delayed action at national level, as the focus of Member States has primarily been on drinking water standards. Thanks to the comprehensive framework and requirements provided by the WFD and the mutual efforts between the Commission and the Member States, there has been increased awareness and measures taken, and with it a better reporting from Member States. (See also Annex XV on coherence with the WFD.). In particular, Member States have improved the NVZ, the action programmes and the monitoring to tackle better eutrophication.

Effectiveness of the measures set out in the directive

As described in section 2, the measures under the Nitrates Directive aim to enforce good agricultural practices on the use of fertilisers and management of livestock manure[71]. Their relevance and effectiveness is well documented and recognised. Annex XI provides more background with reference to the scientific literature on the environmental effects of the measures set out in the annexes to the Nitrates Directive[72]. A key pillar of action under the directive is the limitation of excess fertiliser use on farms. The directive requires fertilisers to be apportioned in accordance with the foreseeable requirements of the crop and the nitrogen available in the soil, so as to limit the risk of

[70] Consultations with Member State experts have highlighted the Nitrates Directive's lack of standards regarding eutrophication, including on the role of phosphorus.

[71] The measures are briefly described in box 1.

[72] There is a large body of scientific analysis regarding the environmental effects of farming practices. See also Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources, part B [21].

losses. In practice, the fertiliser amounts tend to reflect a compromise between agronomic and environmental considerations. The requirement of balanced fertilisation, combined with the manure limit, is seen as a major contribution to the reduction of nitrogen and phosphorus surpluses, thereby reducing the risk of leaching. The directive also promotes an improved utilisation of livestock manure by restricting its application during the winter while promoting its positive use as an organic fertiliser during the growing season, hence reducing the need for chemical fertilisers and contributing to soil organic matter. Other critical measures aim to reduce the risk of leaching and run-off by restricting fertiliser and manure application along watercourses and on steep slopes or by requiring the main crops to be followed by catch crops to retain nitrogen in soils during the autumn and winter where the risk of leaching and run-off is the greatest.

The most effective measures include restrictions on the application of fertilisers in winterly or wet conditions and during rainy autumn and winter months, as well as the related minimum capacity for manure storage. This was pointed out by Member State experts consulted for the evaluation and is consistent with the scientific literature which indicates that restrictions on the spreading of fertilisers and manure during sensitive periods is a highly effective measure with relevance for all Member States[73]. The balanced fertilisation requirement, crop rotation and minimum land cover are also seen as very effective measures, followed by buffer strips. Industry organisations tended to stress precision farming as a cost-effective strategy to manage nutrients and reduce environmental impacts. Such practices can indeed support the objective of complying with the balanced fertilisation requirement. As mentioned in section 2, certain measures are optional for Member States, notably the requirements on fertiliser planning and record keeping, land cover and crop rotation. These measures are nevertheless widely implemented in the Member States and are generally recognised as relevant and effective (see Annex XI and XII).

The limit on the application of manure is necessary to address the high risk of losses from livestock manure. Excessive application of livestock manure contributes to the risk of nitrogen losses due to slow mineralisation, ammonia emissions, and lower fertiliser use efficiency, as explained in section 2. Compared to chemical fertilisers, livestock manure is associated with higher risks of nitrogen losses due to a more unpredictable release of nitrogen to the soil, high ammonia emissions, low efficiency of uptake by crops, and the fact that livestock manure is continuously available. The limit of manure application not only limits nitrates emissions to water but also critically contributes to address other pathways and forms of emissions from manure (ammonia and phosphorus), which are key additional factors for eutrophication of surface waters[74]. Thirty-five years after the adoption of the Nitrates Directive, there is little doubt that limiting the amount of manure applied on agriculture land remains necessary and justified to control nitrogen and phosphorus emissions from manure and processed manure, including with regard to other EU environmental goals. Setting a common limit for the application of nitrogen from manure has served as a pivotal benchmark in curbing different pathways of nutrient pollution from manure, contributing positively to limiting nitrates pollution and eutrophication. The multi-pathway role of the limit is intrinsically linked to the cascading effect of nitrogen pollution and the policy objective to limit negative environmental effects of intensive

[73] See Annex XI and XII.

[74] As mentioned in section 3, some Member States have separate rules to regulate phosphorus inputs.

livestock production. This also explains why the limit equally applies to processed manure as it generally presents similar risks of emissions to air, water and soil as raw manure[75]. A large majority of national experts considered the manure limit effective in preventing and reducing water pollution and important for managing the impact of intensive livestock. In the public consultation most stakeholders also considered the manure limit to be either effective or somewhat effective. Further discussion on the relevance and added value of the manure application limit can be found in Sections 4.2 and 4.3. See also Annex XVII which examines the effectiveness and relevance of the manure limit.

While the practices and measures required under the directive are generally recognised as relevant and effective to address nutrient pollution, it does not necessarily mean that the national implementation has been sufficient to address the pollution. The implementation of the directive was initially slow and very gradual. The directive itself set out a gradual process of implementation of the four-year cycle and further allowed a higher manure nitrogen limit during the implementation of the initial action programmes. In addition, the Commission initially had to launch a high number of infringement procedures due to delays in the Member States' compliance with basic requirements under the Directive. (See details in Annex VIII and IX). As mentioned in Section 3 and detailed in Annex XII, the national or regional action programmes in 2020 include all the basic requirements set by the directive, but their implementation is not seen as equally effective across the measures or the Member States. Where assessments vary most between stakeholders is indeed with regard to whether the practices have been sufficiently well implemented and enforced. Among stakeholders, a widely held view of water supply companies and environmental NGOs was that the directive is lacking in implementation and proper enforcement, while farmers and industry tended to consider the directive as already sufficiently effective. A large majority of national experts consulted considered that the directive remained an effective legal instrument for achieving the objectives set out, and that it provided sufficient mechanisms and tools for both the Commission and the Member States to facilitate effective implementation and enforcement.

Over time the preventive approach of the directive has been strengthened in the national implementation. Data on groundwater and surface water quality show that the directive plays an important preventative role. For example, thanks to the implementation of a minimum common set of mandatory measures in NVZ or in Member States that apply the whole territory approach, which together include the most intensively farmed regions, the very large majority of groundwater and surface water nitrates concentrations have remained below the 50 mg/l threshold, despite further intensification of production in the last 30 years. As shown in section 2, there is a direct connection between the manure and fertilisers application and nitrate concentration in groundwater and surface waters, and the main objective and effect of the directive is to keep manure and fertilisers application in check, which is particularly important when the production intensifies. The fact that there are mandatory measures in at least two-thirds of agricultural area in the EU (NVZ and

[75] Processing may take many forms ranging from mechanical separation into solid and liquid part or storage and composting over anaerobic digestion in a biogas plant to advanced processing for the recovery of nutrients in forms that are similar to chemical fertilisers (RENURE). The associated environmental risks will vary depending on the process and needs to be checked on a case-by case basis so that adequate safeguards be provided.

whole territory approach) is a key factor in the prevention of pollution. Over time, Member States have enlarged this common basis of mandatory measures, either by moving to a whole territory approach where mandatory measures apply throughout the territory, or by enforcing some mandatory measures also outside NVZ confirming the importance of the preventive approach supported by a minimum set of mandatory measures rather than voluntary measures only. Today there are 12 Member States with a whole territory approach. Many of the Member States with NVZ informed that they are also applying mandatory measures outside NVZ as part of the implementation of the Nitrates Directive, further complemented by mandatory requirements under the CAP (such as the GAECS).

Over time, compliance with basic requirements has improved and the enforcement mechanisms have allowed to address shortcomings in the national implementation. The four yearly implementation report prepared by the Commission based on the data and reports from the Member States has been an important mechanism to take stock and address implementation issues. The evolving jurisprudence of the Court of Justice bolstered the implementation of the directive. The integration of the Nitrates Directive as basic measures in the Water Framework Directive was an important step in setting water quality objectives and deadlines, and helped to progress on the implementation, as explained in Section 3. Conditionality (or cross-compliance) under the Common Agriculture Policy introduced in 2003 was also an important factor in improving compliance and awareness with the Nitrates Directive measures at farm level and further supported the implementation of the directive (see Section 3). The continued dialogue between Member States and the Commission in the Nitrates Committee and Nitrates Expert Group has allowed developments of guidelines and exchange of best practices. Following this progress in implementation, in recent years, the focus of Commission's enforcement has increasingly moved on from compliance with basic requirements of the directive to the more complex question of whether the actual measures implemented in the Member States are sufficient to reach the objectives of the directive. In this context, in view of the water quality results, conditions for derogations to the manure limit were adjusted, or derogations were phased out. The enforcement mechanism eventually allows to address shortcomings in the effectiveness of measures, but there will always be a time lag, as the Commission's enforcement would primarily be based on absence or reversal of progress in water pollution.

Factors hampering effectiveness of the Nitrates Directive

The extensive flexibility of the directive in terms of its national implementation works in both directions and may limit effectiveness when faced with strong market pressure. The flexibility that the directive gives to Member States is important as it allows Member States to tailor the NVZ and action programmes to national and regional variations and design the most cost-effective measures for their national context and to react quickly and effectively to new challenges[76]. Annex II and III of the Directive specify the type of measure that is required, outlining the minimum measures to be included in NAPs, but it is up to the Member State to prescribe how each of the measures will be applied throughout its territory and to tailor and build upon these to account for national

[76] Member States have many years of experience with the implementation of measures under the directive and have therefore developed a broad knowledge base on the cost-effectiveness of measures in their different national contexts.

and regional circumstances[77]. This should also support acceptance by farmers unlike a one-size-fits-all, prescriptive approach. **The assessment of Member States' approaches to the implementation of the measures in Annex II and III of the directive has also focused on determining whether the flexibility linked to the national implementations influences its effectiveness.** Annex XII of this report gives an overview of how the measures of Annex II and III of the Nitrates Directive are implemented in the Member States in NVZ and whether the flexibility linked to the national implementations has an effect on the effectiveness of the directive. It first examines what measures have been implemented in which Member State and then provides examples of how the implementation varies between Member States. To the extent possible, it also describes if the variation is linked with the flexibility to adapt to local circumstances and whether this flexibility increases the risk of losses to the environment and thus has a potential impact on the effectiveness of the measures. Three measures are analysed in more detail: closed periods, balanced fertilisation, including manure application, and the manure application limit and derogations. The conclusion is that high variation in designing measures does not necessarily correlate with variation in the risk of nitrate loss, as often the choice of measures is justified by the tailoring to regional circumstances. A specific assessment focused on the variation of closed periods, showing that the different approaches translated into tailored measures with high coverage of risk periods. However, the flexibility can also result in a lower capacity of Member States to implement necessary measures that are strongly resisted by the agricultural sector, in particular regarding limits on fertilisation or on manure production. Several Member States have relied on voluntary measures and incentives where the overall effectiveness seemed to have been reduced due to low take-up especially from the biggest polluters. Conversely, that is why the limit on manure application at EU level has been particularly relevant.

The discretion left for Member States can also make it more challenging for the Commission to enforce the directive when the issue concerns the level of ambition in measures rather than just the inclusion of the types of measures listed in the annexes to the directive. As reported in Annex XII, there are more than 75 NAPs for the 27 Member States with variations as national and regional circumstances are taken into account. These include (1) geo-physical characteristics such as hydrology, geography, soil and climate and their associated risk of pollution (2) sensitivity of the waters to nutrients, current levels of water pollution and water quality objectives; (3) type of farming activity and level of intensity of farming.

Market pressures generally tend to result in higher fertiliser inputs and more intensive and concentrated livestock production and manure surpluses, thereby increasing the risk of nutrient pollution[78]. A key external factor influencing the implementation of the Directive has been the intensification of agriculture, also resulting in high spatial concentrations of livestock and manure production. Competitive pressure

[77] The local circumstances include (1) geo-physical characteristics such as hydrology, geography, soil and climate and their associated risk of pollution (2) sensitivity of the waters to nutrients, current levels of water pollution and water quality objectives; (3) type of farming activity and level of intensity of farming.

[78] One example of this is evident in Northwestern Europe where infrastructure and port facilities give access to the global markets for feed imports and exports of animal-based products. Coupled with high land prices, this has created the basis for very intensive livestock production disconnected from available land on which manure could be spread, especially in the low countries where livestock densities are significantly higher than anywhere else in the EU, resulting in major manure surpluses.

felt by farms from competitors in other Member States and in global markets can result in a relaxation of the Nitrates Directive measures, as the directive leaves flexibility for the Member States to increase fertilisation limits and allow for higher livestock concentration and manure production, thereby increasing the risks of pollution especially if the manure and fertilisation application limits are not strictly enforced. Inherent mechanisms of the directive, notably Article 5.5 and 5.6, provide the tools and set the obligations for Member States to react rapidly and strengthen measures when necessary[79]. Furthermore, some of the market pressures have been mediated by the common agricultural policy of the EU such as the gradual 'decoupling' of agricultural support since the early 1990s. On the other hand, policy choices such as the abolition of the milk quotas in the mid-2010s may also have contributed to increasing the market pressures as farms reacted with intensification of dairy farming in some Member States in the number of animals or in the amount of milk produced per cow[80].

Strong market pressures also make it more difficult for authorities to enforce strict requirement and may have contributed to delays in the national implementation and in low levels of compliance. Even if the acceptance and compliance has increased, difficulties to step up national implementation necessary to reach water quality standards remain an issue. In the consultations with Member States experts, this was also referred to in the sense that the "low hanging fruits" have already been picked in the early years, making it increasingly difficult to further increase the impact and level of implementation in recent years. One manifestation of this has been a tendency of measures to become more complex in some cases as Member States strive to implement more flexible approaches in response to farmers' concerns over "one-size fits all" or immediately impactful restrictions. In this respect, some Member State experts have highlighted the existence of an inverse relationship between flexibility and simplicity in measures, with the demand for more flexibility for farms resulting in higher cost of implementation and enforcement due to the increased complexity of the various schemes.

In general, fundamental changes in agricultural practices, such as in the choice of crops[81] or reduction of fertiliser rates below the economic optimum, may be difficult to implement. The challenge for Member States to define and enforce stricter fertilisation limits under the balanced fertilisation is a good example. There may be cases where the fertiliser rate needs to be lower than the economically optimal rate to attain environmental objectives[82]. However, the limitation of fertiliser use below the economic optimum is strongly resisted by the sector, as such restrictions can affect the yield and quality of crops as well as the profitability of farms. The directive leaves it to Member States to set the specific fertilisation standards and, although there are exceptions where more restrictive

[79] Article 5.5 requests that Member States strengthen their NAP as soon as it becomes clear that measures are insufficient for achieving the objectives, and Article 5.6 that Member States establish suitable monitoring programmes to assess the effectiveness of the NAP.

[80] Eurostat: The EU dairy herd has been decreasing in recent years as the milk yield per cow has improved. In 2023 there were around 20 million cows in the EU, with an average of 7800 kg of milk produced per cow. In 2024, the EU produced 161.8 million tonnes of raw milk, 0.9 million tonnes more than in 2023. The average apparent milk yield per cow in the EU reached 8 120 kg in 2024.

[81] Apart from intensive livestock production, certain crops such as potatoes and maize are recognised as being associated with a higher risk of nitrate leaching.

[82] In welfare economic terms, such a lower rate could be economically efficient where externality effects that are not reflected in current market prices mean that the "social" optimum (for society) is different from the "private" optimum from the perspective of the farm [25].

limits have been set in some areas, there has been a tendency to rely on the economically optimal amounts. Examples described in Annex XII on variations of balanced fertilisation approaches show that Member States often set fertilisation application limits that exceed recommended fertilisation levels for low leaching risk areas and fail to adequately reduce limits in high and medium risk zones. The development of precision fertilisation techniques may help to alleviate some aspects of over-fertilisation, but do not address the issue of whether the limit is adequate from an environmental point of view.

Derogations to the manure limit may have limited the achievement of the objectives of the Directive. Member States can apply for derogations to apply manure above the 170 kg N/ha limit under specific conditions, such as long growing seasons, crops with high nitrogen uptake, high net precipitation and soils with exceptionally high denitrification capacity. A key basis of derogations is the recognition that the risk of leaching and runoff from grasslands in rainy climates is often lower than from arable crops such as maize (see Annex XVII), and derogation decisions have typically required a certain share of grassland to be maintained on derogation farms. The first derogation was granted in 2002, and the number has increased and reached 6 Member States in 2013. The amounts of manure authorised under the derogations typically varied between 220 and 250 kg N/ha per year. After 2013, the number of derogations has been steadily reduced following water quality concerns. Experience with the granting of derogations has shown that significant exceedance of the 170 kg/ha limit often results in increased pollution both at the level of water and air. While under favourable conditions, higher manure application limits on grassland may result in lower groundwater pollution than on arable crops, the risks of pollution and especially of eutrophication of surface waters significantly increase with many derogations in the same area. It should also be noted that the intensification of production allowed under derogations is often combined with significant application of chemical fertiliser on the farm, linked to the need for intensive production of feed. Indeed, high livestock density is a driver of agricultural intensification and nitrogen surpluses, as shown in section 3. Therefore, derogations to the manure limit have come under increased societal and legal scrutiny as there is increasing concern that the higher livestock concentration and manure production allowed by derogations have contributed to negative effects on water, soil, air quality and protected habitats in the Member States concerned (See also Annex XII and Annex XVII).

That is why derogation decisions have come with additional conditions, higher scrutiny as well as higher engagement of farmers and authorities. This kept in check the negative impacts of the additional manure allowed, but they have also created expectations and entrenched the derogated farms in high nutrient-output farming that may have led to an accumulation of impacts over time, and thus contributed to the stagnation in water quality improvement in the 2010s described in section 3 [36]. Very high levels of manure production concentrated in a few regions have consequences beyond the Nitrates Directive, as it is also responsible for high ammonia emissions, with negative consequences on human health and on nature[83], and a large number of Member State experts considered that derogations are affecting competition between agricultural producers within the internal market. The experience with derogations has clearly

[83] See on coherence below.

underscored the necessity of a coherent livestock policy at EU level that would consider the effects of high for livestock concentration[84].

Climate change also has an increasing impact on the implementation of the Nitrates Directive, exacerbating the impact of eutrophication of aquatic ecosystems and making the management of fertiliser use more challenging. Climate change has added further complexity to an already complex environment in which to implement the directive. For example, the increasing water temperatures tend to exacerbate the impact of eutrophication, increasing the risk of oxygen depletion in bottom waters[85]. Climate change also leads to new weather extremes with longer droughts, longer growing seasons, stronger rains and floods during different periods of the year, complicating fertilisation management in agriculture and increasing the risks of nutrient losses. The directive leaves wide margins of manoeuvre for Member States to consider climate change effects in the design of measures. Hence, policymakers may find it necessary to implement measures to effectively address these challenges, as warming waters and unpredictable weather extremes can reduce the effectiveness of their efforts. At the same time, climate change has resulted in large fluctuations in yields and difficulties to keep livestock in conditions of prolonged and repeated droughts, and the increased uncertainty is reflected in calls from farmers for greater flexibility in the implementation of rules such as closing periods for manure spreading or deadlines for sowing, harvesting, or for planting of catch crops, often phrased in terms of complaints over "calendar farming".

The impact of climate change has already become evident and may have contributed to the stagnation of progress in water quality in recent years. Moreover, it is likely to intensify in the coming years [37]**.** As climate change impacts worsen, it raises questions on the sustainability of agricultural practices with high inputs, as the risks of nutrient pollution increase. At the same time, it becomes more challenging to identify the correct level of ambition needed to reach the required improvements in the aquatic environment. Importantly, in terms of the measures set out under the directive, the inherent flexibility of the Nitrates Directive makes it possible for Member States to adapt their design to take account of such challenges, through more flexibility or more cautious approaches to fertiliser application and targeted advice and information actions for farmers. The fast-developing knowledge and technology would assist in these efforts.

4.1.2 Efficiency

To evaluate the efficiency (cost-effectiveness) of the directive, economic estimates have been calculated of the adjustment and administrative costs for farms and public authorities resulting from the implementation of the directive in the Member States[86]. This was complemented with estimates of the societal costs of nutrient pollution and of the benefits of the directive in reducing these societal costs. The benefits of the

[84] See for example the *Vision for EU Agriculture and Food* [3] which states that priority should be given to "addressing nutrient pollution hotspots and promoting integrated territorial approaches. A key aspect of this would be the management and control of nutrients from livestock farming to limit negative externalities, support extensification in regions with high livestock concentrations, and promote circularity which can help reduce the use of synthetic fertilisers."

[85] While the primary cause of oxygen depletion is nutrient input from agricultural fertilisers, which cause eutrophication, the effects of eutrophication are exacerbated by climate change, in particular increases in sea temperature and in water column stratification (see EEA Open ocean — ocean chemistry).

[86] The economic analysis was informed by consultations with stakeholders and with experts from national authorities. See also **Annexes II and IV**. For details see [25].

Nitrates Directive go to society as a whole and to all economic activities benefitting from clean waters, while the costs fall on public authorities tasked with implementing the directive as well as on farms (in line with the polluter pays principle). Farms can also derive benefits from some of the measures implemented under the directive and can receive public support in some cases[87]. Such benefits are not directly reflected in the estimates below.

In concrete terms the **benefits of the directive** include reduced costs for water purification for drinking water purposes, long-term protection of drinking water resources, and clean rivers, lakes and coastal waters. Benefits go to economic activities, in particular tourism, water utilities, fisheries, aquaculture and other food producers, as well as to recreational activities and citizens in general through general amenity value of nature and the avoidance of negative health risks from polluted drinking water wells, especially in rural areas. While the directive is primarily aimed at protecting the aquatic environment, in practice it also has some indirect effect on reducing ammonia emissions from livestock production, hence improving air quality and reducing deposition of nitrogen on terrestrial habitats, especially in regions with high livestock densities. The directive also indirectly reduces nitrous oxide emissions, a potent greenhouse gas, linked to the land application of chemical fertilisers and manure.

An essential part of the benefits of the directive are linked to protecting human health and the directive's preventive effect. For example, the benefits for protecting drinking water can be measured by comparing the cost of the measures under the directive to reduce nitrate concentrations and prevent their increasing and reaching unsafe levels against the cost of water treatment (or securing an alternative drinking water source) and the potential number of people affected when nitrate levels exceed the drinking water threshold. It may also be the case that the drinking water reservoir is affected by eutrophication, rendering the water equally unsafe to drink. Technical solutions to treat such waters require substantial capital and operational expenditure, while preventive measures to minimize nitrogen runoff offer a more sustainable and cost-efficient solution. The economic implications of these strategies vary significantly based on the scale of implementation and local conditions. A 2024 Danish study[88] estimated technical nitrate removal costs between €0.15 and €1.60 per m³, whereas preventive measures range from €0.02 to €0.26 per m³. In some Member States (for example Germany and France), drinking water companies reported that they pay farmers for implementing good practices and reducing fertiliser use near drinking water extraction points. These examples illustrate the benefits of the Nitrates Directive in maintaining potential drinking waters below the 50 mg/l threshold and in keeping drinking costs lower, including where nitrates levels are low. Finally, an assessment of the value of health benefits of the Nitrates Directive needs to include not only drinking water, but also the impacts of eutrophication and ammonia emissions. With regard to these aspects, the developing science relating to health impacts of nutrient pollution from agriculture such as evidence of carcinogenic effects of nitrates at much lower level than 50 mg/l, premature deaths caused by ammonia emissions or jurisprudence on compensations for the death of a person due to toxic algae blooms (green tides in

[87] Farms can benefit from improved soil quality due to cover crops etc. (see [55]) and receive support for some investments (e.g. in manure storage) under the CAP.

[88] https://doi.org/10.1016/j.scitotenv.2023.167368

Brittany)[89] should also be taken into account. The fact that the nitrate pollution is below the drinking water threshold in many areas underlines the importance of the directive's preventive approach for the protection of human health and it does not imply that the health benefits of the directive are insignificant.

To estimate the economic value accruing to society from the implementation of the directive, the starting point is to estimate the costs to society of nitrogen pollution from agricultural sources. Pioneering work carried out in 2011 and in 2013, as part the European Nitrogen Assessment project [38], estimated the total yearly cost to society of nitrogen pollution in the form of nitrates, ammonia, nitrous oxide and nitrogen oxides from agricultural sources amounted to EUR 35-230 billion in 2008 [25]. The European Nitrogen Assessment had highlighted that an important aspect of those costs is linked to the cascading effect of nitrogen flows and pollution in the environment [38]. The cost estimates of the European Nitrogen Assessment have become a key reference. For this evaluation this estimate was updated based on cost figures gathered from more recent literature as well as updating for inflation, and the new cost estimates have been compared with the European Nitrogen Assessment estimates. Annex II and IV and the underlying study offer further details on the methodological approach.

The costs to society of nitrogen pollution from agricultural sources was estimated to EUR 68-182 billion annually in 2023 prices[90]. The estimate covers all four forms of nitrogen emissions, but the main costs are associated with emissions of nitrates (EUR 48-102 billion) and ammonia (EUR 17-76 billion). Based on these updated societal costs and an estimate of the impact of the Nitrates Directive's impact on the reduction of nitrogen emissions [39], **the societal benefit from the implementation of the Nitrates Directive is estimated to EUR 10-22 billion annually.** As in the original studies, these estimates relate to 2008 nitrogen emission levels, as it has not been possible to repeat the analysis with more recent data. Given the evolution of nitrogen input parameters detailed in section 3 and the overall stagnation of implementation observed in the 2010s, the estimates for 2008 emission levels are considered to remain broadly representative in terms of their overall order of magnitude. The largest benefit is related to the reduction in nitrate emissions to water, which is what one would expect since the directive aims primarily to affect nitrate emissions, but there is also a significant contribution from reduction of ammonia emissions[91]. The estimated value is based on an assumed constant marginal cost of pollution, which means that the estimate is conservative and could be significantly

[89] https://nantes.cour-administrative-appel.fr/decisions-de-justice/dernieres-decisions/responsabilite-de-l-etat-du-fait-de-la-proliferation-des-algues-vertes-en-bretagne

[90] The lower bound figure corresponds to the median cost estimate in the reviewed literature, whereas the higher bound corresponds to the average of the cost estimates in the literature. This served to indicate different interpretations of what would account as the "central estimates" in a very diverse population of studies, covering many different types of situations and approaches, and aimed to exclude extreme outliers. The final estimates were within the range of the original estimates arrived at in the Nitrogen Assessment and related studies, which formed the basis for the analysis, supporting the results. Annex II and IV and the underlying study itself explain the method used for arriving at the range.

[91] The directive's impact nitrates emissions was estimated to 16% of the total emissions. The impact on ammonia emissions was estimated to 3% of total ammonia emissions.

higher in reality[92], as further detailed in the sensitivity analysis provided in Annex II and IV.

In general, it should be noted that these estimates are associated with significant uncertainty, **however, the estimates allow to indicate the general order of magnitude, which is sufficient to draw conclusions and comparing to the implementation costs.** The uncertainties are due to the difficulties involved in correctly measuring both the impact of the directive and the associated value to society. Nevertheless, the aim here is not to provide precise estimates of all benefits but simply to reach a broad estimate of the overall order of magnitude of the total benefit of the directive to society, as a basis for comparison with the estimated cost of implementation. In other words, the analysis should be sufficient to serve as a basis for assessing the overall efficiency of the directive in terms of a welfare economic calculus at the level of society as a whole[93]. Going beyond the goal and scope of this evaluation, more extensive national level studies on the costs of nutrient pollution and the benefits of the measures modulated on the specific national context and reflecting the diversity of situations could be crucial tools for Member States to draw conclusions supporting policy choices and discussions with stakeholders.[94]

As regards the costs associated with the implementation of the directive, these fall on farms in NVZ and in Member States applying mandatory measures on the whole territory, who need to comply with requirement to follow good agricultural practices and limitations on fertiliser use, as well as on public authorities, who are responsible for identifying and monitoring pollution, designating NVZ, designing action programmes, supporting farms in the implementation of the measures and enforcing the measures.

The net adjustment costs borne by farms in the EU are estimated to approximately EUR 1.5 billion. These costs correspond to approximately 0.4 % of standard output of the agricultural sector in the EU in 2023. The distribution of the costs across Member States and sectors are shown in the graphs below. Figure 33 shows the total cost per Member State, reflecting the variations in the size and nature of the agricultural sectors across the EU. Figure 34 shows the same amounts as a share of total agricultural standard output, which gives a better idea of the relative importance of the costs compared to the size of the agricultural sector as a whole within each Member State[95].

[92] As nitrogen pollution increases the first kilos of nitrogen are likely to have little impact whereas at a certain point the impact becomes more significant. When reducing pollution, the Nitrates Directive removes the kilos "at the top of the pile" which are likely to be associated with higher cost than the average.

[93] For further discussion of the methodological issues, see Annex II and IV.

[94] For example, a study published in October 2025 (using national cost estimates) estimated the cost of nitrogen and phosphorus pollution (air pollution and eutrophication) in the Netherlands alone to be EUR 7.3 billion annually, which as a general order of magnitude seems consistent with the estimates provided in the evaluation study for the whole EU and the fact that costs of nutrient pollution in the Netherlands would be higher than average, due to the level of pollution, the population density and age distribution.

[95] As explained below these averages cover wide differences between different sectors. In particular, cost structure is very different between livestock farms and arable farms.

Figure 33 Adjustment costs for farms due to the Nitrates Directive for the EU-27 (€/year)

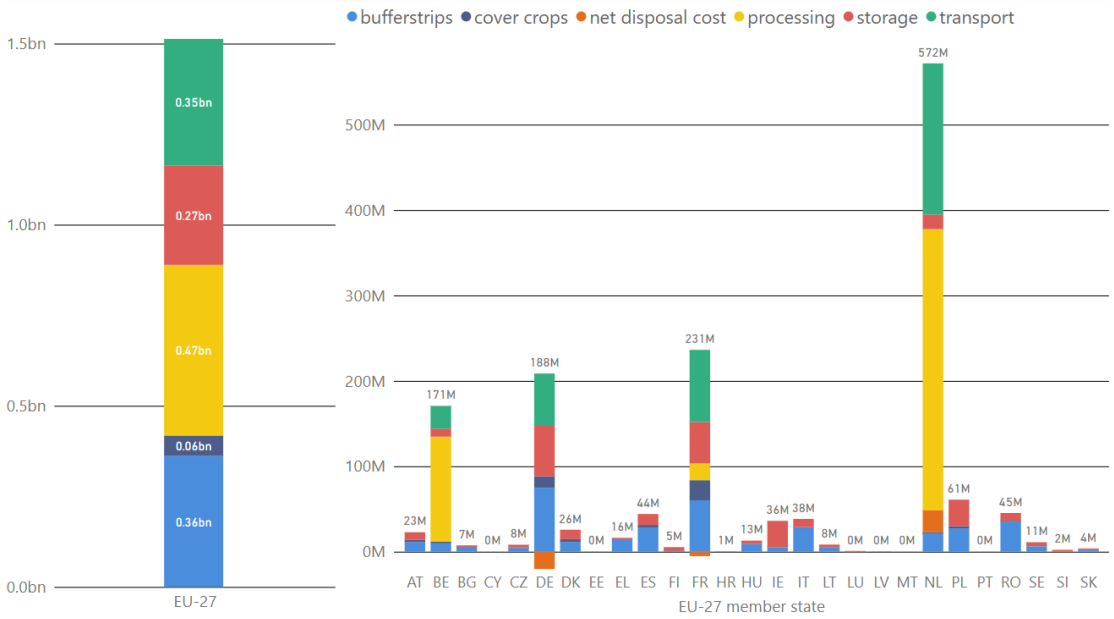
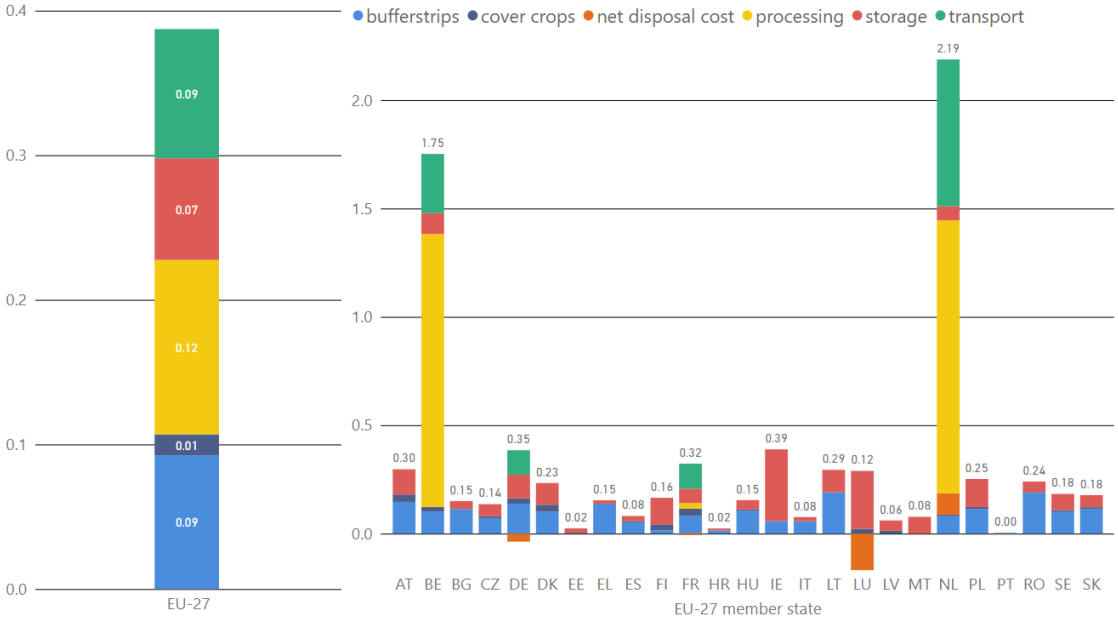


Figure 34 Adjustment costs for farms due to the Nitrates Directive for the EU-27 (percentage of standard output)



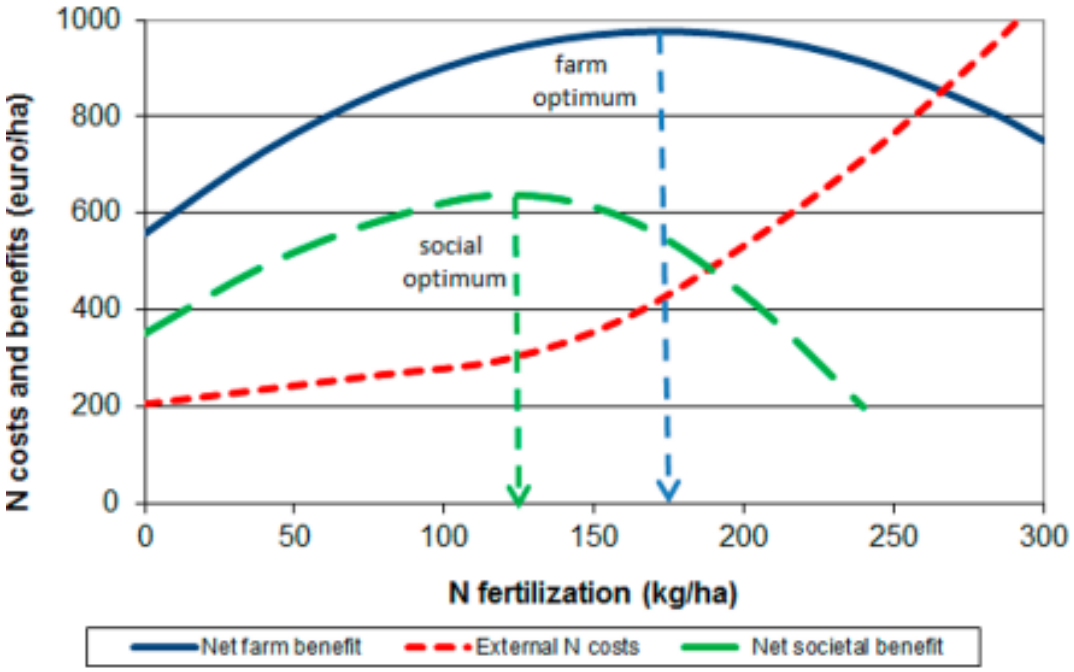
Around 55% of the overall costs are costs for livestock farms in a few Member States, associated with the processing, transport and disposal of excess manure[96] in regions with very high livestock density. The remaining 45% of the overall costs are more evenly distributed among farms in all Member States and are significantly lower as a share of output. These costs are generated by storage requirements stemming from the limitation of manure application during sensitive periods of the year, a significant investment cost for livestock farms across the EU, and

[96] This covers separation in solid and liquid fraction, composting and biological treatment (denitrification), transport to fields including exports to other farms and Member States, and payments to farms accepting the manure for spreading on their fields (the last point gives rise to negative costs in some Member States, due to payments from farms abroad).

by land management measures, where estimates have been developed for buffer strips along water courses and cover crops.

On the other hand, **the cost of balanced fertilisation which limits fertiliser application in function of the crop needs and the nitrogen present in the soil was found to be insignificant in terms of adjustment costs**, as they are generally not associated with a loss of agricultural yield[97]. As explained in Annex XI, the cost-efficiency of balanced fertilisation depends on the farm type, the standard for mineral or organic fertilisers and the economic situation. The fact that the cost of balanced fertilization is found to be insignificant, indicates that the fertilisation standards are usually close to the economic and agronomic optimum for the farmer. However there can be a further mismatch between the private economic optimum of the farmer on the one hand and the social economic optimum for society on the other, due to the externality costs associated with fertiliser use, which fall on society as a whole (see Figure 35).

Figure 35 Mismatch between the economic optimum for the farmer and for society (van Grinsven et al. (2013)



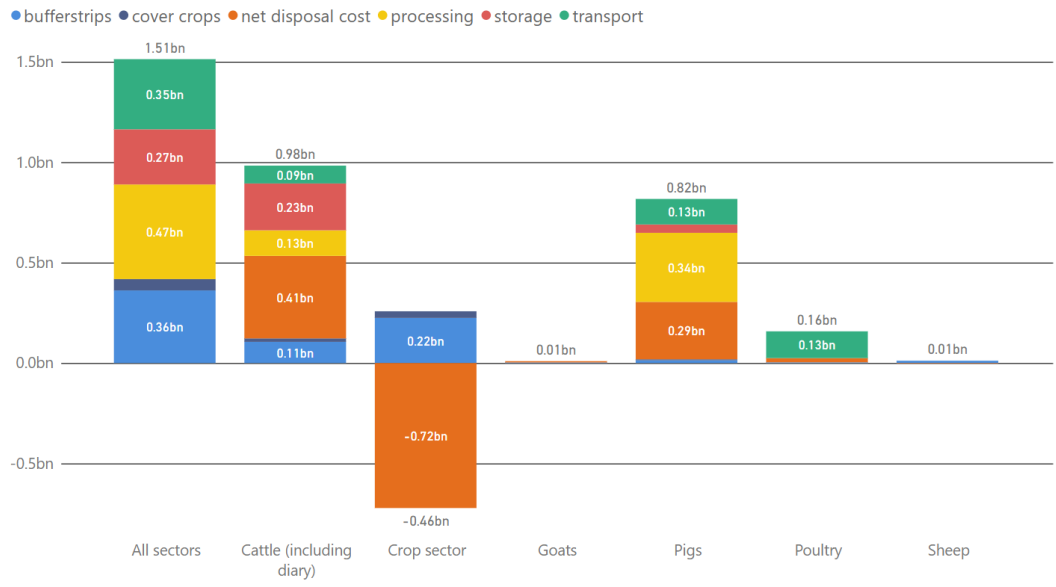
For arable farms without livestock production, the application standards will generally limit the input of chemical fertilisers, which reduces costs for the purchasing of such fertilisers. On livestock farms the application limit for manure applies in addition to the overall fertiliser application standards and can imply a need to export manure from the farm and replace it by chemical fertilisers, both of which involve costs for the farmer. Therefore, from the farmer's perspective, the incentive to apply livestock manure is evident. Using all the manure available on the farm is less costly as it reduces or removes the costs of storage, transport or processing of manure. Nevertheless, to reach an economic optimum through manure application, it would require application of very high amounts of total nitrogen, due to the generally lower efficiency of manure as a fertiliser (optimum

[97] They are however associated with administrative costs (see below).

agronomic fertilisation rates are based on the amount of nitrogen that is expected to be available to the crop during the growing season). In addition, the mismatch between the private economic optimum of the farmer and the social optimum becomes disproportionally high as the external costs for manure are linked to its high pollution risk, especially when concentrating all the manure application on the farm. Reducing societal costs of manure therefore calls for a redistribution of the manure between livestock and arable farms. Figure 36 below illustrates how the Nitrates Directive acts to redistribute and shows that it helps reducing costs for arable farmers. See also section 4.3 exploring how some forms of manure processing can reduce the environmental risks and allow for substitution of chemical fertilisers.

As shown in Figure 36, the overall adjustment costs are mostly concentrated in the livestock sector (EUR 2 billion in total) whereas the arable sector as a whole has a net negative cost (EUR 0.5 billion), as arable farms in and around intensive livestock regions benefit from by receiving a payment for allowing the use of their land for spreading excess manure. The intervention has the highest impact on cattle and pig farms, however, the high costs mainly reflect the specific situation in Belgium and the Netherlands, and outside these two Member States the overall cost is both much lower and more evenly balanced between arable and livestock farms. The significant cost increases are therefore concentrated in the regions with high excess of manure production. In regions where the manure production largely exceeds the amount of manure that can be applied on land within the limits of the directive (nutrient hotspots)(see Annex XII), the costs of disposal, processing and transport are significantly higher. But the excess of manure in these nutrient hotspots is also responsible for high nitrogen pollution in air and water (see section 3 figure 15 map on nitrogen surplus and section 4 figure 39 map on ammonia emissions).

Figure 36 Adjustment costs for farms due to the Nitrates Directive per sector (€/year)



The distribution of adjustment costs within each Member State and from one Member State to another in Figures 33 to 35 further illustrates how the flexibility in the implementation of measures may impact on their efficiency. The choice of the NL and BE to allow manure production far above the amounts that can be applied on land according to the directive has a very high impact on the costs for farms (and also on the overall effectiveness as discussed earlier). In other Member States where the difference

between the manure produced and the manure that can be applied on land is not as high overall, the costs for excess manure disposal, transport or processing are still a major part of the costs, but these are significantly lower. In those Member States nearby arable farms further benefit from the excess manure from nearby livestock farms and are able to reduce their costs. For Member states with a derogation (allowing more manure to be applied directly on land such as NL and IE), the costs of manure disposal and transport are lowered for part of the farmers. Manure storage is a key cost component for livestock farms and is influenced by the length of the closing periods (depending on climatic conditions), the type of farms and the extend of the NVZ. As explained in annexes XI and XII, closing periods are recognised as effective measures to limit the pollution from manure and it appears that the high flexibility in the implementations which has been used by all Member States to modulate the closing periods at national, regional or even crop level, has an overall positive impact on the effectiveness. As regards the costs, Figures 34 and 35 show that storage costs are more important for cattle farms (as these produce more manure) and may also be influenced by the climatic zone of the country, rather than other country specific flexibilities. For example, storage costs are overall more important in LU and IE with agriculture dominated by cattle and dairy farming, or proportionally dominant in Finland and Poland with long winter periods and mandatory measures covering the whole territory. Buffer strips along water courses are a much lower but non-negligeable part of the costs in all Member States. While there are large variations in the implementations of the buffer strips among the Member States (width and cover) which has a direct impact on their effectiveness (see Annex XI), it is not apparent that this flexibility has allowed for a more cost-effective implementation. While larger buffer strips with permanent cover are generally more effective, these are more commonly adopted in Member States with large agricultural parcels and where land prices are low, and found to be more strongly resisted in Member States with high land prices and high value crops, where buffer strips tend to be narrow and still allow crop production, making them generally less effective. Implementing cover crops is a choice of the Member State as it is not a mandatory measure under the directive. It is however recognised as an effective measure (see Annex XI), and its cost in percentage of standard output is relatively low in all Member States.

The administrative costs for farms have been estimated [26] **to approximately EUR 1.2-1.5 billion annually for the EU as a whole, or approximately 1.5-10.8 working days per year per affected farm.** The administrative costs are related to activities such as fertiliser planning and record keeping, controls by public authorities, and familiarisation with changing rules and restrictions. Table 1 sets out the average time estimates used for the calculation per activity and farm size. On average, administrative and enforcement costs under the Nitrates Directive are estimated to **EUR 350 to EUR 430 per year per farm across the EU, or 0.3% - 0,4% of standard output**. Farm size is an important factor as shown in the Table 2.

In contrast to the adjustment costs, the administrative costs are more evenly distributed across the EU, with the total cost per Member State being highest for France, Germany and Poland. Based on the lower bound estimates, the highest average cost estimates can be observed in northwestern Member States, such as Denmark, Luxembourg, France, Belgium, Sweden, Germany, Ireland and Netherlands, where the average cost tends to exceed EUR 600 per farm. By contrast, the average cost was estimated to less than EUR 200 per year per farm in nine Member States. **The cost estimates are likely to include a**

significant share of "business as usual" costs, as tasks such as fertiliser planning and record keeping would generally have been performed to a certain extent on most farms also in the absence of the Nitrates Directive[98].

Table 1 Lower and upper bound estimates of time spent by activity (in days)

Time spent on	*<10 ha*		*10 ha - 100 ha*		*>100 ha*	
	Lower	*Upper*	*Lower*	*Upper*	*Lower*	*Upper*
Familiarisation and training	0.5	0.5	0.5	1	0.5	1
Fertiliser planning	0.5	1.4	1	1.4	1.4	3
Record keeping	0.5	1	1.7	1.7	5.8	5.8
Controls	(*)	(*)	0.5	1	0.5	1
Total number of days	**1.5**	**2.9**	**3.7**	**5.1**	**8.2**	**10.8**

Table 2 Average costs by farm, year, and farm size

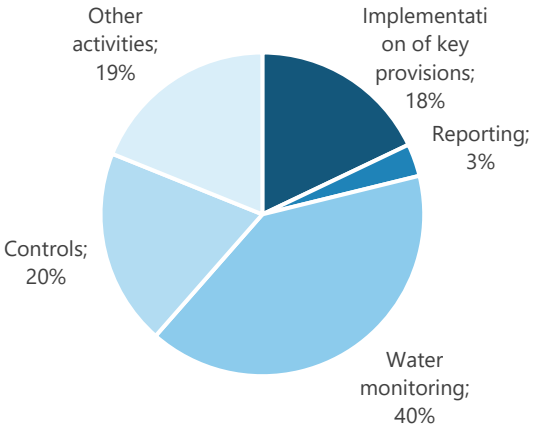
Farm size	< 10 ha (EUR)	10 ha - 100 ha (EUR)	>100 ha (EUR)
Lower bound estimate	138.93	461.48	1,465.42
Upper bound estimate	225.04	580.53	1,682.23

Overall, the adjustment and administrative costs for farms correspond to around to 0.8% of standard output of the agricultural sector in the EU. The simple average for the approximately 3.6 million affected farms[99] across the EU would be around EUR 780 to 860 per farm per year, although this amount would vary widely reflecting the broad diversity of farm types and sizes in the EU. Furthermore, considering the significant share of "business as usual" in the administrative costs and the impact of the high adjustment costs in the Netherlands and Belgium, the **effective burden would be significantly lower for most farms in the EU**.

The yearly administrative and enforcement costs borne by public authorities for the implementation of the directive have been estimated to EUR 120 million in total. This includes costs for coordination, designation of NVZ, design of action programmes and measures, monitoring water quality, reporting to the EU, and enforcement costs linked to inspections and controls. Around 40% of the public administrative costs are associated with the monitoring of water quality and 20% are linked to enforcement[100]. Reporting costs represent around 3% of the total administrative costs. The majority of the costs are concentrated in Member States with large farm populations or intensive livestock production[101].

[98] This was confirmed by farm associations which were consulted on the administrative cost estimates.
[99] This includes farms in vulnerable zones and in Member States with whole territory approach, excluding the very smallest farms (less than 2 hectares) considered not to be significantly affected by the directive.
[100] A significant part of the enforcement is done as part of the joint conditionality checks under the CAP, which helps increase efficiency.
[101] Belgium, Denmark, Germany, the Netherlands, Italy, France, Spain, Ireland, Poland, and Romania.

Figure 37 Composition of the Nitrates Directive implementation costs for authorities at EU level



In around half of the Member States public administrative costs linked to the implementation of the Nitrates Directive are below EUR 1 million per year. The cost to public authorities depends to a certain extent on national choices as the directive leaves wide discretion to Member States in its implementation[102], the exception being the 4-year cycle for the reporting and for the review of NVZ and action programmes.

Overall, as set out in Figure 38**,** the **burdens are generally proportionate and justifiable in light of the societal benefits due to the implementation of the directive.** In most of the Member States the adjustment costs are dominated by manure storage and area-based measures, while in a few Member States intensive livestock farms have particular costs linked to the disposal of excess manure. National measures implemented under the directive are associated with some administrative costs for farms, although this is likely to include a significant share of "business as usual" costs. Costs for public authorities are also reasonable overall and vary among the Member States in line with the size and nature of their agricultural sectors and implementation choices. While the overall costs are assessed as proportionate to the benefits, the evaluation nevertheless looked into the scope for simplification and burden reduction (see section 4.1.4 below).

For some livestock producers located in regions with *very* high livestock density and manure production, the cost of processing and transport of the excess manure means that the cost of complying with the limit on manure application is very significant. In these regions, mostly located in the Netherlands and Belgium[103], the livestock density and associated manure production in relation to the agricultural area typically goes far beyond levels corresponding to the manure application standard set out in the directive. **At the same time, the persistence of pollution due to excess nutrients from the high manure production exacerbate the societal costs of pollution in these regions**, affecting not only water quality but also air quality, nature and biodiversity[104]. This situation is thus in line

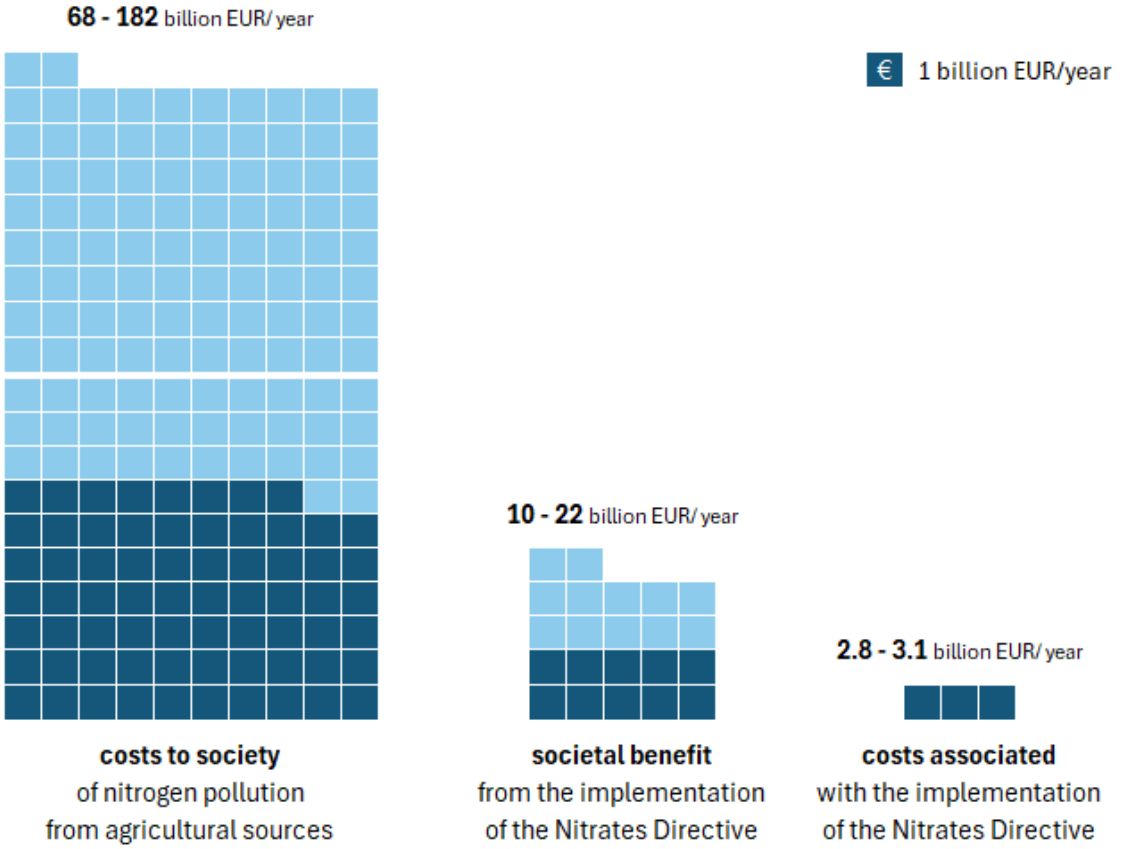
[102] Including whether to designate NVZ or apply a whole territory approach, or on the design of the water monitoring or the control programmes. Also, some Member States have developed complex and differentiated schemes for farms where others have generally applicable measures for all.

[103] Livestock concentrations are also high in certain other parts of the EU, such as in Brittany (France), Catalonia (Spain), Lombardi (Italy) and Lower Saxony (Germany). However, the concentrations are by far the highest in the Netherlands and Flanders.

[104] A study published in October 2025 after this analysis was performed estimated the cost of nitrogen and phosphorus pollution (air pollution and eutrophication) in the Netherlands alone to EUR 7.3 billion annually [40].

with polluter pays principle. In general, there would seem to be a good correlation between costs and level of pollution, as the directive generally imposes higher implementation costs in situations when pollution is more severe. In areas where there is no pollution risk, the implementation costs can be close to zero (outside NVZ), so the geographic distribution of costs and benefits of the directive would tend to be coherent in this sense.

Figure 38 Cost of nutrient pollution, benefits of the Nitrates Directive and implementation costs



The Nitrates Directive has in general not been a hindrance for the maintenance of a highly competitive agricultural sector in the EU. Considering regional specificities, the competitiveness of livestock farming remains generally unaffected by the Nitrates Directive. Even in Member States with *very* high livestock density, the livestock sector has successfully managed to retain its competitiveness despite the fact that costs of implementation of the Directive increase significantly. Indeed, economic analysis detailed in Annex XVIII[105] indicates that while the Nitrates Directive has increased costs for livestock farms in high-density regions, this has not generally been sufficient to reverse the territorial concentration of livestock activities. Other factors such as improvements in animal performance, technological progress, the consolidation of strategies between upstream and downstream sectors, and the pursuit of economies of scale and agglomeration have been the main drivers influencing developments in animal numbers in such regions. Economic efficiency has been improved through rationalisation of livestock management practices, technological advances, specialisation and farm consolidation, which facilitates economies of scale in the execution of specific operations. This conclusion is also supported by international competitiveness indicators, indicating that the relative share of the EU-27 plus the UK in the total global dairy product exports in 2025 is comparable to

[105] See Annex XVIII on the impact of the directive on the competitiveness of agriculture and [26].

the share in the 1990s. A dip in the mid-2000s for butter and skimmed milk powder can be explained by the fact that the dairy quota from the CAP kept the dairy industry from growing, resulting in a loss of market share. After the abolition of the dairy quota, the EU share for butter and skim milk powder returned to levels comparable to those of the 1990s, without the Nitrates Directive preventing this. Overall, these statistics suggest that other forces are significantly more influential in shaping the industry's development than the Nitrates Directive. Furthermore, the relative long-term stability of the export share of the EU livestock sector suggests that the impact of the Nitrates Directive on competitiveness has been limited. This conclusion is also supported by an econometric analysis of the impact of the Nitrates Directive on the evolution in agricultural costs, margins and incomes as well as in crop yields and livestock numbers across the EU, as detailed in Annex XVIII analysing the impact of the directive on the competitiveness of agriculture. For livestock farms, exposure to NVZ measures is associated with higher specific production costs and higher specific outputs. These effects offset each other at low livestock density levels, resulting in no significant change in livestock margins, whereas in Member States with higher livestock density, costs increase further, resulting in reduced livestock margins, consistent with the notion that higher-density regions incur greater costs. However, no statistically significant effect is observed at the level of farm net income. The effects found at the farm income level are consistent with those identified at the activity level, where the analysis provides no evidence of significant changes in animal numbers in regions impacted by the directive. For crop farms, no statistically significant effects are found for any of the variables. Only a weak negative association is observed for farm net income, which becomes positive in regions with higher livestock density.

4.1.3 Coherence

The Nitrates Directive forms part of a broader framework of EU environmental laws on water, air, nature and agriculture developed since its adoption, complementing and in some cases building on the directive. It should be noted at the outset that the Nitrates Directive is the only set of norms that regulate the management of manure at EU level in consideration of its pollution potential.

Coherence with EU water legislation

The Water Framework Directive (WFD) and the Nitrates Directive (ND) are intricately linked and work together to achieve water quality objectives in the EU. As explained in Annex XV, the WFD provides an overarching framework for water protection with water quality objectives[106], while the Nitrates Directive contributes to these objectives through its specific focus on reducing nutrient pollution from agriculture. As explained earlier in section 3, the WFD has had a generally positive impact on the implementation of the Nitrates Directive but has not made the Nitrates Directive redundant as the WFD is relying on it to reach its objectives. **The WFD does not replace the ND, rather it has integrated it, with measures under the ND recognised as a basic measures in the Programmes of measures of the RBMPs[107]. The ND is fundamental in reaching the WFD's objectives** as nitrates pollution and eutrophication remain significant obstacles to reaching water quality objectives. Similarly, the Groundwater Directive (GWD), which sets the detailed procedures for meeting the WFD's environmental objectives for

[106] Good ecological status or good potential for surface water and good chemical status for groundwater
[107] Article 11.3(a) and annex VI of the Water Framework Directive.

groundwater quality, complements the ND by defining additional thresholds but depends on the measures of the ND to reduce nitrates pollution from agriculture. **The measures under the ND are also essential to reduce the eutrophication of the coastal and marine environments, a key objective of the MSFD.** Eutrophication is one of the descriptors (No 5) that define the Good Environmental Status (GES) of marine waters and should be monitored in line with specifications and standardised methods defined under the MSFD.

The integration and synergy between these directives have grown over time, highlighting their mutual interdependence in achieving both overarching and specific water quality targets within the EU. Member States have had to take into account the objectives of the WFD in the design of their action programmes under the Nitrates Directive and adapt the measures and ambitions to the new requirements. In the River Basin Management Plans (RBMPs) under the WFD, the nitrate action programmes are a cornerstone with mandatory agriculture practices for addressing nutrient pollution from agriculture, complemented by additional voluntary or mandatory programmes. Some Member States differentiate measures or NVZ according to river catchments and basins. The results from the monitoring of nitrate concentrations under the Nitrates Directive are used to assess pressures and impacts in the context of the WFD and the other way around, as there has been an increasing reliance on the WFD to assess eutrophication. **Nevertheless, the integration of the ND and the WFD remains incomplete and uneven among Member States, especially in the preparation and design of national measures and objectives to be achieved, although awareness has been improving with the approaching 2027 deadline**. Incomplete integration may reduce the effectiveness and cost-efficiency of the national measures to achieve WFD objectives. The high flexibility under the ND and the WFD also creates important differences of approaches between Member States.

The water quality criteria and thresholds are generally coherent but there are overlaps and different approaches in the monitoring and reporting under the Nitrates Directive and the WFD. See also Annex XV for details. The flexibility provided to Member States under both directives allows adapting the implementation to local conditions. At the same time, this has also translated into discrepancies in monitoring networks, reporting data and status assessment. Differences and overlaps in the monitoring and reporting touch upon a number of aspects, including the monitoring networks themselves, the thresholds for pollution, standards and criteria for water quality, the way data is aggregated, the identification of starting points for trend reversal, the overall assessments and duration of the reporting cycle. While some of the differences follow legal requirements, most can be traced back to divergences in implementation. The quality standard for nitrates in groundwaters under the GWD and WFD (50 mg/l) is fully aligned with the Nitrates Directive, but the groundwater monitoring networks, the methodology for aggregation of data, for calculating trends in groundwater quality, the reporting cycles and the threshold to reverse deteriorating trends are different. As nitrates is only one of the pollutants examined under the GWD, reporting on the chemical status at groundwater body level can be difficult to reconcile with the geographical view of nitrates pollution under the Nitrates Directive. Similarly for surface waters, different approaches to the assessments of eutrophication under the Nitrates Directive and ecological status under the WFD can result in different results under the two directives [41]. Member States and the Commission have developed studies and guidelines to improve coherence (see text box 2), but experts consulted for the evaluation generally agreed that further integration would be desirable.

In 2025, collaboration between the relevant expert groups under both directives have been initiated to improve coordination, information exchange and streamlining of efforts among competent authorities dealing with the monitoring and reporting.

Stakeholders recognise the important contribution of the Nitrates Directive to the EU water quality objectives and find that it is generally coherent. In particular, a large majority of Member State experts considered that the directive supports the objectives of other environmental legislation. However, it was also found that the differences in monitoring and reporting between the Nitrates Directive and the WFD, as explained above, have made it more difficult to show a coherent picture on the nutrient pollution in water and its evolution. In turn this could make it more difficult to bring a clear message to policy makers and stakeholders on the extent of pollution and the efforts needed to reduce it, which would be necessary in helping farmers buying in on the measures and civil society in keeping decision makers accountable. In the consultations, some stakeholders reported that it could have contributed to delays or avoidance of policy decisions to address nutrient pollution from agriculture. It was also highlighted that the difference in duration of the policy cycles (4 years under the Nitrates Directive and 6 years under the Water Framework Directive) renders more challenging a coherent approach and can increase administrative burden (see also section 4.1.4 below).

The Nitrates Directive contributes critically to ensuring that Member States and water distribution companies can respect the standard for nitrate set out in the Drinking Water Directive (DWD)[108]. The Nitrates Directive has a clear objective of protecting human health and drinking water resources from diffuse pollution of nutrients from agriculture. This includes reducing nitrate concentrations in groundwaters and fresh surface waters, as well as avoiding eutrophication in all surface waters, including those used for abstraction of drinking water. The evaluation found [26] that there is some overlap in the water monitoring requirements regarding nitrate concentrations in waters abstracted for drinking water purposes under the Nitrates Directive and the DWD. However, it did not find that the monitoring under the Nitrates Directive was redundant, but rather that both were complementary, as the Nitrates Directive monitoring focuses on the areas affected by agriculture, whereas the Drinking Water Directive monitors extraction points for drinking water where overall pressures, including from agriculture, are generally low.

The Nitrates Directive is fully coherent and complementary with its "sister" Directive the UWWTD. The directives were adopted shortly after each other and both aim at reducing nutrient pollution in water, but each addressing one of the two main sources of nutrient pollution, agriculture and wastewaters respectively, and both contributing to reaching good status for surface waters, including by addressing eutrophication. While it can be challenging for Member States to decide on the source of nutrient pollution in downstream water and untangle the sources (agriculture vs wastewater), the CJEU has clarified that whenever agricultural sources are significant they require action under the Nitrates Directive. The WFD also provides a coherent framework for addressing all nutrient pollution, so that "ping-pong blame games" between different sources can be avoided. It is also the case that today agriculture tends in most cases to be responsible for

[108] Likewise, the directive contributes to the objectives of Directive 2009/54/EC on the exploitation and marketing of natural mineral waters, which requires that these waters need to be protected from all risk of pollution.

the majority of nutrient pollution in both of freshwaters and in the seas [42]. The recast UWWTD in force since 2024 reinforces complementarity between the directives by strengthening the standards for treatment of urban wastewaters and by promoting the recovery of the nutrients, allowing these to be safely reused in agriculture, enhancing circularity. (See also section 3)

Coherence with clean air directives[109] and Industrial Emissions Directive (IED)

The Nitrates Directive and the NECD are found to be overall coherent and complementary in tackling nitrogen pollution from agriculture. This was also highlighted in the evaluation of the NECD published in December 2025 [43] (See also Annex XV). The complementarity of the Nitrates Directive and the NECD can be seen as a positive development as there is always a risk of pollution swapping between nitrogen emissions in the air (ammonia - addressed under the NECD) and nitrogen emissions in water (nitrates - addressed under the Nitrates Directive) which could reduce the effectiveness of the measures under both directives. The risk of pollution swapping is particularly important for manure management measures under both directives, such as storage conditions and closed periods, and therefore many Member States have an integrated approach balancing priorities and risks in function of local circumstances. Over time, Member States have increasingly introduced mandatory measures that reduce ammonia emissions from manure management (in their nitrates action programmes or other laws), for example requiring a cover for manure storages, direct incorporation of manure or the use of low emission manure application techniques, ensuring a coherent approach at national level[110]. Some of the measures to address ammonia emissions are similar to requirements of the Nitrates Directive, though under the NECD the inclusion of many of these measures into the national air pollution control programmes is optional for Member States[111]. Given the flexibility provided by both directive, the overlaps and complementarities are generally positive, as they allow for synergies and tailoring at national and at farm level to address both objectives in an effective and proportionate manner[112].

Without the Nitrates Directive, it would be more difficult for the Member States to control ammonia emissions from agriculture, a source of air pollution. The measures under the Nitrates Directive, including the balanced fertilisation requirement and the limit on manure application, help Member States to reach their goals on reduction of ammonia emissions under the NECD, as the majority of ammonia emissions from agriculture originate from livestock manure – either from stables and storages or from application on the fields.

[109] https://environment.ec.europa.eu/topics/air_en

[110] See examples of AT, DK, IE provided in the NECD evaluation

[111] For example, according to Annex III of the NECD, Member States "may" promote the spreading of fertilisers and livestock manure in line with the foreseeable requirements of the receiving crop, which duplicates the balanced fertilisation requirement under the Nitrates Directive but only has the legal force of a recommendation to the Member States, whereas under the Nitrates Directive it is a mandatory measure in vulnerable zones. Likewise, the NECD recommends ensuring farms have sufficient manure storage capacity to spread manure only during periods that are suitable for crop growth, which is a mandatory measure under the Nitrates Directive.

[112] The evaluation of the NECD further found that the Nitrates Directive and the NECD are mostly coherent. Only a few marginal measures from either the Nitrates Directive or the NECD have been identified as having unintended negative effects on the other.

As shown in Figure 39, almost all ammonia emissions in the EU originate in agriculture and mainly from livestock. Figure 40 in turn shows the spatial distribution of agricultural ammonia emissions across the EU27, showing hotspots in darker colours. The link between the hotspots and livestock concentration is clear from a comparison with Figure 16 in section 3.2.3. Furthermore, the implementation of the measures under the Nitrates Directive can have an impact on the achievement of the objectives of the Ambient Air Quality Directives, as ammonia is an important precursor to particulate matter, an air pollutant for which the Ambient Air Quality Directive sets limit values.

Figure 39 Evolution in ammonia emissions since 1990 in the EU27[113]

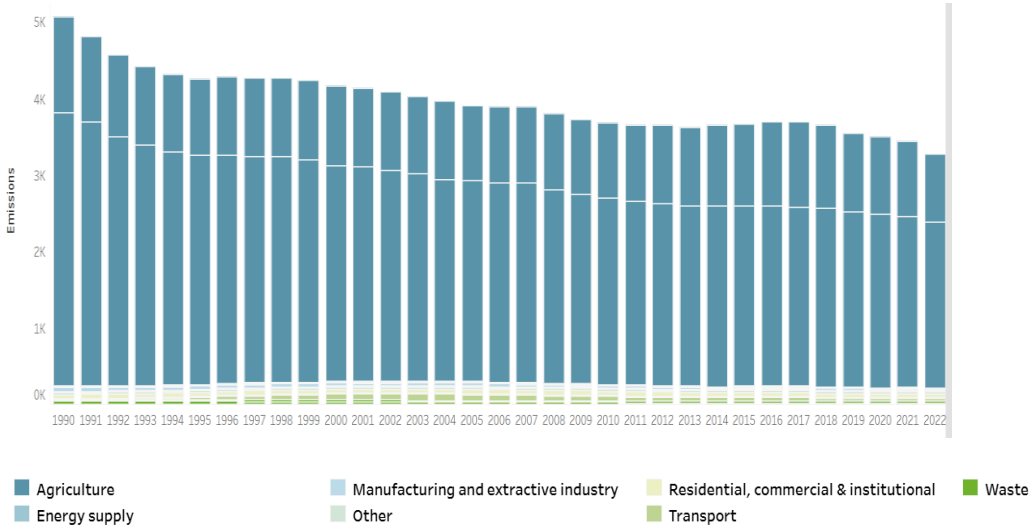
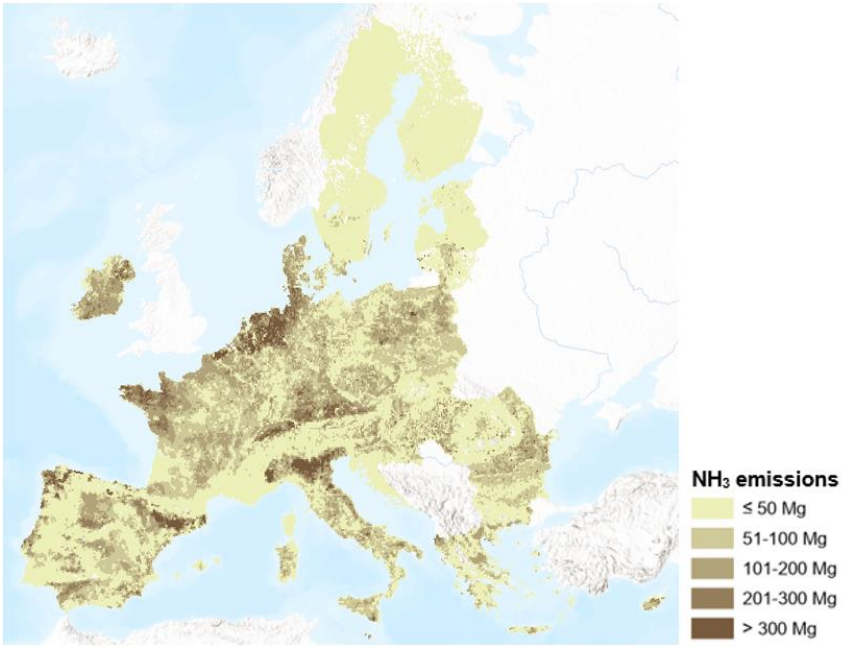


Figure 40 Spatial distribution of agricultural ammonia emission in EU27[114]



There could be benefits from a more integrated approach to the various forms of nitrogen emissions from agriculture. Some stakeholders and national experts suggested

[113] Air pollutant emissions data viewer (Gothenburg Protocol, Air Convention) 1990-2022 | European Environment Agency's home page

[114] Based on EMEP data: https://www.ceip.at/the-emep-grid/gridded-emissions/nh3, year 2023

that the scope of the Nitrates Directive should be extended to include also ammonia emissions from agriculture, which they argue would allow to capture more comprehensively the environmental impacts on air and water due to excess manure both in stables and when applied on the field. Others have called for the directive to retain its current scope and focus. More generally, there have been calls for an action plan to promote integrated nutrient management. Recently, this became an element in the strategic dialogue on the future of European agriculture[115]. The Commission responded in *A Vision for Agriculture and Food* [3] emphasising the need to improve nutrient management at farm level and promoting integrated territorial approaches, as well as in the *European Water Resilience Strategy* [2], which envisages to launch an assistance Toolbox for Member States to support actions to reduce nutrients pollution, including through enhanced modelling, interactive maps and exchanges of best practices.

The IED is relevant in the context of the Nitrates Directive, as it addresses the prevention and control of all pollution resulting from the intensive rearing of poultry or pigs[116]. However, the IED mainly addresses pollution from installations (e.g. housing of pigs and poultry and associated manure storages). The issue of the land application of livestock manure is left primarily to the Nitrates Directive. As intensive pig and poultry rearing results in large amounts of manure, it can contribute significantly to the environmental problems linked with the disposal of the manure in hotspot regions characterised by high livestock density and related pollution issues. This is also the case for the intensive cattle and dairy farms, but these fall out of the scope of the IED. However, in both cases it falls on the Member States to make sure that the amount of manure cumulatively produced by the intensive rearing plants and by other farms in the region remains in line with the amount of manure that can be put on land in this region under the Nitrates Directive. As explained in the previous sections, when there is an important imbalance, the risks of pollution, the costs of manure disposal and the societal costs of pollution increase significantly. This also illustrates the importance of using all the levers provided by these acts in complementarity and coherently. Leaving the Nitrates Directive shouldering the burden alone reduces its effectiveness.

Coherence with nature legislation (Birds and Habitats directives, Nature Restoration Regulation)

Fertilisation and manure management can have a significant impact on protected habitats and species and hence on the Natura 2000 network of protected areas. In particular, the fertilisation by chemical fertilisers or manure can have an important impact on protected habitats and species both on land and in water, when these are sensitive to nitrogen or phosphorus. Therefore, the limits of fertilisation or manure application in nitrate vulnerable zones generally contribute to protect nature and biodiversity against excessive fertilisation. On the other hand, these limits may turn out to be insufficient to prevent the deterioration of protected habitats or species or ensure their conservation objectives when farming within or near Natura 2000 areas. Guidelines of 2018 explain that

[115] Strategic dialogue on the future of EU agriculture - European Commission

[116] The revised IED (Directive 2010/75/EU or 'IED 2.0') as amended by Directive 2024/1785 covers about 38500 farms targeting the largest and most polluting intensive pig and poultry farms, which amounts to 30% of pig and poultry farms in the EU. A review clause requests that the Commission assess the need for Union action to comprehensively address the emissions from the rearing of livestock within the Union, in particular from cattle by 31 December 2026.

when potential adverse effects of a draft nitrates action programmes are identified on one or several Natura 2000 sites, including in the context of the Strategic Environmental Assessment of the Action Programme, an assessment under Article 6(3) of the Habitats Directive would have to be conducted [44]. While it is for the Member States to ensure that appropriate measures are in place, experience shows that it has not always been applied, including when derogations allowing the application of manure above the limit of the Nitrates Directive have been authorised within or close to Natura 2000 areas.

Over time, Member States have therefore been gradually brought to integrating the requirements stemming from the Birds and Habitat's Directives in their national nitrates action programmes on the basis of dedicated environmental assessments, notably by ensuring limits on fertilisation and manure compatible with the objectives for protected sites. This evolution is still ongoing and can be controversial among stakeholders[117], as illustrated by the fact that the changes have often come about as a result of court cases. As explained in Annex IX, CJEU jurisprudence from 2018 has clarified the need for appropriate environmental assessment vis-à-vis the objectives of the Birds and Habitats Directives as regards manure application, including from grazing, which would be particularly relevant in the case of derogations from the manure limit. In 2023, the European Court of Auditors [36] recommended that the Commission, when granting derogations, should include in its assessment a review of potential conflicting objectives arising in other EU policy areas. The Commission has published a guidance note in 2019 to support Member States in coordinating the implementation of the Nature directives and the Nitrates Directive [45]. Experience from the last years have highlighted that despite the guidance from the CJEU and from the Commission, the assessment process in relation to nitrates derogations or manure application around N2000 areas are often cumbersome and controversial. Therefore, a better integration in the design and preparation of nitrates action programmes of the specific requirements for the conservation and restauration of EU's natural heritage on land and seas would increase transparency, simplify the application of the programmes at farm level, and facilitate the early adoption of mitigation measures and financial support for farmers and responsible authorities.

As the nitrate action programmes are relevant for several environmental directives and their measures have impacts beyond the Nitrates Directive, the requirement, confirmed by the CJEU (see Annex IX) that the programmes must be subject to an environmental assessment under the SEA Directive, allows Member States to assess their overall environmental effects, thereby strengthening a coherent approach, as well as publicity and accountability in the decision making process.

Coherence with CAP and the organic farming regulation.

The Common Agricultural Policy (CAP Regulation) and the Nitrates Directive (ND) are closely linked and work together for the sustainability of agriculture in the EU[118]**.** The integration and synergy between these instruments highlight their mutual interdependence in implementing good agricultural practices for sustainable farming and

[117] While there can be financial compensation of farms under the CAP, to mitigate additional costs and income foregone due to the additional constraints on the farming activity, farmers have complained that the constraints can be disproportionate. Nature organisations responsible for managing protected sites highlighted that high nitrate levels in nature reserves hinder the ability to meet habitat quality standards.

[118] Annex XVI describes in detail the interlinks between the CAP and ND. See also Section 3 describing how the CAP has influenced the implementation of the ND since its adoption.

environmental protection throughout the EU. (Annex XVI describes in detail the interlinks between the CAP and ND).

The ND and the CAP support each other in the achievement of their respective objectives. The ND ensures that all farms in nitrate vulnerable areas apply the same type of environmental protection rules as regards nutrient pollution, thus providing a common baseline and facilitating a level playing field. Through the promotion of good agriculture practices for all farms in the EU, with mandatory requirements for farms in NVZ and voluntary requirements for farms outside the NVZ, the ND contributes to the general and specific objectives of the CAP. On the other hand, the CAP Strategic Plans also contribute to the objectives of the Nitrates Directive. The core of the ND (Articles 4 and 5 including the Member States' Nitrates Action Plans), are part of Statutory Mandatory Requirement (SMR) 2, legally integrating the Nitrates Directive as an element of the CAP Regulation. Additionally, ND measures are a baseline for all payments under the CAP. This has strengthened awareness and enforcement of the ND. This also creates synergies between the Nitrates Directive and the CAP when it comes to controls of compliance on farms, as all Member States authorities perform compliance controls as part of the conditionality under the CAP. Almost all Member States also carry out specific desk-based and on-the-spot checks under the Nitrates Directive (in addition to the checks under the CAP)

There is a strong complementarity between the Nitrates Directive measures and the CAP interventions. The CAP GAECs[119] (4, 5, 6 and 7) complement the good agriculture practices under the ND by extending the scope and coverage of mandatory requirements of the latter. Some GAECs and ND measures are partly similar (e.g. requirement to have buffer strips); however, these mostly help to strengthen the implementation overall and are not generally a problem (e.g. buffer strips - farmers outside NVZ and beneficiaries of the CAP also apply mandatory buffer strips). It should be noted though that GAECs only apply to recipients of CAP support, whereas the ND is mandatory for all farms in NVZ or in whole countries with a whole territory approach. Voluntary measures (including eco-schemes and agri-environment-climate commitments) build upon the ND baseline and provide incentives for farms to go further in reducing nutrient losses, thereby strengthening the implementation of the ND and further contributing to its objectives. The CAP farm advisory services (FAS) and exchanges of best practices for the implementation of the CAP complement and reenforce the implementation of measures to reduce nutrient losses of the ND.

Member States and farms can receive CAP support for certain investments under the Nitrates Directive (up to 2 years after the measures are considered mandatory)120. However, some Member State experts highlighted a tension between supporting voluntary measures through CAP funds and implementing them as a mandatory measure under the Nitrates Directive without funding support: while the CAP provides a legal basis for compensating mandatory restrictions under the WFD and the Habitats Directive, this has not been the case for the Nitrates Directive, which could possibly discourage Member States from imposing more demanding measures on farms under the directive.

Overall, there are no major overlaps of the measures or duplication of efforts. The CAP support is to a large extent relying on voluntary additional measures underpinned by

[119] Good Agricultural and Environmental Condition requirements.
[120] The period was prolonged to 3 years in the simplification package [27]

funding, whereas the Nitrates Directive remains focused on the baseline requirements. A majority of respondents to the public consultation and the Member States considered that both policies are coherent, although some stakeholders have pointed to a need for better integration of environmental objectives within the CAP.

The Nitrates Directive is also found to be fully coherent with the Organic Farming (OF) Regulation. Indeed, the approach of organic farming on fertilisation, protection of soils and water, and on livestock makes the compliance with the requirements of the Nitrates Directive more straightforward. The OF Regulation mirrors some of the requirement of the Nitrates Directive, in particular the limit on the use of animal manure (170 kg N/ha). It also limits the use of fertilisers to low solubility mineral fertilisers (mineral nitrogen fertilisers being prohibited), requires that livestock farming be land based and limits the concentration of livestock per hectare. Mandatory practices such as crop rotation and practices that encourage soil cover go further than the Nitrates Directive where these are not mandatory measures. Member State experts mentioned organic farming as a model with overall less fertiliser inputs and better impact on soil health that increases resilience to climate change impacts, although some also pointed to the lower yields in organic farming. Some stakeholders were of the view that the national implementation of the Nitrates Directive may not sufficiently contribute to promoting organic farming, as the rules are modelled on conventional farming practices. Organic farming associations have in turn emphasised that the national implementation of the Nitrates Directive can be difficult to reconcile with organic farming practices, in particular as regards calendar requirements for sowing, harvesting or fertiliser use. In view of supporting organic farming, some have highlighted the option of exempting such farms from certain requirements[121].

4.1.4 Potential for simplification and burden reduction

This evaluation also examined the potential for simplification and burden reduction under the Nitrates Directive. The assessment is based on the analysis of effectiveness, efficiency and coherence and the extensive consultations with stakeholders and public authorities. The analysis highlighted a number of areas with simplification potential, both for farms and for public authorities. In line with the simplification objectives of this Commission[122] and as requested by the Regulatory Scrutiny Board, the evaluation already puts forward simplification options that the Commission could consider as a follow-up to the evaluation, after necessary assessments and consultations. The options are presented here below. As will be clear from the presentation below, most of the options could be implemented without requiring any legislative changes to the directive. This reflects the flexibility that the directive gives Member States in its concrete implementation.

Reduction of administrative costs for farms and public administrations. As the Nitrates Directive leaves wide discretion to the Member States in the design of measures under the directive, the burden posed on farms depends largely on the implementation at national level. The cost estimates presented in section 4.1.2 indicate that activities related to the implementation of the directive, such as fertiliser planning, record keeping,

[121] In the CAP simplification proposal [27], final certified organic farms will automatically be considered as meeting some of the EU's environmental requirements for CAP funding.

[122] The template for the evaluation staff working document explains that: “Where appropriate, evaluation findings should pinpoint areas where there is potential to reduce inefficiencies (particularly unnecessary costs) and simplify the intervention”.

familiarisation with rules and public controls, are associated with administrative costs for farms. A significant share of these costs is likely to be "business as usual" costs that would have been incurred under any circumstances as part of normal farm management practices, but some part would be directly attributable to the implementation of the Nitrates Directive. In the public consultation a large majority of stakeholders linked to the agricultural sector and related industry still considered that implementation costs for farms were disproportionate. On the other hand, environmental NGOs and water supply managers considered that the costs for farms were proportionate, indicating a certain polarisation on the issue[123]. Farmers have raised concerns over administrative burdens[124].The directive leaves it as optional for Member States whether they want to impose specific rules on fertiliser planning and record keeping as part of their binding measures, but most Member States have seen a need to impose such requirements in one form or another[125]. Other potential avenues for simplification mentioned included reducing the need for administrative or on-site controls, for example by exempting small farms or farms in areas with good water quality. Member State experts also mentioned technological solutions (remote sensing), and clear rules with minimal exceptions making enforcement easier.

(1) **Administrative burden reduction for small farms**: National rules could be adapted following the model of the 2025 simplification of the CAP, exempting or reducing some administrative obligations for small farms. In effect, this would also be a simplification for the public administrations.

Actionable simplification: This potential simplification would need to be enacted at national level, but it could benefit from clear guidance from the Commission so that Member States can operate within a clear and common framework. The Commission, together with the Member States in the Nitrates Committee, could adopt recommendations around possibilities to reduce requirements or exempt small farms from certain administrative requirements.

(2) **Simplification for farms and authorities through technological solutions**: The use of digital tools for record keeping and data gathering could be promoted to minimise burden on farms and Member State authorities[126]. This could also include technological solutions for remote monitoring and providing information to farms. The simplification and burden reduction potential would depend on the concrete implementation in the Member States.

Actionable simplification: This potential simplification is based on national implementation choices but would benefit from exchange of best practices and experiences among Member States experts. The Commission together with the Member States in the Nitrates Expert Group will organise exchanges of best-practices,

[123] Public consultation Q 3.8.

[124] Record keeping could be a case in point here. While Member States often require records to be able to check during control visits, the extent and nature of these requirements differ across the EU.

[125] The establishment of fertilizer plans on a farm-by-farm basis and the keeping of records on fertilizer use is listed among the optional measures for inclusion in national codes of good practice and action programmes (part B of Annex II).

[126] Authorities could for instance provide digital tools for fertiliser planning and reporting and other purposes that farms could integrate with their own farm management information systems.

research results and expert information, including on opportunities of financial and technical support[127].

Flexibility in the implementation of the measures set out in Annex II and Annex III of the directive. Annex II and III require that Member States implement certain types of measures in their nitrate action programmes but do not prescribe how it should be implemented. The evaluation finds that Member States are making use of this flexibility to adapt to local circumstances and thus that the national implementation is already extremely varied, with different declinations at national or regional level. The flexibilities in the national implementation should allow Member States to minimise costs and optimise efficiencies in the local context. Nevertheless, farm associations have highlighted the potential for simplification of the national implementation of measures under the directive [46], [47] mentioning for example the need for increased stability of the rules and greater flexibility to avoid a "one-size fits all" approach and unnecessary constraints on farming activities, that are perceived as ineffective and demotivating. This may refer to the need for flexibility in fixed deadlines to take into account climatic conditions, flexibility in the choice of measures at farm level or better taking into account the individual environmental performance of farms. Some of these concerns have also been relayed by Member State experts pointing out that the burden for farms depends on how the measures are applied and that local conditions play an important role in that. Climate change is also increasingly affecting agricultural practices creating new conditions that may not yet have been sufficiently reflected into national measures. Some of the concerns raised by farm organisations also reflected situations where water quality challenges necessitated stricter measures and the "low-hanging fruits" had already been picked, leading to the need for more costly measures such as reducing fertiliser use below the economic optimum or requirements of increasing complexity (See Annex XII). In this area, specific suggestions for simplification of national rules, included:

(1) **Flexibility in closed periods** (prohibition periods for fertiliser application)[128]. Farm organisations and Member State experts have pointed to the impact of climatic unpredictability on the effects of closed periods. Closed periods in winter may need to be adapted to changes in temperature and growing seasons, which may also include less stable weather patterns with larger variations between years. More generally, risk periods for nutrient losses are becoming more unpredictable due to extreme climatic events such as droughts and concentrated rains, consequently requiring a better management of fertilisation throughout the year.

(2) **Limiting other aspects of "calendar farming"[129].** Concerns were raised by farm organisations that rules are not always flexible enough to adapt to climatic uncertainty or specific soil conditions, agricultural practices and crop types, and that farms not

[127] The EU CAP network https://eu-cap-network.ec.europa.eu/index_en could also play a role. The 2025 study on simplification and administrative burden for farms is relevant in the simplification discussion.

[128] The Nitrates Directive requires Member States to impose in nitrate sensitive areas closed periods when fertilisers and manure cannot be spread due to high risks of nitrate losses related to the climate and soil conditions (heavy rains, frozen soils, water-logged fields.). It is up to the Member States to define the closed periods, which can also be differentiated in light of local conditions, crops and types of fertilisers.

[129] In addition for closing periods for the application of fertilisers, national nitrate action programmes may include dates and deadlines in various other contexts, such as for the sowing of catch crops in the early autumn, for the establishment of a new crop after spreading of fertilisers or ploughing of grasslands, or for ensuring the existence of a plant cover on soils at a certain point of the autumn or winter.

respecting set dates might be penalised for following what they otherwise consider as good agricultural practices adapted to prevailing circumstances. Such constraints should be limited to what is needed to mitigate the risk of nutrient losses and should be based on scientific assessments of local environmental conditions, climatic uncertainty and the needs of specific agricultural practices (e.g. organic farming).

(3) **Flexibility in function of environmental performance of individual farms**: Concerns were also raised that the "one-size fits all" approach in the nitrates action programmes is not providing enough flexibility for farms to choose alternative ways to reach results, suggesting that "result-based" approaches could provide more flexibility[130]. Examples could include a better recognition of farms applying advanced technology to target the use of fertilisers (precision farming), farms with a verified high environmental performance (based on measurements) or sustainable farming approaches such as organic farming. Some stakeholders have raised the possibility of exemptions for farms in areas with good water quality. The evaluation has elaborated on the importance and success of the preventive approach of the intervention, especially in all areas with intensive agriculture and high fertiliser use. The fact that nitrate pollution is not currently significant in an area does not make a case for abolishing preventive measures, in the same way as the absence of accidents does not make the aviation safety policies irrelevant. That said the intervention is by design targeted to areas where pollution or the risk of pollution is a problem, and not to farms. Nothing prevents Member States to design a more differentiated treatment between the farms in accordance to (a) local circumstances, (b) the actual level and risk of pollution, (c) the environmental performance of a farm.

Actionable simplification: Similarly to the examples above, this type of simplification is based on national implementation choices, but it could be facilitated at EU level. The Commission could facilitate the uptake of best practices and innovative solution, opportunities of financial and technical support for better design of nitrates action programmes. Together with the Member States in the Nitrates Expert Group, the Commission could organise **structured exchanges** of best practice and scientific knowledge including results from deployed innovative solutions[131]. This could focus on issues such as unnecessary calendar-based constraints on farms and enhancing flexibility in ways that still achieve results. Another focus could be on the adaptation to climate change and how to effectively mitigate related risks[132]. Solutions like advisory services and technological tools such as precision farming and more accurate weather forecasts could also be relevant. Depending on the issues, the outcome of these structured exchanges could also entail **development of recommendations** to help Member States in their implementation of the simplification measures.

[130] Results-based measures refer to systems were farms have relative freedom of implementation (within the limits of the required measures) and are inspected on results, which can be defined generally or at farm level. It was however recognised that result based measures can also lead to a need for monitoring and verification, which may impose additional burdens both on farms and public authorities. The time lag between measures and results explained in section 3 would also make this approach difficult.

[131] The Commission through research programmes, such as Horizon Europe and Life, provides extensive support for research to close knowledge gaps and promote innovative solutions.

[132] For example, while closed periods remain fully relevant as it remains appropriate to have restrictions on spreading fertilisers in high-risk periods with heavy rains and no crop growth, there may be ways of making them more flexible while enhancing risk management more broadly throughout the year.

Developing and sharing knowledge on the effectiveness of measures, as already planned as part of the **nutrient toolbox announced in the Water Resilience Strategy** [2], could help national administrations in designing flexible and effective action programmes, which could also have a positive effect on the stability of measures. The aim is to support Member States in identifying the right level of effort required and the most cost-effective measures adapted to the local circumstances, thereby ensuring transparency and fairness towards farmers and other operators and encourage engagement and result-based approaches.

Increased flexibility will sometimes have to be weighed against the interest in having simple and effective measures that are easily verifiable and controllable. In this context it should be pointed out that burden reduction for farms does not necessarily align with burden reduction for the public administration, and that there could be a trade-off between flexibility on the one hand and simplicity on the other, as flexibility tends to add complexity to measures[133].

Other simplification suggestions from farm organisations have focussed on the application limit for manure and processed manure. Reflecting on these suggestions in light of the findings of the evaluation, it is important to distinguish between concerns about specific aspects of national implementation that impose unnecessary burdens and proposals to change core environmental safeguards of the Directive. Indeed, as described in earlier sections, the livestock manure limit is a core aspect of the directive. In general, application of manure above this limit leads to water pollution, and tackling eutrophication would rather point to applying lower amounts of manure in polluted areas. Setting a common limit for the application of nitrogen from manure and processed manure is essential in curbing different pathways of nutrient pollution from manure and limit negative environmental effects of intensive livestock production. It should also be reiterated that the limit is subject to flexibilities such as the possibility of derogations when Member States can justify a higher amount. However, the likely environmental impacts, the implications for the level playing field in the internal market, as well as the sensitivity of these discussions make a common EU mechanisms to assess and approve such derogations necessary. The Commission also recently put forward an amendment of the Directive to allow a higher limit for certain types of materials derived from the advanced process of livestock manure (RENURE). This amendment was carried out through a comitology procedure [48][134] and will facilitate the use of excess nutrients in high livestock density regions. This topic is further discussed in section 4.3 on relevance below.

Actionable simplification: As part of the simplification exercise, the Commission has amended the Nitrates Directive to allow Member States to authorise certain processed manure products (RENURE) above the limit with appropriate safeguards. Following the adoption of the RENURE amendment in February 2026, the Commission will support Member states in its implementation.

Furthermore, the evaluation has identified a potential for simplification in the monitoring and reporting to the EU by national authorities and better integration

[133] An example of this could be when farms are exempted from a mandatory reduction in fertiliser limits if they comply with some specific practices or can show that they reach certain results. Such exemptions create additional complexity both in the design and control of measures.

[134] Comitology register

with the WFD. The analysis on effectiveness, efficiency and coherence shows that increased coherence and integration of the monitoring of waters under the Nitrates Directive and the WFD could be beneficial and bring simplification**.** It would facilitate the identification of polluted waters and reduce the burden for public administrations[135]. Eventually it would also facilitate and make more robust the designation of NVZ, seen as an important burden for public administrations. These findings are largely shared by Member States experts. As a response to the objective of streamlining processes to foster simplification, cooperation between relevant working groups under the Nitrates Directive and the WFD, which include Member State experts, has already been reinforced in 2025[136]. The aim is to assess the best way forward which would combine simplification in monitoring and reporting and increased coherence in the national implementation. Options for streamlining are being examined both for the monitoring of nitrate concentrations and for the assessment of eutrophication, where the challenges and the level of integration are different. Key potential aspects include the finetuning of monitoring networks, frequency of monitoring, alignment of parameters, indicators, thresholds, criteria to assess nitrate concentrations in groundwater and surface water, and trophic status of surface waters. It is also the case that both the Nitrates Directive and the WFD leave wide margins in the concrete implementation of monitoring and reporting, resulting in wide differences of approaches among Member States, but at the same time this provides significant flexibility to align approaches. The result of this work will inform the Commission and the Member States on how far the streamlining can be brought, and on the technical adaptations that would be needed to achieve the desired simplification and coherence. A revision of the guidelines for monitoring and reporting under the Nitrates Directive could be a first step and provide a baseline to explore avenues to simplify the framework.

Many stakeholders have further suggested to align the reporting deadlines for the Nitrates Directive on the WFD by extending the Nitrates Directive cycle from 4 years to 6 years. As it happens, reporting cycles under the WFD and the Nitrates Directive are set to converge end of 2027, which will also be a key moment to take stock on the achievement of water quality objectives and potentially better align reporting processes. From that moment, there is scope to align reporting processes. A change of the Nitrates Directive cycle to 6 years as from 2027 has the potential to reduce burdens of public administrations. As the cycle is also linked to the requirement for review of NVZ and the national action programmes, it could also provide more stability and certainty for farms. The simplification potential would also depend on the results of above technical analysis and would need to be well prepared[137]. The evaluation has indeed highlighted many constraints due to the large variations in the national implementation in different Member States as well as potential challenges due to different approaches under the directives, which, if not addressed correctly, would risk bringing additional burden for Member State authorities or reducing the effectiveness of monitoring and reporting. It would also be necessary to

[135] Monitoring of water quality constitutes the largest single cost item for public administrations in connection with the implementation of the Nitrates Directive (see section 4.1.2)

[136] This concerns the Nitrates Expert Group under the ND as well as the Groundwater Working Group and the ECOSTAT working group under the WFD.

[137] Some stakeholders have suggested a reporting cycle of 8 years, but there is a high risk that such long period hampers timely reaction compared to the current cycle and in relation to the time lag of the effect of measures on water quality and undermines the effectiveness and enforceability of the directive. An eight-year period would be long compared to most other related EU instruments, such as the Water Framework Directive (6 years) and the CAP (7 years).

ensure consistency with the new monitoring and reporting requirements in the recent amendment of the WFD [57].

Streamlining monitoring and reporting across the directives could further improve the coherence of public messaging on nitrate pollution and eutrophication from agriculture in Member States to policymakers, farmers, other stakeholders, and the public and would be in line with the "source to sea" approach to nutrients promoted in the Water Resilience Strategy. In consultations with Member State experts there was openness to exploring a more extensive reliance on water quality assessments made in the context of the WFD and alignment of reporting deadlines, but it was particularly stressed that the link with agricultural practices and the impact of agriculture on waters should not be lost. It was also stressed that some specific monitoring would still be needed for the Nitrates Directive to follow nitrate concentrations in waters affected by agriculture and to be able to assess the effectiveness of the national action programmes[138]. Finally, Member State experts highlighted there are many technical and practical challenges that will need to be examined with the Member States in view to maximise the potential simplification benefits[139].

Actionable simplification: The Commission is already working at technical level with the Member State experts in the working groups under the Nitrates Directive and the WFD, to identify options to streamline monitoring and reporting of nitrate concentrations and eutrophication, with work initiated in 2025.

These consultations will be taken into account in the work to revise the reporting guidelines under the Nitrates Directive for the next reporting period 2024-2027.

In the longer term, the potential of aligning the reporting deadlines and cycles as from 2028 could be explored, also taking into account upcoming new reporting requirements under the WFD.

Finally, the evaluation has highlighted that it may be beneficial to facilitate processes and diffuse tensions around derogations near protected areas. Experience from the last years have highlighted that despite the guidance from the CJEU and from the Commission, the assessment process under the Habitats Directive in relation to nitrate derogations or manure application projects around N2000 areas, when carried out, are often cumbersome and controversial. This is a national implementation issue where the requirements from the Habitats Directive interact with the implementation of the Nitrates Directive in certain areas. It is not a feature of the Nitrates Directive itself but reflects the fact that these interactions are either overlooked or considered very late in the process of designing action programmes and nitrate derogations. As a result, the additional mitigation measures aimed to protect the habitats and species from degradation and ensure their conservation according to the law, are not sufficiently prepared and the situation is creating a lot of tensions. Therefore, the Commission could support Member States in integrating in the design and preparation of nitrate action programmes the specific requirements for the

[138] Assessing the effectiveness of action programmes requires more specific water monitoring than what is needed to assess the quality status of waters or to identify pollution in the first place.

[139] Questions such as the frequency and times periods of monitoring and data reporting, the parameters for nitrogen and phosphorous in relation to eutrophication in all waters in agriculture areas, the trend setting and continuity of data sets, the adequacy of WFD reporting in identifying the needs and effects of agriculture practices, the necessity of maintaining several networks, including the networks to monitor the effects of NAP measures and the identification of NVZ in the river basins, will need to be looked at.

conservation and restauration of EU's natural heritage on land and seas. The aim would be to increase transparency and facilitate assessments and the early adoption of mitigation measures as well as financial support for farmers and responsible authorities.

Actionable simplification: In this context, based on the upcoming interpretations of the CJEU (Case C-531/24) and the outcome of the stress test for the Birds and Habitats Directives, the Commission could update the guidelines for Member States on manure application and nitrate derogations in Natura 2000 areas, with the aim of facilitating a simple and practical implementation process and access to financial support for Member States and farmers.

4.2 How did the Nitrates Directive make a difference and to whom?

By putting a check on nitrate pollution of surface and groundwaters throughout the EU, the directive has provided benefits to EU citizens, as consumers of water and beneficiaries of a well-functioning environment, and to economic sectors depending on clean water and healthy aquatic ecosystems, including the food, fisheries and tourism sectors. The analysis on coherence shows that the directive has not been made redundant by new legislation but is essential to reaching EU environmental objectives. In the public consultation all stakeholder groups tended to support the view that the directive has contributed to a more harmonised and ambitious approach to addressing nitrates pollution from agriculture. In consultations with Member State experts, it was further stressed that separate efforts by Member States would risk being undermined due to socio-economic pressures and that common action is needed to ensure similar market conditions across the EU and to address transboundary pollution and marine eutrophication.

Besides its positive impact on the environment and public health, the Nitrates Directive also contributes to a level playing field improving the functioning of the Union Market by promoting good agricultural practices to reduce pollution across the EU. The directive supports public goods such as clean freshwater resources and well-functioning aquatic ecosystems by setting harmonised standards and by promoting and where necessary enforcing good agricultural practices for nutrient management across the Member States. While ensuring the adherence to these practices should be in the interest of national populations of every Member State, agricultural market pressures could push agricultural production in the direction of lower standards to maximise short term productivity and competitiveness. Public policy in line with the Nitrates Directive helps reassure farmers that others are also adhering to the same basic practices, carrying each their share of the burden to protect essential public goods.

The common manure application limit and the derogation process through the comitology committee help to maintain a common baseline and avoid distortion. The application limit for livestock manure provides a common threshold as part of the minimum common basis for all farmers in the EU (in NVZ) to mitigate environmental and health risks related to intensive livestock production. It provides a common legally binding value promoting a level playing field among farmers across the EU, which is also an important objective of the common agricultural policy. It has acted as a common minimum standard to comply with at EU level, allowing Member States to decide whether to use lower levels or to apply for derogations when they wanted to apply higher ones. In areas of very high livestock concentration, it could be argued that the manure application limit acts in an analogous way to a cap-and-trade system for the availability of manure space,

establishing a price signal for farms to moderate livestock intensification due to the additional costs, rising in line with the excess production of livestock manure to be disposed of, which helps internalise the externality costs associated with high livestock concentrations. In the absence of any such limitation, pressures for the concentration of EU livestock production within a few regions could only get stronger, possibly resulting in additional distortion and environmental and health-related challenges in those regions[140].The comitology procedure for derogations has the added benefit of improving transparency and peer review among the Member States, which can contribute to greater attention to mitigating environmental effects, better trust in the rules and hence compliance throughout the EU.

If the Directive would have let Member States set their own manure application limits, the pollution risks from manure may have been higher. The Commission would not have had the opportunity to monitor and assess the impacts of higher limits through the derogation procedure. Without a common legally binding limit and the specific derogation procedure, there would have been a risk of distortion of competition between livestock sectors in different Member States, resulting in a pressure on authorities to set more lenient limits than what would be optimal for society as a whole in each region ("race to the bottom"). As shown in Annex XII, experience with the balanced fertilisation where nitrogen limits per crop are set at Member States level has shown that in the large majority of cases the limits set by Member States are much higher than what would be advisable for water protection and the risks due to soil and climate. The risk of excessive flexibility is even higher for the manure limit than for the broader fertilisation limits. The latter have an economic upper limit in the form of the optimal economic rate (for the farmer) of fertiliser application. The corresponding optimal economic rate limit for manure application would far exceed the environmentally sustainable level.

The common manure application limit is essential as a basis for organic farming and allows organic farms, where no chemical fertilisers are allowed above the manure limit, to compete with other farms. Without a common limit for the EU, there is an additional risk of unfair competition with organic farming, while the EU is promoting its expansion as one of the paths to increase sustainability of EU agriculture.

The Nitrates Directive plays a crucial role in addressing transboundary water pollution by promoting efforts across the Member States. Although fertilizer and manure pollution often falls within national boundaries, surface water pollution can cross borders via interconnected rivers, lakes, and coastal waters. A significant portion of agricultural nutrients lost from farmland ends up in coastal waters, impacting shared seas from the Baltic and the North Sea to the Mediterranean and Black Sea. Protecting these waters from excess nutrients presents a collective challenge that requires collaborative efforts to ensure all countries contribute to pollution reduction. Effective coordination of action can ensure that political and economic stakeholders in each Member State understand that other countries are also committed to taking action, thereby encouraging more robust measures within their own country.

[140] It should be noted however that the assessment of the impact of the directive on the competitiveness of agriculture indicates that the economic impact of the directive may have been limited in most cases (Annex XVIII). See also the section on efficiency in section 4.1.3 above.

Despite its strategic importance, expert consultations suggest that the directive has not fully addressed transboundary challenges, as Member States find them complex and demanding[141]. While the directive empowers the European Commission to facilitate cooperation in specific cases (Art. 3(3)), this mechanism remains underused. However, important complementary frameworks, such as the WFD and the MSFD, provide river basin management and marine protection approaches. These directives incorporate common standards and intercalibration efforts to achieve good status across borders. Moreover, transnational initiatives and international conventions, focusing on regions like the Baltic Sea, North Sea, Mediterranean Sea, Rhine, and Danube, reinforce cross-border solutions and concerted strategies focussed on specific aquatic environments. The Nitrates Directive plays a key complementary role as a basic measure and instrument for the attainment of agreed objectives under these other frameworks.

4.3 Is the Nitrates Directive still relevant?

The Nitrates Directive was designed to address the pollution of waters by agricultural nutrients, and sets out a targeted and flexible approach to addressing the challenge. While the water acquis has evolved significantly since the early 1990s, notably with the adoption of the WFD in 2000 and the MSFD in 2008, the Nitrates Directive with its targeted intervention logic remains fully relevant and fills a specific and crucial role within this broader context, contributing to the effectiveness of the general water acquis. Consultations with stakeholders and experts confirmed this[142]. Its simple and flexible design has helped to accommodate without changes the evolution of the broader water acquis. Meanwhile, as described in the effectiveness section above, nitrate pollution of surface and groundwaters and eutrophication freshwaters and seas remain a significant challenge across large parts of the EU.

The fact that most European measurement points for ground and surface waters exhibit nitrate concentrations well below the 50 mg threshold does not detract from the directive's continued relevance. On the contrary, it illustrates the effectiveness and success of the preventive approach of the Directive. The prevention of pollution is achieved through mandatory measures on 70% of agriculture land in areas where pollution is already a problem or that are at risk of being polluted if no action is taken, and section 3 explored the effectiveness of such measures in these areas. Outside such areas, the directive works through voluntary measures, which is a risk-based approach, providing flexibility for Member States and farmers where pollution is not yet an acute issue. The preventive role of the Directive has also been recognised by the national Courts, such as the Las Conchas ruling (Galicia) in 2025 recognised inaction of the authorities in preventing pollution of ground and surface waters by nitrates due to agriculture. The stagnation in progress that appears to have taken place after 2010 only serves to further underline the indispensable role of the Nitrates Directive in stemming the pressure towards intensification of agricultural production and consequent environmental impacts. On the other hand, eutrophication which occurs at much lower nitrate concentrations than 50 mg/l remains

[141] Stakeholder responses in the public consultation in turn highlighted the continued relevance of tackling cross-border pollution (Q 3.9).

[142] In their replies to the public consultation, a majority of all types of stakeholders considered that the objectives of the directive were still either "relevant" or "somewhat relevant". National experts consulted also considered that the scope and objectives of the directive remain relevant. In particular, reference was made to the directive's focus on mandatory measures directly applicable at farm level.

significant throughout the EU, recalling that further effort is needed to reduce nutrient losses and the necessity of measures for the larger parts of the EU. This picture is also confirmed by a recent assessment under the WFD [30].

While the objective of the directive is narrowly defined and focussed on a particular challenge, the directive plays a role in promoting broader policy goals[143]. This is most evident in reaching the objectives by 2027 in line with Article 4 of the WFD, where the reduction of agricultural nutrients is a key challenge in the attainment of good chemical status of groundwaters as well as the good ecological status of surface waters. Thanks to the limit on manure application, the Nitrates Directive also plays a positive role in limiting ammonia emissions, improving air quality and reducing deposition of nitrogen on waters and on sensitive terrestrial ecosystems. Therefore, the Nitrates Directive clearly contributes to the achievement of the international commitment of the Global Biodiversity Framework target to reduce nutrient losses by 50% by 2030, as regards losses from agriculture. Through its focus on balanced fertilisation and better use of livestock manure the directive also contributes to the reduction of greenhouse gas emissions (carbon dioxide and nitrous oxide) linked to the production and use of nitrogen fertilisers and manure. Moreover, the directive also contributes to the adaptation to climate change through the protection of clean freshwater resources. Finally, the Nitrates Directive makes a non-negligeable contribution to a more balanced and sustainable development of the EU agricultural sector across the EU. By protecting water resources and contributing to reducing emissions of livestock production and sustainable fertiliser use in agriculture, without significant negative impact on the competitiveness of the sector, the directive contributes positively to the objectives of the European Water Resilience Strategy, the Vision for Agriculture and Food and the Competitiveness Compass.

The 50 mg/l threshold for nitrate in freshwaters remains relevant to protect potential drinking water resources. The threshold remains in line with standards set by the World Health Organisation [49] and the EU Drinking Water Directive. Protection of drinking water resources is a societal and economic priority, even more acute with climate change, as less rainfall may lead to a reduction of drinking water resources and to an increase of concentrations of nitrates in freshwaters. The limit is also used as a quality standard for the assessment of good chemical quality of groundwaters under the Groundwater Directive, but more stringent threshold values could be established when it is considered that the standard could result in failure to achieve the environmental objectives for surface water specified in the WFD. Indeed, stakeholders and experts underlined that the threshold is not appropriate for the assessment and management of eutrophication risks, where much lower thresholds would be relevant[144]. Moreover, recent research focussing on the carcinogenic effects of high nitrate levels in drinking water indicates that a stricter approach could also be warranted for public health purposes [50]. Hence, while a majority of the national experts considered that the 50 mg/l threshold for nitrates in freshwaters sufficiently takes

[143] Consultation of Member State experts showed that the directive is seen as relevant in addressing EU policy objectives such as protecting water resources and aquatic ecosystems, as well as to a certain extent protecting soils and biodiversity and sustainable and resilient agriculture and food security.

[144] Contributions to the public consultation and other stakeholder consultations (see Annex V).

into account all relevant health aspects, many consider this threshold too high to provide sufficient protection.[145]

The manure application limit of 170 kg N/ha is recognised as generally appropriate for good agricultural practices in NVZ and has become the reference point for sustainable agricultural practices. The manure application limit was set as a precautionary threshold balancing the needs of agriculture and livestock production with environmental and public health concerns**.** It is not an agronomic limit for specific crops, and it applies in addition to the requirement of balanced fertilisation[146]. When the Directive was adopted, the manure application limit was seen as sufficiently high for the large majority of the livestock sector in the EU but sufficiently constraining to avoid major water pollution situations. The Directive also catered for specific circumstances, such as grassland and high precipitation, by allowing higher amounts through derogations to the limit. Depending on local circumstances, Member States can thus set lower application levels or apply for derogations. By promoting the responsible (re)use of manure in NVZ, limiting key pollutants and enhancing ecosystem protection, the 170 kg N/ha has been integrated as the legal norm for fertilisation in the organic farming regulation throughout the EU. The manure application limit not only contributes to the objectives of the Nitrates Directive, but by promoting sustainable agriculture and livestock production, also plays a key role in the achievement of the objectives of other EU legislation and international commitments (See also Annex XVII).

Environmental and human health protection calls for a precautionary approach on the amount of manure to be applied on land. Applying up to 170 kg N/ha on agricultural land in NVZ may not be appropriate in all situations as it may not sufficiently limit the soil, water and air pollution by nitrogen and phosphorus, nor the negative impacts on biodiversity. The necessity to address eutrophication and the experience gained from the cumulative and long-term environmental effects of high levels of manure application (including derogations) would rather point to the necessity to lower the manure application limit in some polluted areas. In the situations where the manure limit of 170 kg N/ha is too high for reaching environmental goals, it will be for the Member States to set lower limits adapting to local circumstances. (see Annex XVII)

The common limit on the application of livestock manure in NVZ promotes circularity and has been adapted to accommodate new processing techniques. Some stakeholders[147] have seized on this limit and the definition of livestock manure that includes processed as well as unprocessed manure, arguing that the directive does not sufficiently reflect technical progress in manure processing. According to this argument, the Nitrates Directive hinders new "circular" approaches to the recycling of nutrients from manure.

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[145] An international group of experts, convened by the Danish government, has recommended that the limit value of nitrate in drinking water is to be lowered substantially from 50 mg/l to 6 mg/l. The international expert group's report published in December 2025 "Evaluation of the parametric value for Nitrate in drinking Water" concludes that "based on the totality of evidence, a parametric value of 6 mg/L for nitrate in drinking water should provide protection against potential effects on colorectal cancer and developmental effects associated with chronic exposure to nitrate from drinking water".
mim.dk/publikationer/2025/december/evaluation-of-the-parametric-value-for-nitrate-in-drinking-water

[146] The one size fits all manure limit was criticised by some stakeholders for not being scientifically justified as an agro-environmental limit in line with crop needs.

[147] Generally representing intensive livestock farming and related industry as well as the biogas sector among others.

However**,** it is not evident that the livestock manure limit in NVZ represents a constraint on the promotion of recycled organic fertilisers in agriculture. The directive is based on the very notion of better utilising the nutrient content of livestock manure while maintaining the organic link between the livestock and the soil (land-based farming). The limit on livestock manure therefore promotes natural circularity. By putting a constraint on manure application at farm level in NVZ, the limit does not prevent farms to produce more manure, rather, the limit promotes the sharing of livestock manure between farms at the regional level, and further promotes the redistribution of excess nutrients from high livestock density regions where nutrients are a pollutant to regions where nutrients are needed, through processing and transport. It therefore promotes the processing of livestock manure in biogas plants, as this can facilitate the redistribution of nutrients in the form of digestates within the region. Indeed, manure which in excess causes pollution in one area, can be useful in another area. As long as the excess manure or processed manure is reused on another farm, the nutrients from the manure can be used replacing the potential use of chemical fertilisers (with the related CO2 emissions). The directive also provides flexibility in the form of derogations, allowing for balanced outcomes taking into account technical developments as well as the environmental challenges. Apart from derogations in justified cases, the directive also provides for a procedure to update its annexes to technical and scientific progress through a comitology procedure. The latter was recently used by the Commission to initiate a targeted amendment to increase flexibility of the limit in the case of certain highly processed forms of livestock manure (RENURE) [48].

The Directive has contributed to strategic autonomy and food security by promoting the efficient use of fertilisers and manure on farms. A key objective of the directive is to reduce losses of nutrients to the environment on farms. Good agricultural practices such as balanced fertilisation and better manure management contribute to a more efficient use of the existing fertiliser supply, thereby reducing unnecessary use and costs for farmers. Over the years, the directive has significantly reduced chemical fertiliser use, without generally affecting yields. Since the outbreak of the war of aggression in Ukraine in 2022, fertiliser prices have increased dramatically in the EU prompting a debate over the impact on the agricultural sector and calls for action at EU level to promote strategic autonomy in this sector[148]. The RENURE amendment mentioned above will also facilitate the better use of nitrogen from manure in regions with high livestock concentrations replacing chemical fertiliser.

In regions with very high concentration of livestock production, above a certain level of manure production, the manure application limit helps but is not sufficient *on its own* to reduce or maintain levels of nutrient emissions from manure below harmful levels. Thirty-five years after the adoption of the Directive, some Member States continue to struggle with very high levels of manure production concentrated in a few regions, which makes it difficult to comply with the environmental limits and the requirements of EU law in specific areas [149]. In those situations, the farm level manure application limit is

[148] In the RESourceEU Action Plan [51], the Commission announced an action plan to ensure the availability and affordability of domestic fertilisers, including actions to enable recycled nutrients and other alternatives to fertilisers by Q2 2026.

[149] Member States that have regions with particularly high livestock density include Belgium, Denmark, Germany, Spain, France, Italy and the Netherlands.

not always sufficient[150], due to the cumulative impacts on nitrogen pollution of the spatial concentration. Therefore, Member States should further take into consideration the cumulative effects of the manure production by all farms in a region so as to ensure that there is an adequacy between the overall livestock density per region and the manure (and processed manure) that can be applied in the area without exacerbating the negative impacts on the environment. For this reason, in order to avoid the lock-in effect of manure recycling, the RENURE amendment limits increase of livestock density and manure production as a result of RENURE in Member States and regions with *average* manure production above 127,5 kg N/ha. Recent studies based on modelling [8] conclude that reducing livestock density at 1,4 LSU/ha *on average* in an area, could significantly reduce nitrates leaching and runoff, especially in hotspot regions with the highest livestock densities, where reductions in the nitrogen surpluses and nitrogen leaching and run-off could reach 50%[151]. However, any structural changes in farming has also broader socio-economic impacts and need to be carefully assessed[152]. Indeed, in its Vision for agriculture and food, the Commission highlighted that priority should be given to addressing nutrient pollution hotspots and promoting integrated territorial approaches.

Phosphorus is not explicitly covered in the legal text of the directive, but the directive's implementation, alongside the WFD, significantly contributes to address the risk of pollution with phosphorus from agriculture. Water pollution by phosphorus from agriculture is covered in part under the Nitrates Directive implementation and complemented by the Water Framework Directive. Firstly, the Nitrates Directive does not mention measures to limit phosphorus losses explicitly but the agricultural measures in Annex II and III of the directive to limit nitrogen losses contribute to address phosphorus pollution, in particular the manure application limit. Second, a CJEU ruling in 2000 clarified that Member States should identify polluted waters and thus take measures under the Nitrates Directive to reduce and prevent eutrophication, even where phosphorus is the main factor causing eutrophication. Further, the obligation under the WFD to address diffuse phosphorus pollution from agriculture in the programme of measures wherever phosphorus losses from agriculture has been identified as a pressure on a waterbody complements the obligation to take action under the Nitrates Directive, the measures taken under the latter constituting basic measures under the WFD. Therefore, when designing the programme of measures under the WFD, Member States can rely exclusively on the measures of the Nitrates Directive to address phosphorus pollution from agriculture but, if this proves insufficient to reach the overall objective of reducing phosphorus emissions from agriculture, they should add further measures.

All in all, at least half of the Member States have added measures to limit phosphorus fertiliser application in their national legislation (either under the Nitrates Directive action

[150] Other requirements from the other EU environmental laws will also play a role (e.g. IED, NECD, HD).

[151] As the analysis did not take into account manure trade (exports) from these regions, the leaching and runoff reduction effect could however be somewhat overestimated. As we have seen, processing and exports of excess manure can be significant in these regions.

[152] From the EU agriculture outlook 2022, chapter 7. The study also analyses the impacts of several scenarios of reduction of livestock density in hotspots regions. The Impacts on prices, net trade, food consumption and farm income show that in all scenarios agriculture income of livestock farmers would increase despite reduction in production, but there would be important increase of production costs in certain sectors and a less important increase in consumer prices. There would also be reductions in exports and in feed production, with impacts on arable farms.

programme or other legislation). The obligation to address phosphorus pollution from agriculture is further reinforced through conditionality, GAEC requirements and voluntary measures under the CAP. Annex XII describes how measures to address phosphorus emissions have been tackled.

Consultations with Member States experts confirmed that national measures to address phosphorus pollution from agriculture are often a mix of mandatory and voluntary measures under different legal instruments. However, phosphorus concentrations and specific measures on phosphorus are not part of the reporting under the Nitrates Directive, creating a blind spot in terms of causes of the eutrophication, which is not filled by the WFD reporting.

While originally it was decided not to include requirements to limit phosphorus fertilisation in the Nitrates Directive, the question as to whether this should be done today remains valid. When consulted, Member States experts were divided on whether rules on addressing emissions of phosphorus were sufficiently well covered. Overall, measures taken under the Nitrates Directive in combination with the WFD have contributed to reducing phosphorus inputs from agriculture as well as run-off and erosion of phosphorus from soils and thus contributed to reduce phosphorus concentrations in water. Therefore, the measures have allowed progressing towards the reduction and prevention of eutrophication, and achievement of water protection goals and the pertinence of including specific rules on phosphorus in the Nitrates Directive would need to be weighed against the risk of excessive regulation. Furthermore, the WFD provides an encompassing approach to all forms of phosphorus pollution, and Member States should address the different sources of the pollutant. The UWWTD also plays a key role in addressing eutrophication and phosphorus pollution. Urban wastewater remains a major source of phosphorus, even though the reduced concentrations in rivers and lakes that has taken place since the 1990s can mostly be attributed to progress in wastewater treatment.

The directive is compatible with an expanding production of biogas in the EU, which represents an opportunity for improved circularity in the use of nutrients through the use of biogas digestates as organic fertilisers in agriculture [26]**.** The biogas sector has expanded significantly in Europe over the past years. Biogas production is based on a variety of inputs, including agricultural and other waste streams, including livestock manure. Through anaerobic digestion, biogas plants transform such inputs into energy in the form of biogas on one hand and on the other hand a byproduct - digestates - that can be used as an organic fertiliser. Indeed, the utilisation and valorisation of the digestates potentially represents an important income stream for the developing biogas sector. As a fertiliser, digestate poses some of the same challenges as those associated with untreated manure, such as variability in nutrient concentrations, higher bulk and water content, and inconsistency in nutrient release dynamics due to the slow mineralisation of organic nitrogen. While nutrients contained in digestate are generally more readily available for plant uptake than those in untreated manure, improving nutrient use efficiency, they remain organic fertilisers, which means that the risk of losses, including ammonia, remains higher than for chemical fertilisers. The RENURE amendment mentioned above would allow Member States to authorise the application of manure-based biogas digestates above the limit provided that they are further processed in line with the provisions of the directive, ensuring that they attain qualities close to chemical fertilisers. Overall, the analysis

indicates that the directive is fully compatible with the use of biogas digestates in agriculture, which is confirmed by the already significant development of the biogas sector in several Member States, including Member States where the manure limit applies throughout the whole territory (See Annex XIX). Nevertheless, improving the circularity of nutrients continues to be high on the agenda of the Commission and an important focus of attention from stakeholders in the livestock and biogas sectors [52]. In November 2025, the Bioeconomy strategy [53] highlighted that closing the nutrient cycle is essential for environmental and economic resilience, that circular manure use, including through RENURE, can reduce dependence on synthetic fertilisers, and announced that the Commission will promote nitrogen efficiency in bioeconomy systems. The Fertilisers Action Plan[54] announced work towards possible extension of the RENURE Act for certain types of liquid digestates based on manure, to enable their use above the manure limit in NVZs with appropriate environmental safeguards. Innovation on products and processing techniques from processed manure is essential to develop fertilising products of consistent quality that can replace chemical fertilisers without affecting the progress towards water quality objectives. The existing legislative flexibility to modify the annexes of the Nitrates Directive to scientific and technical progress offers the possibility to adapt to such future innovation.

The Directive is sufficiently flexible to adapt to climate change through the adaptation of national implementation. A key question in the evaluation was whether the directive is sufficiently able to respond to challenges related to climate change, which is impacting agricultural practices in profound ways. For example, a more unpredictable climate presents a challenge for rules that are based on the presumption of seasonal regularities. As already mentioned above, critics have coined the term “calendar farming” to denote rigid restrictions on the timing of certain activities that are not taking account of the natural variability of the climate from years to year. This can refer to such things as periods where livestock manure cannot be spread on the fields or deadlines for sowing and harvesting. Climatic extremes such as droughts and heavy rains also can affect yields and the risk of leaching and run-off from fields, which would need to be taken into account in the definition of good practices for the application of fertilisers. The detailed design of the measures is within the purview of the national authorities responsible for the implementation of the directive in each Member State, not of the directive or the Commission. From the consultations, it appears that the challenges of nutrient management vis-à-vis climate change challenge are increasingly being taken into account in national action programmes and advisory services following extreme events in recent years. However, there may be a need to step up national response as Member States are reporting that climate change is aggravating water pollution with nutrients, but also that measures may require more flexibility so as to be able to adapt from one year to another or through the season. Section 4.1.4 above investigates potentials for simplification for a discussion of calendar farming and possible actions that could be taken to facilitate the exchange of best practice between Member States.

The directive’s technological neutrality and flexibility allows Member States to support innovation and introduce new technological developments supporting the implementation of measures. Introducing new technologies to implement the measures of the Nitrates Directive is fully compatible with its technology neutral legal framework, relying on the flexibility provided to Member States to design and adapt measures

accordingly. One such example is precision fertilisation which helps farmers to implement the requirements of the directive to fertilise soils at the right time and in the right amounts to avoid losses. Member states also have the possibility to support and test innovative implementations (sand-boxes).

5. WHAT ARE THE CONCLUSIONS AND LESSONS LEARNED?

The Nitrates Directive adopted in 1991, aims to protect human health and aquatic ecosystems across Europe by reducing and preventing diffuse water pollution by nitrates from agriculture. Pollution is caused the losses of nutrients[153] when chemical fertilisers and livestock manure are used for crop production. It is defined in terms of either nitrate concentrations in fresh groundwaters and surface waters exceeding the drinking water standard of 50 mg of nitrates per litre or the eutrophication of rivers, lakes and coastal waters. Too high nitrate concentrations make freshwaters unsuitable for drinking water abstraction or involve additional treatment costs. In surface waters, high nutrient concentrations lead to eutrophication, due to excessive growth of algae and other plants, resulting in oxygen depletion and liberation of toxic substances, thereby affecting aquatic and marine ecosystems.

The Directive acts at farm level by promoting and enforcing agricultural practices to reduce nitrate losses to water in a context where agricultural activity was and remains the dominant source of nitrates pollution in waters. Specifically, Member States are required to promote good agricultural practices by setting out basic principles for all farms on managing and using manure and other fertilisers (right amount, type, place and time). In areas that are identified as polluted or at risk of pollution, Member States should enforce those practices by implementing action programmes with specific mandatory requirements for all farms in those areas.

The Directive was adopted in 1991, and at that time, after a period of steady growth in fertiliser use since the 1960s, the nitrate content in waters in some Member States was found to be increasing and was already high compared with drinking water standards. There was also a need for protecting the North Sea and other waters in the EU. The eutrophication of marine waters caused by nitrogen run-off from agriculture land was found to be a major problem in many European coastal areas.

This is the first comprehensive evaluation of the Nitrates Directive. It therefore covers the entire period from the early 1990s to the present day to the extent that data was available.

Effectiveness, Efficiency and Coherence

1. Looking back over 30 years of implementation, the intervention is found to be effective and the Directive's measures scientifically sound. Significant progress has been achieved in more efficient fertiliser use and in reducing fertiliser losses to water which have so far been partially translated to reductions in water pollution. A temporary stagnation or even increase of agricultural pressures in the 2010s, was reflected in some stagnation or deterioration in overall water quality in recent years. But renewed progress in reduction of agricultural pressures in the last years should bring positive impacts on water quality

[153] Nutrients designate nitrogen and phosphorus. Nitrates is a form of nitrogen soluble in water. Manure contains nitrogen and phosphorus.

in the coming years. This overall picture includes a large variety of developments across regions and Member States.

As illustrated in Section 3 and Annexes XI and XII, an extensive body of scientific literature and more than 30 years' worth of data (on fertiliser use, nitrogen surplus, nitrate and phosphorus concentrations in water) and experience in the Member States, have demonstrated the causal links between the management of chemical fertilisers and manure at farm level and losses of nitrates and phosphorus to water. Experience has also shown the relevance and effectiveness of the measures under the Directive in reducing these losses. Moreover, recent EU legislation [56] has further harmonised the collection of key indicators such as the nutrient surplus, which will fill data gaps and provide important data for evaluating future progress[154].

Data and analysis in sections 3.1,3.2, 3.3 and 4.1.1 show that the Directive is generally an effective instrument and has had a significant impact in reducing and preventing water pollution with nitrates of agricultural origin. In terms of results, the Directive has contributed to increasing fertiliser use efficiency and limiting nitrogen fertiliser application (including manure), which has in turn contributed to reducing nitrogen surpluses across the EU, a key indicator of the risk of nitrate pollution.

In terms of impacts on water quality, national and EU data shows that the Directive has only been only partially successful so far in lowering nitrate concentrations in surface waters and groundwaters below the threshold value of 50 mg/l and in eliminating eutrophication of surface waters. However, the Directive has been fairly successful in stabilising nitrate concentrations in groundwaters and reducing concentrations in surface waters since the 1990s, after decades of increasing pollution. The Directive has thereby significantly contributed to protecting drinking water resources. One important factor explaining the partial success in lowering nitrate concentrations is the response time lag, which can span several decades for groundwaters due to complex underlying physical and biological processes.

Nevertheless, the results of the Nitrates Directive seem to have stagnated and even partly reversed in the 2010s, which was reflected in a temporary increase in fertiliser use and deteriorating nitrogen surplus in some Member States. During this period, generous derogations from the manure limit allowed high or increasing livestock concentration to continue in some regions, driven by external regulatory and market factors. However, this aggregated EU level view hides examples in Member States where reduction of nitrate concentrations continues in the most polluted monitoring points between 2008 and 2023. In recent years, policy has been tightened, with stricter conditions for granting derogations and successful enforcement actions taken by the Commission against Member States. Recent reductions in fertiliser use, manure application and nitrogen surpluses, shown by data in the last reporting cycle (2020-2023), reflect strengthened implementation in Member States, and over time are expected to lead to water quality improvements.

2. The Directive helped reduce and prevent eutrophication thanks to general reduction of fertiliser and manure use and of nitrate and phosphorus concentrations in surface

[154] Gross nitrogen and phosphorus surplus are key indicators for nutrient pressures, but since 2015, reporting by Member States has been incomplete, resulting in significant data gaps. With the new rules, Member States shall provide data to Eurostat on a mandatory basis as of 2026, with the first reporting to take place in 2029. In the meantime, Eurostat continues to rely on the voluntary reporting.

waters but measuring progress and success has been less straightforward. The Water Framework Directive (WFD) provides a comprehensive and scientific basis for assessing eutrophication in relation to the ecological status of surface water, for attributing loads to different sources and for defining nitrogen and phosphorus concentration thresholds compatible with good ecological status and absence of eutrophication. Thus, the WFD provides a framework to develop progress indicators and assess success. However, gaps remain in ensuring full coherence of the monitoring and reporting of eutrophication between the Nitrates Directive and the WFD.

Data and analysis in Sections 3, 4.1.1 and Annexes XI to XIV allow to conclude that the Directive has been less successful so far in addressing eutrophication and protecting aquatic ecosystems, although as explained in Section 2, the Nitrates Directive is not the only intervention acting on eutrophication. The excess of nitrates and phosphorus responsible for eutrophication can be caused by other sources besides agriculture, such as urban and industrial wastewater discharge. The UWWTD has played and continues to play an important role in reducing such pollution. In addition, eutrophication is a complex and multifaceted phenomenon. Excess nitrogen and phosphorus act as triggers in unbalancing the aquatic ecosystems and eventually causing eutrophication. However, nitrate and phosphorus concentrations below a safe level is a necessary but not necessarily a sufficient condition for the recovery of the aquatic ecosystems in the short term. Therefore, assessing the success of the Nitrates Directive in addressing eutrophication is less straightforward than for nitrate concentrations. However, by acting on the main factors responsible for triggering eutrophication, it has certainly contributed to preventing and reducing the phenomenon, which was widespread in fresh and coastal waters when the Directive was adopted. Section 3 describes the temporal evolution of key result indicators such as nitrogen surplus, which can be directly linked with the reduction of nitrogen loads and reduction of nitrate concentrations in water, as well as the temporal evolution of water quality indicators. It further describes the challenges in addressing and measuring progress on eutrophication and the measures taken to remedy it. In particular, the report explains how the Nitrates Directive initially lacked the parameters and framework for monitoring and reporting eutrophication and the criteria for success. The nitrate concentration thresholds for eutrophication are much lower than the drinking water threshold and therefore the reduction to be achieved much greater. Whereas the measures of the Nitrates Directive are also effective in reducing phosphorus losses to water, the absence in the Nitrates Directive of explicit measures and limits for phosphorus, and the absence of reporting obligation are also part of the difficulty to assess success. Section 4.1.1 on effectiveness refers to both positive developments and remaining challenges regarding eutrophication and reiterates the point made in Section 2 regarding the need for a long-term perspective on eutrophication.

Finally, Section 4.1.3 on coherence clarifies that the WFD provides the framework, criteria and parameters for measuring overall progress on eutrophication in relation to good ecological status, for identifying the necessary nutrient load reduction and the respective attribution to different sectors, and for defining nitrogen and phosphorus concentrations thresholds compatible with good ecological status and absence of eutrophication. The analysis of coherence finds that while significant progress has been done, gaps remain in ensuring coherence of the monitoring and reporting of eutrophication between the Nitrates Directive and the WFD. Finally, Section 4.2 analyses how phosphorus pollution as a key

factor for eutrophication and the absence of explicit phosphorus limits in the Nitrates Directive have been dealt with, and eventually been sufficiently addressed in combination with the WFD, noting that end of 2025 more than half of the Member States reported to have set explicit rules to limit phosphorus inputs in their national laws.

3. Climate change is increasingly affecting outcomes in terms of impacts on water quality and it will significantly alter the physical and societal context within which the Nitrates Directive is implemented in the future. The Directive is capable of responding to climate change, with its generic and adaptable measures, through evolution in its practical implementation, not necessitating legal amendments. The inherent flexibility of the Directive should allow for innovative and resilient approaches to address the challenges coming along with climate change and help farms to adapt, notably through the exchange of knowledge and best practice, allowing Member States to design more flexible and effective measures.

As discussed in Sections 3.3.6 and 4.1.1, an additional factor affecting the ultimate impact of the Directive on water quality is climate change, which has made fertiliser management more challenging in recent years, resulting in higher losses (lower nitrogen use efficiency) and hence in higher nitrate concentrations in surface and groundwaters. Climate change has also exacerbated the effects of eutrophication due to warmer waters, which further accelerates the growth of biomass and the subsequent depletion of oxygen when the biomass decomposes.

4. Nitrogen pollution from agriculture imposes significant costs on society, estimated to be in the general order of magnitude of EUR 68-182 billion annually. The benefits of the Directive in lowering cost of pollution are estimated to be in the general order of magnitude of EUR 10-22 billion per year, and are found to be three to seven times the total implementation costs for farms and public authorities, which have been estimated to EUR 2.8 - 3.1 billion per year. The costs for farms represent less than 1% of agricultural output in the EU. In general, there would seem to be a good correlation between the implementations costs and level of pollution, as the Directive generally imposes higher implementation costs in situations when pollution is more severe. The highest costs linked to the implementation of the Directive are concentrated in nutrient pollution hotspot regions and mostly borne by intensive livestock production, which is a key driver of nutrient pollution due to the high manure production. However, the evaluation shows that even in Member States with high livestock density the competitiveness of livestock farming remains generally unaffected by the Directive. In areas where there is no pollution risk, the implementation costs can be close to zero (outside NVZ), so the geographic distribution of costs and benefits of the Directive would tend to be coherent in this sense. The general distribution of costs would seem consistent with the polluter pays principle.

As regards the efficiency of the intervention, data and analysis in section 4.1 conclude that nitrogen pollution from agriculture imposes significant costs on society, estimated to be in the general order of magnitude of EUR 68-182 billion annually, and are found to be in the same range as the reference scientific work of the European Nitrogen Assessment in 2013. Not all forms of nitrogen pollution are directly addressed by the Nitrates Directive, as it mainly aims to address nitrate pollution, but the Directive has significantly reduced the societal cost of nitrogen pollution. The benefits of the Directive in lowering cost of pollution are estimated to be in the general order of magnitude of EUR 10-22 billion per

year. In general, it should be noted that due to methodological challenges, these estimates are associated with significant uncertainty. However, they allow to indicate a general order of magnitude, which is sufficient to draw general conclusions and to compare with the implementation costs. The estimated societal benefits of the Directive are three to seven times the total implementation costs for farms and public authorities, which have been estimated to EUR 2.8 - 3.1 billion per year. The implementation costs include net adjustment costs of approximately EUR 1.5 billion and administrative costs of approximately of EUR 1.2-1.5 billion annually for farms. These costs represent less than 1% of agricultural output in the EU.

The overall adjustment costs are mostly concentrated in the livestock sector (EUR 2 billion in total) whereas the arable sector as a whole has a net negative cost (EUR 0.5 billion), as arable farms in and around intensive livestock regions benefit by receiving a payment for allowing the use of their land for spreading excess manure and by reducing their chemical fertiliser need. The high costs at EU level for livestock farms mainly reflect the specific situation in two Member states, and outside these, the overall cost is both much lower and more evenly balanced between arable and livestock farms. In addition, the costs linked to the implementation of the Directive tend to be concentrated in regions with high nutrient pollution, which appears consistent with the polluter pays principle.

Further analysis in Annex XVIII and section 4.1.2 concludes that the Nitrates Directive has in general not been a hindrance for the maintenance of a highly competitive agricultural sector in the EU, even in Member States with high livestock density. Economic analysis performed for the evaluation indicates that the impact of the Nitrates Directive on agricultural competitiveness has likely been rather insignificant in most cases. Although implementation costs can be significant for livestock producers in certain regions with very high livestock density, the analysis suggests that other forces are substantially more influential in shaping the industry's development. This conclusion is supported by international competitiveness indicators as well as an econometric analysis of indicators linked to costs, margins, incomes and agricultural activity at regional level.

The administrative costs for farms in implementing the Directive are driven by time spent on fertiliser planning, record keeping and familiarisation with the rules and are estimated between 1.5-10.8 working days per farm, with the range varying depending on the size of the farm. A significant part of these costs are “business as usual” costs, as farmers would for example have an interest in some level of planning and record keeping in any case. The costs of implementation depend to a large extent on the design of the measures determined by Member States. Also, it is the Member States that set the requirements on fertiliser planning and record keeping on farms, as such measures are optional under the Directive, and rules can vary widely. The evaluation has identified potential simplification in this respect. Finally, the yearly costs borne by national administrations for the implementation of the Directive have been estimated to EUR 120 million in total. These costs vary widely across the Member State and in around half of the Member States public administrative costs are below EUR 1 million per year.

5. The agricultural practices promoted under the Nitrates Directive are generally effective in addressing pollution if properly implemented. Over time Member States have strengthened the preventive approach of the Directive. Currently, problems in implementation are usually linked to the insufficiency rather than the absence of

mandatory measures, as illustrated in the recent enforcement actions by the Commission or national courts.

As regards the effectiveness of the measures, as discussed in section 3.1, 4.1.1 and detailed in the relevant annexes, the agricultural practices promoted under the Nitrates Directive, based on basic principles of responsible fertiliser and manure use (right amount, right type, right place and right moment) and focusing efforts on polluted areas are generally found to be effective in addressing pollution *if properly implemented*. In the early days of the Directive, the implementation has been slow and incomplete. Enforcement through infringement procedures and cross-compliance with the CAP have been key factors to ensure that NVZ and monitoring networks were in place and nitrates action programmes included the necessary mandatory measures. It is also the case that over time Member States have strengthened the preventive approach of the Directive, either by enforcing mandatory measures throughout the whole country (whole territory approach) or by imposing some mandatory measures outside NVZ. In the last decade, problems in implementation are usually linked to the insufficiency rather than the absence of mandatory measures. It is also the case that some of the agricultural practices that are generally recognised as effective are not implemented in all Member States, as it is not mandatory for the Member States to include these in the action programmes.

6. Balanced fertilisation is an effective and efficient measure to promote nitrogen use efficiency and balance between the private economic interests of the farm and the societal interests to prevent and reduce nitrogen pollution and its associated costs. It has ensured considerable reductions in fertiliser use while agricultural production has continued to increase, thereby contributing to strategic autonomy and food security.

Balanced fertilisation requires Member States to set limits on nitrogen fertilisation in function of the needs of the crop and the nitrogen available in the soil and allows to adapt fertilisation limits in function of agricultural, environmental and economic conditions. As explained in section 2, 4.1 and Annex XI, an effective implementation of balanced fertilisation is a key measure to reduce the farm's nutrient balance and minimise the loss of nutrients to the environment. Section 4.1.2 explains that the cost of balanced fertilization is found to be insignificant, indicating that the fertilisation standards are usually close to the economic and agronomic optimum for the farmer. However, there can be a mismatch between the private economic optimum of the farmer and the social economic optimum for society due to the externality costs associated with fertiliser use, which fall on society as a whole. While the price of chemical fertilisers can act as an incentive for farmers to adjust better fertiliser use to the plant uptake, due to its constant short-term fluctuations and the private economic interests of the farm which may not equate the societal economic interests, relying on the fertiliser price factor alone to limit fertiliser use would not be sufficient to ensure a continued and long-term pollution prevention and reduction to achieve water quality objectives.

7. The wide flexibility that the Directive leaves in its concrete implementation allows Member States to adapt implementation to local conditions, which should be more efficient. The flexibility has further allowed to adapt to new and emerging challenges, while regular meetings in the Nitrates Expert Group has allowed sharing of best practices. As a result, national implementation varies considerably between Member States, or even between different regions in the same Member State. However, flexibility also implies an

important responsibility for Member States to impose and enforce necessary measures. Market pressures are pushing the sector in the direction of intensification with high fertiliser inputs to optimise yields and towards the geographic concentration of livestock production in a few regions, which has likely had a negative impact on the Directive's implementation. The evaluation also identifies both positive and negative examples where the flexibility of the Directive and the Member States' choices have favoured cost-effective implementation of measures. However, in some Member States, authorities and farmers' associations have highlighted that in order to accommodate increased flexibility and maintain overall effectiveness, national rules have become more complex and more difficult to implement or control. The evaluation has identified this as a potential area for simplification through exchange of good practice.

The evaluation assessed the overall effectiveness and efficiency of the intervention based on a relevant selection of measures and national contexts. This has allowed to draw some general conclusions on whether the flexibility of the Directive and the Member States choices have favoured cost-efficient implementation of measures. Section 4.1.1 and 4.1.2 on effectiveness and efficiency (and the relevant annexes) analyse the different approaches taken by Member States on key aspects, such as closing periods, fertilisation limits, manure application limit and derogations, and the consequences of those approaches on effectiveness, identifying both positive and negative effects. The cost analysis provides the cost of these key measures in the Member States and across sectors, for buffer strips, manure storage, manure disposal, transport and processing. A measure like cover crops, although not mandatory in NVZ, but effective and with low implementation costs, appears rather cost-efficient. For buffer strips, Member States have in some cases, especially where land prices are high, reacted to the costs by reducing effectiveness.

8. Setting a common limit for the application of nitrogen from manure (and processed manure) in NVZ has served as a pivotal benchmark in curbing different pathways of nutrient pollution from manure, contributing positively to limiting negative environmental effects of intensive livestock production. In general, manure application above the limit leads to a risk of excessive water pollution. The evaluation finds the manure application limit is effective, scientifically sound and cost-efficient, but, in polluted areas, not be sufficient to achieve the objectives of the Directive and additional measures adapted to the local conditions may need to be taken. Furthermore, the analysis highlights how the choice of a few Member States or regions to allow the production of manure far above the limit of what can be applied on land as being both ineffective to tackle pollution and very costly for livestock farms. On the other hand, an excess of manure production on a more limited number of farms in the same region can be seen as beneficial for nearby arable farms while keeping costs for livestock farms on a reasonable level.

As discussed in sections 4.1.1, and 4.2, as well as Annex XX and XII the limitation of manure application (170 kg N/ha) is an effective and necessary instrument to tackle the emissions from manure and leaves sufficient room for farms to operate in most regions, while also allowing for derogations under certain circumstances. While the limit is harmonised at EU level, there are flexibilities at Member State and farm level in its implementation. It is found that the manure application limit of 170 kg N/ha remains justified and appropriate for balancing the needs of agriculture with environment and public health concerns, and has been integrated as the legal norm for fertilisation in the EU organic farming regulation. It remains fully relevant as a means to balance the private

economic interests of the livestock farmer and the societal interest to limit the external costs of nutrient pollution from manure. The Nitrates Directive can achieve this balance by redistributing the manure between regions and between livestock and arable farms, thereby reducing the latter's costs. However, in regions with very high livestock concentration, Member States may need to take additional measures to reduce levels of nutrient pollution from manure below harmful levels.

9. Derogations remain a tool for flexibility regarding the manure limit, but the evaluation shows that they may affect the effectiveness of the Directive and therefore have to be used carefully to avoid long-term negative impacts.

As explained in section 4.1.1 and relevant annexes, over time, derogations to the manure application limit have come with additional conditions, as well as higher engagement of farmers and authorities. These factors may have had some positive environmental effect, but they have also created expectations and entrenched the derogated farms in high nutrient-output farming that may have been damaging over time. Derogations have come under increased societal and legal scrutiny as there is increasing concern that the higher livestock concentration and manure production allowed by derogations have contributed to negative effects on water, soil, air quality and protected habitats in the Member States concerned.

10. The evolution of EU case-law and national court cases, and the numerous consultations with all stakeholders have highlighted the importance of cross-sectoral and societal dialogue in the national or regional implementation of the Nitrates Directive to design robust and proportionate solutions which can reconcile the needs of agricultural production with environmental, public health and other economic interests.

Additional dialogue and exchanges among sectors and with stakeholders would also facilitate the implementation of required measures and improve their efficiency. More extensive national level studies on the costs of nutrient pollution and the benefits of the measures modulated on the specific national context and reflecting the diversity of situations could be crucial tools for Member States to draw conclusions supporting policy choices and in discussions with stakeholders.

11. Environmental laws on water and air quality have not made the Nitrates Directive redundant, on the contrary, they rely on the implementation of the Nitrates Directive because of its targeted focus on reducing nutrient pressures from agriculture. In particular, the Nitrates Directive critically contributes to the WFD objectives as it has been fully integrated in the broader water framework of the WFD as the comprehensive instrument to reduce these pressures. The Nitrates Directive plays an essential role in promoting and enforcing sustainable agriculture and livestock production throughout the EU. It is fully coherent with the CAP and both instruments work together for the sustainability of agriculture in the EU. The balanced fertilisation requirement remains at the centre of the Nitrates Directive, complemented by other good agricultural practices for the management of fertilisers and livestock manure.

As regards coherence, Section 3.1, 3.4 and 4.1.3 (and the relevant annexes) highlight that many EU laws on water, nutrients and agriculture have been adopted since 1991, which has had a major impact on the policy context of the Nitrates Directive and on its implementation. In general, the analysis concludes that the objectives, scope and measures of the Nitrates Directive are largely coherent and complementary with the EU

environmental acquis. In 2000, the Water Framework Directive (WFD) introduced an overarching and comprehensive legal framework for water policy in the EU, setting water quality objectives and deadlines to reach them. By embedding the national measures under the Nitrates Directive as basic measures to be included in WFD Programmes of Measures, the WFD has significantly changed the context for the Nitrates Directive's implementation. The WFD has played a key positive role in the implementation of the Nitrates Directive and has been instrumental in developing attention to eutrophication in the Member States implementations. However, the integration of the implementation of the two directives remains incomplete and could be further improved. In particular, there is scope for a stronger integration and coherence in terms of preparation of the national measures as well as in the monitoring and reporting.

The Nitrates Directive is found to be coherent and complementary to the CAP. The objectives, agriculture measures, financing and enforcement of the Directive and the CAP are very much intertwined, supporting each other in the achievement of their respective objectives highlighting their mutual dependability in implementing good agriculture practices for sustainable farming and environmental protection throughout the EU. There are synergies and complementarity in the national implementation, notably on the conditionality and controls, and through the voluntary measures under EcoSchemes and Agri-Environmental and Climate Commitments. Through major reforms since the adoption of the Nitrates Directive, the CAP has supported the implementation of the Nitrates Directive and shaped how Member States and farmers address nutrient management, although the abolition of the milk quota in 2013 has rather increased nutrient pressures.

A key finding of the coherence analysis in section 4.1.3 is that through its specific sectoral focus on nutrient pollution from agriculture, the Directive critically contributes to achieving objectives of other EU environmental legislation, in particular the WFD and the CAP so that these rely on the effective implementation of the Directive. This is also case for the Marine Strategy Framework Directive (MSFD), aimed at reducing water pollution, but also for other legislation such as the National Emission reduction Commitments Directive (NECD) and the Habitats Directive (HD), notably due to the indirect impact of the Nitrates Directive on reducing ammonia emissions. The limits of fertilisation or manure application under the Nitrates Directive generally contribute to protect nature and biodiversity against excessive fertilisation, but the process for Member States to fully integrate the specific requirements of protected habitats and species when farming within or near Natura 2000 areas is still work in progress. It may therefore be appropriate to facilitate a practical implementation process, including for derogations, for Member States and farmers reflecting the case-law and experience.

EU added value and relevance

12. The Directive has provided benefits to EU citizens, as consumers of water and beneficiaries of a well-functioning environment, and to economic sectors depending on clean water and healthy aquatic ecosystems, including the food, fisheries and tourism sectors. The Directive plays a complementary role alongside other frameworks dedicated to transnational cooperation and the development of coordinated strategies. Addressing nutrient pollution remains necessary and urgent for achieving key EU policy objectives, in particular water resilience and a sustainable and competitive agriculture including the

livestock sector. In spite of the progress under the Nitrates Directive, nitrates pollution in groundwater and eutrophication of surface waters remain important challenges throughout the EU.

The findings in sections 4.1, 4.2, 4.3 and relevant annexes support the conclusion that the Nitrates Directive has clear benefits and EU added value contributing to results that go beyond what could have been achieved through Member States acting on their own. The Directive remains relevant for the protection of surface and groundwaters in the EU as well as for other environmental objectives. Indeed, nitrate pollution of surface and groundwaters and eutrophication of freshwaters and seas remain a significant challenge across large parts of the EU. Effectively reducing pollution and solving these problems require a steady and continuous effort over several decades. Even when the pollution level is low the Directive remains relevant and necessary to prevent pollution for the protection of human health and aquatic ecosystems in all areas where fertiliser use and manure application risk polluting waters.

13. The Nitrates Directive provides a cost-efficient and sustainable approach in protecting drinking water resources. The Directive's objectives to prevent and reduce pollution remain therefore fully relevant for the resilience of drinking water resources, even more so when considering increasing scientific evidence that nitrate levels in drinking water should be lower than 50 mg/l to protect against carcinomic effects.

As illustrated in section 4.1.1 and 4.1.2, significant progress towards the objectives of the Directive has been achieved in the protection of fresh drinking water resources as nitrate pollution has stabilised and further reduced in many places, while experience in Member States shows that the preventive measures promoted by the Directive are also more sustainable and cost-efficient compared to treatment equipment or finding alternative drinking water resources. It is also the case that significant problems with excess nitrates or eutrophication in drinking water reservoirs have recently emerged in several Member States. Therefore, the fact that a very large majority of European measurement points for ground and surface waters exhibit nitrate concentrations well below the 50 mg/l drinking water threshold including in areas with intensive agriculture does not mean that efforts can be relaxed, but rather that the preventive approach is effective and should be pursued to ensure resilience of drinking water resources. The 50 mg/l threshold itself remains relevant and in line with existing EU and international standards for drinking water, based on the possible toxic effects of nitrates in high concentrations. Recent studies indicate that even lower concentrations could also lead to a risk of carcinogenic effects, so this issue needs to be followed. Any future developments around the EU nitrate drinking water standard would have consequences for the implementation of the Nitrates Directive.

14. The Directive contributes to a level playing field among farms across the EU, by setting out the basic standards for nutrient pollution control and a common menu of the types of practices that should be implemented. The common manure application limit in NVZ and the derogation process through the comitology committee help to maintain a common minimum baseline and avoid distortion, including with organic farming.

As further detailed in Annex XVII, the common manure limit and the derogation process through comitology are key elements in this regard. The manure limit provides a common threshold as part of the minimum common basis for all farmers in the EU (in NVZ) to mitigate environmental and health risks related to intensive livestock production. The

comitology procedure for derogations, subject to approval by the Commission and the Member States, reflects the sensitivity linked to the risk of market distortion and has the added benefit of improving transparency and peer review among the Member States. The common manure limit is also essential as a basis for organic farming and allows organic farms, where no chemical fertilisers are allowed, to compete with other farms. Without a common legally binding limit and the specific derogation process, distortion and competition between livestock sectors in different Member States would lead to excessive flexibilities in regions with high livestock concentration and to a risk of a "race to the bottom". This would likely result in significantly more serious negative trends than those, connected with a wide application of derogations witnessed in the 2010s.

15. Overall, the Nitrates Directive remains necessary, relevant and effective, although the evaluation identifies potential areas for improvement. Its intervention logic and key measures are effective to address the problem that it was designed to address. It tackles water pollution by nutrients from agriculture in a generally effective, efficient and coherent way, and is fully complementary to other legislation tackling other sources of nutrient pollution, such as urban wastewater. The Directive contributes to achieving outcomes that could not have been attained by the Member States acting alone, and its provisions generally remain relevant to the current context and emerging policy challenges. In particular, it is by design a very flexible legal instrument, targeting its intervention to areas where pollution or the risk of pollution is a problem and allowing wide discretion for Member States in the national implementation and adaptation to scientific and technological progress, which facilitates the adaptation of measures to new circumstances (e.g. technological innovation, climate change).

Potential for simplification and policy change

16. The evaluation has identified potential areas for improvement on which the Commission and Member States could follow-up as part of a coherent effort. These potential areas for improvement detailed below are linked to simplification potential, better implementation, increased coherence with the WFD, climate change adaptation and better management of excess manure and high livestock concentration, some of which are broader policy issues beyond the Nitrates Directive itself.

Section 4.1.4 examine the potential for simplification and burden reduction. The analysis, including extensive consultations with stakeholders and public authorities, highlighted a number of areas with simplification potential, both for farms and for public authorities. In line with the simplification objectives of this Commission, the evaluation already puts forward general simplification options that the Commission could consider as a follow-up to the evaluation, after necessary assessments and consultations.

17. There are indications that national implementation of the Nitrates Directive modulated by the broad flexibility left to national or regional authorities has not always been sufficiently effective or efficient. At the same time the evaluation identified potential for simplification and burden reduction for farms through the adaptation of national implementation in the Member States, which depends to a large extent on the choices made at national level. The Directive's flexibility should allow Member States to continue to manage the evolving realities faced by farms in the light of changing market conditions, technological pressures and climate change, while both minimising unnecessary burdens

and ensuring that measures are proportionate and effective in reaching EU water quality standards.

The evaluation has identified potential simplification in the national implementation, reflecting the flexibility that the Directive gives Member States concerning:

(a) Reduction of administrative costs for farms and public administrations. The cost estimates presented in section 4.1.2 indicate that activities related to the implementation of the Directive, such as fertiliser planning, record keeping, familiarisation with rules and public controls, are associated with administrative costs for farms. Potential simplifications at national level include looking at options for administrative burden reduction for small farms and simplification for farms and authorities through technological solutions.

(b) Flexibility in the implementation of the measures set out in Annex II and Annex III of the Directive. The evaluation finds that implementation by the Member States is already extremely varied, with different declinations at national or regional level, as the measures under the Directive are already targeted to the areas which are polluted and at risk of being polluted. Potential flexibilities in the national implementation concern in particular calendar-based requirements such a closed periods or modulating rules in function of the environmental performance of the farm. These should allow Member States and farms to minimise costs and optimise efficiencies in the local context while ensuring more effective measures and adapting better to climate change, although there can be trade-offs between flexibility and the interest in having simple and effective measures that are easily implementable and controllable.

The evaluation has identified potential for more flexible and proportionate implementation approaches that are adapted to national specificities, while ensuring that objectives can be effectively achieved, as a potential area for simplification through exchange of best practices, knowledge and research results, as well as dialogue with stakeholders, which can support Member States in designing robust approaches, avoiding the risk of backsliding or postponing difficult decisions. Stronger links could be made between technical, research and innovation progress, and more research could address knowledge gaps and provide innovative solutions for nitrates related challenges.

18. The integration of the Nitrates Directive with the WFD is incomplete. There is scope for a more consistent approach in preparing the national plans, in assessing of eutrophication and in the monitoring and reporting under both directives. In line with the priorities set out in the European water resilience strategy, a more coordinated "source to sea" approach to address both nitrogen and phosphorus pollution, and in particular eutrophication, could help Member States step up national implementation to reach its full potential in complementarity with structural measures under the WFD, improving the tackling of transboundary aspects of nutrient pollution and achieving water quality objectives.

The evaluation has identified potential for simplification in the monitoring and reporting to the EU by national authorities and better integration with the WFD. Increased coherence in monitoring and reporting could provide policy simplification and reduction of burdens for national authorities, although stakeholders have highlighted the importance of the focus on agricultural pollution under the Nitrates Directive. The monitoring cycles are set to converge in 2027 and would be a moment to take stock on the achievement of water quality objectives and potentially align better reporting processes.

19. The manure application limit at farm level acts as a minimum common basis but is not sufficient on its own to reduce or maintain levels of nutrient emissions from manure below harmful levels in areas with very high concentration of livestock production.

The evaluation finds that it has not prevented continued or increased concentrations of livestock in certain regions and Member States, creating a large nutrient imbalance, despite significantly increasing cost of compliance with the Directive for livestock farms and the socio-economic impacts resulting from high levels of nutrient pollution from manure, ultimately undermining the objectives not only of the Nitrates Directive but also of other EU legislation. In its Vision for agriculture and food, the Commission highlighted that "priority should be given to addressing nutrient pollution hotspots and promoting integrated territorial approaches. A key aspect of this would be the management and control of nutrients from livestock farming to limit negative externalities, support extensification in regions with high livestock concentrations". In 2026, the Commission presented a livestock strategy.

20. To reduce nutrient pressure on the environment it remains necessary to improve nutrient management at farm level by reducing losses, increasing circularity and better accounting the nutrients in soil and in manure. Through balanced fertilisation and the manure application limit, the Nitrates Directive promotes responsible use of fertilisers and inherently enforces circularity of nutrients by reusing manure as fertilisers on farms and redistributing excess and processed manure between regions and between livestock and arable farms, which contributes to strategic autonomy. Innovation on products and processing techniques from processed manure can help develop fertilising products of consistent quality that could replace chemical fertilisers without affecting the progress towards water quality objectives. The existing legislative flexibility to modify the annexes of the Nitrates Directive to scientific and technical progress offers the possibility to adapt to future innovation. Recent crises on fertiliser prices highlight the urgency to support Member States and farmers in developing sustainable solutions in this direction.

The Nitrates Directive is technology neutral and flexible to adaptations to technical progress in manure processing practices in the national implementations and through legislative adaptation of the annexes of the Directive to scientific and technological progress. The Commission recently took action in 2026 to adapt the Directive to developments in the advanced processing of livestock manure, by allowing Member States to authorise certain types of materials recovered from livestock manure (RENURE) above the manure limit, while still respecting balanced fertilisation, and with appropriate safeguards to ensure that it does not lead to an increase of concentration of livestock and associated nitrogen pollution. The Commission confirmed its continued commitment to improve availability and circulation of recycled nutrients[155]. Responding to repeated crises around fertiliser prices, the Fertilisers Action Plan of May 2026 further calls to improve nitrogen use efficiency, circularity of nutrients from manure and their distribution in the internal market [54].

[155] In the RESourceEU Action Plan [51], the Commission announced an action plan to ensure the availability and affordability of domestic fertilisers, including actions to enable recycled nutrients and other alternatives to fertilisers by Q2 2026

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Industrial Emissions Directive (IED) - Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast) (OJ L 334, 17.12.2010), Directive - 2010/75 - EN - EUR-Lex

Marine Strategy Framework Directive (MSFD) - Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (OJ L 164, 25.6.2008), Directive - 2008/56 - EN - EUR-Lex

National Emission reduction Commitments Directive (NECD) - Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive

2003/35/EC and repealing Directive 2001/81/EC (OJ L 344, 17.12.2016), Directive - 2016/2284 - EN - EUR-Lex

Nature Restoration Regulation (NRR) - Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (OJ L, 2024/1991, 29.7.2024), Regulation - EU - 2024/1991 - EN - EUR-Lex

Nitrates Directive (ND) - Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) (OJ L 375, 31.12.1991), Directive - 91/676 - EN - EUR-Lex

Organic Farming Regulation - Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007 (OJ L 150, 14.6.2018), Regulation - 2018/848 - EN - EUR-Lex

Regulation 1782/2003 - Council Regulation (EC) No 1782/2003 of 29 September 2003 establishing **common rules for direct support schemes under the common agricultural policy** and establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93, (EC) No 1452/2001, (EC) No 1453/2001, (EC) No 1454/2001, (EC) 1868/94, (EC) No 1251/1999, (EC) No 1254/1999, (EC) No 1673/2000, (EEC) No 2358/71 and (EC) No 2529/2001 (OJ L 270, 21.10.2003), Regulation - 1782/2003 - EN - EUR-Lex

Regulation EU/2022/2379 - Regulation (EU) 2022/2379 of the European Parliament and of the Council of 23 November 2022 **on statistics on agricultural input and output**, amending Commission Regulation (EC) No 617/2008 and repealing Regulations (EC) No 1165/2008, (EC) No 543/2009 and (EC) No 1185/2009 of the European Parliament and of the Council and Council Directive 96/16/EC (OJ L 315, 7.12.2022), Regulation - 2022/2379 - EN - EUR-Lex

Strategic Environmental Assessment Directive (SEA Directive) - Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (OJ L 197, 21.7.2001), Directive - 2001/42 - EN - EUR-Lex

Urban Wastewater Treatment Directive (UWWTD) - Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (recast) (OJ L, 2024/3019, 12.12.2024), Directive - EU - 2024/3019 - EN - EUR-Lex

Water Framework Directive (WFD) - Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000), Directive - 2000/60 - EN - Water Framework Directive - EUR-Lex

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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

Annexes I-X to the SWD on the evaluation of the Nitrates Directive

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ANNEX I. PROCEDURAL INFORMATION

Lead DG, Decide reference and, if relevant, Work Programme reference

This evaluation is led by the Commission's Directorate-General for Environment (DG ENV). It was included as item PLAN/2022/405 in the DECIDE/agenda planning data base and announced in the 2024 Commission's Work Programme (section C – evaluations and fitness checks).

Organisation and timing

A call for evidence was published online on the Commission's "have your say" website on 1 December 2023, accompanied by a 12-week public consultation with a deadline of 8 March 2024 on an online public questionnaire.

An interservice steering group (ISSG) was set up in December 2023 with representatives from all the relevant Commission services:

- Secretariat-General (SG)
- Legal Service (LS)
- Directorate-General for Agriculture and Rural Development (DG AGRI)
- Directorate-General for Budget (DG BUDG)
- Directorate-General for Climate Action (DG CLIMA)
- Directorate-General for Competition (DG COMP)
- Directorate-General for Communications Networks, Content and Technology (DG CNECT)
- Directorate-General for Employment, Social Affairs and Inclusion (DG EMPL)
- Directorate-General for Energy (DG ENER)
- Directorate-General for Eurostat (DG ESTAT)
- Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW)
- Directorate-General for International Partnerships (DG INTPA)
- Directorate-General for Justice and Consumers (DG JUST)
- Directorate-General for Maritime Affairs and Fisheries (DG MARE)
- Directorate-General for Enlargement and Eastern Neighbourhood (DG ENEST)
- Directorate-General for Regional and Urban Policy (DG REGIO)
- Directorate-General for Research and Innovation (DG RTD)
- Directorate-General for Health and Food Safety (DG SANTE)
- Directorate-General for Trade and Economic Security (DG TRADE)
- Joint Research Centre (JRC)

The ISSG met six times during the evaluation process. In addition, the group was consulted in writing on various documents, including on the terms of reference for supporting studies. Some ISSG members also participated in some of the stakeholder workshops and meetings of the nitrate expert group.

The six formal meetings took place as follows:

1. Meeting 11 January 2024: General state of play, planning and consultation strategy.
2. Meeting 18 April 2024: Outcome of call for evidence and public consultation.
3. Meeting 26 September 2024: First interim report of contractor (deliverables on nitrogen flows, legal analysis, enlargements).
4. Meeting 10 December 2024: Second interim report of the contractor (deliverables on costs and benefits, simplification potentials).
5. Meeting 29 April 2025: First draft of evaluation report (SWD) sections 1-3 and revised deliverables from the contractor on costs and benefits.
6. Meeting 30 June 2025: Full draft evaluation report (SWD) for submission to the Regulatory Scrutiny Board.

Consultation of the Regulatory Scrutiny Board

The Regulatory Scrutiny Board held the hearing with DG ENV on the results of the evaluation on 10 September 2025. The outcome was a negative opinion, issued on 12 September 2025. To address the opinion of the RSB, DG ENV thoroughly reviewed the main evaluation report and prepared 9 new annexes (Annexes XI to XIX) to substantiate further the existing and additional findings. The annexes were prepared with inputs from an external contractor ECORYS and the JRC, as well as from existing studies. There were also additional consultations and inputs from stakeholders that were included in the analysis.

On 13 March 2026, the RSB issued a second positive opinion with reservation. The evaluation was further reviewed and updated in line with the suggestions from the Board.

Two tables below provide information on how the comments made by the RSB in the first and second opinion were addressed in the evaluation.

RSB opinion of 12 September 2025
Points to improve from RSB opinion and approach taken
1) The report should more clearly demonstrate the causal link between the intervention and the developments observed. It should go beyond opinion data and also utilise other forms of data to support claims about causality. It should more clearly point to any evidence that indicates that the specific measures under the Directive have led to a reduction of water pollution. The evaluation should better analyse why effectiveness seems particularly limited when it comes to addressing eutrophication. The conclusions of the report should also better account for stagnation in progress
- Intervention logic: **Section 2** has been reviewed to better explain the intervention logic and causal links between the implementation of the directive and effects in terms of result and impact indicators. A **new Annex XI** provides explanation and references to scientific literature on the environmental effects of the key measures implemented under the directive. In particular, **section 2.1. presents more clearly nitrogen balance, use efficiency and justification of limits. Section 2.2. now covers points for comparison and introduces the links to other policies.** - Claims on causality, and how measures have reduced water pollution: **section 2.1** also presents the scope and measures applied on agricultural land and their results/impacts. The new **Annexes XI and XII** cover measures, their variations, effectiveness as well as nitrogen use trends. - Effectiveness of the directive: **section 4** of the report addresses in more detail this aspect, pointing to measures implemented under the directive, result and impact indicators. This assessment is based on the information, data and links with other EU legislation presented in **section 3**. The discussion of effectiveness has been thoroughly reviewed, also considering additional data in section 3, and reflected in the conclusions.

- Limited effectiveness specifically on eutrophication: **Section 2.2.** introduces expected results of the directive in eutrophication, and expectations from other EU legislation. Information on nitrate concentration in ground and surface as well as eutrophication is presented in **sections 3.1.1, 3.1.2, 3.3.3** and the new **Annexes XIII** and **XIV** provide information on water quality in Member States and include specific data on eutrophication. In particular, the **new Annex XIV** addresses how the directive has reduced pollution in Member States and **new Annex XII** addresses the approach followed by Member States when implementing Annex II and III measures.
- **Annex IX** has been updated to reflect the enforcement by the Commission in relation to effectiveness of measures, and this has been further reflected in **sections 3 and 4.1**.
- Conclusions and progress stagnation: this is addressed in **sections 4.1.1, 4.3** and concluding remarks in **section 5.2.**

2) The evaluation should more thoroughly analyse the different approaches taken by Member States and assess to what extent the flexibilities (including derogations) have allowed for a more efficient achievement of objectives, including reducing the related costs, and to what extent the flexibilities have reduced effectiveness and whether they have had a negative impact on the level playing field for farmers in the EU. Differences in how the cost from the intervention differ between different types of geographic regions should be better assessed. Based on such evidence the report should draw conclusions on the flexibilities

- Different approaches taken by Member States: **Section 3.1.1.** now presents how Member States have implemented measures differently. The differences in measures and action programmes among Member States and their variability are presented in more detail in the **new Annex XII** on measures. **New Annex XIII** on water quality data also provides key information on the variability of results per Member States, and **Annex XIV** on pollution reduction provides specific examples per Member State. **Section 3.1.4** also introduces the enforcement action when there has been insufficient or improper implementation (reduced effectiveness) of the Nitrates Directive at Member State level, and **Annex IX** refers to infringement procedures.
- Flexibility of the Nitrates Directive and the efficient achievement of objectives, including derogations: **this aspect is introduced in sections 2.1, 3.1.2, 3.1.3, further discussed in sections 4.1.1, 4.1.2, 4.1.3 and 4.3, and concluding remarks are covered in section 5.1. The new Annex XII and the Annex XVII on the 170 kg N/ha also cover this aspect broadly.**
- Relevant information is also presented in the **new Annex XII** on measures.
    - Reduced effectiveness: see point above.
    - Level playing field of farmers: This is addressed mainly in **section 4.2**, and **section 5.2.** provides concluding remarks.
- Costs in different regions: This is addressed mainly in **section 4.1**, and **Annex XII.**

3) The economic analysis should take better into account market developments and other factors which might have affected the effectiveness and efficiency of the intervention. The costs should be estimated for various practices reflecting the flexibilities. The report should attempt to analyse marginal costs from the intervention and also compare the estimated costs to profit margins to better understand the impact of the Directive on the profitability of the farms concerned. It should analyse the incentives why farmers would cover crops with more (and costly) nitrates than what is optimal for the crops' growth. The report should better analyse the distribution of costs and their pass through. The impact of the intervention on the competitiveness of the EU farming sector in relation to international trade and competitors should also be analysed. It should be made clearer in the report to what extent the conditions and payments under CAP help to attain the benefits and mitigate the costs of the Nitrates Directive.

- Economic analysis (market developments, costs of various practices, marginal costs, profit margins, incentives, distribution of costs): these aspects are mainly addressed in **Annex IV** on the overview of benefits and costs.
- **Competitiveness of EU farming sector: This is mainly covered in the new Annex XVIII, and section covers its analysis 4.1.2. Concluding remarks are included in section 5.2.**

- CAP payments and mitigation of Nitrates Directive costs: These aspects are mainly covered in **new section 3.2.3**, **section 4.1.3** and the **New Annex XVI** on the interlinks between the Nitrates Directive and the CAP.
4) The assessment of benefits needs to be more transparent and robust. Given the reliance on average and median values the report needs to be clear about the reliability, representativity and comparability of the underlying data points. The assignment of values for improved aquatic environment needs to be clear and credible. When relying on underlying academic studies the report needs to provide and compare alternative academic approaches and conclusions.
- Benefits based on data: **section 4.1.2** presents the main benefits the directive has provided, supported by data and graphs. - Values on improved waters: **New Annex XIII and** addresses specific information on water quality in Member States and the **new Annex XIV** covers pollution reduction in Member States. - Comparison of studies: This is addressed mainly in **section 4.1.2.**
5) The assessment of coherence needs to be clearer regarding the interplay with CAP, Water Framework Directive, National Emissions Commitments Directive. The report should clarify to what extent the measures under the CAP in particular contributed to the progress on the objectives and whether their interplay ensures sufficient incentives for appropriate practices at farms.
- Coherence with CAP: the **new section 3.2.3** addresses the CAP influence on the Nitrates Directive implementation, the **new Annex XVI** covers the interlinks between the CAP and the Nitrates Directive. Coherence analysis in **section 4.1.3** on coherence was updated. Concluding remarks are included and the corresponding part in **section 5.1.** - Coherence with Water Framework Directive (WFD): **section 3.1.1** addresses the links between monitoring networks, **section 3.3.5.** presents the main links with the WFD, and the **new Annex XV** covers in more detail the interlinks between both directives. Concluding remarks are included in **section 4.1.3** on coherence and the corresponding part in **section 5.1.** - Coherence with National Emissions Commitment Directive (NECD): **section 2.2**. already introduces the coherence. The new **Annex XV** also covers the coherence with the NECD and concluding remarks are included in **section 4.1.3** on coherence
6) The evaluation should better explain to what extent the Directive is still fit for purpose. It should analyse to what extent the measures and their parameters remain relevant considering the limited effectiveness in particular during the last ten years and considering the evolution of key external factors including the changes on relevant markets, climate change and technological developments (e.g. precision farming). Since the report claims that a large part of European observation points for ground and surface waters have nitrate concentrations well below the 50 mg threshold, the report needs to better assess how relevant this intervention remains for the larger part of the EU.
- Fit for purpose, relevance of measures and parameters considering key external factors: based on the information presented throughout the report, **section 4.3**. now assesses more clearly the relevance of the ND and the new **Annex XI** provides more information on environmental effects of the measures. In addition, the new **Annex XII** covers the differences on how the measures are applied, and the new **Annex XVII** examines the relevance of the manure limit. Furthermore, new **Annex XIX** on biogas addresses adaptation of the Directive to technological development and the continued relevance of the manure limit. - Relevant intervention of the directive: This is addressed mainly in **section 4.1, 4.2**, and **section 5.1.** provides concluding remarks
7) The evaluation should more clearly explain whether the fact that the Directive does not explicitly cover phosphorus has a negative impact on the achievement of the objectives regarding eutrophication.
- **Section 4.1 presents the analysis on phosphorus**. The new **Annex XII** on implementation of measures explains how the directive addresses phosphorus losses, in combination with other EU legislation.
8) When it comes to simplification and burden reduction, the report presents the views of different stakeholders but does not sufficiently present the Commission's analysis of the issues raised and the

possible opportunities for simplification for future action.
- Commissions views on simplification: **Section 4.1.4** now presents more clearly the Commission's analysis and the opportunities for simplification. **Section 5.2** summarises these opportunities in the concluding remarks.

2nd RSB opinion 13 March 2026 – Points to improve and approach taken
(1) The evaluation should more thoroughly analyse the different approaches taken by Member States and the consequences of this for effectiveness, to the extent possible including based on an assessment of effectiveness under different local circumstances. The report should analyse to what extent the flexibilities (including derogations) have allowed for a more efficient achievement of objectives, and to what extent the flexibilities might have reduced effectiveness, including in hot spot areas. The report should draw related lessons including lessons for the data needed for future evaluation.
Answer and enacted change: This analysis is reflected in Section 4.1 on effectiveness and more in detail in Annex XII, reinforced following the opinion of the RSB. These sections analyse the different approaches taken by Member States on key aspects, such as closing periods, fertilisation limits, manure production and derogations, and the consequences of those approaches on effectiveness, identifying both positive and negative effects. The analysis in Annex XII also discusses the effect of local circumstances and draws on further studies on the implementation of the measures in different pedo-climatic zones. The cost analysis in Section 4.1, based on the underlying cost study, analyses the cost of these key measures in the Member States and across sectors, and thus allows to draw general conclusions on the efficiency of measures, which is done in Section 4.1. For example, this analysis shows cost distribution among Member States for buffer strips, manure storage, transport and processing, and that costs for balanced fertilisation are negligeable. However, the data available does not allow for detailed assessment in the case of each Member State and this was not the purpose of the evaluation. The evaluation assessed the overall effectiveness and efficiency of the intervention based on a relevant selection of measures and national contexts. **Enacted change: In section 4.1 and in the conclusions/lessons learned, additional text was added in relation to key findings on flexibility, emphasising different approaches in Member States and the impact on effectiveness and efficiency, drawing on section 4.1 and annex XII.**
(2) Given that the expected impact includes no eutrophication of fresh and marine waters due to nutrients of agriculture origin, the report should specify how success would be identified and measured. The evaluation should also better analyse why effectiveness seems limited when it comes to addressing eutrophication and develop clearer conclusions for the EU-level intervention.
Answer and enacted change: These elements have been analysed and reinforced in various sections: The objectives and intervention logic are laid out in Section 2 of the report. Section 2.1 and 2.2 explain in more detail what eutrophication is and how success can be measured. In particular it explains the relationship between the measures of the Nitrates Directive, the results indicators in terms of fertiliser and manure application and the eutrophication requiring nitrogen concentrations well below the drinking water threshold of 50 mg/l. This is why the indicators of reduction of nutrient concentrations and loads to waters are also relevant in discussing the success of the Nitrates Directive in addressing eutrophication. It further highlights that reduction of eutrophication cannot be addressed through the Nitrates Directive alone, and explains the relationship between nitrogen and phosphorus concentrations in water and the risk of eutrophication where nitrogen and phosphorus concentrations below a certain threshold are necessary but not always sufficient conditions to eliminate eutrophication.

Section 3 describes first the temporal evolution of key result indicators such as fertiliser and manure use, nitrogen surplus, which can be directly linked with the reduction of nutrient loads and reduction of nutrient concentrations in water, and then the evolution of water quality indicators such as nitrate concentration reductions and the trophic status in surface water. These are relevant parameters to discuss impacts of the intervention on eutrophication, although the nitrate concentration thresholds for eutrophication are much lower than the drinking water threshold and therefore the reduction to be achieved much greater. Section 3 further describes the challenges in addressing and measuring progress on eutrophication and the measures taken to remedy it. In particular, the report explains how the Nitrates Directive initially lacked the parameters and framework for monitoring and reporting eutrophication and the criteria for success. The absence in the Nitrates Directive of explicit measures and limits for phosphorus, and the absence of reporting obligation were also part of the difficulty to assess success. Section 4.2 analyses how phosphorus pollution as a key factor for eutrophication and the absence of explicit phosphorus limits in the Nitrates Directive have been dealt with and eventually been sufficiently addressed in combination with the Water Framework Directive.

Annexes XII, XIII and XIV of the report further illustrate water quality results in all the Member States, the approaches to phosphorus and the effectiveness of the Directive in reducing nitrate levels.

Building on data presented in Section 3 and relevant annexes, Section 4.1 on effectiveness refers to both positive developments and remaining challenges regarding eutrophication and reiterates the point made in Section 2 regarding the need for a long-term perspective on eutrophication. Section 4.1 on coherence clarifies that the WFD provides the framework, criteria and parameters for measuring overall progress and success on eutrophication in relation to good ecological status, for identifying the necessary nutrient load reduction and the respective attribution to different sectors. The analysis of coherence finds that while enormous progress has been done, gaps remain in ensuring coherence of the monitoring and reporting of eutrophication between the Nitrates Directive and the WFD and suggests that this could be taken forward as part of the simplification effort.

Enacted change: Analysis has been reenforced in sections 2, 3 and 4 to clarify how success can be measured and on the results achieved. Key findings for eutrophication have been strengthened in the conclusions/lessons learned.

(3) (a) The estimation of benefits and the benefit cost ratio presented are not robust. The report should be clear on how monetary values are assigned to different possible such environmental improvements. The findings on benefits need to reflect the methodological challenges and limitations involved in combining means and medians from different studies, without having discussed the comparability, weighting or representativeness of the underlying data points in the different studies

Answer and enacted change:

The evaluation report and the extensive methodological notes in Annex II and Annex IV recognise the challenges and uncertainties in assessing societal costs for various forms of nutrient pollution in the different Member States and further bringing these costs together in one EU level estimate. The analysis is also clear about the uncertainty attached to the estimate of the benefit flowing from the directive's impact. However, regardless of the uncertainties involved, the estimates allow to indicate the general order of magnitude, which is sufficient to draw robust conclusions and comparing to the implementation costs.

Section 4.1, reinforced following the RSB opinion, explains that the estimates of costs of nutrient pollution and ensuing benefits of the Nitrates Directive build on the recognised cost study of the European Nitrogen Assessment and that the new cost estimates have been compared with this study. The estimates are based on updated cost values of the various forms of pollution derived from peer reviewed scientific studies. The choice of ranges by means and medians of estimated values found in the literature served to indicate different interpretations of what would account as the "central estimates" in a very diverse population of studies, covering many different types of

situations and approaches. In other words, the approach aimed to exclude extreme outliers. The report explains the method used for arriving at the range. Overall, a finer approach linked to the comparability, weighing or representativeness of the various costs estimates from the peer-reviewed studies was not feasible for this study and would have involved a disproportionate amount of work to categorise and assess in substance a high number of scientific studies, for the scope of this analysis and given the other uncertainties linked to assessing societal costs for various forms of nutrient pollution in the different Member States and further bringing these costs together in one EU level estimate.. Nevertheless, the final estimates were within the range of the original estimates arrived at in the Nitrogen Assessment and related studies, which formed the basis for the analysis, supporting the results. Moreover, as mentioned in the evaluation report, a study published in October 2025 (after the cost analysis was performed and using national cost estimates) estimated the cost of nitrogen and phosphorus pollution (air pollution and eutrophication) in the Netherlands alone to be EUR 7.3 billion annually, which as a general order of magnitude seems consistent with the estimates provided in the evaluation study for the whole EU and the fact that costs of nutrient pollution in the Netherlands would be higher than average, due to the level of pollution, the population density and age distribution.

With regard to the request for further analysis of the marginal value of benefits at low levels of pollution, the approach taken was based on the existing literature, where unit costs have generally been assigned to pollution based on the kg values of nutrients. Furthermore, a sensitivity analysis is presented in Annex II and IV, indicating that the estimates are generally conservative and could be significantly higher in reality. In general, there would seem to be a good correlation between costs and benefits, as the directive generally imposes higher implementation costs in situations when pollution is more severe. In areas where there is no pollution risk, the implementation costs can be close to zero (outside NVZ), so the geographic distribution of costs and benefits of the directive would tend to be coherent in this sense.

Going beyond the goal and scope of this evaluation, more extensive national level studies on the costs of nutrient pollution and the benefits of the measures modulated on the specific national context and reflecting the diversity of situations could be crucial tools for Member States to draw conclusions supporting policy choices and discussions with stakeholders.

Enacted change: Section 4.1 has been updated and conclusions/lessons learned further clarifies the robustness and uncertainties in perspective, and beyond the evaluation, highlights usefulness to have more detailed cost benefit studies in the national contexts.

(b) The report needs to adequately assess the marginal value of health benefits following from the reduction of nitrate concentrations in a situation where most of the ground and surface waters do not appear to have nitrate concentrations at or above the set safety threshold.

Answer and enacted change

While assessment of the marginal value of health benefits from the Nitrates Directive would add further detail and understanding, especially as regards the cost benefits in preventing nutrient pollution from agriculture, such assessment is not available and would require important time and resources. However, it would not at this stage lead to a different understanding of the fundamental mechanics and cost structure of nutrient pollution or the benefits of the Directive. It would also not lead to lowering the estimated range of benefits as presented in the evaluation, as these are already considered to be rather on the low side. In particular, based on the distribution of nitrate concentrations for monitoring points as given under the Nitrates Directive, it is not possible to infer that the water extracted for drinking water at drinking water extraction points (that may have different locations) satisfies the nitrate threshold nor the impacts and costs of supplying clean drinking water.

The role of the Nitrates Directive is to prevent the water to be polluted in the first place and where necessary to reduce the pollution. Therefore, the benefits of the directive for drinking water have to

be measured also with regard to its preventive effect (see also points 6 and 7). What counts is the cost of the preventive measures under the directive against the cost of water treatment (or securing an alternative drinking water source) and the potential number of people affected when nitrate levels exceed the drinking water threshold. It may also be the case that the drinking water reservoir is affected by eutrophication, rendering the water equally unsafe to drink. Technical solutions to treat such water require substantial capital and operational expenditure, while preventive measures to minimize nitrogen runoff offer a more sustainable and cost-efficient solution. The economic implications of these strategies vary significantly based on the scale of implementation and local conditions. A 2024 Danish study estimated technical nitrate removal costs between €0.15 and €1.60 per m³, whereas preventive measures range from €0.02 to €0.26 per m³. In some parts of Germany and France, drinking water companies pay farmers for implementing good practices and reducing fertiliser use near drinking water extraction points. These examples illustrate the benefits of the Nitrates Directive in maintaining potential drinking waters below the 50 mg/l threshold and in keeping drinking costs lower where nitrates levels are low. On the other hand, there are recent documented cases in several cities or areas in Member States where the drinking water situation has reached critical levels where prevention has failed, highlighting that excess nitrates in water can still be a critical issue with impactful effects on population and local resources. Finally, an assessment of the marginal value of health benefits of the Nitrates Directive needs to include not only nitrates in drinking water, but also eutrophication and ammonia emissions. It should also take into account the developing science relating to health impacts of nutrient pollution from agriculture such as evidence of carcinogenic effects of nitrates at much lower level than 50 mg/l, premature deaths caused by ammonia emissions or the developing jurisprudence of compensations for the death of a person due to toxic algae blooms (green tides in Brittany).

Enacted change: The relevant part in Section 4.1 reflects further on the health benefits of the Nitrates Directive, in particular in preventing pollution (and associated costs) of drinking water. In the conclusions/lessons learned, additional input emphasises the importance of health impacts of nitrate pollution and their societal costs, and linked to that the crucial role of the Nitrates Directive in reducing and preventing the pollution.

(c) The report should more clearly demonstrate the causal link between the intervention and the developments observed, supported by data.

Answer and enacted change

The causal link between the intervention and the developments observed is demonstrated in the report and its annexes, with substantial evidence added responding to the RSB opinion. Sections 2 and 3 identify and describe the temporal evolution of key indicators based on data from Eurostat, Member States, the EC, and EEA that relate to the implementation of the directive, the expected results and to the expected impacts. The annexes further explain the scientific basis underpinning the relevance of the indicators as well as the temporal evolution of the indicators in all the Member States. Section 4 draws findings based on the indicators and the underlying data in terms of effectiveness, efficiency and coherence. It is already acknowledged that the links (especially on impacts) are complex at macrolevel due to multiple intervening factors, but the intervention logic remains solid and sound. Annexes further bring together scientific studies from the JRC and the Member States environmental agencies analysing the causal link between the measures under the Nitrates Directive, the evolution of the nutrient surplus and the changes in nitrates and phosphate concentrations in ground and surface waters. In particular, the studies show how nitrate concentrations in surface waters in France have been reduced following action under the Nitrates Directive and what the average time lag is, other studies in Denmark show how the measures under the Nitrates Directive have a direct impact on the reduction of nitrogen surplus and how the reduction of the nitrogen surplus can be directly correlated with the reduction of nitrates in groundwaters, and the average time lag. There are also discussions on the availability of data and the needs for future evaluations.

Enacted change: In Sections 2, 3 and 4 the evidence of the causal links between intervention, the result and impact indicators is further highlighted with references to the annexes where these are mentioned. Key findings on the link between the intervention and the developments

observed are further highlighted in the conclusions/lessons learned, pointing to the different indicators (result and impact) and the relevant section or annexes.

(4) The report should analyse the incentives for farmers to cover crops with more nitrate nutrients than what is optimal for the crops' growth, in cases where chemical nutrients are costly for the farmers to obtain.

Answer and enacted change:

The report extensively covers evolution of fertiliser use and how with continued increase of production and lower fertiliser use, the nitrogen use efficiency in the EU has improved since the implementation of the Nitrates Directive, but also that using more nitrogen fertilisers than crop needs is still widespread. The report analyses the evolution of fertiliser use including chemical fertiliser use as a key parameter influenced by the directive. Section 2 and Annex VII describe the period before the implementation of the Directive, showing steady increase of fertiliser use and the environmental consequences. Section 3 describes the evolution of chemical fertiliser use showing a clear reduction after 1991 in EU15, as a result of the measures in the Nitrates Directive and supported by a change of approach in CAP subsidies away from production (decoupling), and a progressive alignment of fertiliser use in the Member States that joined the EU after 2004. It also shows that fertiliser use is price sensitive causing short-term fluctuations, e.g. as the war in Ukraine in 2022 and a rapid rise of fertiliser prices has promoted further fertiliser use efficiency. Annex XII further illustrates this: compared with countries outside the EU there is clear improvement in nitrogen use efficiency in EU countries, however the analysis of the implementation of balanced fertilisation in different Member States indicates how fertilisation in many cases can still exceed not only safe environmental limits but also the limits that were considered optimal for crop growth.

The incentives for farmers to over-fertilise are linked to the relation between the expected yield and the amount of fertiliser. As explained in section 3 and Annex XI on balanced fertilisation, the take-up of nitrogen by crops is not linear, there are also strong annual and regional variations, and the fertiliser application standard will have a direct effect on the amount of leaching. The application standards are ideally based on a dose response curve. The economically optimal rate is strongly dependent on the economic situation (including the market prices of fertilisers and crops), can be highly variable, is not known at the beginning of the season, and does not necessarily coincide with agriculturally optimal dose. When fertilisers are cheap there is little incentive to use less fertilisers and increase nitrogen use efficiency so as to coincide with the agricultural optimal dose. As long as fertiliser prices remain low and the market price for the crop is sustained, the economic optimum for the farm will tend to be equal or higher than the agronomic optimum, as the economic losses due to over-fertilisation in one year would be compensated by high yields in another. However, high application standards based on unrealistically high yield figures will result in nutrient losses and have a negative effect on the environment. On the other hand, when fertilisers are expensive, there is a strong incentive to adjust the standard to the agriculturally optimal dose (higher nitrogen use efficiency).

Moreover, as further explained in Section 4.1.2 there can be a further mismatch between the private economic optimum of the farmer on the one hand and the social economic optimum for society on the other, due to the externality costs associated with fertiliser use, which fall on society as a whole. As explained in Section 4.2 and Annex XVII, the incentive to apply livestock manure is evident. Using all the manure available on the farm is less costly as it reduces or removes the costs of storage, transport or processing of manure. Nevertheless, to reach an economic optimum through manure application, it would require application of very high amounts of total nitrogen, due to the generally lower efficiency of manure as a fertiliser (optimum agronomic fertilisation rates are based on the amount of nitrogen that is expected to be available to the crop during the growing season). In addition, the mismatch between the private economic optimum of the farmer and the social optimum becomes disproportionally high as the external costs for manure are linked to its high pollution risk, especially when concentrating all the manure application on the farm. Reducing societal costs of manure therefore calls for a redistribution of the manure between livestock and arable farms. Section 4.3 further explores how some forms of manure processing can reduce the

environmental risks and allow for substitution of chemical fertilisers.

Enacted change: Based on the analysis of Annex XI, Section 3 elaborates further the discussion of the farmers' motivations and practices regarding fertiliser application. Section 4 provides more analysis on the links between the economic optimum for society and the farmer in terms of fertiliser use. Key findings on balanced fertilisation and nitrogen use efficiency are summarised in the conclusions/lessons learned.

(5) The impacts on competitiveness and proportionality need to be adequately assessed and presented in the main report. To the extent possible, the marginal costs from the intervention should be assessed and compliance costs should be compared to profit margins, in order to better understand how the Directive enters the cost functions and impacts the profitability of different types of farms, beyond merely comparing farms in different areas in Europe. Findings relevant to assessing the impacts on competitiveness, such as those showing that the intervention leads to large cost increases for cattle farms, and seems mostly to hit the most productive farms, should be integrated into the analysis in the main report.

Answer and enacted change:

Responding to the RSB opinion, an additional dedicated analysis of the potential impact of the directive on farm competitiveness was added in Section 4 with further background in annex XVIII (including econometric analysis). An assessment of the marginal costs of the intervention was not feasible for this evaluation as it would have required very extensive economic analysis of costs of different measures in different local contexts as well as their deployment across the EU. However, the evaluation study does highlight key variations in costs depending on sector and regional context, such as the significantly higher costs for livestock farms in regions with very high livestock density compared to the generally much lower costs across the EU. The lowest cost is outside the designated areas where mandatory measures are applied (where costs are effectively zero).

The comparison of compliance costs of the intervention with the profit margins as requested was in turn considered to raise methodological issues. First of all, while the impact of short-term shocks may usefully be compared with profit margins to assess the immediate impact on producers, such an analysis is not useful for structural framework conditions such as the Nitrates Directive, as any cost impact of the directive will eventually be reflected in prices rather than in profit margins. Hence, a direct comparison with profit margins would be misleading. This said, however, Annex XVIII (referred to in the Section 4.1.1) presents an econometric analysis to assess the possible impact of the directive on the evolution in agricultural costs, margins and incomes as well as in crop yields and livestock numbers, without finding a clear impact on agricultural competitiveness.

The specific impact on some livestock farms in certain regions is extensively discussed in the report and mentioned in the conclusion and lessons learned. While the analysis in Section 4.1 shows that the intervention leads to cost increases for cattle and pig farms farms, it also shows that the significant cost increases are concentrated in a few Member States/regions with high excess of manure production, which are also the regions where the level and cost of nutrient pollution are the highest, in line with polluter pays principle. The significant costs for certain livestock regions are explained and discussed also in relation to the particular risk of pollution in such regions. Outside these Member States the overall cost is both much lower and more evenly balanced between arable and livestock farms while arable farms further benefit from the excess manure from nearby livestock farms and are able to reduce their costs.

Enacted change: Analysis has been extended in Section 4.1.1 and key findings reviewed and clarified where appropriate in conclusions and lessons learned

(6) The report should better substantiate its claim that most European measurement points for ground and surface waters exhibit nitrate concentrations well below the 50 mg threshold. Given this claim, this evaluation needs to assess if and how relevant the intervention still is for the larger parts of the EU.

Answer and enacted change:

The statements on water quality in the report as illustrated in maps and graphs in Section 3 and further in Annex XIII are factual and reproduce data from the four yearly implementation reports based on nitrate concentration measurement data provided by the Member States. The sources of data and their origin are provided.

A discussion of the continued relevance of the Directive in all parts of the EU has been further expanded in Section 4.1 and Section 4.3. responding to the RSB opinion. The fact that most European measurement points for ground and surface waters exhibit nitrate concentrations well below the 50 mg threshold does not make the intervention irrelevant but rather illustrates the effectiveness and success of the preventive approach of the Directive. The prevention of pollution is achieved through mandatory measures on 70% of agriculture land in areas where pollution is already a problem or that are at risk of being polluted if no action is taken, and the evaluation explored the effectiveness of such measures in these areas. Outside such areas, the directive works through voluntary measures, which is a risk-based approach, providing flexibility Member States and farmers where pollution is not yet an acute issue. The preventive role of the Directive has also been recognised by the national Courts, such as the Las Conchas ruling (Galicia) in 2025 recognised inaction of the authorities in preventing pollution of ground and surface waters by nitrates due to agriculture. On the other hand, eutrophication which occurs at much lower nitrate concentrations than 50 mg/l remains significant throughout the EU, recalling that further effort is needed to reduce nutrient losses and the necessity of measures for the larger parts of the EU. This picture is also confirmed by a recent assessment under the WFD (2025), which concludes that, although considerable improvements have been observed compared to the 1990s and most Member States and farms have made significant efforts to reduce nutrient losses in waters, current measures are still not sufficient to reach the water quality objectives.

Enacted change: Sections 4.1 and 4.3 as well as the conclusions/lessons learned elaborate further on the preventive role of the Directive and its continued relevance to address nitrates pollution and eutrophication throughout the EU.

(7) The report should identify the opportunities for the reduction of regulatory burdens at an adequate level of detail and concreteness. In this context, the report should furthermore also assess the possibility of exemptions for farms in areas with good water quality.

Answer and enacted change:

Section 4.1.4 elaborates as far as possible in the evaluation context on concrete simplification options, without prejudging future policy choices. The conclusions and lessons learned further mention the possibilities for simplification in relevant paragraphs.

As regards the possibility of exemptions for farms in areas with good water quality, in general, the directive does not prevent differentiated treatment between farms as it is by design targeted to vulnerable zones and not to farms in particular. As explained in Section 3 and 4, Member States have extensive flexibility, *first,* to designate areas where mandatory measures will apply (and those where it would not) and, *second,* to adapt the measures and the effort to be achieved in accordance to (a) local circumstances, (b) the actual level and risk of pollution, (c) the environmental performance of a farm. Therefore, the intervention is by design targeted to areas where pollution or the risk of pollution is a problem. On the other hand, the reply to point (6) above has already elaborated on the importance and success of the preventive approach of the intervention, especially in all areas with intensive agriculture and high fertiliser use. The fact that nitrate pollution is not currently significant in an area does not make a case for abolishing preventive measures, in the same way as the absence of accidents does not make the aviation safety policies irrelevant.

Enacted change: Review section 4.1.4 and summarise in one place simplification options in conclusions/lessons learned.

(8) The conclusions presented in the report need to be revised, so that they do not go beyond what is supported by the evidence and analysis in the report, corresponding to the points

raised above.
Answer and enacted change: The conclusions have been reviewed and where relevant revised to reflect the comments and clarifications above. Links with the findings and evidence in the relevant sections have been highlighted.

Evidence, sources and use of external expertise

- Support study conducted by RPA Europe and partners "Support for the evaluation of the Nitrates Directive" [1]. This study was contracted on 25 July 2022 and the final deliverables were received on 23 September 2024. It was meant as a comprehensive evaluation study but had to be terminated before completion due to delays in the launch of the evaluation process.
- Support study conducted by Ecorys "Complementary study to provide specific elements for the evaluation of the Nitrates Directive" [2]. This study was contracted on 22 May 2024 and the final report was delivered on … 2025. The main objective of the study was to provide specific elements needed for the completion of the evaluation.
- JRC study for Nitrates Directive evaluation "*Assessing the effectiveness of the Nitrates Directive: implications for agriculture and for water, soil and air quality*" [3]. This study was delivered in 2025 and published on … 2025. It provided scientific inputs on the impacts of the Nitrates Directive and in relation to the limit on livestock manure set out in annex III of the directive.
- Information and results from EU research and development projects (mainly from the Horizon Europe and Life programmes).
- Various stakeholder consultations including feedback on the call for evidence and the public consultation carried out in 2023-2024.
- Nitrates Expert Group made up of representatives of national authorities responsible for implementation of the directive was consulted through six dedicated discussion sessions in the course of 2024 to elicit expert views on various aspects of the directive and its implementation.
- Soil Service of Belgium conducted a study [4] in 2024 about the effectiveness of the measures included in the annexes II and III to the directive and other measures based on a review of technical documents, evaluations and guidance produced by public institutions as well as the existing scientific literature. This task was commissioned on 14 December 2023 and delivered on 15 September 2024.
- Implementation reports submitted by Member States under Article 10 and the Commission summary reports under Article 11 of the Nitrates Directive every four years since the 1990s provides a significant amount of data and information on the implementation of the directive over the years and the impact on waters.
- Tzivilakis et al, Identification of approaches and measures in action programmes under Directive 91/676/EEC, 2020. Study prepared for the Commission.

ANNEX II. METHODOLOGY AND ANALYTICAL MODELS USED

For completing the evaluation which covers more than 30 years of implementation of the Nitrates Directive, the Commission relied on available Commission reports (namely on the reports implementation of the Nitrates Directive published every four years since 1991), on reports from the European Environmental Agency and international organisations, on scientific literature, on EUROSTAT and FAOSTAT data, on case-law, on reports from a number of external studies and further organised extensive consultations with Member States authorities and stakeholders. Eventually, the Commission did not have a comprehensive external evaluation study, so it brought together the analysis and the findings on the basis of these different support elements.

The Commission was initially supported by a study contracted under the framework contract for impact assessments and evaluation of DG ENV (period 2019-2024)[1]. The "Study for the support for the evaluation of the Nitrates Directive" started in July 2022 and ended in August 2024. The consortium for this study included RPA, Air Quality Consultants Ltd, Ecologic Institute and University of Hertfordshire. It was intended as an evaluation study covering all data collection and analytical assessments in line line with the better regulation criteria. However, due to delays in the start of the public consultation and the consultation activities in general until December 2023, the study and the deliverables as initially planned could not be finalised. It was not possible to finalise the key elements of the evaluation such as the intervention logic, assessments of the evaluation questions and the evaluation criteria which depended critically on the inputs from the various consultation activities. To remedy this problem, firstly the Commission extended the contract to the maximum possible period under the framework contract and negotiated the delivery of the tasks that could still be finalised within the given timeframe. The deliverables under the first study cover:

- Evolution of key results and impact parameters for the Nitrates Directive at Member State and EU level.
- Overview tables on the implementation of the NAP measures in Member States.
- Analysis and summary of the open public consultation and call for evidence.
- Four case studies analysing the impact of the Nitrates Directive in four Member States since its adoption/first application.

As regards the quality and limitations of the above deliverables, the analysis and summary of the public consultation and call for evidence used statistical analysis methods, and in depth analysis of the individual replies and position papers. An initial challenge in the analysis was the overrepresentation of one group of stakeholders. After extensive discussions, including with the ISSG, solutions were found to be able to reflect the positions of other stakeholders through a separate analysis of each stakeholder's

[1] Framework Contract No: ENV.F.1/FRA/2019/0001

group responses, and present these alongside the rich inputs of the dominant group. The four case studies based on interviews of national stakeholders and national data benefited from a review by the competent national authorities to check on correctness. The overview tables on the implementation of the NAP measures were largely based on a previous extensive study from Hertfordshire University. The evolution of key parameters was largely based on EUROSTAT and FAOSTAT data. The latter deliverables could not be verified with national authorities or stakeholders due to the termination of the contract early in the evaluation process.

Secondly, the Commission launched a new study in May 2024 contracted under the framework contract for evaluation and studies of DG ENV (2024-2027)[2]: Complementary study [2] to provide specific elements for the evaluation of the Nitrates Directive. The consortium for this study included Ecorys, Ghent University, Ecologic, Spark Legal and Policy consultant, CSERGE (Centre for Social and Economic Research on the Global Environment). This study included tasks covering the following topics that were completed as separate deliverables.

- Task 1: Organisation of targeted consultation activities: workshops and interviews.
- Task 2: Assessment of cost related to interventions under the Directive.
- Task 3: Costs of nutrient pollution and benefits of the Directive.
- Task 4: Coherence of monitoring and reporting framework with other EU legislation.
- Task 5: Overview of court jurisprudence under the directive.
- Task 6: Description of the historic N and P flows in agriculture and environmental challenges.
- Task 7: Review of the implementation of the Nitrates Directive in the EU recent enlargement processes.
- Task 8: Simplification and administrative cost reductions.
- Task 9: Integrated nutrients approaches and Digestates.

Each task had its own methodology and approach, which is detailed in the respective deliverables. Methodologies for tasks 4, 5, 6 and 7 mostly relied on data gathering and desk research from existing sources at EU and national level. Task 4 further added workshop, questionnaires and interviews. Task 2, 8 and 9 relied on modelling and on data gathering through questionnaires, workshop and interviews. For more details on methodology and modelling used for costs estimates see Annex IV. As such, the tasks are supporting elements that do not provide conclusions with regard to the evaluation criteria.

On the quality and limitations of the deliverables: as the study was split in separate well defined tasks, these were each carried out by entities with specific and recognised

[2] Framework Contract No: ENV.01/FRA/2023/000

expertise which provided a solid basis for the study. In addition to the strong expertise and methodology from Ghent University and ECORYS, task 2 and 8 (analysis of costs) benefited from extensive consultations with Member States experts from all Member States and stakeholders (academic experts, farmer's organisation, environmental organisations, water companies) from many parts of the EU. In early 2025, the Commission decided to transfer part of the yet unused budget of the study to ensure additional consultations on the findings for costs for farms and for authorities, so as to be sufficiently representative of the diversity of situations and implementations of the Nitrates Directive throughout the EU. This has significantly improved the confidence in the results.

The estimate of nutrient pollution and the benefits of the Nitrates Directive (Task 3) was carried out based on scientific literature for costs of the various types of nutrient pollution, using also an ecosystem services and a willingness to pay approach. There are many challenges on defining costs per pollutants based on a "meta" analysis approach, given the differences of scope and methodologies underlying each of the sources. However, in order to calculate the total costs of nutrient pollution, the contractor relied on the method used in the most recognised scientific work in this field from 2013, which ensured several comparison points and provided confidence on the soundness of the approach. Overall the Commission has reasonable confidence on the results presented in Task 3, as it allows a straightforward comparison with recognised scientific results while further providing up-to date cost estimates based on the most recent literature. A sensitivity analysis on the benefits of the Nitrates Directive with regard to the costs was also performed.

The Commission also relied on specialised research institutes to prepare scientific analysis on the measures and effects of the Nitrates Directive.

The Soil Service of Belgium[3] prepared a study *Analysis of efficiency and effectiveness of measures referred to in Annex II and III of the Nitrates Directive* [4]. The study assesses the effectiveness of the measures included in the annexes II and III to the directive and other measures based on a review of technical documents, evaluations and guidance produced by public institutions as well as the existing scientific literature.

The Joint Research Centre prepared a study *Assessing the effectiveness of the Nitrates Directive: implications for agriculture and for water, soil and air quality* [3]. The purpose of this scientific study was to shed light on the effectiveness of the Nitrates Directive in achieving its goal and reflect critically on the implication/efficacy of the limit of manure application (170 kgN/ha), set by the directive in Nitrates Vulnerable Zones, considering environmental, health and agronomic implications. This multiauthor and multidisciplinary study brings together different methods and approaches, using data analysis, modelling and overview of the available scientific literature and knowledge on the topics addressed. The modelling studies on the effectiveness of the Nitrates Directive will be peer-reviewed. The study provides further scientific underpinning confirming the

[3] Service Contract – 09.0201/2022/881726/ENV.D.1 "Scientific support for the implementation of the Nitrates Directive (Directive 91/676/EEC) and for an Integrated Nutrient Management"

effectiveness and the continued relevance of the mechanisms and intervention logic and of the manure limit set by the Directive with regard to today's challenges.

As regards data input to analyse the evolution of result and impact indicators, the Commission heavily relied on the data provided by the 4-yearly Member States reports since 1991. This has been an invaluable source of water quality data and national analysis on the implementation of the directive for the whole evaluation period, and also helped to understand the situation at the start of the implementation of the Nitrates Directive, as there was no specific impact assessment. In the process leading to the publication of the Commission's implementation reports based on the national reports, there were several stages of quality checks and feedback. Even when data from the 1990s cannot directly be compared anymore with today's data, the seven Nitrates Directive implementation reports published since 1991 have provided invaluable insights in the context prevailing at the different periods as well as assessments on the progress in the implementation of the Directive. Other sources of data from EUROSTAT, FAOSTAT and the EEA available on a long time period and external to the Nitrates Directive reporting have complemented the data sources (Specific limitations for these data sources are provided in the evaluation itself).

This evaluation could not have been completed without the inputs from the Member States authorities responsible for the implementation of the directive at national level. As the Nitrates Directive largely leaves the design and enforcement of the agriculture measures and water monitoring programmes to Member States, gathering their experience and their views with regard to the criteria of the evaluation was essential. Therefore, the Commission organised structured consultations of the Member States authorities and experts implementing the Directive through the Nitrates Expert group on key aspects of the Nitrates Directive in six dedicated sessions throughout 2024. The sessions covered (i) scope and objectives of the directive, (ii) identification of polluted waters and designation of vulnerable zones, (iii) measures set out in annex II and III of the directive, (iv) balanced fertilisation, limitation of manure land application and derogations, (iv) monitoring and reporting and (vi) implementation and enforcement. The Commission drafted a summary of these consultations which was then reviewed with Member States authorities in the Nitrates Expert Group. (Annex VI). While the experts' views cannot be referred to as representing the official position of a Member State, they are representative of the extensive technical knowledge and practical experience in the implementation of the Directive in all Member States including several departments (environment, agriculture, water) and regional authorities. The summary has been extensively referred to in section 4.

Methodological note on the points of comparison:

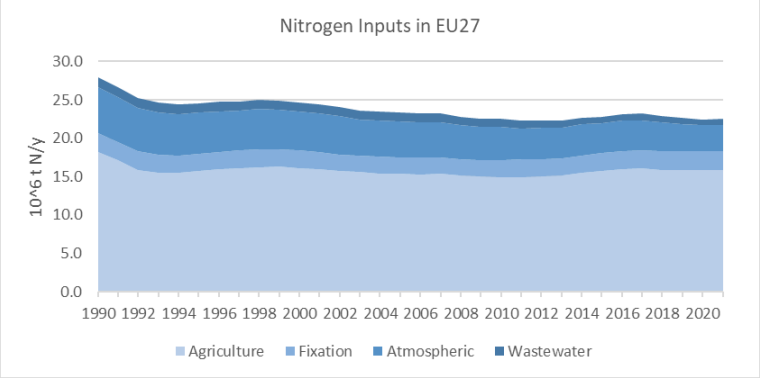
When the Nitrates Directive was adopted in 1991, there was no impact assessment accompanying the proposal. In this evaluation we therefore established two points of comparison, first the situation before and after the Nitrates Directive, and second the objectives set by the ND. Building a baseline in the sense of the likely evolution in the absence of the ND was not deemed feasible. This also means that in the analytical part (section 4) there is a legitimate question on how much the observed evolutions are attributable to the Nitrates Directive. It is evident that other factors have also played a

role, such as market pressures and other legislations, and this is already reflected in Section 4. However, the data and indicators presented in Section 3, which are the basis of the analysis in section 4, have been selected as being the ones which would reflect best the impact of the Nitrates Directive compared to other legislations or factors. So in the results presented in Section 3 and Section 4, there is an underlying assumption that the Nitrates Directive plays a significant role in the evolution, except when otherwise mentioned.

As regards the evolution of results indicators, there is a reasonable understanding that the observed evolutions in the reduction of fertiliser inputs (chemical fertilisers and manure), and of nitrogen balances after 1991 in western Europe can be attributed to a very large part to the Nitrates Directive. As the text in section 3 and 4 also explains, the evolution is also tributary to external factors such as agriculture production and market pressures, which have a tendency to increase the use of fertilisers, while fertiliser prices may cause rapid fluctuations in use. However on long periods the limitations and reductions can be mostly attributed to the effects of the Nitrates Directive.

As regards the evolution of water quality indicators, it is obvious that these cannot be attributed to the Nitrates Directive alone, as nitrates concentration and eutrophication can also be influenced by other factors, including wastewater and atmospheric deposition. However, this does not mean that the data presented is not reflecting well the impact of the Nitrates Directive. Firstly, agriculture was and remains by far the largest source of nitrates in water in the rivers and seas in the EU. The graph below illustrates total nitrogen and phosphorus inputs to river basins in EU 27. Figure 1 shows the amounts in terms of sources, for example the nitrogen in fertilisers applied to agricultural land or discharged from treatment plants into rivers. As most of the agricultural inputs are retained in crops or soils or emitted to air, the amounts actually ending up in rivers, lakes and coastal waters will show a different distribution. Figure 2 below shows the estimated contributions from different sources in European seas, which can be seen as the ultimate end point. Wastewaters remain an important contributor, especially for phosphorus, but agriculture is also significant and the most important one for nitrogen.

Figure 1 Total inputs of nitrogen and phosphorus to the river basins in EU27 countries between 1990 and 2020 from different sources: agriculture (including mineral and manure fertilisers), fixation (only for nitrogen, including crop and soil nitrogen fixation), atmospheric deposition and wastewater discharges from domestic and industrial sources. (source: JRC [5])



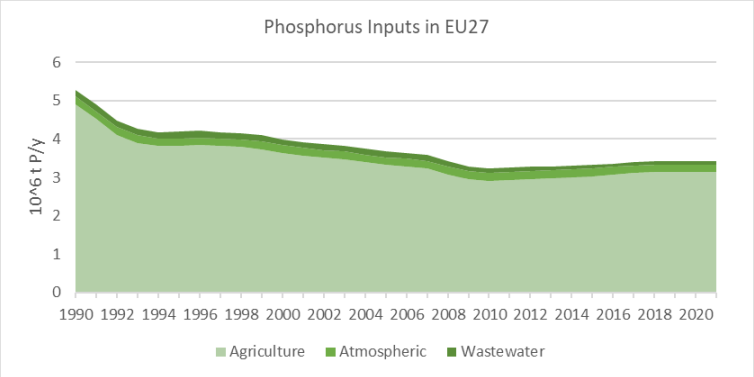
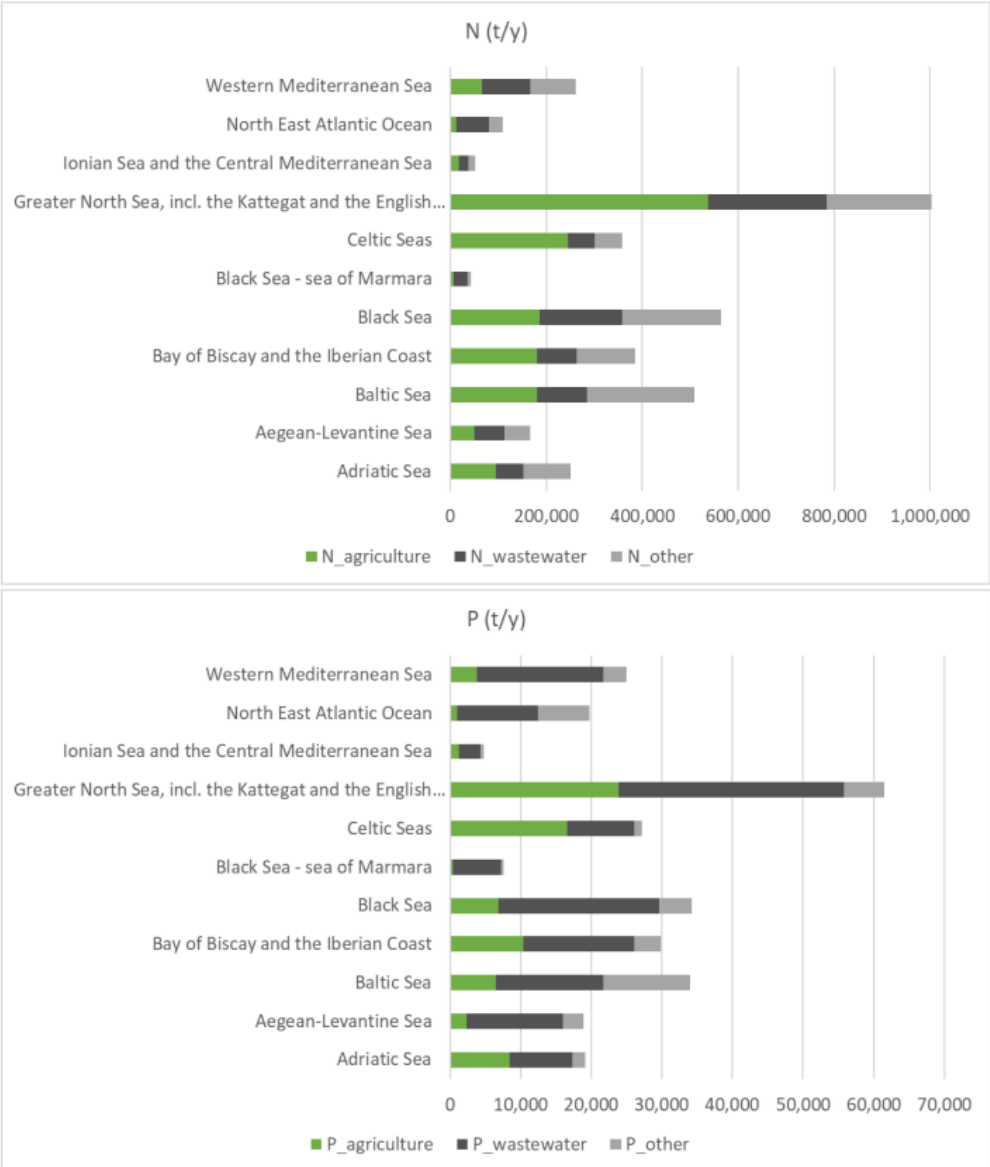


Figure 2 Nitrogen and phosphorus loads to European seas, tonnes per year (Source: JRC [5])



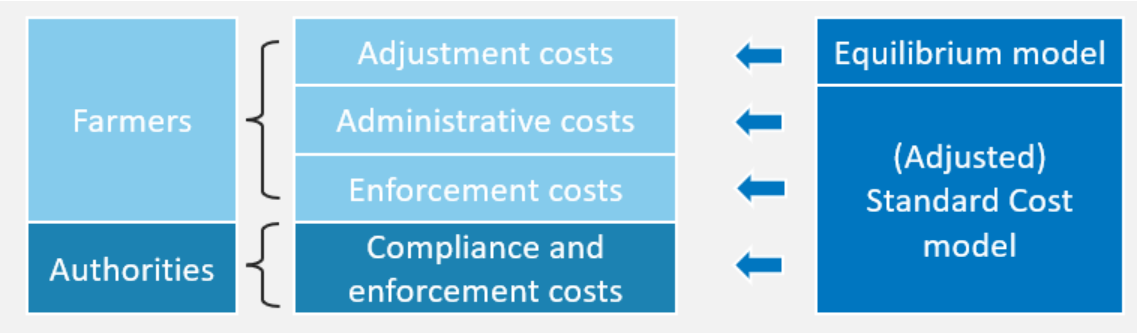
Secondly, the water quality data reported by the Member States under the Nitrates Directive which is extensively used in this report aims to reflect the influence of agriculture and would focus on the areas where agriculture contribution is significant. The diffuse character of the nutrient pollution from agriculture is a significant factor in its omnipresence.

Therefore, the evolution of water quality data presented in this evaluation report will reflect significantly the impacts of the Nitrates Directive. This does not mean that other legislation such as UWWTD or the NECD will not have a significant impact, and local situations may show different pictures depending on the influence of different sources on the nutrient pollution in the water. It is also important to remember that the WFD and GWD rely on the Nitrates Directive measures as basic measures to reduce diffuse pollution of nutrients from agriculture, so that progress on addressing such pollution reported under these directives can also largely be attributed to the Nitrates Directive.

Use of modelling in the cost estimates:

The contractor prepared extensive estimates of the cost of implementation of the directive, based on inputs from surveys and interviews as well as Eurostat data. The standard cost model was used to estimate administrative and enforcement costs for both farms and public authorities, whereas an equilibrium model was used for the estimation of adjustment costs on farms.

Figure 3 Methodological approaches to estimate the cost of the Directive



The estimates based on the standard cost model relied to a large extent on survey and interview inputs from public authorities and farmer organisations[4]. While efforts were made to ensure comprehensive coverage, such inputs are inherently incomplete. The contractor therefore had to rely on extrapolation and assumptions to complement the data gathered. For example, the data on small and very small farms was very limited, while much of the stakeholder input focussed on the situation for larger commercial farms in Member States with intensive farming and strong livestock sectors, perhaps because these are particularly affected by the directive. The contractor addressed this by distinguishing between farms of different sizes and assigning lower bound and upper bound estimates from stakeholders to different categories. Eurostat statistics also include a significant number of very small farms with no significant production, which are unlikely to have significant costs under the directive. To control for this, the overall EU estimates are based on extrapolation across the EU farm population but excluding farms with less than 2 hectares. While some farms with less than 2 hectares may have

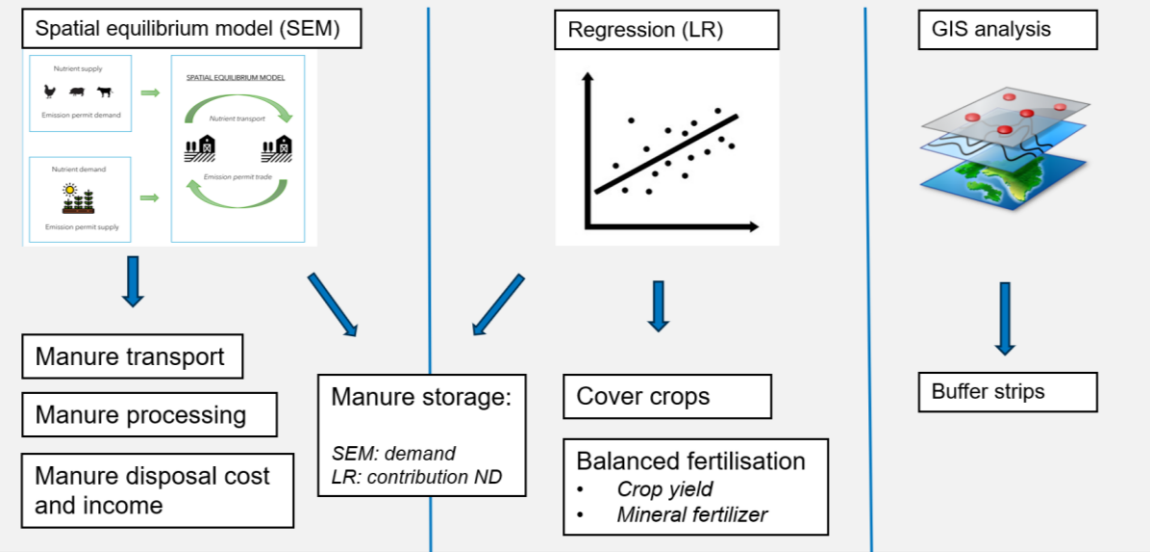
[4] This included several surveys distributed via EU farm organisations and the Commission's Nitrates Expert Group, which gathers representatives of the national authorities involved in the implementation of the directive. In addition, discussion groups were organised with farm representatives and follow interviews were conducted with select farmer representatives and public authorities.

significant production (e.g. vineyards), most of them do not, and even many farms with more than 2 hectares of land do not have any significant production. The approach was therefore assessed to be a sound basis for adjusting the overall population to avoid significantly overestimating overall EU level administrative costs.

It is considered that the cost estimates include a significant business as usual element, which could not be controlled for, as this would have required significantly more extensive data gathering, which was not feasible for this study. Other limitations of the standard cost model estimates include the risk of double counting as survey respondents may not distinguish clearly or consistently between cost categories, the fact that cost estimates are based on converting estimates of time spent via Eurostat earnings statistics in the different Member States, and the assumption that farmers are generally fully compliant with the requirements set out under the directive.

Regarding the estimation of adjustment costs on farms, the contractor applied different modelling approaches for the estimation of the different cost items, as illustrated in the graph below.

Figure 4 Methodological approach to calculate the adjustment cost for farmers



The model approach aimed to capture the main adjustment costs on farms flowing from the implementation of the directive, which is challenging due to wide variation in national measures and situations. Nevertheless, it is the assessment that the calculation provides a good estimate of the overall level of costs linked to the various types of measures. Some limitations should be noted. For the estimate of the cost of buffer strips a standard 3 metres has been assumed across the EU, even though the widths differs according to the Member State and the watercourse concerned. No correction was made for the fact that other policies may also impose buffer strip requirements, including the CAP. For cover crops, balanced fertilisation and storage on the other hand, the additional impact of the directive was estimated based on regression analysis comparing the situation in NVZ with non-NVZ areas. For the cost of manure management an equilibrium model was applied, with input of Eurostat data at NUTS2 level. This level of

aggregation means that the short distance cost of manure transport may be underestimated whereas long distance transport may be overestimated.

Finally, the contractor also carried out an estimate of the total cost of pollution as well as of the benefit of the directive in reducing those costs. The approach was based on the approach set out in the European Nitrogen Assessment in 2011 and refined by van Grinsven et al in 2013. This was supplemented with updated estimates of the societal cost of pollution, based on an extensive review of scientific literature to identify and consolidate such cost estimates across the different types of nitrogen pollution from agricultural sources. The range presented is based on the median values of those estimates for the lower bound and the average value for the upper bound. The actual variability is therefore much larger. However, the assessment is that neither the highest nor the lowest values found in the literature would be representative for the overall European reality. Ultimately, using a range from the median to the average gives a better idea of the general order of magnitude of the total costs. Perhaps the median (lower bound) would be the most prudent value. However, here it should be noted that the estimates are based on an assumed constant unit cost of pollution, whereas a more likely scenario would be that reducing the current level of pollution would have a relatively higher impact per kilogramme, assuming that the impact of nitrogen losses tends to increase with the total amount[5]. The contractor therefore performed a sensitivity analysis to illustrate what would happen with the benefit estimate if different value functions were assumed: respectively an exponential and a logarithmic value function instead of the linear one. The results shown here below are based on two theoretical examples, and are therefore only illustrative in nature, but they do make clear that the share of the total pollution cost addressed by the directive may be significantly higher than what appear from the headline estimate presented in section 4. Since we do not know the "actual" underlying value function, however, it is not possible to give a precise number or range.

Cost Function	Estimated Benefit (UB)	Estimated Benefit (LB)
Exponential	€48.2 million	€21.6 million
Logarithmic	€34.4 million	€15.5 million
Linear	€22 million	€10 million

While the overall cost for society is difficult to estimate precisely, the assessment is that the estimates do give a general idea of the overall order of magnitude of these costs. It should be added that the range is broadly in line with the estimates developed in the context of the European Nitrogen Assessment in 2011, as updated in Grinsven et al (2013).

[5] The first kilogramme of nitrogen emitted may not have much of an impact but at a certain level the impact begins to be felt more acutely and each additional kilogramme would tend to have a higher societal cost.

ANNEX III. EVALUATION MATRIX AND ANSWERS TO THE EVALUATION QUESTIONS

Table 3 Evaluation matrix

Question	Judgement criteria/ Indicator	Sources of information
Effectiveness		
Has the directive been effective in achieving its objectives?	• Evolution of nitrate concentrations in groundwater • Evolutions of nitrate concentrations and trophic status of surface water. • Changes in the use of chemical fertilisers. • Changes in the application of livestock manure on land. • Evolution of nitrogen gross balance	• For basic data on impact and result indicators, see chapter 3. • Stakeholder workshops. • Expert group outcome paper. • JRC study on the effectiveness of the Nitrates Directive • EUROSTAT data • FAOSTAT data • National data
Has the implementation been affected by delays or unexpected problems? Has the directive been properly enforced?	• Identification of delays with respect to the initial deadlines planned. • Existence of issues of compliance by farmers. • Replies from experts about whether the directive provides tools to Member States to enforce the Directive.	• Reports on the implementation of the Nitrates Directive • Overview of stakeholder consultations • Expert group outcome paper • Case-law • 2012 Fitness Check of EU Freshwater Policy
Has the role and action of the Commission been effective? Is the Directive providing enough means to the Commission to enforce the directive? (monitoring, comitology, guidelines, infringements)	• Replies from experts about whether the directive is an instrument providing the Commission with tools and mechanism for the Commission to facilitate effective implementation • History of enforcement	• Reports on the implementation of the Nitrates Directive • Expert Group outcome paper • Germany Case Study • Case-law (incl. ECORYS study)
Which are the most effective measures in the action programmes applied under the directive in terms of addressing pollution?	• Comparison of the level effectiveness of the measures included of actions in Annexes II and III to the Directive.	• Expert group outcome paper. • SSB study • JRC study on the effectiveness of the Nitrates Directive • Online public consultation
How effective is the 170 kgN/ha limit for livestock manure in NVZs?	• Assessment of the limit with regard to water, soil and air pollution	• Expert group outcome paper. • JRC study on the effectiveness of the Nitrates Directive • ECA Report

		• Case law
How effective is the designation of nitrate vulnerable zones as a way of targeting measures towards pollution?	• Expert replies about the effectiveness of the designation of nitrate vulnerable zones	• Reports on the implementation of the Nitrates Directive • Expert group outcome paper. • Case-law
Do Member States have sufficient flexibility to adapt measures to local circumstances?	• Stakeholder views about the flexibility allowed by the Nitrates Directive to adapt measures to local circumstances.	• Expert Group outcome paper • Online public consultation • Reports on the implementation of the Nitrates Directive • Stakeholder workshops • Case-law
Which external factors may have had an impact on the attainment of the directive's objectives?	• Assessment of links between external factors and agricultural system. • Assessment of links between climate change and the achievement of the objectives Nitrates Directive	• Literature review • Expert Group outcome paper • EUROSTAT • ECA report • JRC reports on climate change
Has there been unintended effects that have impacted the effectiveness of the Directive?	• Effects of the Nitrates Directive on ammonia emissions	• Expert Group outcome paper • JRC study on the effectiveness of the Nitrates Directive
Has the Directive been sufficiently effective in addressing transboundary pollution issues?	• Replies from experts about the extent to which the Nitrates Directive has contributed to address transboundary issues	• Expert group outcome paper • Reports on the implementation of the Nitrates Directive • Reports on WFD and MSFD
Efficiency		
Are the costs associated with the directive proportionate given the benefits that the directive has delivered?	• Cost of implementation of the Directive • Benefits of the directive • Quantitative comparison between costs and benefits	• ECORYS study •
How are the costs and benefits distributed among stakeholders?	• Costs of the implementation for different stakeholders	• ECORYS study • Online public consultation
Which are the costliest measures for farmers and for public authorities?	• Adjustment and implementation costs for farmers • Implementation costs for public authorities	• ECORYS study
Have some measures been highlighted by stakeholders as particularly cost-effective?	• Stakeholders' views about costs of different measures	• Stakeholder workshops • Online public consultation
How efficient is the monitoring and reporting framework?	• Costs of monitoring and reporting for Member States	• ECORYS study • Reports on the implementation of the Nitrates Directive

		• Expert group outcome paper
Would there be a potential for simplification and burden reduction for public administrations in national implementations?	• Implementation costs for national authorities • Existence of potential actions to reduce burden for public administrations	• ECORYS study • Expert group outcome paper • Legal text of relevant legislation • Reports on the implementation of the Nitrates Directive • Online public consultation • Stakeholder workshops
Would there be a potential for simplification of the monitoring and reporting framework by streamlining it with other legislation?	• Implementation costs for national authorities • Level of harmonisation of the assessments and reporting periods between various directives	• ECORYS study • Expert group outcome paper • Stakeholder workshops • Commission guidance document on eutrophication assessment
Would there be potential for simplification for farms in national implementation?	• Implementation costs for farmers • Existence of potential actions to reduce burden for farmers	• ECORYS study • Expert group outcome paper • Stakeholder workshops
Coherence		
Is the directive coherent with other EU legislation and policies in the area of water and the environment?	• Consistency or complementarity of measures and objectives of relevant legislation	• Expert group outcome paper • Online public consultation • Legal text of relevant legislation • ECORYS study • Implementation reports of WFD and MSFD • Evaluation MSFD • Evaluation UWWTD • Evaluation NECD • I IED • Fitness check 2012 on water • Case-law • JRC report on Knowledge for Integrated Nutrient Management Action Plan
Is the directive coherent with the common agricultural policy?	• Consistency or complementarity of measures and objectives of the CAP and the ND	• Expert group outcome paper • Online public consultation • Legal text of relevant legislation
Is the directive coherent with other policies?	• Consistency or complementarity of measures and objectives of the organic farming regulation and the ND	• Stakeholder workshops • Online public consultation • Legal text of relevant legislation

Relevance		
To what extent did the scope and objectives of the intervention remain relevant over the implementation period?	• Extent to which the scope and intervention has remained relevant over the implementation period.	• Expert group outcome paper • Online public consultation • Reports on the implementation of the Nitrates Directive •
Does the intervention logic, scope and objectives of the directive, remain relevant in the light of current challenges?	• Extent to which the scope and intervention is still relevant. • Replies to question about question relevance of objectives linked to the public consultation in the public consultation	• Expert group outcome paper • Online public consultation • Commission reports on WFD and MSFD • International commitments COP 15 • Zero pollution outlook
To what extent is the Directive able to respond to new or emerging environmental issues? Including: • Climate change adaptation • Droughts and water scarcity/reuse • biodiversity loss	• Extent to which the Nitrates Directive is able to contribute to climate change adaptation. • Extent to which the Nitrates Directive is able to contribute to reducing biodiversity loss.	• Expert group outcome paper • Online public consultation • EEA reports • JRC reports on droughts • Commission reports on water and climate • Water Resilience Strategy
To what extent is the Directive able to respond to new or emerging technological or scientific developments, societal and agricultural changes? Including: • new agricultural practices: organic farming, agroecology, mixed farming,.. • nature based solutions • strategic autonomy	• Extent to which the Nitrates Directive is able to contribute to new agricultural practices, nature-based solutions and strategic autonomy.	• Stakeholders' views • SSB study • Reports from the Commission on organic agriculture • JRC study on the effectiveness of the Nitrates Directive
Are the limits set for fertilisers and manure sufficiently taking into account the evolving characteristics and risks associated with all types of fertilisers, including new fertilisers based on recycled nutrients?	• Extent to which the limits set for fertilisers and manure sufficiently take into account the evolving characteristics and risks associated with all types of fertilisers, • Replies from stakeholders about the extent to which the limits consider the evolving characteristics and risks associated with all types of fertilisers	• Expert group outcome paper • Stakeholder workshop • JRC study on Knowledge for Integrated Nutrient Management Action Plan • JRC study on RENURE • ECORYS study
Is the directive able to respond to new or emerging technological or scientific developments, and policy priorities?	• Extent to which the Directive is able to respond to new or emerging technological or scientific developments, and policy priorities. •	• Online public consultation • JRC study on the effectiveness of the Nitrates Directive • Stakeholder workshop

		• ECORYS study • Water Resilience Strategy • Vision for Agriculture and Food
How relevant is the intervention to EU citizens? Will it continue to be relevant for them in the near future?	• Extent to which water pollution by nutrients is still a problem •	• Online public consultation • SDG • JRC study on the effectiveness of the Nitrates Directive • Reports on the implementation of the Nitrates Directive
EU added value		
Does the directive bring added value in addressing transboundary pollution?	• Contribution of the Nitrates Directive to address transboundary pollution.	• Expert group outcome paper • Online public consultation • Commission reports on WFD and MSFD
Has the directive contributed to a more harmonised and ambitious approach of the Member States to addressing pollution by nutrients from agriculture?	• Extent to which the directive has contributed to a more harmonised and ambitious approach, level playing field. • Replies from stakeholders about the contribution of the Nitrates Directive to a more harmonised and ambitious approach to addressing pollution by nutrients from agriculture	• Expert group outcome paper • Online public consultation • Stakeholder workshops • Strategic dialogue on agriculture • Commission reports on WFD and MSFD • ECORYS study

Table 4 Answers to the evaluation questions

Evaluation questions	Assessment
Effectiveness	
Has the directive been effective in achieving its objectives?	• The Directive has been generally effective in reducing and preventing pollution of nitrates and eutrophication from agriculture. • It has so far been partially successful in reaching its objectives. • The trend towards increasing nitrate concentrations in groundwater until the 1990s has been stopped. • For surface waters, aggregated data at EU level show an overall downward trend in nitrates concentrations starting in the 1990s, although progress has stagnated after 2010. • Continued widespread eutrophication of surface waters is an indication that the directive has not yet been fully effective in this respect. Joint efforts under the Nitrates Directive, the WFD and the MSFD are necessary to tackle eutrophication effectively. • The 1990s saw a clear reversal of the increasing trend in fertiliser inputs that had characterised the 1960-1980s, reflecting the increased acceptance and awareness of the concept of balanced fertilisation.
Has the implementation been affected by delays or unexpected problems?	• The early years of the directive's implementation was affected by significant delays and transposition issues. • The achievement of the objectives of the directive in Member State is affected by non-compliance by farmers.

Has the directive been properly enforced?	• The Directive provides sufficient tools to Member States to effectively implement and enforce it. Advisory services have played a crucial role in communicating and trust-building with farmers. • Since the 2000s, derogations may have contributed to the reversal of progress in the 2010s by facilitating a renewed intensification and concentration of the livestock sector (mostly dairy) in some of these Member States
Has the role and action of the Commission been effective? Is the Directive providing enough means to the Commission to enforce the directive? (monitoring, comitology, guidelines, infringements)	• The Directive is an effective legal instrument and provides sufficient tools and mechanisms for the Commission to facilitate effective implementation and enforcement. • The exchanges in the Nitrates Committee between the Commission and Member States have resulted in the development of guidelines and exchanges of good practices. • Infringement proceedings have contributed not only to fine tune the interpretation of key aspects of the Nitrates Directive but also have promoted a strengthened level of implementation in Member States. • Where assessments vary most between stakeholders is with regard to whether the practices have been sufficiently well implemented and enforced.
Which are the most effective measures in the action programmes applied under the directive in terms of addressing pollution?	• Both stakeholders and experts have indicated that the practices promoted under the directive are effective in addressing the objectives of the directive. This assessment is also generally supported by the scientific literature • The most effective measures include the restrictions on the application of fertilisers in winterly or wet conditions and during rainy autumn and winter months as well as the related minimum capacity for manure storage. • The balanced fertilisation requirement, crop rotation and minimum land cover are also very effective measures, followed by buffer strips and the limitation of manure application (170 kg N/ha limit). • Requirements on fertiliser planning and record keeping are also considered very effective and included in most national action programmes (Member States are free to include these requirements or not).
How effective is the 170 limit of the Nitrates Directive for NVZs?	• This limit has been effective in moderating inputs of organic livestock manure in the EU. • A large majority of national experts consulted considered the manure limit effective in preventing and reducing water pollution and important for managing the impact of intensive livestock. • In the public consultation most stakeholders considered the manure limit to be either effective or somewhat effective. • Recent scientific research concludes that the application of manure containing 170 Kg of N indirectly limits P application, although resulting in the application of phosphorus above the limit for reaching optimal P soil values. • The 170 limit indirectly limit high livestock density and modelling shows that reductions of Livestock densities below 2 LSU/ha (more or less equivalent to manure production of 170 kg/ha) have a significant impact on reducing nitrates leaching and runoff specifically for hotspot regions characterised by high livestock densities. • Research also point out that the 170 limit of manure application could indirectly affect the achievement of ammonia emissions reduction targets. • Derogations since the early 2000s have allowed to apply manure above the 170 limit. The European Court of Auditors found in its special report 19/2023 that policy decisions such as the abolition of milk quotas led to an increase in the herd size in farms benefiting from a derogation and in this context the derogation had limited the achievement of the Directive's objective.
How effective is the designation of nitrate vulnerable zones as a way of targeting measures towards pollution?	• Designation of vulnerable zones allows for the targeting of measures towards more polluted areas. In some cases, designated vulnerable zones have not adequately covered polluted waters. At the same time, the voluntary approach outside vulnerable zones is less effective in preventing pollution and the correct designation can be challenging. • The directive allows Member States to apply their programmes across their territory, in which case they do not need to designate

	vulnerable zones. Over the years, an increasing number of Member States have resorted to a whole territory approach. Many Member States are also applying some mandatory measures also outside vulnerable zones, which is in effect an intermediate approach between the two foreseen in the directive. • Experts from Member States that had designated nitrate vulnerable zones considered that it had been effective in reducing pollution, but the picture was not unanimous. A clear majority of experts from Member States that had applied the "whole territory" approach considered that this approach had been effective.
Do Member States have sufficient flexibility to adapt measures to local circumstances?	• With the exception of the 170 limit set directly by the Directive, although still subject to flexibility via derogations, all other measures under the directive can be designed and implemented by the Member States to adapt to local conditions. • Member States experts consulted considered that the wording of the Directive Measures provides sufficiently flexibility to allow Member States to put in place rules fitting to local environmental and climatic conditions as well as local agricultural practices. • Some experts noted that measures listed in Annex II allow higher flexibility to adapt to local circumstances. • Calendar measures are particularly noted as rigid and costly to implement in some cases, even more in a context of climate change.
Which external factors may have had an impact on the attainment of the directive's objectives?	• The directive acts in a complex environment where many different pressures and policies have an impact on the practices that the directive aims to affect. • One important external factor is the broader agricultural market. In the absence of regulation, general price pressures in agricultural commodity markets tend to push the sector towards intensification of production. • Originally the common agricultural policy also promoted increased production by supporting minimum prices in the common market, but reforms in the 1990s relaxed this focus through so-called 'decoupling'. • More recently, however, the abolishment of milk quotas lifted a key constrain on intensification and concentration in the dairy sector. • In parallel, increasing liberalisation of global markets have opened up new export markets for European agricultural produce and contributed to competitive pressures. • Climate change have has added further complexity to an already complex physical environment and resulted in further difficulty to identify the level of ambition necessary to achieve the objectives of the directive.
Has there been unintended effects that have impacted the effectiveness of the Directive?	• Beyond their effect on water quality, the measures included in the national action programmes can have an impact in achieving other objectives such as reducing ammonia and greenhouse gas emissions. • The measures under the Nitrates Directive already contribute to addressing ammonia emissions through limitations on manure and fertiliser application. • Member States have increasingly integrated measures to address ammonia emissions in their NAP. This has helped to reduce the pollution swapping between nitrogen emissions in the air (ammonia) and nitrogen emissions in water (nitrates).
Has the Directive been sufficiently effective in addressing transboundary pollution issues?	• The Nitrates Directive might not have been sufficiently effective in tackling all transboundary aspects of water pollution by nutrients from agriculture, but other initiatives may have played this role. • Transboundary pollution aspects are better tackled in a river basin management approach under the remit of the Water Framework Directive or the Marine Strategic Framework Directive. • Transnational initiatives have been set-up to deal with specific waters and group the Member States and third countries adjacent to it, such as initiatives covering the Baltic Sea, the North Sea, the Rhine, the Danube.
Efficiency	
Are the costs associated with the	• Overall, the directive is generally efficient in reaching its objectives. The costs associated with the implementation of the directive are

directive proportionate given the benefits that the directive has delivered?	considered to be largely proportionate to the benefits to society stemming from its implementation. • The costs to society of nitrogen pollution from agricultural sources was estimated to EUR 68-182 billion annually in 2023 euro. The societal benefit from the implementation of the Nitrates Directive is estimated to EUR 10-22 billion annually. • The net adjustment costs borne by farms in the EU are estimated to approximately EUR 1.5 billion. These costs correspond to approximately 0.4 % of standard output of the agricultural sector in the EU in 2023. • 55% of the overall costs are costs for livestock farms in a few Member States associated with the processing, transport and disposal of excess manure in regions with very high livestock density. On the other hand, 45% of the overall cost estimates are more evenly distributed among farms in all Member States and are significantly lower. • The administrative costs for farms have been estimated to approximately of EUR 1.2-1.5 billion annually for the EU as a whole, or approximately 1.5-10.8 working days per year per affected farm. • Overall, the adjustment and administrative costs for farms correspond to around to 0.8% of standard output of the agricultural sector in the EU. • The yearly administrative and enforcement costs borne by public authorities for the implementation of the directive have been estimated to EUR 120 million in total. • On the basis of the cost and benefit estimates, the assessment of this evaluation is that the burdens are generally proportionate and justifiable in light of the societal benefits due to the implementation of the directive.
How are the costs and benefits distributed among stakeholders?	• The main implementation costs falls on farmers these costs generally constitute a rather small share of gross output (0,8% on average). A large share of the costs concerns administrative tasks such as fertiliser planning and record keeping. • The livestock sector has significant cost for investments in manure storage, which is linked to the requirement for manure to be applied during the growing season rather than during the sensitive periods during the autumn and winter. • For some livestock producers located in regions with very high livestock density and manure production, the cost of processing and transport of the excess manure makes that the cost of complying with the limit on manure application is very significant • Costs for public authorities are lower than the cost for farmers. They concern tasks such as controls on farms, monitoring of water quality, reporting and general implementation tasks related to designation of vulnerable zones and design of action programmes.
Which are the costliest measures for farmers and for public authorities?	• For farmers, regarding adjustment costs, an important driver is the limitation of manure application during sensitive periods of the year and the related storage requirement, which is associated with significant investment costs. • In regions with very high livestock density, livestock farmers tend to have significant costs associated with the disposal of excess manure. Arable farmers in and around these intensive livestock regions have on the other hand been able to benefit from this situation by receiving a payment for allowing the use of their land for spreading excess manure. • Besides manure management, there are also significant costs linked to maintenance of buffer strips along water courses and other measures such as cover crops. • As regards administrative costs, requirements linked to fertiliser planning and record keeping as well as familiarisation with changing rules and restrictions constitute significant cost drivers for farmers. This may include significant share of “business as usual” costs - for example, fertiliser planning is also beneficial for the farmer. • For public authorities the largest cost item (representing 40% of the total 0.12 billion euro) is the monitoring and analysis of water quality data, with the remainder more or less equally divided between compliance checks on farms, revision of action programmes and vulnerable

	zones etc., and other costs (information campaigns etc.). Reporting costs constitute 4% of the total.
Have some measures been highlighted by stakeholders as particularly cost-effective?	• All stakeholders including farmers and environmental NGOs agree that balanced fertilisation is a cost-effective measure. Environmental NGOs have highlighted crop rotation including the use of cover and catch crops. • The industry highlights that precision farming and technological advancements are cost-effective strategies to manage nutrients and reduce environmental impacts
How efficient is the monitoring and reporting framework?	• The monitoring and reporting framework has evolved over the years and is generally effective in identifying nitrate pollution. • Guidelines developed by the Commission and the Member states on monitoring, on reporting, on eutrophication have been instrumental in streamlining and improving the monitoring and reporting from the Member states. • Member States experts consulted identified monitoring as costly due to the lack of harmonisation of the assessments and reporting periods between various directives as well as determination of the sources of the pollution. • The monitoring of the effectiveness of the action programmes remains a challenge many places, although different effective approaches have been developed in different Member States.
Would there be a potential for simplification and burden reduction for public administrations in national implementations?	• There would be a potential for simplification and burden reduction for public administrations in national implementations as regards the review of NVZ and national nitrates action programmes, as well as the measures, their design and implementation. • There was broad consensus that increased coherence between the Nitrates Directive and the WFD would be beneficial as it could bring simplification to the identification of polluted waters and reduce the burden for public administrations • Activities representing significant burdens for the administration included enforcement of the measures on farms as well as monitoring the effectiveness of measures. • The 4-yearly review of NVZ and design of the programmes of measures is seen as potentially burdensome, and several Member States experts suggested to align the periods with the 6-year cycle under the WFD, which would reduce the frequency of reporting as well as the review of NVZ designations and action programmes.
Would there be a potential for simplification of the monitoring and reporting framework by streamlining it with other legislation?	• The Nitrates Directive leaves a wide margin for interpretation when it comes to its concrete implementation of monitoring and reporting. • With regard to monitoring and reporting, there was broad consensus that increased coherence between the Nitrates Directive and the WFD would be beneficial as it could bring simplification to the identification of polluted waters and reduce the burden for public administrations • Concrete ideas for simplification included streamlining the approaches under the different directives (parameters used, monitoring stations, status assessment, trend evaluation, monitoring periods), reducing the frequency of surface water sampling, allowing modelling in order to reduce the density of the required monitoring network, longer deadlines and simpler upload of data. • Further simplification would be to align the four-year reporting cycle, which is set out in the legal text of the directive, to the six-year cycle under the Water Framework Directive as from the 2028-2034 cycle.
Would there be potential for simplification for farms in national implementation?	• As the Nitrates Directive leaves wide discretion to the Member States to design national implementation measures under the directive, the burden posed on farms depends largely on the concrete implementation at national level. • A broad majority of the national experts consulted for this evaluation considered that there is potential for simplification and burden reduction for farms. There was general consensus among the experts that it would make sense to tailor measures and controls to the size and type of farms. • Member States have wide discretion over the specific design of their national measures. For example, the directive leaves it to Member

	States whether to impose requirements on farms regarding fertiliser planning and record keeping.
Coherence	
Is the directive coherent with other EU legislation and policies in the area of water and the environment?	• The directive forms part of a broader environmental acquis on water, air, nature and agriculture developed since the adoption of the Nitrates Directive, which complements and builds on the Nitrates Directive. The objectives and measures set by the Nitrates Directive are found to be largely coherent with these laws. The evaluation further found that the Directive critically contributes to achieving environmental objectives set by many EU laws. *Coherence with water acquis* • The Water Framework Directive has embedded it in a broader water policy framework with water quality targets to be reached within clear deadlines. The measures implemented under the Nitrates Directive are found to contribute critically to the achievement of the WFD objectives to reduce diffuse pollution of nutrients from agriculture. Member States have had to take into account the objectives of the WFD in the design of their action programmes under the Nitrates Directive, as these are recognised as basic measures under the WFD. • The measures under the Nitrates Directives are essential to reduce the eutrophication of the coastal and marine environments, a key objective of the Marine Strategy Framework Directive. • There is scope for a stronger integration in the preparation of the national measures and in the monitoring and reporting on nutrient pollution from agriculture across the different water laws. • The Nitrates Directive also contributes critically to ensuring that Member States and water distribution companies can respect the standards for nitrates concentrations of the Drinking Water Directive. • The Nitrates Directive is fully coherent and complementary with the Directive on the Urban Waste-Water Treatment Directive. While it can be challenging for Member States to decide on the source of nutrient pollution in downstream water and untangle the sources so as to decide where action is needed, the EUCJ has clarified when agriculture sources are significant and require action under the Nitrates Directive. *Coherence with air quality directives and Industrial Emissions Directive* • The Nitrates Directive and the NEC Directive are found to be coherent and complementary. The complementary of the Nitrates Directive and the NECD can be seen as a positive development as there is always a risk of pollution swapping between nitrogen emissions in the air (ammonia) and nitrogen emissions in water (nitrates) if nitrogen emissions from the same source (here nitrogen fertilisation and manure management) are not addressed in an integrated way, reducing the overall effectiveness under both Directives. • The implementation of the measures under the Nitrates Directive can affect the achievement of the objectives of the Ambient Air Quality Directives, as ammonia is an important precursor to particulate matter, an air pollutant for which the Ambient Air Quality Directive sets limit values. • The IED is relevant in the context of the Nitrates Directive, as it addresses the prevention and control of all pollution resulting from the intensive rearing of poultry or pigs. However, the IED mainly addresses pollution from stables and storages, leaving the issue of the land application of livestock manure to the Nitrates Directive *Coherence with nature legislation (Birds and Habitats directives, Nature Restoration Regulation)* • Fertilisation and manure management can have a significant impact on protected habitats and species and on the Natura 2000 network of protected areas.

	• Over time, Member States have been gradually brought to integrating the requirements stemming from the Habitat's Directives in their national nitrates action programmes on the basis of dedicated environmental assessments, notably by ensuring limits on fertilisation and manure compatible with the objectives for protected sites.
Is the directive coherent with the common agricultural policy?	• The Nitrates Directive is found to be very much coherent with the CAP as objectives, agriculture measures, financing and enforcement are very much intertwined. There are many synergies between the Nitrates Directive and the CAP, notably on the measures, the GAECs and on the controls. • A majority of almost all types of respondents to the public consultation (with the exception of the water supply and management sector) considered that the ND and the CAP are coherent. • The measures for farmers set in Annex II and III of the Nitrates Directive are also found to be coherent with those under the CAP.
Is the directive coherent with other policies?	• The Nitrates Directive is found to be fully coherent with the Organic farming Regulation. • The approach of organic farming towards fertilisation, protection of soils and water, and livestock make the compliance with the requirements of the Nitrates Directive more straightforward. • Organic farming associations have explained that the national implementations of the Nitrates Directive can be difficult to reconcile with organic farming practices, in particular as regard calendar requirements for sowing, harvesting or fertiliser use
Relevance	
To what extent did the scope and objectives of the intervention remain relevant over the implementation period?	• Both the scope and the objectives of the Directive have remained relevant over the implementation period. • While the water acquis has evolved significantly since the early 1990s, the Nitrates Directive remains fully relevant and fills a specific and crucial role addressing water pollution by nutrients from agriculture within this broader context, contributing to the effectiveness of the general water acquis • Some Member States experts noted that a more integrated approach, including to address ammonia and greenhouse gas emissions, would be necessary as the problems arising from intensive livestock farming. • The inclusion of risk of phosphorus pollution was also mentioned as a necessity in the replies to the public consultation.
Does the intervention logic, scope and objectives of the directive, remain relevant in the light of current challenges?	• The directive remains relevant for the protection of water. Its core objective is to protect freshwater resources and aquatic ecosystems against pollution with nitrates (and phosphates) from agricultural sources. • While some progress has been made in addressing the problem over the past decades, the challenge has not gone away. On the contrary, there are signs that progress has stagnated in recent years in the face of resistance from the agricultural sector. • The nitrate pollution of freshwater resources and eutrophication of surface waters remain significant challenges across large parts of the EU. Solving these problems requires a steady and continuous effort over several decades.
To what extent is the Directive able to respond to new or emerging environmental issues? Including: • Climate change adaptation • Droughts and water scarcity/reuse • Biodiversity loss	• The Directive is sufficiently flexible to adapt to climate change, but national implementations should step up taking all aspects into account. • The challenges of nutrient management vis-à-vis climate change challenge are increasingly being taken into account in national action programmes and advisory services following extreme events in recent years. However, there may be a need to step up the adaptations as Member States are increasingly finding out that climate change is aggravating water pollution with nutrients. • The wording for the measures in the Directive is sufficiently general to allow the required flexibility for future adaptation. • Advisory services are perceived as key to climate change adaptation. • The Directive is perceived as relevant, up to a certain extent, to protecting soils and biodiversity.

	• The directive's objectives and actions are relevant for the attainment of wider EU policy goals and priorities, notably the protection of EU waters, air quality and biodiversity. • The Nitrates Directive clearly contributes to the achievement of the international commitment of the Global Biodiversity Framework target to reduce nutrient losses by 50% by 2030, as regards losses from agriculture.
To what extent is the Directive able to respond to new or emerging technological or scientific developments, societal and agricultural changes? Including: • new agricultural practices: organic farming, agroecology, mixed farming,.. • nature based solutions • strategic autonomy	• The accommodation of new agricultural practices into the measures implemented nationally presents its challenges. • Organic farming associations have explained that the national implementations of the Nitrates Directive can be difficult to reconcile with organic farming practices, in particular as regard calendar requirements for sowing, harvesting or fertiliser use. Some Member States have exempted organic farmers from certain national rules. • The use of measures supported by natural processes such as buffer areas has proven effective in protecting water quality and may present environmental co-benefits in terms of contributing to maintaining biodiversity. • By promoting the circularity of nutrients, the directive also contributes to foster the strategic autonomy in the use of fertilisers. • Member states have wide discretion to design measures while taking into account evolving knowledge.
Are the limits set for fertilisers and manure sufficiently taking into account the evolving characteristics and risks associated with all types of fertilisers, including new fertilisers based on recycled nutrients	• The directive allows the update of the annexes through comitology to adapt to technical and scientific progress. • This possibility was used by the Commission to initiate an amendment to increase flexibility of the 170 limit for certain highly processed types of livestock manure (RENURE).
Is the directive able to respond to new or emerging technological or scientific developments, and policy priorities?	• The directive's objectives and actions are relevant for the attainment of wider EU policy goals and priorities. • This is most evident in reaching the objectives of the WFD by 2027, where the reduction of agricultural nutrients is a key challenge in the attainment of good chemical status of groundwaters as well as the good ecological status of surface waters. • By limiting ammonia emissions, improving air quality and reducing deposition of nitrogen on waters and on sensitive terrestrial ecosystems, the Nitrates Directive clearly contributes to the achievement of the international commitment of the Global Biodiversity Framework target to reduce nutrient losses by 50% by 2030, as regards losses from agriculture • Through its focus on balanced fertilisation and better use of livestock manure the directive also contributes to the reduction of greenhouse gas emissions linked to the production and use of nitrogen fertilisers. • By protecting water resources and contributing to the regulation of intensive livestock production and fertiliser use in agriculture, the directive contributes positively to the objectives of the European Water Resilience Strategy and the Vision for Agriculture and Food.
How relevant is the intervention to EU citizens? Will it continue to be relevant for them in the near future?	• The Nitrates Directive helps to protects drinking water resources, to protect human health, to protect nature and all ecosystem services and the economical development around clean surface and groundwater. • It also helps farmers to adopt sustainable practices necessary to ensure soil fertility and food security. • It promotes a moderation in the use of scarce resources and circularity of nutrients. • Given the current challenges with regard to nutrient pollution, the Nitrates Directive will continue to be relevant in the near future

EU added value	
Does the directive bring added value in addressing transboundary pollution?	• The Nitrates Directive might not have been sufficiently effective in tackling all transboundary aspects of water pollution by nutrients from agriculture • Common action was stressed when consulting Member states experts as necessary to ensure similar market conditions across the EU and to address transboundary pollution and marine eutrophication. • The consultation with Member State experts indicated that such transboundary aspects are seen as difficult to tackle and that the prevailing view is that the directive has generally not been sufficiently effective so far in this respect. • The directive includes a provision calling on the Commission to support Member States in tackling cross-border pollution, this mechanism has never been invoked. One explanation could be that transboundary pollution aspects have been partially tackled in a river basin management approach under the remit of the WFD or the MSFD
Has the directive contributed to a more harmonised and ambitious approach of the Member States to addressing pollution by nutrients from agriculture?	• The Nitrates Directive has clear benefits and EU added value by contributing to results that go beyond what could have been achieved through Member States acting on their own. • In consultations with Member State experts, it was stressed that separate efforts by Member States would risk being undermined due to socio-economic pressures • Besides its positive impact on the environment and public health, the Nitrates Directive also contributes to improving the functioning of the Union Market by promoting good agricultural practices to reduce pollution across the EU.

ANNEX IV. OVERVIEW OF BENEFITS AND COSTS

Table 5 Overview of costs and benefits identified in the evaluation

		Citizens/Consumers		Businesses		Administrations		[Other…] specify	
		Quantitative	Comment	Quantitative	Comment	Quantitative	Comment	Quantitative	Comment
Direct benefit to society in general (reduction in nitrogen pollution of agricultural origin, mainly nitrate concentrations in ground and surface water, eutrophication of surface waters and seas, and ammonia emissions to air)	**recurrent**	EUR 10-22 billion per year	The range is based on a simulation of the impact of directive in 2008 (Velthof et al (2014) [6]) and on a review of the scientific literature for estimates of the societal cost of nitrogen pollution: Upper bound is based on average of values, lower bound on median of estimates found in the literature.						
Direct compliance costs for farms (adjustment costs linked to compliance with specific requirements imposed by Member States as part of the implementation of the directive)	**recurrent**			EUR 1.5 billion per year	Covers investments in manure storage, expenses and income foregone linked to area-based measures, and costs for the processing, transport and disposal of excess manure in certain high-density regions.				
Direct compliance costs for farms (administrative costs linked to compliance with requirements imposed by Member	**recurrent**			EUR 1.2-1.5 billion per year	Covers administrative activities related to fertiliser planning, record keeping, and familiarisation with rules.				

States as part of the implementation of the directive)									
Enforcement costs for farms and public authorities (costs associated with administrative and on-site inspections on farms)	**recurrent**			EUR 0.004-0.007 billion per year	Costs on farms for on-site inspections by public authorities, including CAP conditionality.	EUR 0.024 billion per year	Costs of public authorities for administrative checks and on-site inspections, including CAP conditionality.		
Direct compliance costs for public authorities (administrative costs linked to the implementation of the directive)	**recurrent**					EUR 0.1 billion per year	Covers monitoring of nitrates and eutrophication in ground and surface waters, designation of vulnerable zones, establishment of action programmes, reporting to EU.		

Methodology of cost-benefit analysis

BENEFITS

To assess the overall societal costs of pollution caused by nitrates and other related nutrients impacted by the Nitrates Directive, the following steps were undertaken:

1. Estimating the unit costs of various forms of nitrogen emissions based on the nature of their impacts.
2. Determining the actual levels of pollution from agriculture for different nitrogen compounds to scale up the estimated unit costs and calculate the total societal cost of pollution.
3. Quantifying the impact of the Nitrates Directive (i.e., avoided societal costs due to the implementation of the directive).

Ad 1. Using a meta-analysis approach the contractor applied statistical methods to summarise the results of independent studies. They derived the average and median values based on multiple observations collected through the systematic literature review, to estimate the cost of nutrient pollution by unit amount. The final dataset included 30 primary studies (and 381 specific estimates) covering most European countries. The impacts of nitrogen (and associated pollutants) on society found in these studies were mapped using the Ecosystem Service Framework. When feasible, estimates were standardised as euro/kg nitrogen for each type of pollutant (nitrates, ammonia, nitrous-oxide, nitrogen oxides). A number of estimates were

reported in Euro/household/year and these were not included in the calculation. Studies reported estimates based on cost-based approaches (e.g., replacement cost, avoided cost) and/or welfare economics methods (e.g. stated and revealed preference methods).

Ad 2. Both Velthof et al. (2014) [6] and Van Grinsven et al. (2013) [7] estimate the proportion of nitrogen pollutants lost through agricultural emissions using 2008 data. Both sources were deemed appropriate for aggregating societal costs and used as a basis for the analysis.

Ad 3. Additionally, Velthof et al. (2014) [6] include a simulation exercise assessing how pollutant levels would change in the absence of the Nitrates Directive as implemented in 2008. Based on these estimates, using the estimates for cost of pollution per kg nitrogen from each pollution type, as produced from the meta-analysis in step 1, the contractor calculated the cost of pollution with and without the Nitrates Directive and from there deduced the monetary benefit of the Nitrates Directive (the difference). The range is based on the mean and median respectively of the cost estimates found in the literature. The mean estimates were significantly higher than the median estimates.

The significant variation across the 381 observations likely stems from differences in valuation approaches, geographic coverage, and pollutant pathways. Given this heterogeneity, the median provides a more robust central estimate, as it represents the midpoint of the distribution, reducing the influence of extreme values and ensuring a more stable aggregation of societal costs.

On the other hand, the benefit calculation assumes constant marginal cost of pollution. A more realistic assumption would be that the cost per kg of pollution rises with the total level of pollution. If this were the case, the benefit as calculated here would be too low, and the actual benefit to society could be significantly higher than the estimate presented above. See also Annex II above for concrete examples of how different assumptions could affect the values.

ADJUSTMENT COSTS

Adjustment costs were identified for farms in relation to the various mandatory requirements imposed by Member States as part of the implementation of action programme measures under the directive. The table below lists the adjustment costs for which estimates were developed and where positive adjustment costs were identified, as well as the methods used.

Table 6 Lists of adjustment costs identified and methodology used

Cost	ND measure causing the cost	Explanation	Research Methodology
Manure Storage	Limits to the timing of application of manure	The ND limits the application of manure during winter months, which causes farmers to incur extra costs for storing manure.	Regional equilibrium modelling to simulate the demand for storage. Regression analysis is used to differentiate between ND and other factors that influence the amount of manure storage[6].

[6] Costs for storage per cubic meter are assigned to different types of manure storage.

Cost	ND measure causing the cost	Explanation	Research Methodology
Manure Transport	Livestock manure limit (170 kg N/ha/y)	Because of the limits to manure disposal, some farmers have excess manure that requires disposal on other farmers' land. This involved transport costs.	Regional equilibrium modelling to simulate the demand for manure transport[7].
Manure processing	Livestock manure limit (170 kg N/ha/y)	Because of the limits to manure disposal, some farmers have excess manure that requires industrial processing.	Regional equilibrium modelling is used to simulate the demand for manure processing.
Manure disposal cost and income	Livestock manure limit (170 kg N/ha/y)	Limits to manure disposal create a scarcity in nutrient disposal space, leading to a trade in manure: Farmers with excess manure will try to dispose of it on the land of farmers who do not have this excess. Since a market situation arises, with many farmers on both sides, manure-excess farmers pay an equilibrium disposal cost, and the accepting farmer receives an equilibrium disposal income.	Regional equilibrium modelling to simulate the equilibrium cost and income of disposal.
Cover Crops	Good agricultural practices	Good agricultural practices are a measure of the ND, and amongst these measures is the use of cover crops. Cover crops refer to sowing a second crop after harvest of the primary crop to uptake any remaining nitrogen and reduce losses in winter.	Regression analysis to differentiate between ND and other factors that influence the adoption of cover crops.
Buffer Strips	Good agricultural practices	Good agricultural practices are a measure of the ND, and buffer strips are included among these measures. Buffer strips refer to keeping a buffer zone around surface water bodies free from fertilisation to avoid runoff.	GIS-analysis to estimate the total surface that is allocated to buffer strips by overlaying geographical maps that contain agricultural and waterbody information.

ADMINISTRATIVE COSTS

Administrative costs were identified for farmers and for public authorities.

Farms

Administrative costs for farms under the Nitrates Directive entail all costs related to gathering, compiling, and reporting information and data. The table below lists the types of administrative costs identified and the methodology used for developing EU level estimates.

[7] A fixed price for transport per cubic meter per kilometre has been assigned.

Table 7 List of administrative cost identified and methodology used

Cost	ND measure causing the cost	Explanation	Research Methodology
Familiarisation and training	Good agricultural practices	Farmers need to familiarise themselves and stay informed on the regulatory requirements under the ND. They may need advice and guidance to be fully compliant with the obligations Member States set and which are linked to the ND.	The bottom-up approach relies on a combination of data from Eurostat and consultation activities. Development of estimates building on the Standard Cost Model.
Fertilisation planning	Good agricultural practices	Under the ND, farmers in NVZs are required to apply balanced fertilisation which implies the need to plan and manage the fertilisation by developing a fertilisation plan. The specific requirements depend on the Member State.	Bottom-up approach relying on a combination of data from Eurostat and consultation activities. Development of estimates building on the Standard Cost Model.
Record keeping	Good agriculture practices. The balanced fertilisation and limit on manure and processed manure application (170 kg N/ha/y)	Costs incurred for farmers to comply with requirements to keep records of the application of nitrogen from fertilisers and manure, yields, and manure management and to report these to the authorities if requested.	Bottom-up approach relying on a combination of data from Eurostat and consultation activities. Development of estimates building on the Standard Cost Model.

The calculations rely on a bottom-up model based on data collected through surveys and interviews with national authorities and farmer organisations. Combining the information collected on different administrative activities suggests that farmers spend between 1.5 and 10.8 days per year (depending on farm size) on administrative tasks related to the Nitrates Directive. These estimates were converted into monetary values based on data for labour costs by Member States from the Eurostat earnings survey and extrapolated to the entire population of farms affected by mandatory measures under the Nitrates Directive, i.e. located within designated nitrate vulnerable zones. Farms were stratified according to size and cost estimates were assigned to them based on the data gathered through surveys and interviews. Very small farms with less than 2 ha were excluded due to lack of data and because most of these are unlikely to have any significant costs related to the Nitrates Directive. The total farm population considered is set out in the table below. It should be noted that as noted in the contractor's report, the estimates are likely to overestimate the true administrative costs for farmers and the administrative burden (excluding "business as usual" costs) is likely to be considerably lower.

Table 8 Number and share of farms according to the size of the farm

Farm size	<5 ha*	5 ha – 9.9 ha	10 ha – 99.9 ha	>100 ha	Total
Number of farms	1,320,000	768,000	1,260,000	217,000	3,568,000
Share of total	37.1%	21.5%	35.3%	6.1%	100%

**excluding farms of below 2 ha*

Public authorities

Administrative costs identified for authorities include activities related to coordination, designation of vulnerable zones, reviewing action programme measures, monitoring water quality, and reporting. Estimates of time used were based on data from a dedicated survey to competent authorities. The survey results included 50 replies from different types of authorities (such as ministries of agriculture, environmental agencies, ministries of climate, etc) across 22 Member States, with varying degrees of completeness across questions. The survey had dedicated questions for various cost categories, and respondents could either report the FTE, a lump sum cost, or both. To the greatest extent possible, the contractor prioritized total cost lump sums. When the respondent reported both FTE and total cost, both types of information was retained, and the FTE data point was used to inform the interpolation of missing data points in other MS. When neither FTE nor total costs were reported, then a generic FTE was used, informed by the cases with data (e.g. averages of similar/neighbouring MS). While efforts were made to follow-up with authorities across Member States to validate the information provided and derived estimates, averages of other Member States values and assumptions were used to fill the data gaps for countries with missing or incomplete replies.

ENFORCEMENT COSTS

Enforcement costs were identified for farms and for public authorities. Estimates were based on data collected though surveys sent to public administrations and farm organisations as well as follow up interviews (as for administrative costs above).

Farms

The cost estimates for farms are based on the monetised value (based on Eurostat earnings survey) of the time that farmers need to spend with the inspectors. During the consultations, stakeholders also suggested that some time might be needed to prepare for the controls and that in some instances follow-up activities are required. However, stakeholders were not able to provide an indication of the time needed for these activities. To avoid double-counting (with record-keeping costs above), the time needed to prepare for controls and to follow up on these has not been factored in into the cost estimates for farms.

Generally, farms are subject to both administrative (i.e. remote) controls and on-the-spot controls. Administrative controls are performed remotely based on the documents that farmers provide, for example when applying for support under the CAP. Costs for administrative controls are covered through the costs of record keeping discussed above already. On-the-spot controls can take two forms:

- Conditionality controls are performed as part of the support through the Common Agricultural Policy. Article 83(6)(d)(iii) of Regulation (EU) 2021/2116 obliges Member States to perform on-the-spot controls on the compliance with conditionality rules – which includes rules under the Nitrates Directive – for 1% of all beneficiaries.

- In addition, Member States can perform on-the-spot controls outside of the framework of the CAP. Their scope and numbers can vary across Member States.

Usually, through on-the-spot checks – either related to the CAP or not – compliance with the requirements of the Nitrates Directive is controlled as one among several elements. Therefore, the questionnaire with stakeholders included questions on what share of the controls were focused on the Nitrates Directive, and if farmers had to be present for the full duration of controls.

Public authorities

As for the farms, the estimated costs for public authorities related to controls include the Nitrates Directive relevant part of conditionality controls within the CAP as well as non-CAP related controls. Respondents had the possibility to report on both types in the survey. In addition, several of the national implementation reports feature the number of controls performed per year.

When a lumpsum value for the total cost was clearly reported for a category, the contractor gave it priority in the model. Alternatively, the contractor relied on the reported number of FTE dedicated to the controls if available. If those two questions were left unanswered in the survey, they inferred the number of CAP conditionality controls and used data on the number of controls specific to the Nitrates Directive, multiplied by an hourly cost of the duration of control. The number of CAP conditionality controls were obtained by using the reported share of the farm population controlled (assuming at least 1% is controlled). Therefore, the cost estimate focuses on on-the-spot controls, due to limited data availability and the heterogeneity of the reported data on administrative controls. However, at least for controls not related to the CAP it can be assumed that some of the time and efforts spend on the administrative controls are reflected in the time that survey respondents reported on the duration of controls, which at times included preparatory and follow-up activities.

Assumptions on the average time used per control were based on data collected through the surveys. In cases where no time estimates were provided, we used the estimated time spent on the farm as used for the calculation of administrative and enforcement costs for farmers. Where respondents to the survey provided a time estimate that clearly captured the time spent on the farm only, the contractor multiplied the indicated time by a factor 3 to reflect the addition of preparation and follow-up activities for public authorities.

ANNEX V. STAKEHOLDERS CONSULTATIONS - SYNOPSIS REPORT

1. STAKEHOLDER CONSULTATION STRATEGY

1.1. Objectives of the consultation

To **support the evaluation of the Nitrates Directive**, the European Commission (DG ENV) conducted an extensive stakeholder consultation to ensure that the public's interests across the EU are properly reflected in the evaluation of the Directive. The evaluation aims to assess if the Nitrates Directive (ND) remains fit for purpose, if it is in line with the EU environmental and climate ambitions and contributes to a sustainable and resilient agriculture and food security.

Several consultation activities were undertaken and summarised in this synopsis report. Activities aimed to gather stakeholders' and citizens' views on the legislation, collect their feedback and ideas, as well as additional information that may support the evaluation of the Directive.

1.2. Approach to consult stakeholders

The stakeholder consultation process consisted of a series of open and targeted consultation activities. These included:

- The launch of a **call for evidence** through the European Commission's Have your say portal for a period of 14 weeks between 01 December 2023 and 08 March 2024, which aimed to collect feedback on how well rules on nitrates to protect water quality have worked and whether they are still fit for purpose in light of the EU's ambition on environmental and climate policy. It also invited stakeholders and citizens to provide their views on whether such rules have reached their goals to achieve sustainable and resilient agriculture and food security.
- In parallel, a **public consultation** was also released to provide all stakeholders and citizens affected by nutrient losses from agriculture and implementing the Nitrates Directive across the EU, the opportunity to provide their feedback. The public consultation was available online for 14 weeks between 01 December 2023 and 08 March 2024 through the European Commission's *Have your say* portal.
- **Eight online targeted interviews** were conducted with public authorities from Austria, France, the Netherlands, Spain and Sweden (five initial interviews between October and November 2024, three follow-up interviews between March and May 2025) to gain deeper insights into specific implementation challenges and policy considerations, especially in relation to overlaps and synergies in monitoring and reporting requirements across several pieces of legislation.
- **Five online targeted interviews** were conducted with representatives of European agencies or the European Commission (four initial interviews in October 2024, one follow-up interview in May 2025) to gain insights into their perspectives on the overall monitoring and reporting approach of the Nitrates Directives and its strengths and weaknesses.
- **Three online/hybrid/in-person stakeholder workshops** were organised to discuss specific issues of the Directive. A first workshop on the objectives, scope and relevance of the Directive was held in June 2024 with EU-level organisations representing farmers, agricultural entities, environmental and animal welfare

NGOs, and water supply and management entities. A second workshop with public authorities, farmers and civil society organisations was organised in October 2024 to discuss costs and benefits of the implementation of the Directive. A third workshop with public authorities was held in October 2024 to identify opportunities for streamlining and simplification.

- **Two targeted surveys** were conducted for public authorities and farmers' organisations to collect additional evidence for assessing the costs of the Nitrates Directive. The surveys were run during October and November 2024. The results were complemented by **targeted follow-up interviews and a focus group** with farmer associations from Belgium, the Netherlands, Ireland, Spain, Sweden, Poland, and Romania.
- Interviews for the preparation of four Member States' case studies (Bulgaria, Germany, Denmark and Lithuania). These reports analyse the impact of the Nitrates Directive in these Member States since its adoption or first application, focusing on its practical implementation and evolution over the time. For the case studies, several interviews were conducted in the first half of 2024 with different types of stakeholders, including representatives from the environmental authorities, agricultural authorities, farmer associations, academia, NGOs.
- The Nitrates Expert Group was consulted in three meetings during 2024 on various aspects of the Nitrates Directive with the objective to gather views and insights from the Member State experts. Member States experts shared their national experiences and provided technical insights. These consultations covered the following aspects: Scope and objectives of the directive.
  - Identification of polluted waters and designation of vulnerable zones.
  - The measures set out in annex II and III of the directive.
  - Balanced fertilisation, limitation of manure land application and derogations.
  - Monitoring and reporting.
  - Implementation and enforcement.

1.3 Overview of stakeholders consulted

The table below provides an overview of the number of stakeholders consulted per activity and stakeholder group. No campaigns were identified in the replies to the consultation activities. However, in line with the Better Regulation Guidelines, 5 answers were excluded from the analysis for the following activities:

- **Three duplicated answers** were excluded from the public consultation.
- **Two answers were excluded** from the call for evidence: one response was removed as it consisted of an unreadable combination of letters, and two responses were merged as they were submitted by the same respondent.

Table 9 Overview of the stakeholder consulted per stakeholder consultation activity[8]

	Public authorities	Farmer entities	Other agricultural entities	Water supply and management entities	NGOs	Other stakeholders	Citizens	Total
Call for Evidence	5	72	25	10	8	23 (Academic/ research institution, biogas entity, consumer association)	103	246
Public consultation	49	512	130	23	52	49 (academic/ research institutions, chamber of commerce, aquaculture and fishery organisations	252	1067
Targeted surveys (2)	50	34	-	-	-	-	-	84
Targeted interviews (5)	8 (AT, FR, NL, ES, SE)	4 (BE, ES, IE, NL, PL, RO, SE)	-	-	-	4 (representatives of European agencies or European Commission)	-	16
Stakeholder workshops	48	17	10	9	15	-	-	99

[8] The figures in the table indicate the number of authorities or organisations represented in the stakeholder consultation. They do not reflect the total number of individual participants, as multiple representatives from a single organisation may have taken part.

2. RESULTS OF THE STAKEHOLDER CONSULTATION ACTIVITIES

2.1. Call for evidence (CfE)

The call for evidence collected 246 valid responses as well as 46 attached documents. Contributions received discussed the effectiveness, efficiency, relevance and coherence of the Directive.

Effectiveness

Farmer entities expressed **mixed views on the effectiveness** of the Nitrates Directive. Some recognised its progress in preventing, controlling, and reducing water pollution by nitrates from agriculture, while others were sceptical about its outcomes. Criticisms included issues with derogations, maximum nutrient limits for manure application, monitoring, and the lack of adaptation to specific conditions. Some **farmer entities emphasised the importance of derogations** to reflect different conditions across EU Member States. They argued that decreased manure application did not necessarily lead to lower nitrogen emissions and that limitations led to increased use of chemical fertilisers. On the contrary, **organic farming representatives opposed derogations**, indicating that they weakened the Directive's effectiveness. Some citizens recognised the progress in preventing, controlling and reducing water pollution, others criticised the achieved outcomes. Some citizens also criticised the limit value of 170 N kg/ha and the varying monitoring practices across Member States. They highlighted the need for uniform and comparable monitoring activities. **Environmental NGOs** recognised the importance of the Directive but called for improvements in implementation and enforcement. They opposed derogations and the application of RENURE, advocating for stricter environmental requirements for farmers. **Public authorities noted the complexity and generic nature of the Directive**, calling for tailored measures that consider local circumstances and agricultural practices. Water supply and management entities emphasised the importance of the Directive for protecting drinking water sources but recognised challenges in achieving good water quality due to contaminants from various sources. **Academic and research institutions** highlighted the Directive's lag behind technological advances in nitrogen recycling.

Efficiency

Farmer entities highlighted **administrative burdens and costs** experienced by farmers to meet the Directive's requirements. Some comments emphasised the **complexity of the requirements and the need for additional resources and technologies**. Some citizens also discussed administrative burdens and costs, considering them detrimental to farms and agricultural development.

Relevance

Farmer entities believed the Directive **did not accommodate scientific and technological developments in agriculture**, diminishing its relevance. They emphasised the need for precision agriculture and digital tools for planning fertilisation. Citizens shared similar concerns, highlighting the need for balanced fertilisation practices that consider various factors. Public authorities noted the **need for tailored measures that**

consider local circumstances and agricultural practices. Water supply and management entities emphasised the **importance of the Directive** for protecting drinking water sources. NGOs recognised the importance of the Nitrates Directive in preventing, controlling and reducing nitrate pollution of water and considered that this legal act should be maintained and reinforced. NGOs strongly opposed eliminating or changing the limit value of 170 N kg/ha per year.

Coherence

Some farmer entities noted the need to **increase the coherence** of the Directive with other EU legislation, particularly **air pollution and industrial emissions legislation and the Common Agricultural Policy (CAP)**. Citizens shared similar concerns, emphasising the need for uniform and comparable monitoring activities across the EU. Environmental NGOs and water supply and management entities called for greater coherence between the Directive and other water legislation, such as **the Water Framework Directive (**

).

2.2. Public consultation

The public consultation gathered **1,067 valid responses** discussing the effectiveness, relevance, coherence of the Directive, and to a limited extent, its efficiency. The questionnaire consisted of 26 questions organised into a) an introductory section focused on the demographic profile of the respondents, b) a section with questions for the general public, c) a section with questions for experts, and d) a final section for submitting general comments and uploading documents.

Effectiveness

Over two-thirds of respondents considered that the Nitrates Directive had sufficiently contributed to protecting EU water resources (69%, 733), reaching EU environmental objectives (68%, 725), protecting EU soils (62%, 657), and protecting biodiversity (59%, 629). However, over half felt it did **not sufficiently** help farmers adapt to changing conditions (56%, 601), align with farm practices and technology (52%, 554), or support new agricultural practices (51%, 544). More respondents **agreed that EU policies and legislation were more effective** (65%, 698) compared to national (58%, 623) and regional/local policies (55%, 583).74% of respondents considered that the directive has been either “somewhat effective” of “effective” in reducing and preventing water pollution by nutrients from agriculture to protect human health and living resources. Among farmers and industry these shares go up to until 76% and 92% respectively, while for NGOs (51%) and water companies (31%) the perception of effectiveness is lower.

72% of respondents considered that the directive has been either “somewhat effective” of “effective” in reducing and preventing water pollution by nutrients from agriculture to protect aquatic ecosystems.57% of respondents considered that the 170 limit has been either “somewhat effective” of “effective” in reducing and preventing water pollution by nutrients from agricultural activities. Farmers, industry and citizens show overall higher perception of effectiveness than other stakeholders.

Efficiency

Many respondents, especially farmers, highlighted disproportionate **administrative burdens and costs associated with the Directive**. Farmers felt the high costs of compliance did not yield notable health benefits and that the Directive's measures at national level were complex and burdensome. Farmers noted that the implementation of the Directive has sometimes resulted in rigid 'one size fits all' rules that are not well suited to local agronomic realities, such as mandatory dates for certain operations or prohibition periods for the spreading of manure. A majority of respondents from NGOs considered that the costs of implementation are proportionate in view of the objectives to be achieved. Respondents pointed out that the delay between implementing a measure and observing its effects must be considered.

Relevance

About 50% of respondents thought **the Directive was important for achieving the goal of good ecological status by all water bodies** (57%, 429) **and for reducing nutrient losses** by at least 50% by 2030 (55%, 420). 41% (430) believed it contributed to a harmonised and ambitious approach in the Member States. However, many respondents felt the Directive **did not keep up with scientific and technological developments in agriculture**, particularly in precision agriculture and fertilisation practices. Farmer entities emphasised that the 170 limit value was too restrictive and did not consider the scientific and technological progress. The industry expressed the same opinions as farmers with regard to the limit value of manure application (170 N kg/ha).

Coherence

Over 50% of respondents believed the **Nitrates Directive is coherent** with the WFD (63%, 481), Common Agricultural Policy (60%, 454), and Drinking Water Directive (55%, 420). However, many indicated room for improving coherence with other water legislations and agricultural policies. NGOs and public authorities highlighted the need for **better consistency** between the Nitrates Directive and other EU legislation on water and agricultural policies**.**

Added Value

A majority of respondents from all type of stakeholders considered that the Nitrates Directive contributed to a more harmonised and ambitious approach of the Member States to addressing pollution by nutrients from agriculture.

2.3. Interviews

Eight online targeted interviews were conducted with representatives from Member States' authorities in Austria, France, the Netherlands, Spain and Sweden (incl. three follow-up interviews), providing qualitative data to complement findings for the evaluation.

Monitoring and assessment approaches

Public authorities from four Member States indicated having established robust monitoring systems tailored to their national contexts. Two Member States operate integrated national networks aligned with the WFD, while other Member State uses a

targeted subset of stations in agricultural catchments. One Member State stands out with a farm-level monitoring network designed to assess the impact of manure policy, offering rapid feedback on agricultural practices.

Assessment methods vary but show convergence in using both chemical and biological indicators to evaluate eutrophication. Two Member States indicated combining nitrate concentration thresholds with biological quality elements, while two other Member Statesrely heavily on WFD and Marine Strategy Framework Directive (MSFD) assessments. One Member State also leverages trend analysis of water quality data at the regional level to assess the effectiveness of manure policy and track progress over time.

Reporting, compliance, and administrative burden

Reporting under the Nitrates Directive is seen as administratively demanding, especially when timelines and formats differ from those of the WFD. Two Member States' representativeshighlighted the strain of aligning reporting cycles, while other Member State representatioveraised concerns about data privacy and the complexity of aggregating farm-level data for EU reporting.

Compliance checks also differ in scope and intensity. Two Member States integrate CAP conditionality checks with national inspections, while other Member Stateseparates them. One Member state implements a multi-layered approach, combining CAP checks with extensive manure policy enforcement and derogation-specific inspections.

Shared challenges and opportunities

Despite challenges regarding monitoring and reporting, interviewed Member States' authorities agreed on the added value of the Nitrates Directive in maintaining a strong agricultural focus and driving targeted action. Opportunities for simplification include harmonising definitions of eutrophication, aligning monitoring frequencies and reporting cycles between the Nitrates Directive and the WFD and the MSFD, and improving the interoperability of reporting tools, while preserving the Directive's specificity in addressing agricultural pressures.

2.4. Surveys

Two targeted surveys were implemented focusing on relevant authorities and farmers organisations. These surveys, conducted during October and November 2024, focused on collecting additional evidence to assess the costs of the Nitrates Directive.

The survey targeting competent authorities captured the resources needed for the implementation of the ND, including costs related to the designation of Nitrates Vulnerable Zones (NVZs), the development of Nitrates Action Programmes (NAPs) and GAPs, reporting, as well as monitoring and enforcement. The survey received 50 replies from authorities at national and regional levels, covering 22 Member States. The survey results covered different types of authorities (such as ministries of agriculture, environmental agencies, ministries of climate, etc.) with varying degrees of completeness across questions.

The survey targeting farmer organisations focused on capturing information regarding administrative costs related to the ND, including the record-keeping of fertiliser planning, purchases, application, soil testing, etc. This survey received 34 replies in total,

33 of which were from farmers and farmer organisations covering 13 Member States and one reply from an EU-wide farmers' organisation.

In their replies, farmers indicated that the administrative activities linked to the Nitrates Directive can be substantial. In particular, record keeping and fertiliser planning are considered to be time-consuming. At the same time, the replies suggest that the time spent on administrative activities is dependent on a number of factors, including the farm size, and that the administrative costs are to a considerable part business-as-usual costs.

The responses from authorities suggest that the implementation costs vary considerably across Member States, which can be partially explained by the size of the countries, and which is partially also linked to the implementation choices of the Member States and to what extent nitrates pollution presents a smaller or larger problem in the country. Activities linked to the monitoring of the water quality under the Nitrates Directive appear to be one of the key cost drivers for Member State authorities.

2.5. Stakeholder Workshops

Three stakeholder workshops were organised to discuss 1) the objectives, scope and relevance of the Directive, 2) the costs and benefits induced by the legislation and 3) the opportunities for streamlining and simplification.

Workshop 1 – Relevance and Effectiveness of the Directive

The first workshop's discussions centred around the Directive's effectiveness in reaching its objectives and its relevance in addressing issues related to nitrates.

Overall, stakeholders noted that **the Directive has contributed to raising awareness and improving nutrient management practices**, particularly through technological advances and better fertilisation strategies. Stakeholders also concurred on the need for improved implementation and enforcement, greater flexibility to reflect regional conditions, and better alignment with other EU policies, notably the WFD.

However, **views diverged across stakeholders on several issues**. Farmers' representatives generally recognise that the Directive has made significant strides in achieving its objectives but acknowledge that there are areas needing improvement. Farmers and industrycalled for more region-specific and outcome-based approaches, criticising current input restrictions and advocating for the revalorisation of organic fertilisers, including RENURE. Representatives from industry recognise that the Directive has made notable progress towards its objectives. Yet, they also identify several areas that require further attention. One key point raised is the importance of considering the generic threshold of 170kg/ha and the differing behaviours of liquid fractions, particularly in regions with intensive livestock farming. NGOs opposed the inclusion of RENURE, citing risks of intensifying livestock farming and nutrient pollution. They also perceived need for increased coherence between the CAP and the Nitrates Directive and called for systemic changes, including stricter implementation and enforcement, better coherence with food policies, and the application of the polluter-pays principle. Water supply entities echoed concerns about uneven implementation and stressed the need for more effective prevention and policy integration, particularly in light of climate change and rising treatment costs.

On the Directive's scope, **most stakeholders agreed it remains relevant, especially for nitrate pollution**, but differed on whether it should evolve into a broader nutrient management instrument. Farmers and agricultural actors favoured expanding the scope to include other nutrients and modern agronomic practices, while NGOs and water managers warned against overextension that could dilute the Directive's focus and create regulatory conflicts. Across all groups, there was a shared call for better policy coherence, particularly with the CAP, WFD, and other environmental instruments, to ensure the Directive remains fit for purpose in addressing today's environmental and agricultural challenges.

Workshop 2 – Costs and benefits of the Directive

The second workshop's discussions centred on the Directive's costs and benefits, the effectiveness and enforceability of its measures, and its alignment with broader EU environmental and agricultural objectives.

Farmers and agricultural entities acknowledged the environmental improvements driven by the Directive, such as better soil structure and nutrient management, but stressed the significant financial and operational burdens it imposes, particularly in regions high manure production. Farmers express frustration with the timing restrictions on fertilisation which may reduce yields by disregarding local weather conditions and crop readiness. They called for more flexibility, region-specific approaches, and financial support to adapt to local conditions. In contrast, NGOs and water supply representatives emphasised the societal costs of nitrate pollution, including increased water treatment expenses and ecosystem degradation. They advocated for stricter enforcement, the application of the polluter-pays principle, and a precautionary approach to avoid backsliding on environmental gains.

There was broad consensus on the value of balanced fertilisation, robust monitoring systems, and the role of modern technologies in improving compliance. However, views diverged on regulatory stringency: farmers favoured flexible, goal-oriented measures, while NGOs and water entities pushed for stricter, input-based rules to ensure water quality. Public authorities generally supported a middle ground, recognising the need for both environmental protection and economic viability.

On enforceability, input-based measures such as fertiliser limits were widely seen as more practical than output-based ones. Farmers stressed the importance of advisory services and risk-based inspections, while NGOs highlighted the need for clear thresholds and consistent enforcement. Water entities and public authorities echoed the need for better coordination between the Directive and other policies, particularly the WFD and the CAP, to ensure coherence and cost-effectiveness.

Overall, while stakeholders agreed on the Directive's relevance and **its role in stabilising pollution levels**, they differed on how best to balance environmental ambition with economic realities. The workshop underscored the need for a more integrated, adaptive, and regionally tailored approach to nutrient management across the EU.

Workshop 3 – Opportunities for streamlining and simplification of monitoring and reporting

The third workshop-s discussions focused on opportunities for streamlining and simplification of public authorities' monitoring and reporting under the Directive.

Workshop participants highlighted **challenges in the monitoring and reporting obligations for both nitrate concentrations and eutrophication** across EU water-related legislation, particularly between the ND and the WFD), as well as the Groundwater Directive (GWD), MSFD, and Drinking Water Directive (DWD). A key challenge is the misalignment of monitoring periods and reporting cycles, which leads to different outcomes of assessments, which in turn creates confusion among stakeholders regarding the actual status of water bodies in their MS. Several Member States have made efforts to align monitoring networks, particularly between ND and WFD.

Across both nitrate concentrations and eutrophication, Member States emphasised the potential benefits of aligning the ND's reporting cycle with that of the WFD, particularly in terms of improved data coherence, clearer communication with stakeholders, and reduced administrative burden. However, concerns were raised that such alignment could disrupt established time series, compromise responsiveness to agricultural changes, and risk diluting the ND's targeted focus, especially in the context of nitrate concentrations monitoring, where data granularity and frequency are essential for defining Nitrate Vulnerable Zones (NVZs).

There was broad support for options promoting **data integration and interoperability**, such as the use of **continuous data submission systems (e.g. via WISE)** and the **prefilling of ND reporting templates with WFD data**. Nonetheless, challenges remain due to different reporting cycles, data standards, and institutional responsibilities across directives. These issues are particularly pronounced for eutrophication, where reliance on WFD or MSFD ecological or environmental status assessments raises questions about the visibility of nutrient-specific pressures and the adequacy of current indicators and thresholds. In contrast, for nitrates concentrations, the discussion focused more on aligning trend methodologies with the GWD.

Participants agreed that simplification efforts must be accompanied by safeguards to ensure that core policy objectives, particularly the ND's role in tracking agricultural nutrient pressures, are not compromised. Achieving greater coherence and efficiency will depend on striking the right balance between integration and specificity, supported by improved communication, shared platforms, and greater alignment of data use across the EU water acquis.

2.6 Interviews for the preparation of four Case Studies

The interviews were used as a data source for the preparation of four Member States' case studies (Bulgaria, Germany, Denmark and Lithuania). These reports analyse the impact of the Nitrates Directive in these Member States since its first application. The preparation of the case studies included interviews with different types of stakeholders authorities, farmer associations, academia, NGOs.

In the interviews for one of the Member States it was mentioned that the adoption of the Nitrates Directive in 1991 had not entailed significant changes for the agricultural sector but rather continuity and that the adoption of a whole territory approach had simplified administrative processes, ensuring consistent regulatory enforcement nationwide. Also, measures such as fertiliser planning and nitrogen accounting rules, facing initial scepticism from farmers, have garnered support over time and have resulted in a significant reduction in chemical fertiliser usage.

Several interviewees in other case study attributed a strengthening of the measures under the Nitrates Directive to the infringement proceeding process opened by the Commission and the European Court of Justice court case.

In other Case study, a representative from a farmers' organisation stressed that fertilisation plans are the most effective measure to combat nitrogen pollution of surface waters. Some interviewees referred to the need to adapt measures to climate change effects.

2.7. Consultations to Member States experts in the Nitrates Expert Group.

Member States experts' were consulted during three meetings about six key aspects of the directive. The experts shared their experiences acquired on these key aspects through the national implementation of the directive. The consultations covered (i) scope and objectives of the directive, (ii) identification of polluted waters and designation of vulnerable zones, (iii) the measures set out in annex II and III of the directive, (iv) balanced fertilisation, limitation of manure land application and derogations, (iv) monitoring and reporting, (v) implementation and enforcement.

The outcomes of these consultations are included in Annex VI.

Evaluation of the Nitrates Directive

Consultation of Nitrates Expert Group - outcome paper

Final version

1. Introduction

In the context of the evaluation of the Nitrates Directive[9], the Commission's Directorate General for Environment has consulted the Nitrates Expert group[10] during 2024 on various aspects of the Nitrates Directive (ND) in order to gather views and insights from the Member State experts on the directive's implementation. Throughout the consultations Member States experts shared their national experiences and provided technical insights to complement their perspectives. The consultations have taken place over the course of three meetings[11] of the group and have covered the main aspects of the directive, including:

- Scope and objectives of the directive
- Identification of polluted waters and designation of vulnerable zones
- The measures set out in annex II and III of the directive
- Balanced fertilisation, limitation of manure land application and derogations
- Monitoring and reporting
- Implementation and enforcement

For each of these aspects, the consultations aimed to explore effectiveness, cost-efficiency, relevance, coherence and EU-added value, in line with the guidelines for the evaluation of EU legislation. Opportunities for simplification and reduction of administrative burden were also discussed.

This document aims to summarise the key take-aways from these consultations. A draft version was presented to the Nitrates Expert Group for its meeting in December 2024 to allow for inputs and comments from Member State experts. This final version was completed in February 2025 and will inform the Commission's ongoing evaluation of the ND and will be attached to the final Evaluation report.

2. Summary feedback from the Nitrates Expert Group

The document is structured in accordance with the six consultation sessions focused on the key aspects of the directive as set out above.

9 CWP 2024 - https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0638

10 The Nitrates Expert Group is a permanent group composed of experts from Member States competent authorities in the field of water pollution by nitrates of agricultural origin.

11 13 March 2024, 13 June 2024, 9 and 10 September 2024

Session 1: Scope and objectives of the directive

The first session covered the scope and objectives as set out in Article 1 of the directive. The directive aims to reduce pollution of waters with nitrates of agricultural origin and to prevent any further such pollution.

Key input from the expert group:

[on effectiveness]

1. Many experts considered that the objective of the directive was sufficiently clearly defined and the level of ambition appropriate.
2. However, important exceptions were also raised. Key elements mentioned as not sufficiently clearly set out in the directive included: the definition of eutrophication, the role of phosphorus as a cause of eutrophication to be addressed under the directive, how to distinguish between sources of nitrates pollution, the timeframe for reaching objectives, and the need for action before the 50 mg/l nitrates threshold is reached. It was also suggested that the directive could benefit from a definition of agriculture, to more clearly delimit its scope, for example in relation to forestry.
3. With regard to whether the Nitrates Directive had been sufficiently effective at reducing pollution, there were diverging views among the experts. Some experts noted a pattern of progress in the early years followed by stagnation in more recent years. Others pointed out that despite the progress in many places, the levels of pollution remained high 30 years after the adoption of the directive. It was indicated that the situation would likely have been worse without the directive.
4. The majority of experts found that the directive has been effective as regards the objective of preventing further pollution. The importance of prevention of nitrates pollution was highlighted, due to the difficulty to address the pollution once it is there.
5. The directive was generally not considered sufficiently effective in addressing transboundary issues. Transboundary contributions to pollution and eutrophication were seen as a difficult issue to tackle, while waters in many Member States are affected by transboundary pollution. This is especially the case for coastal waters.
6. Experts suggested, inter alia, the following actions to make the Directive more effective: result oriented approach with targets, better enforcement of rules, integrated vision for the future of agriculture with financial support from the common agricultural policy (CAP), applying the polluter pays principle, alignment with the Water Framework Directive (WFD), strengthening measures in the annex, better nutrient management, and taking into account climate change and biodiversity loss.

[on coherence]

7. The objectives of the ND are considered as generally coherent with the WFD, but the differences in approach can create overlaps or inconsistencies. It was pointed out that the WFD is now the main framework for water protection and that in this context the ND effectively contributes to achieving good status of water bodies by setting mandatory measures directly applicable at farm level. However, the WFD has a

broader scope and the level of ambition is also higher under the WFD due to the deadline for reaching a specific environmental outcome (good status) by 2027.

8. Objectives on eutrophication/good ecological status of surface waters were seen as more clearly defined in the WFD and the Marine Strategy Framework Directive (MSFD). In addition, the Groundwater Directive (GWD) sets out specific standards for trend assessment and trend reversal below the 50 mg/l threshold. These aspects and different timeframes for assessments between the various directives can create inconsistencies.
9. ND was generally considered very coherent with the CAP, setting the baseline and contributing to the objectives of the CAP. At the same time, this also reflects the rather broadly formulated objectives under the CAP. However, the absence of financial support through the CAP to support farmers in the implementation of measures under the Nitrates Directive was highlighted as an important obstacle for adopting more ambitious measures and transition to sustainable farming.

[on relevance and EU added value]

10. As regards the continued relevance of the directive's objective to reduce and prevent pollution with nitrates from agriculture, there was broad consensus among the experts that this issue still requires action at EU level. By imposing mandatory measures directly applicable at farm level, the Nitrates Directive remains relevant and is not redundant. Separate efforts by Member States would risk being undermined due to socio-economic pressures. Common action is needed to ensure similar market conditions across the EU and to address transboundary pollution and marine eutrophication.
11. The directive is seen as relevant in addressing societal needs and EU policy objectives such as protecting water resources and aquatic ecosystems, and, up to a certain extent, to protecting soils and biodiversity, or sustainable and resilient agriculture and food security.

12. On the other hand, it was pointed out that the directive may not sufficiently contribute to climate objectives, in helping farmers to adapt to climate change, supporting organic farming or promoting the recycling of nutrients.

13. Some experts also mentioned that the directive is relevant with regard to managing intensive livestock production, but that a more integrated approach, including to address ammonia and greenhouse gas emissions, would be necessary as the problems arising from intensive livestock farming cannot be addressed under the ND alone.

14. Concerning the scope of action under the directive, there was a consensus that the focus on water pollution with nitrates from agriculture remained relevant, but there were divergent views as to whether the current scope remained appropriate to ensure sufficient environmental protection from pollution with nutrients from agriculture. Some saw opportunities to take a more integrated approach, focussing on the efficient use of nitrogen and phosphorus, but also pointed to possible further environmental benefits from an integrated perspective including air emissions and greenhouse gasses. Others considered that it would be helpful to break silos with other legislation but extending the scope could take away the focus from tackling water pollution, which is the original purpose of the directive, and duplication should be avoided.

15. Asked specifically on whether the directive would have been more effective if it had included a more explicit focus on ammonia, some experts considered that the measures under the Nitrates Directive already sufficiently contribute to addressing ammonia emissions through limitations on manure and fertiliser application.

16. As regards phosphorus, it was pointed out that the measures of the directive are also effective in preventing phosphorus pollution. However, many highlighted that the legal text is not in line with the interpretation given by the Court of Justice of the EU, that there is a high level of divergence in the measures for phosphorus applied between the Member States and that the overall effects of phosphorus on water pollution are not sufficiently taken into account.

Session 2: Identification of polluted waters and designation of vulnerable zones

The second session covered the identification of polluted waters and designation of vulnerable zones. In accordance with Article 3, Member States identify the waters that are affected by pollution or could be affected by pollution if action is not taken. They then designate as vulnerable zones the areas of land in their territories which drain into those waters and which contribute to the pollution. Instead of designating vulnerable zones, Member States may decide to apply their action programme across their entire territory. The criteria for identifying polluted waters are defined in Annex I.

Key input from the expert group:

As regards identification of polluted waters…

[on effectiveness]

1. Many experts highlighted that part of the criteria for identification of polluted waters are not sufficiently clear.
    a. Overall, the definition of pollution and the limits for nitrate concentrations appeared generally clear (although the reference to the Drinking Water Directive (DWD) is outdated.
    b. Many pointed out that the criteria for eutrophication are not sufficiently well defined, also citing lack of harmonisation with the WFD assessment or with the MSFD for marine waters or absence of reference thresholds for N or P.
    c. When it came to the identification of waters that *could* be affected by pollution, in particular, a large majority of experts considered that the criteria were not sufficiently clear. It was pointed out that the directive lacks both definitions, methodologies, criteria and thresholds.
    d. Experts also pointed to a lack of alignment with the WFD and the GWD in the assessment of trends for nitrates in groundwater and in the criteria determining the need to act already before reaching the 50 mg/l threshold.
2. The identification of the contribution of agriculture to pollution was seen as challenging by most Member States. It was pointed out that methodologies and modelling have been developed at national level to distinguish between different sources of pollution, but that it remained technically complex and costly, and could benefit from more guidance at EU level.

[on coherence]

3. A majority of experts highlighted insufficient coherence between the approach under the ND and under the WFD, namely as regards (i) the identification of "waters" vs "waterbodies and river basins" and (ii) the identification of "waters affected by pollution" (or at risk of pollution) vs "water bodies in less than good status".

4. There was a broad consensus that increased coherence between the ND and the WFD would be beneficial and could bring simplification to the identification of polluted waters and reduce the burden for public administrations, including by harmonising the approach and timetable with the WFD.

[on relevance]

5. A number of experts highlighted that the criteria and thresholds for identifying pollution or at risk of being polluted may not be sufficiently appropriate in relation to current challenges linked to climate change. For example, shifts in water patterns, increasing temperatures, droughts and floods increasingly influence pollution and its impacts, so that the risks of pollution may vary strongly with the same amount of fertilisers or detrimental impacts from pollution may increase at lower concentrations.

6. While a majority of experts considered that the 50 mg/l threshold for nitrates in freshwaters sufficiently takes into account all relevant health aspects, many experts did not consider this to be the case. It was pointed out that some studies have identified health risks at much lower concentrations.

As regards designation of vulnerable zones…

[on effectiveness]

7. A significant share of experts from Member States that had designated vulnerable zones considered that it had been effective in reducing pollution, but the picture was far from unanimous. In comparison, a clear majority of experts from Member States that had used the alternative "whole territory" approach considered that this approach had been effective.

8. An advantage of the designation of vulnerable zones was the more efficient targeting of funds and efforts in polluted areas. On the other hand, it was also pointed out that there could be risks associated with a lack of binding rules outside the designated areas.

9. Advantages of the "whole territory" approach included the fact that the same rules applied to all farmers, that binding rules helped prevent pollution across the territory by providing a basic level of protection everywhere, and that it made implementation and enforcement easier, including in the context of the CAP.

10. There was a consensus that the designation of vulnerable zones was challenging. The designation requires a high level of expertise, representing a significant burden for the administration, and can be met with opposition from local communities in designated areas. The challenges are compounded by a perceived lack of clear criteria for the designation and the correct identification of the sources of pollution.

11. On the other hand, a significant majority of experts using the "whole territory" approach also considered this approach to be challenging. Examples of challenges included the need to adopt binding measures in areas where waters were not affected by pollution, a larger number of inspections required to cover the whole territory, and the need in some cases to nevertheless designate specific areas for the implementation of reinforced measures to address particular pollution problems. Several experts clarified that spatial differentiation of measures according to the level of pollution was often a request from the agricultural sector in Member States applying the "whole territory" approach.

[on potential for simplification / administrative burden reduction]

12. A majority of experts considered that there are significant administrative burdens linked to the identification of polluted waters and that there is potential for simplification and burden reduction. It was explained that one source of the burden is related to the monitoring costs due to the lack of harmonisation of the assessments and reporting periods between various directives. Another source of administrative burden is linked to the determination of the sources of the pollution.

13. Other experts, however, argued that they mostly relied on monitoring and identification already done under the WFD and so the additional burden under the ND was minimal.

14. The designation of nitrate vulnerable zones is also seen as a significant burden on the administration. Experts were evenly divided on whether there was scope to simplify and reduce burdens in connection with the designation.

15. Proposals to reduce the burden mostly suggested using the assessments and adopting the timeframes of the WFD and GWD. Others suggested that switching to a "whole territory" approach might reduce the burden.

Session 3: Action programmes and codes of good agricultural practice

The third session covered the establishment of codes of good agricultural practice and action programmes, and the measures therein as prescribed by the Directive. According to Article 4, Member States establish and promote voluntary codes of good agricultural practice with the aim of providing for all waters a general level of protection against pollution. Moreover, in accordance with Article 5, Member States establish action programmes containing mandatory measures to be implemented by farmers in vulnerable zones. The measures to be included in the codes of good agricultural practice and action programmes are set out in annex II and III.

Key input from the expert group:

[on effectiveness]

1. A large majority of experts considered the measures set out in the annexes of the directive to be effective in preventing and reducing pollution. At the same time, some experts highlighted that the measures were most effective at the beginning when Member States were reaping the "low hanging fruits" and that the remaining challenges may require additional measures.

2. A majority also considered the measures were generally verifiable and enforceable.
3. When asked to rank the effectiveness of the specific measures set out in the annexes, experts tended to give the highest scores to measures restricting the application of fertilisers in winterly or wet conditions, including prohibition periods during the winter months, as well as measures such as minimum capacity for manure storage, the balanced fertilisation requirement, and minimum land cover during rainy periods.
4. At the other end of the scale, the limit on manure application combined with a derogation (i.e. a higher limit) stood out as the least effective measure. If *not* combined with a derogation, however, the limit on manure application was ranked significantly higher, together with measures such as restricting fertiliser application near watercourses and on steep slopes.
5. Overall, however, all measures were mostly considered to be effective, with the possible exception of the manure limit when combined with a derogation. It was pointed out that the effectiveness of the measures depends on their concrete implementation in the Member States and on the local conditions. Some experts further highlighted the differences between measures in Annex III and Annex II, with the latter inherently more flexible and able to be adapted to local conditions.
6. Regarding the measures in Annex II.B (which are not mandatory for Member States to include), there was near consensus among the experts that fertiliser planning and record keeping on fertiliser use was a measure that would be considered necessary in most Member States. A large majority of experts also considered requirements on minimum land cover to be necessary in most Member States. The views were more mixed with regard to the remaining two types of measures listed (concerning irrigation and crop rotation), but still a majority considered these relevant in most Member States.
7. According to the experts, almost all Member States require fertiliser planning and record keeping in one form or another. A large majority of Member States have rules on minimum land cover. It was pointed out that some of the requirements mentioned are also mandatory under the CAP.
8. When asked to rank the measures according to enforceability, experts tended to give the highest scores to the measures on minimum land cover, prohibition periods for fertiliser application, capacity of manure storage, and crop rotation requirements. At the other end of the scale, measures that were ranked as the most difficult to enforce were the balanced fertilisation requirement and requirements linked to irrigation.
9. The experts further highlighted differences in the enforceability of measures based on the timing and methods of checks, as some measures are verifiable only on site at an exact time or during a very limited period.
10. From experience in several Member States, it was found that the collection of reliable data is key to facilitating checks on the enforcement of the rules, especially as regards balanced fertilisation and the manure limit.
11. Several experts highlighted that flexibility given to farmers on the implementation of the measures can also make the enforcement more challenging. On the other hand, it

is also important to design the measures so that they can be enforced and checked more easily, for example by prohibiting cultivation on buffer strips.

12. A large majority of experts considered that the implementation of voluntary codes of good agricultural practice was insufficient to prevent pollution outside vulnerable zones. According to experts, the large majority of Member States do implement some form of mandatory measures also outside the vulnerable zones.

[on coherence]

13. A large majority of experts considered that the measures listed in Annexes II and III of Nitrates Directive adequately support the achievement of the objectives of other environmental legislation.

14. A large majority also considered that the measures were coherent with those under the CAP. Most experts found that the relationship between the measures as defined under the ND and the CAP was clearly defined. Farmers receiving support from the CAP must comply with the Nitrates Directive and also with certain requirements to keep their land in good agricultural and environmental condition (GAEC requirements), most of which also support the objectives of the ND.

15. On the other hand, a few experts pointed out that there is a tension between supporting measures through CAP funds or implementing them as a mandatory under the ND, which limits the capacity of the CAP to support the green transition.

16. A significant majority considered that the relationship between the measures under the ND and the WFD was well defined. The ND contributes to achieving WFD objectives. Experts also highlight that more synergies, coherence in timeframes, criteria and water quality assessments would make the link more effective.

17. As regards the MSFD, while the measures under the ND help reduce the nutrient load to the sea hence contributing to the achievement of MSFD objectives, it was also pointed out that what was required to achieve the objectives of the MSFD was not necessarily adequately reflected in the measures under the ND.

18. Regarding the NECD, experts highlighted that the ND can contribute to reducing ammonia emissions, hence supporting the objectives of the NECD. While some considered this link could be better exploited, others considered that the two legal frameworks work fine side by side in view of their separate objectives.

19. The ND also contributes to the objectives of the Habitats Directive (HD). Some found that the link was not clearly defined. The point was made that there is a lack of guidance on how to make the "appropriate assessment" required under the HD with regard to the action plans under the ND.

[on relevance and EU added value]

20. All experts found that it has been useful to have the common list of specific measures and farming practices in the annexes.

21. The fact that Member States all implement a certain number of minimum measures contributes to level the playing field between farmers in different Member States,

even if the way the measures are implemented differs considerably from one Member State to another.

22. Several Member States highlighted that while measures listed in the annexes all remain relevant, they may not be sufficient to close the gap in water quality, especially in relation to the objectives of the WFD. Additional measures might be required.

23. There was no consensus on whether the measures are sufficiently "future proof" in terms of climate change, biodiversity, soil health, and water resilience (quantity and quality). The measures are sufficiently general to offer the required flexibility for future adaptation. New technologies can support better adaptation. It was pointed out that increasingly unpredictable climate and weather conditions make it harder to adhere to measures that include dates, that certain measures may be counterproductive in terms of reducing greenhouse gas emissions, or that a stronger focus on water management, including quantity, might also be necessary.

24. Several experts considered that further research is necessary to ensure that the measures remain effective and can be adapted to evolving environmental conditions.

25. Most experts found that beyond their effect on water quality the measures included in the national action programmes are also relevant for achieving other objectives such as reducing ammonia and greenhouse gas emissions. The most relevant measures in this regard were the balanced fertilisation requirement, construction of manure storage, prohibition periods for the application of fertilisers, and low emissions application methods.

26. Several experts explained that it would be relevant to consider all nutrient pathways in an integrated approach. This would allow increased effectiveness and balancing between sometimes conflicting effects, as some measures which are good for water quality might be less so for greenhouse gas emissions etc.

[on cost-efficiency]

27. Experts were divided on whether, in general, the measures listed in the annexes were cost-effective. Experts explained the difficulty in estimating the costs of measures as they pointed out that the burden for farmers depends on how the measures are applied and that local conditions play an important role in that. A view was also raised that while some measures tend to have diminishing returns in effectiveness as they are applied more strictly, the burden tends to increase disproportionately.

28. Experts were evenly divided on the question of whether the CAP provides sufficient support to farmers for the implementation of the measures under the directive.

29. The majority of experts considered that farm advisory services are effective in supporting farmers in the implementation of the measures. However, a sizeable minority was of the opposite view. It was highlighted that advisers tended to focus on fertiliser planning and that there could be a lack of public sector advisors focussed on environmental impacts.

30. When experts were asked to rank the different measures on how costly they were for farmers, the requirement on manure storage capacity stood out as by far the costliest measure. Other measures seen as relatively costly included fertiliser planning and

record keeping, the limit on manure application, the balanced fertilisation requirement, prohibition periods for the application of fertilisers, and restrictions near water courses.

31. There was a general consensus among the experts that it would make sense to tailor measures to the size and type of farms. It was pointed out though that it could involve additional administrative burden for the authorities and that it could also be considered important to treat all farms equally.

32. Some Member States tailor measures to the size and type of farm, according to the experts. Examples include requirements on fertilisation planning and on manure storage and application, and exemptions for organic farmers. Other Member States mentioned exemptions based on performance or gradual introduction of measures starting from the most intensive farms.

33. As regards the acceptance by farmers of the measures under the directive, most experts considered that acceptance has evolved over time. Experts noted an increased awareness and sensitivity to environmental issues, a positive effect from advisory services and training and a positive contribution of the cross-compliance/conditionality rules under the CAP.

34. Derogations were mentioned as something that had facilitated acceptance of new requirements by farmers. A few experts further mentioned increasing frustration of some farmers with the complexity and regular changes of rules, which can be related both to EU rules and national implementation.

35. Experts also report that in the large majority of Member States there is scientific or academic support provided for the design and assessment of measures and the stakeholders are involved at various stages. As reported by experts, in a number of Member States, specific working groups with stakeholders from farmers organisations and civil society have been set up and are closely involved in the preparation of programmes of measures, which has also increased acceptance and dialogue.

36. When experts were asked to rank the measures with regard to the burden imposed on the public administration, the limit on manure application stood out as the most burdensome measure, especially in the case of a derogation. Other measures with a relatively high burden for the administration were the requirements on fertiliser planning and record keeping, balanced fertilisation, capacity of manure storage, prohibition periods for the application of fertilisers, and restrictions near watercourses.

[on potential for simplification and burden reduction]

37. A large majority of experts considered that there is a potential for simplification and burden reduction for public administrations as regards the measures, their design and implementation. Likewise, a large majority considered that there is potential for simplification and burden reduction for farmers. In both cases, there was also a significant number of experts that did not find that there is potential for simplification or burden reduction. Several experts remarked that simplification and burden

reduction for farmers do not necessarily align with burden reduction for public administration.

38. Activities representing significant burdens for the administration included controls/enforcement of the measures on farms as well as monitoring the effectiveness of the implementation of the measures. The 4-yearly review and design of the programme of measures is also seen as potentially burdensome, and several experts suggested to align the periods with the 6-year cycle under the WFD. Other potential avenues for simplification mentioned included reducing the need for administrative or on-site controls, for example by exempting small farms or farms in areas with good water quality. Developing and sharing knowledge on expected effectiveness of measures could also help national administrations in designing action programmes.
39. Potential for reducing burdens on farmers is also linked to flexibility in the implementation of measures, e.g. on prohibition periods for fertiliser application, exemption from the need to keep records on manure application on farms where the use of manure is low, use of electronic field record books, and less restrictions on fertiliser application on slopes where there are no watercourses nearby.
40. Other proposals included use of smart enforcement methods based on new technology, remote monitoring, data collection systems that do not include farmers, and good communication of requirements.

Session 4: Balanced fertilisation, manure limit and derogations

The fourth session covered the application of the principle of balanced fertilisation in line with the provisions set out in Annex III of the directive. According to these provisions, Member States should limit the land application of fertilisers, consistent with good agricultural practice, and taking into account the characteristics of the vulnerable zone concerned, based on the balance between foreseeable nitrogen requirements of the crops and the nitrogen supply to the crops from the soil and from fertilisation. The latter includes the nitrogen present in the soil at the start of the growing season and the net mineralisation from the organic nitrogen reserve in the soil as well as nitrogen from livestock manure and chemical and other fertilisers. Moreover, point 2 of Annex III specifies that the amount of livestock manure applied should not contain more than 170 kg nitrogen per hectare. Derogations from this amount are possible provided it does not prejudice the attainment of the directive's objectives and can be justified based on objective criteria.

Key input from the expert group:

As regards the principle of balanced fertilisation…

[on effectiveness]

1. A large majority of experts agreed that the concept of balanced fertilisation is sufficiently clearly defined in the directive. A majority of experts also considered the principle to be well understood and accepted by farmers.

2. The most prevalent measures that Member States use to support the implementation of balanced fertilisation at national level include: a requirement for farmers to prepare fertilisation plans and keep them on the farm, a requirement to keep records of fertiliser application at the farm, a requirement to keep records of manure movements to and from the farm, binding nitrogen fertilisation limits per crop, and availability of advisory services or digital tools.
3. Only a few Member States require online fertiliser plans or record keeping of fertiliser use in an online system.
4. Some good practices mentioned include the use of digital tools such as remote sensing, gathering of data from fertiliser suppliers and the biogas sector, online recording of manure movements, and determining the fertiliser balance at the end of the growing season, including through soil tests to determine the level of nitrates remaining in the soil after harvest.
5. Acceptance by farmers was seen as influenced by the cost of measures (for example soil tests), but also by the availability of good guidance documents and advisory services. The latter were seen as key to effective implementation and to climate change adaptation.
6. The unpredictability of crop yields due to variations in climatic conditions was raised as an issue that could be partly addressed through splitting fertilisation in several doses over the growing season.
7. It was highlighted that fertiliser application standards tend to reflect crop requirements in a situation with average 'good' yields, and that climate change is expected to lead to higher variability of yields between years, if not necessarily lower average yields.
8. Several experts highlighted that the fertilisation application standards are driven by economic factors instead of environmental considerations, also pointing out that the wording of the directive may not be clear enough.
9. When asked about how to improve effectiveness of the balanced fertilisation concept in achieving water quality objectives, experts mentioned the application of stricter limits in sensitive areas, setting in place a precautionary principle, exchanging "foreseeable" with "expected" in the formulation, defining the nitrogen balance calculation formula in the directive, applying balanced fertilisation also outside nitrate vulnerable zones and defining maximum allowable total fertilisation limits including artificial fertilisers in order to establish a foundation for further regulation.
10. Some suggested that the principle of balanced fertilisation should be applied to phosphorus as well, to prevent accumulation in soil and eutrophication of surface waters.
11. Some Member States have experience reducing the nitrogen fertilisation rates below the economic optimum rate, which was considered effective in reducing the environmental impact. This practice still requires a definition of the optimum rate.
12. It was pointed out that grasslands can have a high nitrogen requirement, which can be partly met through the spreading of livestock manure.

13. Several experts also mentioned organic agriculture as a model with overall less fertiliser inputs and better soil health. Others pointed to the often lower yields in organic farming.

[on coherence]

14. A very large majority of experts considered that balanced fertilisation including the limit on manure application provided a significant contribution to achieving the objectives of the WFD, the DWD, the MSFD, the NECD, the CAP and climate objectives.

As regards the limit on manure application…

[on effectiveness]

15. A large majority of experts considered that the limit of 170 kg nitrogen from manure per hectare had been effective in preventing and reducing water pollution and that the limit remained important for managing the impact of intensive livestock production.

16. On the more specific question of whether the limit had been effective in controlling the intensification of livestock production, a majority of experts agreed that it had, but there was also a significant minority that disagreed.

17. A number of Member States have defined ceilings for phosphorus and considered that this could potentially be more effective than the limit defined in terms of nitrogen.

18. Key challenges mentioned in connection with the limit on manure application included the assessment of the nitrogen content in manure, the costs of manure storage and transport, and monitoring of compliance.

19. Manure processing - including anaerobic digestion (biogas) - was mentioned as a factor facilitating implementation of the limit.

[on relevance]

20. Some experts considered it relevant for the limit to apply not only to livestock manure but to all organic fertilisers. It was however noted that this could be a challenge for organic farmers.

As regards derogations…

[on effectiveness]

21. Experts were rather evenly divided on the question of whether derogations have a negative impact on the effectiveness of the directive or whether, on the contrary, derogations are a necessary element to adapt the implementation of the manure limit to specific national conditions.

22. A large number of experts agreed that derogations are affecting competition between agricultural producers within the internal market.

Session 5: Monitoring and reporting

The fifth session covered the framework for monitoring and reporting by Member State authorities. According to Article 6 of the directive, Member States are required every four years to monitor the nitrate concentrations in their fresh ground and surface waters and review the eutrophic status of their fresh surface waters as well as estuarial and coastal waters. Under Article 5(6) Member States should furthermore implement suitable monitoring programmes to assess the effectiveness of their action programmes and – for Member States implementing the whole territory approach – monitor the nitrates concentrations at selected measuring points which make it possible to establish the extent of nitrate pollution from agricultural sources. In accordance with Article 10, Member States report to the Commission every four years on the implementation of the directive and the results of their monitoring. Annex V states the information to be contained in those reports.

Key input from the expert group:

[on effectiveness]

1. A large majority of experts agreed that in general the provisions of the directive are clear enough as regards the obligation to monitor waters.
2. Nevertheless, the views of experts were more divided on whether the expectations were sufficiently clear when they were asked about specific aspects such as the parameters for assessment of eutrophication, how to ensure a representative monitoring network, the density of the monitoring network, the depth of groundwater stations and how to monitor the effectiveness of action programmes.
3. Experts considered in general that the directive was clear enough on the content of the reports required under Article 10, although it was also noted that this clarity was partly due to the existence of informal guidance from the Commission.
4. A large majority of experts considered the current 4-year monitoring and reporting cycle to be inappropriate. It was suggested that it could be aligned with the 6-year cycle in the WFD.

[on relevance]

5. Most experts considered that the reporting under the directive remained relevant as it generated the necessary information for the decision-making process of the administration and that monitoring data had influenced policy decisions.
6. The reporting was found to be less relevant in raising awareness among farmers and the public and it was mentioned that some Member States present data on water quality in separate national reports that are considered more fit for public consumption and policy making.

[on coherence]

7. A large majority of experts highlighted significant overlaps with the monitoring and reporting under the WFD and the GWD.
8. Experts generally agreed that the monitoring under the WFD could also be used for the detection of nutrient pollution from agriculture. It was highlighted that

representative monitoring was a requirement under the WFD and that relying on the general assessment under that directive could produce a more coherent picture.

9. In many Member States the water monitoring networks and programmes were already aligned to some extent with that of the WFD or the MSFD, even if the requirements were not the same and the use of the data differed under those legal frameworks. However, several Member States maintain separate monitoring networks and programmes, as they consider it more appropriate to implement the specific requirements of the ND (such as focus on agricultural pollution and areas, definition of nitrate vulnerable zones) through a dedicated network.

[on potential for simplification and burden reduction]

10. As regards the burden for the public administrations in monitoring and reporting under the directive, a large majority of experts found that there was potential for simplification while not undermining the attainment of the objectives.

11. In particular, experts considered that there was a potential for simplification through better alignment with the monitoring and reporting under the WFD, the GWD and the MSFD.

12. Concrete ideas for simplification included streamlining the reporting cycles and the requirements under the different directives (parameters used, monitoring stations, status assessment, trend evaluation, monitoring periods), reducing the frequency of surface water sampling, allowing modelling in order to reduce the density of the required monitoring network, longer deadlines and simpler upload of data.

13. At the same time, while there was a large consensus on the need to increase coherence and exploit potential simplification with monitoring and reporting under the WFD, the experts also stressed that the link with agricultural practices and the impact of agriculture on waters should not be lost. For example, the definition of ground water bodies might have to be adapted in some cases to properly identify the specific pollution due to nitrates from agriculture. Alternatively, it was suggested that separate monitoring of nitrates could still be useful. The distinction between monitoring for drinking water purposes and for eutrophication was also stressed.

14. In any case, experts highlighted that specific monitoring would still be needed under the ND concerning the effectiveness of action programmes, which may require a different type of monitoring from that what is carried out to assess the general quality status of waters or identify pollution.

15. It was mentioned that the monitoring under the ND also includes other indicators related to nutrient emissions from agriculture rather than water such as fertiliser use, livestock densities, and nutrient balances.

16. Finally, a majority of experts agreed that it could be useful to have complementary monitoring at EU level (e.g. satellite) and that the use of technological innovation (tele detection, real-time monitoring or modelling) should be better promoted as these could reduce some of the administrative burden linked to the directive.

Session 6: Implementation and enforcement

The sixth session covered the implementation and enforcement of the Nitrates Directive within the Member States. The directive does not include specific provisions on administrative implementation or enforcement and as such it leaves broad discretion for the Member States to organise themselves in accordance with their respective national contexts.

Key input from the expert group:

As regards the implementation and enforcement tools provided by the directive…

[on effectiveness]

1. At a general level, a large majority of experts considered that the directive remained an effective legal instrument for achieving the objectives set out, and that it provided sufficient mechanisms and tools for both the Commission and the Member States to facilitate effective implementation and enforcement.
2. Experts explained that the wording of the directive provided sufficient flexibility for Member States to implement and enforce rules fitting to the local environmental, climatic conditions and agricultural practices. They highlighted that it remains relevant today.
3. As an exception, a majority of experts did not find that deadlines set out in the directive were appropriate, as regards the implementation by national authorities of the various requirements. On the one hand it is explained that 4 years is too short to evaluate the results of measures, on the other, there is the discrepancy with the 6 year cycle of the WFD in which the ND is considered a basic measure.
4. Among the challenges encountered in implementation of the directive experts referred to the fact that effectiveness of measures can only be determined with a time delay, that changes to the action programmes are often met with incomprehension and resistance by farmers, and that 'low hanging fruits' had mostly been exhausted, entailing higher costs of additional measures.
5. The limited number of explicit targets and thresholds included in the directive was also mentioned - the main ones are the 50 mg/l for nitrates concentration in freshwaters and the 170 kg N/ha limit on manure application.
6. A large majority found that the directive mandates enough tools for the involvement of stakeholders in the implementation.
7. The crucial role of advisory services in communication and trust-building with farmers was highlighted, as a means of promoting compliance and achievement of objectives.

[on potential for simplification and burden reduction]

8. Suggestions for simplification of the directive in terms of implementation in the Member States included higher flexibility for Member States to choose between measures and the possibility to rely on result-based measures to a greater extent (rather than means-based measures).

As regards enforcement in the Member States…

[on effectiveness]

9. Experts explained that they implement a wide range of effective tools for enforcement of the directive. The most widely used actions taken by Member States to ensure proper application of measures by farmers include desk-based and on-the-spot checks, requirements for record keeping by farmers, sanctions for non-compliance as well as advisory services, information activities and training. Many Member States also make use of surveys or impose reporting requirements on farmers. A minority of Member States use remote sensing technologies for compliance monitoring.

10. Many experts indicated that the achievement of the objectives of the directive in their Member State is affected by non-compliance by farmers.

11. The measures considered to be most affected by compliance problems were the requirements on manure storage capacity, balanced fertilisation, prohibition periods for application of fertilisers, buffer zones, record keeping, and the 170 kg limit for manure application.

12. In general, it was pointed out that it is important that measures and requirements are controllable and verifiable by both farmers and authorities.

[on coherence]

13. As regards coherence/overlaps with the CAP, all Member States perform controls of compliance with the Nitrates Directive as part of the conditionality checks. Almost all Member States also carry out specific desk-based and on-the-spot checks under the directive (in addition to the checks under the CAP).

[on potential for simplification and burden reduction]

14. Suggestions for measures that could simplify or reduce burdens for farmers and the administration in connection with controls and inspections included technological solutions (including remote sensing), certification systems, result-based measures, exceptions for smaller farms, clear rules with minimal exceptions, flexible choice of measures by farmers, and guidance on enforcement and compliance.

15. It was pointed out that there could be a contradiction between flexibility on the one hand and simplicity on the other, as exemptions tend to add complexity.

16. As regards result-based measures, it was pointed out that certainty in measurements could be a challenge in some cases.

ANNEX VII. BACKGROUND ON THE NITRATES DIRECTIVE'S ADOPTION IN 1991

The Nitrates Directive's adoption in 1991 should be seen in the context of wider developments in global and European agriculture during the post-Second World War years and the environmental impacts that followed from these developments. The second half of the 20th century saw transformative changes in European agriculture, primarily driven by post-war reconstruction and population growth, which increased the demand for food production. Mechanisation became widespread during this period, reducing labour costs and enabling large-scale farming. The advent of containerisation in the 1950s revolutionised maritime transport, enhancing the efficiency of agricultural trade. These developments were complemented by advances in veterinary medicine and breeding techniques, which further intensified livestock production. The 1960s and 1970s was a period of significant investment in crop genetics and agricultural technology. This era saw the development of high-yielding crop varieties and increased chemical inputs in agriculture, including chemical fertilisers.

Box 4: High emissions of agricultural nutrients contribute to environmental risks

In 2001, based on the assessments by international sea conventions during the 1990s and on earlier literature and measurements since 1985, the EEA concluded "that eutrophication of marine waters caused by excess load with nitrogen and phosphorus nutrients from human activities is a major problem in many European coastal areas. The main source of nitrogen is run-off from agricultural land brought to the sea via rivers" and further: "Negative impacts include periodic disturbances of the ecosystem such as oxygen depletion and the subsequent mortality of benthic organisms, as well as changes in abundance and diversity of the different animal and plant communities, e.g. increased phytoplankton blooms including harmful species and drifting algal mats. As a result of periodic oxygen depletion in the southern Kattegat bottom water in 1985-88, the fishery for Norwegian lobster had almost ceased in this area until 1999." The pictures below show examples of eutrophication effects in the North Sea (left) and the Baltic Sea (right) in the 1990s (source: EEA [19]).





The shift from a "low input system" to a "high input system" reduced the use efficiency of nitrogen and phosphorus in crop production, leading to higher nutrient surpluses and resulting in environmental and health impacts. During this time, Europe also began importing and using more feed concentrates, such as oilcakes and soy, as substitutes for more expensive EU-produced grains in livestock feed rations. The trend towards increased use of chemical fertilisers and imported feed concentrates, which started in the 1960s, significantly increased nutrient inputs into agricultural systems and the associated

application of livestock manure on fields. The 1980s were characterised by production surpluses in various areas and policies, such as the introduction of milk quotas, aimed at controlling production. However, the intensification of agriculture continued, driven by globalisation and trade liberalisation. By the late 1980s, the negative environmental impacts of excessive nitrogen and phosphorus emissions were evident (see box 4).

ANNEX VIII. IMPLEMENTATION OF THE NITRATES DIRECTIVE

Transposition and Implementation

The Nitrates Directive is based on a four-year implementation cycle (Figure 5). Each reporting period (RP) comprises a cycle of obligations to be implemented under the Nitrates Directive, as Member States are required to review their NVZ and action programmes every four years, and to revise them where needed.

Figure 5 Implementation cycle of the Nitrates Directive



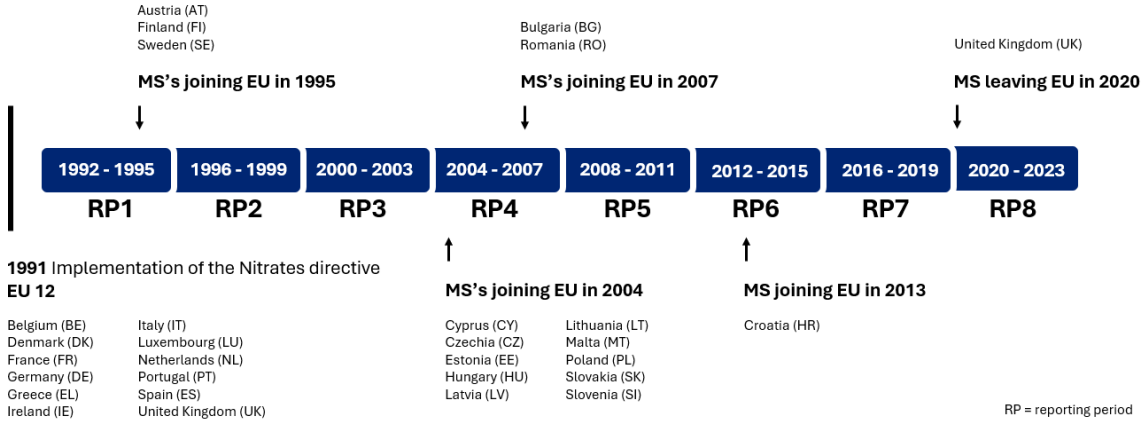
After adoption of the directive in 1991, Member States were required to transpose its provisions into national law by 20 December 1993. By then Member States were also required to designate for the first time the nitrate vulnerable zones and establish codes of good agricultural practice. The first action programmes were to be established two years later by December 1995 and be implemented in the next four years by December 1999. By then, Member States should also submit their first monitoring reports under Article 10 in 1996 and perform the first review of their designation of vulnerable areas in 1997. In this way, the directive set out a coherent policy cycle to be reiterated every four years up until today (Figure 6).

Based on the reports of the Member States, the Commission presents an overview of progress in an implementation report to the European Parliament and the Council every four years[12]. In order to improve the comparability of reporting by Member States and streamline the implementation of the directive, the Commission has since the mid-1990s promoted the use of common reporting guidelines. While these remain informal guidelines, they have allowed for the evolution over time of a broadly accepted common

[12] The reports can be found here: Nitrates - European Commission

methodological approach to the reporting, including common templates and agreed formats for electronic reporting of data[13]. The most recent update of the reporting guidelines was finalised for the 2024 reporting exercise[14].

Figure 6 Graphic representation of implementation cycles and enlargements



For the implementation of the Directive, the Commission is supported by a comitology Committee (Nitrates Committee[15]) and an expert group that bring together Member States authorities responsible for the implementation of the Directive. In the majority of Member States, the responsibility for the implementation of the Directive is coordinated through several ministries, primarily ministries responsible for water protection and agriculture. The Directive allows the Commission to adapt non-essential elements of the Directive of the Annexes to scientific and technical progress, guidelines for monitoring and derogations to the manure application limit through comitology procedures.

In practice, the initial transposition and implementation in the Member States showed significant delays and transposition issues. The Commission's first implementation report adopted in 1997 highlighted significative problems due to the absence of or non-conformity of transposition and absence of or non-compliant implementation of the various obligations, prompting the Commission to open a high number of infringement cases. By 2000, RP2 implementation report noted that significant improvements had taken place with regard to the implementation of the Directive. Most Member States had put in place monitoring networks, NVZ and nitrates action programmes.

The 2007 RP3 implementation report indicated that progress was being made in the implementation of the Directive, but that considerable further work in improving the designation of NVZ and in the quality of the nitrates action programmes was necessary to achieve the Directive's objective. The report also noted that progress was often driven by infringement procedures. On the other hand, there were no significant delays in the implementation of the Directive in the Member States joining in 2004 and 2007. They had already put in place the necessary legal framework before joining the EU in line with the commitments taken in the negotiation for accession, and most had a monitoring network, designated NVZ and adopted a nitrates action programme from the start.

13 Reports and data are submitted electronically to the European Environment Agency.
14 https://reportnet.europa.eu/public/dataflow/1208
15 https://ec.europa.eu/transparency/comitology-register/screen/committees/C11400/consult?lang=en

The 2012 Fitness Check of EU Freshwater Policy [8] found that the implementation of the Nitrates Directive had been slow overall and that problems persisted, mainly in relation to insufficient designation of NVZ and non-conformity of action programmes. During the next cycles, Member States kept reviewing their action programmes and designation of NVZ, with the Commission promoting full implementation of the various obligations under the Directive, with the development of guidelines, exchanges of good practices and through infringement procedures.

The RP6 implementation report identified challenges such as the assessment of eutrophication, strengthening water quality monitoring or developing nitrates action programmes. In the RP7 implementation report, the Commission prepared country specific reports and gave recommendations to the Member States to improve further the national implementation. The main challenges identified related to the prevalence of eutrophication and effectiveness of the action programmes.

The overall cycle of the Nitrates Directive at national level and the reporting at EU level is now well established. Nevertheless, the implementation cycles vary a lot from one Member State to the other. Some Member States have established NVZ which do not require regular updates, others have had to update NVZ every four years. As regards the nitrates action programmes, Member States also have different approaches to the timing of adaptation of their measures. Experience shows that a four-year implementation cycle can be tight, as the time required to finalise the procedure for updating NVZ or reviewing the nitrate action programmes, including assessments and consultation requirements, can make it challenging to close the cycle within a four-year period.

The implementation of the Nitrates Directive in the Member States has seen an increasing involvement of stakeholders in the various steps of the process. In 2010, the CJEU [9] confirmed that the SEA Directive[16] also applies to the adoption of nitrates action programmes, including an obligation of public consultation. Many Member States have also established working groups that include farmers' organisations to consult on the design of the measures of the nitrates action programmes. In recent years, some Member states have further involved civil society (nature organisations) or drinking water companies in these groups.

Monitoring Networks

The creation of an appropriate water monitoring framework based on a representative network of monitoring stations is a key step in the implementation of the Nitrates Directive, necessary for the identification of polluted waters and designation of NVZ. Initially, the development of appropriate monitoring networks took time and the Nitrates Committee developed informal monitoring guidelines, completed in the early 2000s. The adoption of the WFD in 2000 gave a positive boost to the development of the monitoring networks in the following years (RP3 and RP4), with several Member States integrating nitrate monitoring within the networks established under the WFD.

[16] Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment. OJ L 197, 21.7.2001, p. 30–37

In 2004, ten Member States joined the EU, which added a significant number of monitoring points (RP4). The density of monitoring points further increased in RP8[17] .

With the establishment of the networks and common guidelines, the monitoring and reporting of nitrate concentrations has proceeded on a regular basis, even if comparability between periods is somewhat affected by changes in the networks over time. On the other hand, the complexity of assessing the trophic status of surface waters delayed its effective monitoring. The absence in the directive of explicit reference thresholds for nitrates in respect of eutrophication and for phosphorus has been a factor in this respect. After the adoption of the WFD, the Commission published in 2009 a guidance document providing elements for the assessment of eutrophication [19]. However, subsequent Commission reports still highlighted the difficulty of drawing conclusions regarding the evolution of trophic status because of the lack of data and the different methodologies used by Member States to assess eutrophication.

This situation has impacted the identification of eutrophic waters and the subsequent designation of NVZ. Since 2016 the Commission has promoted the use of methodologies being developed in the context of the ECOSTAT working group under the WFD[18], where nutrient conditions are included among the supporting elements in the assessment of good ecological status of surface water bodies. This work builds on the 2009 guidance. The 2021 implementation report for RP 7 (2016-2019) [14] provided an assessment of trophic status for most Member States but methodologies still varied considerably, resulting in further discussions in the context of RP8.

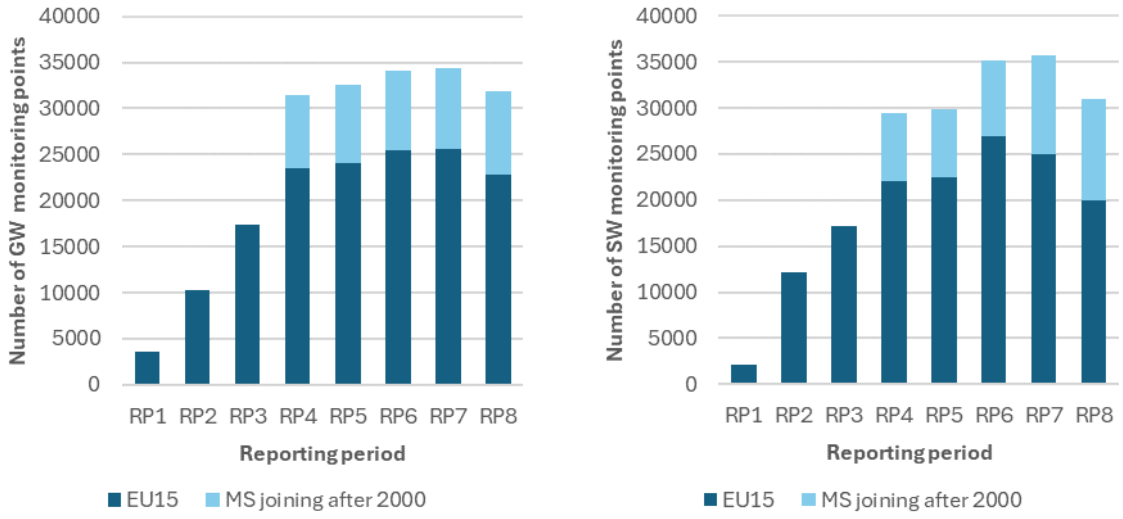
Figure 7 shows the evolution in the monitoring networks. The number of monitoring points both for surface and groundwater increased significantly during the first reporting periods, achieving some level of maturity in the mid- to late-2000s (RP4-RP5). In 2004, ten Member States joined the EU, which added a significant number of monitoring points (RP4). The density of monitoring points further increased in RP8[19].

[17] The drop in the number of stations in RP8 reflects the exit of the UK. In EU 27 the number of monitoring points actually increased between RP7 and RP8.

[18] Working group on ecological status (ECOSTAT) under the common implementation strategy of the Water Framework Directive.

[19] The drop in the number of stations in RP8 reflects the exit of the UK. In EU 27 the number of monitoring points actually increased between RP7 and RP8.

Figure 7 Evolution of the number of groundwater and surface water monitoring points



ANNEX IX. ENFORCEMENT BY THE EUROPEAN COMMISSION AND NATIONAL COURTS

Over more than 30 years since the Nitrates Directive entered into force, the Commission has taken enforcement action to ensure the correct implementation of key obligations under the directive and to ensure the effectiveness of national measures [2]. This has included dialogue with Member States, investigation procedures[20], and where solutions could not be found at this stage, infringement cases were opened, some of them leading to rulings at the CJEU. The four-yearly implementation reports have been an important tool to keep track of progress in the Member States.

The RP1 implementation report noted that the Commission had opened infringement proceedings against 10 Member States, relating to the non-transposition of measures or non-conformity of the measures adopted. The RP3 implementation report referred to open infringement against seven of fifteen Member States, mainly for insufficient designation of NVZ and non-conformity of action programmes. The number decreased to three by RP4, relating to insufficient designation of NVZ and non-conformity of action programmes. In RP5 there were ten open infringement cases against eight Member States and seven pilot requests addressed to seven Member States. In RP6 eight infringement cases were open against seven Member States, mainly covering action programmes and NVZ and one case about monitoring. In RP7 10 cases were ongoing against 10 Member States. In RP8 three cases were open against three Member States in relation to insufficient designation of nitrate vulnerable zones and failure to take reenforced measures in the nitrates action programme. Some of these cases resulted in rulings of the European Court of Justice. In the period 1998 to 2024 the Court issued more than 20 rulings on infringement cases brought by the Commission. The enforcement actions have been essential to improve and strengthen the national implementations. Some of the rulings of the Court, also in cases referred by national courts, have provided important interpretations for the implementation of the directive, including clarifications of Article 3, regarding the identification of polluted waters and designation of NVZ, and of Article 5, regarding action programmes, and of the directive's relationship with other environmental legislation.

The CJEU clarified in 2002 [10] that Member States are required to identify waters as polluted also if phosphorus is the main controlling factor for eutrophication. In 1999, it clarified that for the designation of NVZ Member States should also consider waters where agriculture plays a significant part in the nitrates pollution [11], and further in 2005, that a contribution of 17% or 19% to nitrate pollution from agriculture can be deemed significant [12]. The same ruling clarifies that the identification of polluted waters and the designation of NVZs are two distinct obligations, so that opting for applying an action programme to their whole territory does not dispense Member States from identifying polluted waters. In 2003, the CJEU clarified [13] that the adoption of additional measures reenforcing the national action programme should be taken as early

[20] As of 2008 also through the EU Pilot mechanism.

as their need has first been established[21]. The Court further ruled that it is not sufficient to have adopted additional measures, it is also necessary for those measures to be sufficient to achieve the objectives of the Nitrates Directive. In 2018, the CJEU concluded that the nitrates action programme, and in particular the application of fertilisers and the grazing of cattle, may need an appropriate assessment of its implications for the sites protected under the Habitats Directive [14]. Finally, in a number of Member States, and increasingly in recent years, more cases have been successfully brought before national courts for insufficient or ineffective measures taken by public authorities under the Directive.

The following figures show the different infringement procedures that have taken place or are on-going at EU level for the ND, as well as the resulting court rulings of the EU Court. Many of these rulings have provided important clarifications for the directive's implementation and interlinkages with other environmental policies.

Most infringement cases that have dealt with issues related to non-conformity transposition of the directive into the Member States' national laws took place in the initial reporting periods or soon after the accession of candidate countries into the EU. Later cases dealt primarily with insufficient designation of NVZ, and most recent cases with the need of applying additional or stricter measures (articles 3, 4 and 5, and Annexes II and III of the directive).

[21] See also two recent cases: [18] and [17]

Figure 8 Compilation of infringement cases per reporting period and Member State.

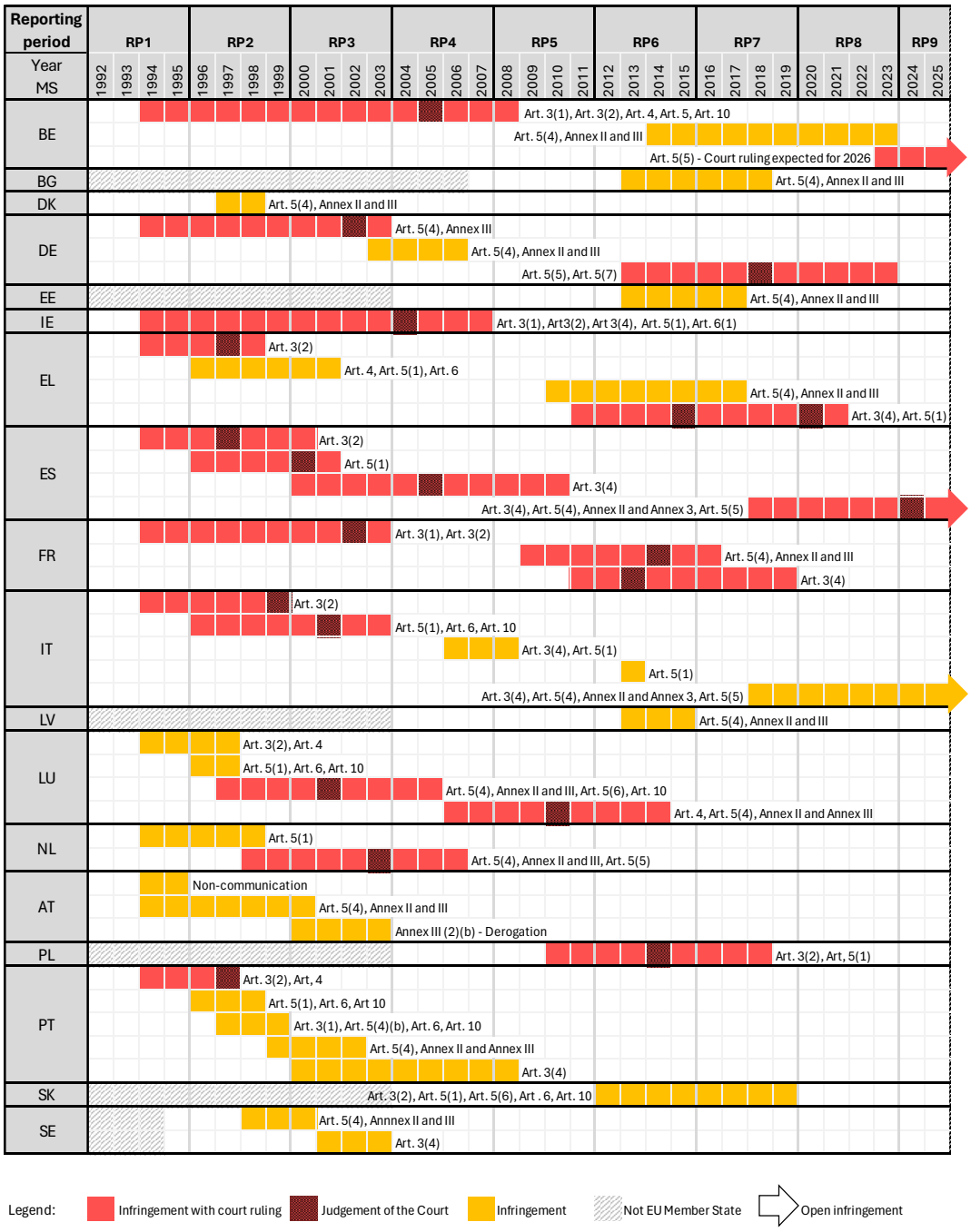
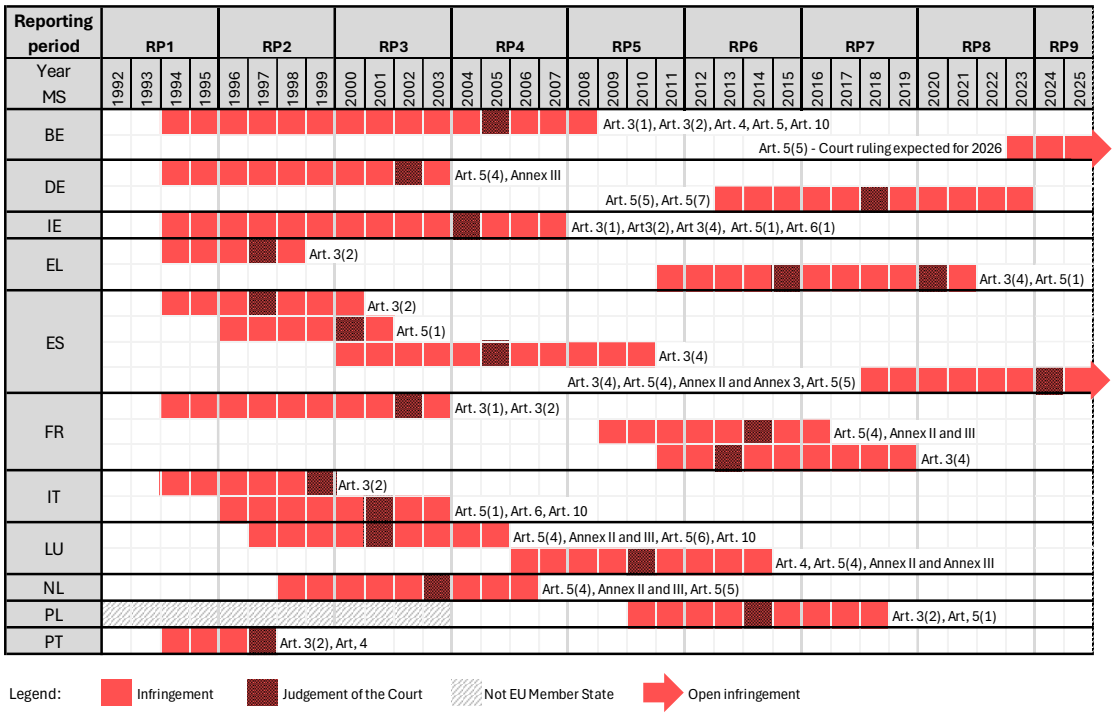


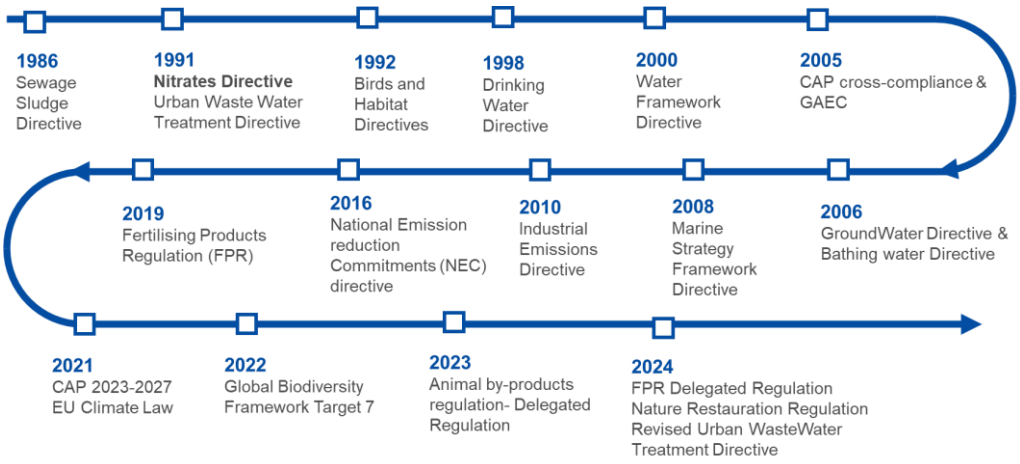
Figure 9 Table compiling court rulings on the Nitrates Directive.



ANNEX X. EVOLUTION OF THE LEGAL CONTEXT

The development of the EU legal framework on water, nutrients and agriculture since the adoption of the Nitrates Directive in 1991 has had a major impact on the policy context of the Nitrates Directive and on its implementation at EU and national level. Figure 10 illustrates this development.

Figure 10 Evolution of EU legal context for the Nitrates Directive



From 2000, the Nitrates Directive has been part of the broader water acquis around the WFD which sets new objectives, criteria and deadlines for water quality in groundwater, rivers, lakes, transitional and coastal waters. This new context has had a positive impact on the implementation of the Nitrates Directive, and has boosted the development of water monitoring networks. In addition, the WFD explicitly recognises the measures under the Nitrates Directive as basic measures within River Basin Management Plans and thus contribute to its objectives[22].. Also, the standards set at national level for nutrient concentrations (both N and P) to achieve good ecological status under the WFD are becoming part of the water quality assessment for eutrophication under the Nitrates Directive as a significant part of nutrients are coming from agriculture (Additional details on the interlinkages between both directives is presented in detail in Annex XV). Similarly, the MSFD also relies on the Nitrates Directive to reduce and prevent nutrient pollution from agriculture in addressing eutrophication in coastal and marine waters. Other legislation in the water acquis such as the UWWTD, the Drinking Water Directive (DWD), and the Groundwater Directive (GWD), are reinforcing the implementation of the Nitrates Directive as reduction of nitrates and phosphates pollution are also in their scope[23].

The NECD adopted in 2016 is also influencing the implementation of the Nitrates Directive, as it requires Member States to reach national emission reduction

[22] Article 11 and Annex VI of the WFD.
[23] Section 4 will examine coherence of the Nitrates Directive with the water acquis.

commitments set out in the directive and to include measures in their national air pollution control programmes to reduce ammonia emissions, the large majority of which come from agricultural sources, in particular livestock production.

The Nitrates Directive has a strong interplay with the CAP. The CAP has had a critical role in supporting the implementation of the Nitrates Directive being part of its conditionality (referred to as "cross-compliance" until 2023), through the standards for Good Agricultural and Environmental Conditions (GAEC) and by financing manure storage in NVZs. A study [15] published in 2007 and a European Court of Auditors report [16] of 2014 concluded that cross compliance has had a positive effect in ensuring compliance with the Nitrates Directive and in raising farmers' awareness and triggered changes in farming practices. (Annex XVI presents in detail the interlinkages between the CAP and the ND, the influence in its implementation and policy coherences)..

Since 2019, the Fertilising Products Regulation defines types and criteria for safe fertiliser product components from organic sources, including based on recovery of nutrients from recycled manure, so that these can be traded on the Internal Market. The Fertilising Products Regulation provides further opportunities for the reuse of excess manure beyond the limits of the Nitrates Directive but in compliance with it[24] supporting its transfer from regions where it cannot be applied to regions that need it. Furthermore, the Commission prepared in 2024 a draft Commission Directive amending Annex III of the Nitrates Directive as regards the use of certain fertilising materials from livestock manure (RENURE). This draft act would allow the use of certain types of processed livestock manure above the limit for land application of livestock manure set out in the Nitrates Directive under certain limits and conditions, allowing them to replace chemical fertilisers.

The implementation of the Nitrates Directive has further been influenced by the legal requirements of protection and restoration of nature and biodiversity, for example under the Birds and Habitats Directives. This is because pollution by nutrients from agriculture can have an important negative effect on nature and biodiversity. Over the years, there has been an increasing public awareness and sense of urgency in relation to nature degradation and biodiversity loss caused by nutrient pollution. Target 7 of the Global Biodiversity Framework undersigned by the EU and all Member States in 2022 to reduce nutrient losses by 50% by 2030 reflects this.

In addition, a new element to consider in this context is the Nature Restoration Regulation (NRR), which entered into force on 18 August 2024. The NRR lays down an overarching objective to put in place effective restoration measures on 20% of EU land and sea by 2030 and for all ecosystems in need of restoration by 2050. To achieve this, it sets out binding targets and obligations for Member States to restore and maintain ecosystems, including terrestrial, coastal, freshwater and marine habitats, as well as urban ecosystems, rivers, agricultural ecosystems and forests, and pollinator populations. The objectives of the NRR and Nitrates Directive are closely interlinked and implementation

[24] Also requesting appropriate labelling concerning the manure origin, so that the rules of the Nitrates Directive can continue to be respected across the Internal Market.

of the NRR will contribute to reaching the objectives of the Nitrates Directive, and vice-versa. For example, measures taken for the reduction and prevention of pollution by nitrates from agriculture can contribute to the restoration targets set for the above-mentioned ecosystems.

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PART 3/11

COMMISSION STAFF WORKING DOCUMENT

EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XI. ENVIRONMENTAL EFFECTS OF THE MEASURES IN ANNEX II AND ANNEX III OF THE NITRATES DIRECTIVE

This annex provides background on the effects of the measures set out in the annexes of the Nitrates Directive and which the Member States should include in their action programmes for nitrates vulnerable zones.

The annex is based on analysis performed by the Soil Service of Belgium during 2024 under a contract[1] with the European Commission for the provision of scientific assistance for the implementation of the Nitrates Directive.

In addition to the strict focus on measures set out in the annexes of the directive, this annex also covers some additional types of measures of relevance for the directive's objectives (buffer strips, nature-based solutions). Member States are free to add such additional elements.

For the analysis, the various types of measures are grouped in 5 clusters: page

1. Prohibition periods, winterly conditions, manure storage 194
2. Sloping ground, water courses 209
3. Balanced fertilization, application methods, fertilizer planning and record keeping 224
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5. Buffers, nature-based solutions 275

1. CLUSTER I – PROHIBITION PERIODS, WINTERLY CONDITIONS, MANURE STORAGE

The risk of nitrate and phosphorus pollution of groundwater and surface waters from agriculture depends on the presence of

- sources of N and P,
- vulnerability of groundwater and surface waters, and
- transfer pathways of N and P from sources to groundwater and surface waters.

Land fertilized with animal manures, fertilizers, composts, and crop residues are one of the possible N and P sources. Regarding the state of the land, this potential source implies a different risk regarding pollution.

Possible transfer pathways are

- surface/subsurface runoff of N and P to surface waters,
- downward leaching of nitrate-N, which directly leads to groundwater pollution by nitrates,
- the emission of gaseous N compounds into the atmosphere and the subsequent deposition of atmospheric N compounds to surface waters and lands, and
- direct application or discharge of fertilizer and manures into surface waters.

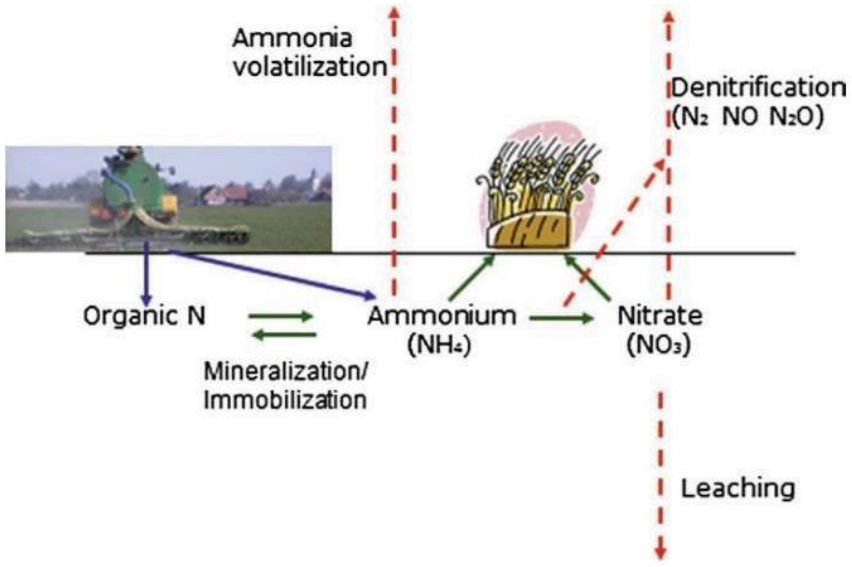
[1] Service contract No. 09.0201/2022/881726/SER/ENV.D.1

1.1. Periods when the land application of certain types of fertilizer is prohibited.

1.1.1. Background

The application of N fertilizer, especially manure, in autumn and winter is particularly linked to the risk of nitrate (NO_3^-)-leaching (Di & Cameron, 2002; Cameron et al., 2013). Nitrate leaching occurs when there is an accumulation of NO_3^- in the soil profile that coincides with or is followed by a period of high drainage. NO_3^--accumulation can occur through (excessive) nitrogen application rates or N applications at the wrong time of the year, not synchronized to plant demand. A decrease in plant growth rate leads to an increase in the organic N-compounds recirculating in the phloem and repressing N absorption by the roots. So the actual N absorption rate of a plant is co-regulated by both soil N supply and its own growth rate potential (Gastal et al., 2015). Leaching occurs when inputs of water exceed the level that can be retained according the water holding capacity of the soil and the level of water use by evapotranspiration. Therefore, autumn applications are likely to increase the risk of nitrate leaching losses, because crop N uptake during the autumn/winter period is generally low and there is sufficient over-winter rainfall to transport manure derived nitrate beyond crop rooting depth. Closed periods are specific times of the year when the application of inorganic and/or organic fertilisers is prohibited, with the objective of reducing the loss of NO_3^- via leaching and run-off. Nitrogen in manures is present in both mineral and organic forms (Figure 1). Mineral-N in manures consists mainly of ammonium (NH_4^+) ions and NH_3 in solution. After aerobic decomposition, manures can also contain mineral-N as NO_3^-. Nitrogen in chemical fertilizers is either in the ammonium or nitrate form, while urea is a chemical fertilizer with nitrogen in an organic form. Nitrate is the nitrogen form that is most susceptible for leaching, due to poor retention by the soil. In soil, ammonium is mineralised to NO_3^-. The organic forms of nitrogen are also aerobically decomposed, first to ammonium, and subsequently to nitrate, but the mineralisation of organic N is a slower process compared to the nitrification of the mineral ammonium. Therefore, the content of mineral nitrogen in the manures determines the immediate risk for leaching. For manures, differences in mineral nitrogen content will therefore result in different leaching risks. For chemical fertilizers, high nitrate containing fertilizers pose more leaching risk compared to ammonium-based fertilizers or urea (Hina, 2024).

Figure 1 The most important N transformations and losses after application of animal manure to soil. (Webb et al., 2013)

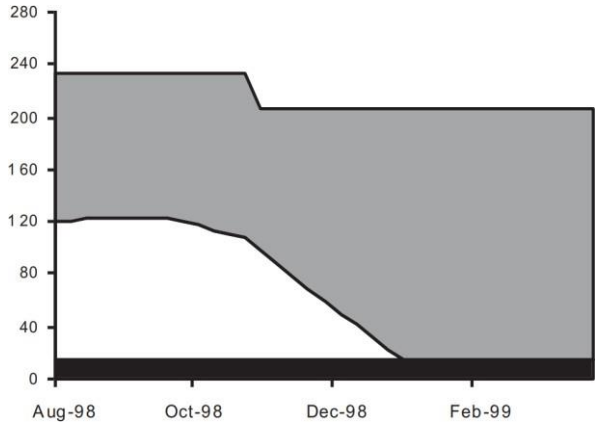


It can be concluded that the leaching risk of applied manures or chemical fertilizers depends on the content of mineral nitrogen or nitrate, the time period between application and sowing/planting, the weather conditions and hydrological status of the soil between application and sowing/planting, and the success and type of crop.

1.1.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses.

The 'closed spreading periods' or 'prohibition periods' are designed to minimise nitrate leaching (and other nutrient) losses. Times of the year when heavy rainfall is expected, temperatures are low, crop growth is limited and/or soils are left bare (limiting evapotranspiration), are particularly vulnerable to both leaching losses and the generation of overland flow (run-off losses) and coincide often with winter months. To a certain extent the measure aims for a better coordination of demand and supply. Synchronizing N supply with crop demand is essential in order to ensure adequate quantity of uptake and utilization and optimum yield (Fageria and Baligar, 2005). This synchronization will improve the N use efficiency (NUE) which is desirable in order to maintain or ameliorate environmental quality. Webb et al. (2013) mention the timing of manure applications to reduce the risk of NO_3^- leaching as a well-documented approach to increase manure-N efficiency. They refer to Webb et al. (2001) who demonstrated the impact of differences in the time of application for UK conditions (Figure 2). They also refer to Webb and Archer (1993) and their references confirming that autumn applications of manure cause increased leaching in areas with moderate or high precipitation during autumn and winter.

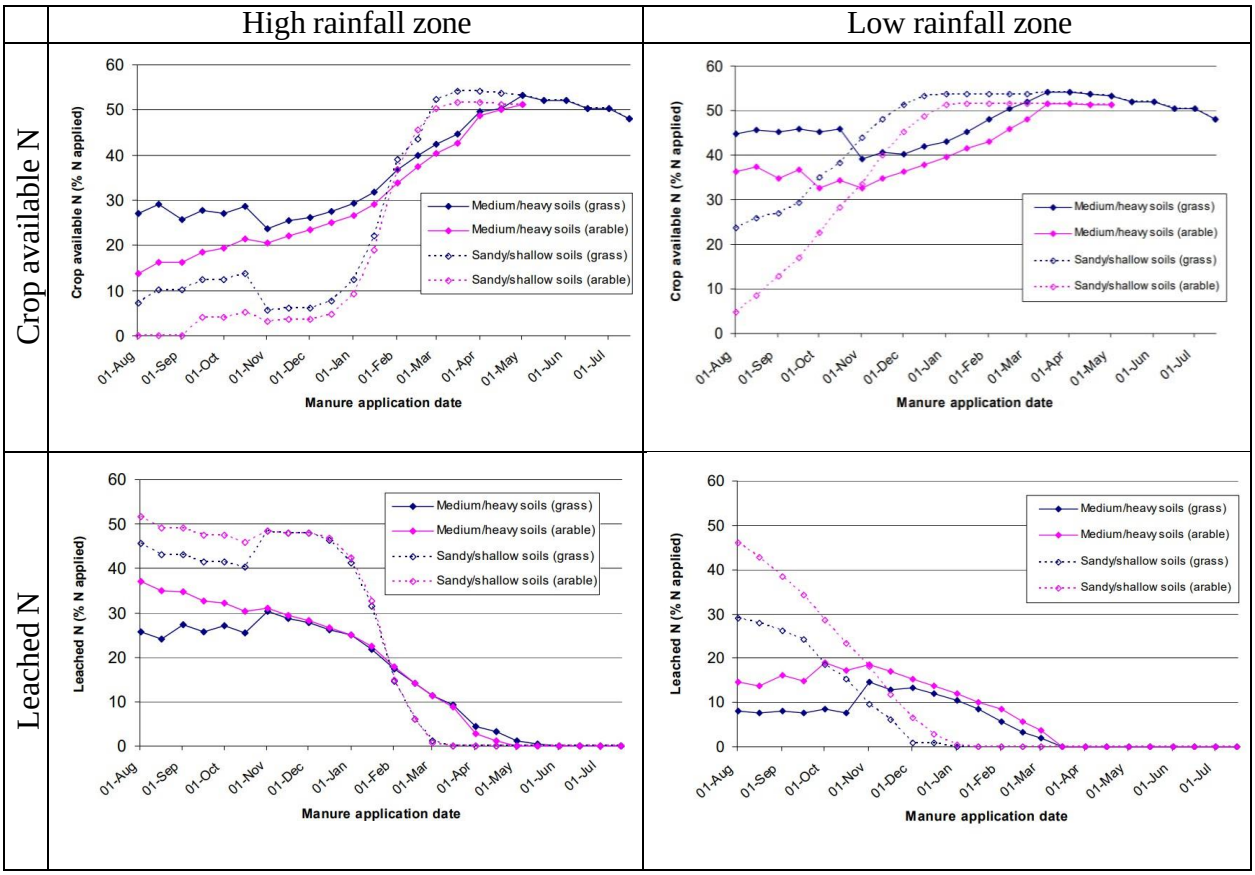
Figure 2 The proportion of N lost by $NO3^-$ leaching from application of broiler manure to a CL soil in Eastern England at times of application between early August and late March in a year of average hydrologically effective rainfall for the location. The white area of the graph represents the manure-N lost by leaching. The black area represents NH3–N emissions. The gray area represents the manure-N remaining in the soil. The units of the y-axis are kg N ha^{-1} (Webb et al., 2001).



Nicholson et al. (2011) reviewed and synthesized some UK research projects and confirmed that autumn slurry applications present the greatest risk of nitrate-N losses to drainage waters. They mentioned the MANNER-NPK-model which can predict manure N efficiencies of high-readily available N manures applied at 2-week intervals throughout the year to grassland and arable crops in the different soil type and agro- climatic zones. These results illustrated how changing the timing of manure application can affect the amount of manure N taken up by the crop (Figure 3-top). By consequence, the outputs from the MANNER- NPK-model were also used to predict nitrate leaching losses from the different high-readily available N manure applications. The

results illustrated how changing the timing of a slurry application can affect the amount of N lost through nitrate leaching (Figure 3-Bottom), and by consequence the effectiveness of a period when fertilisation is prohibited.

Figure 3 MANNER-NPK predicted crop available N (% total N applied) (top) and nitrate-N leaching (% total N applied) losses (bottom) at different application timings (pig slurry broadcast applied and not soil incorporated). High rainfall zone (median rainfall = 1200 mm/annum).- left; Low rainfall zone (median rainfall = 650 mm/annum).- right (Nicholson et al., 2011).



The authors evaluated the impact of extending the closed spreading periods (Table 1) for high-readily available N manures. Crop N uptake increased up to 5 % of total N applied for pig slurry and N leaching losses reduced with up to 3 % of total N applied for cattle and pig slurry (Table 2). For poultry manure the enhanced efficiency coincided with a 4 % of total N applied reduction of ammonia losses. Due to the closed spreading periods, the authors found a decrease in N leaching of 37.5% for cattle slurry and 30 % for pig slurry, compared to the business-as-usual manure spreading.

Table 1 'Closed periods' for spreading manures with readily available N contents greater than 30% of total N, applied for two scenarios by cropping and soil type (Nicholson et al 2011)

Scenario	Grassland	Tillage
BASELINE (2007)		
Sandy/shallow soils	15 Sept – 1 Nov	1 Aug – 1 Nov
All other soils	None	None
CURRENT NVZ-AP		
Sandy/shallow soils	1 Sept – 31 Dec	1 Aug – 31 Dec
All other soils	15 Oct – 15 Jan	1 Oct – 15 Jan

Table 2 Impact of 'closed spreading periods' and increased slurry storage on crop N uptake, nitrate-N leaching losses, ammonia- N emissions and total P losses in NVZ areas. (Nicholson et al., 2011)

	Crop N uptake		Nitrate-N leaching losses		Ammonia-N losses to air		Total P losses to water	
	Total (kt)	% total N applied	Total (kt)	% total N applied	Total (kt)	% total N applied	Total (tonnes)	% total P applied
Baseline[1]								
Cattle slurry	11.6	27	3.3	8	5.5	13	162	1.8
Pig slurry	4.4	44	1.0	10	1.6	16	40	1.7
Poultry manure	12.4	30	3.4	8	7.9	19	26	0.2
Current NVZ-AP[2]								
Cattle slurry	12.7	30	2.2	5	5.5	13	152	1.7
Pig slurry	4.8	49	0.7	7	1.4	14	38	1.6
Poultry manure	13.9	34	3.4	8	6.2	15	26	0.2

[1]Assumes 20% of cattle slurry, 75% of pig slurry and 50% of poultry manure was incorporated by plough within 24 hours.

[2]Assumes 30% of pig slurry and 4% of cattle slurry was applied by trailing hose to arable land or shallow injected to grassland. Of the remainder, 30% of cattle slurry, 80% of pig slurry and 80% of poultry manure applied to arable land was incorporated by plough within 24 hours.

Shore et al. (2016) concluded after a 4-year study in Ireland that the disproportionately high nutrient losses identified during the closed period supported the notion of restricting nutrient applications during this period. They also referred to the soil moisture deficit as a risk determining factor. Soils with a soil moisture deficit of less than 0 mm are more likely to transport available nutrients to water bodies in surface runoff and drainflow rapidly and, therefore, constitute high risk. Shore et al. (2016) noted that in almost all of the study sites the soil moisture deficit was about zero nearly all of the time in the closed period. The results demonstrate that imposing periods when the land application of certain types of fertilizer is prohibited, is effective in reducing N losses.

Figure 4 Example of scoring the coverage of the leaching risk by a closed period in the Atlantic Central environmental zone as described by Tzilivakis et al. (2021).

Environmental zone: Atlantic Central

Closed period of 1 November to 15 January:

Risk during the closed period 1(Nov) + 1 (Dec) + 0.5 (1/2 Half January) = 2.5

Maximum leaching risk in Atlantic Central: 1+0.5+1+1+1+1= 5.5

Coverage score for leaching risk: (2.5 /5.5)*100= **45 %**

Leaching risk periods for environmental zones based on Alterra et al. (2011)

Zone	Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alpine North	All crops	1	1	0	0	0	0	0.5	1	1	1	1	1
Alpine South	All crops	1	1	0	0	0	0	0	0.5	1	1	1	1
Atlantic Central	All crops	1	0	0	0	0	0	0	0.5	1	1	1	1
Atlantic North	All crops	1	1	0	0	0	0	0	0.5	1	1	1	1
Boreal	All crops	1	1	0	0	0	0	0.5	1	1	1	1	1
Continental	Arable	1	0	0	0	0	0	0	1	1	1	1	1
Continental	Grass	1	0	0	0	0	0	0	0.5	1	1	1	1
Lusitanian	All crops	1	0	0	0	0	0	0	0.5	1	1	1	1
Mediterranean Mountain	All crops	1	0	0	0	0	0	0	0.5	1	1	1	1
Mediterranean North	Arable - early summer	1	0	0	0	0	0	0	0	1	1	1	1
Mediterranean North	Arable - late summer	0	0	0	0	1	1	1	0	0	0	0	0
Mediterranean North	Non-irrigated grass/perm crops	1	0	0	0	0	0	0	0	0	0	1	1
Mediterranean South	Arable - early summer	1	0	0	0	0	0	0	0	0.5	1	1	1
Mediterranean South	Arable - late summer	0	0	0	0	1	1	1	0	0	0	0	0
Mediterranean South	Non-irrigated grass/perm crops	1	0	0	0	0	0	0	0	0.5	0.5	1	1
Nemoral	All crops	1	1	0	0	0	0	0	0.5	1	1	1	1
Pannonic-Pontic	Arable	1	0	0	0	0	0	0	1	1	1	1	1
Pannonic-Pontic	Grass	1	0	0	0	0	0	0	0.5	1	1	1	1

Key: 0 = low; 0.5 = medium; 1 = high

Tzilivakis et al. (2021) evaluated the effectiveness of the fertiliser closed periods under the Nitrates Directive. He regarded the overlap of the closed period and the risk of leaching and run-off, the latter based on Alterra et al. (2011, part D). The effectiveness depends on the length and timing of the closed period. Each closed period within each NAP was scored for coverage of the risk periods. The coverage of the risk is determined by summing up the risk scores the closed period covers (to the nearest half month) and expressing this as a percentage of the maximum. An example of a closed period in the Atlantic Central environmental zone is given in Figure 4. Their snapshot (measures in place in 2019-20) showed that in 7 Member States more than 50 % of agricultural NVZ area had more than 61 % coverage of the leaching risk periods and in 11 Member States more than 50 % of agricultural NVZ area had more than 61 % coverage of run-off risk periods.

Leaching risks are highest when rainfall is expected in combination with a period where nitrogen uptake by plants is restricted. This is most likely in cold and rainy periods, i.e., late autumn and winter. However, in dry and hot periods, plant growth is also restricted. In that respect a closed period for fertilizer application could possibly prevent leaching risks in such conditions during a precipitation event. Several Spanish regional action plans refer to respecting critical periods of fertilizer application (region of Andalucia, Extremadura) related to the vegetative state or maximum period between application and sowing/planting. In Spain, closed periods during summer occur in different regional action plans, mostly for cereals, likely due to less growth during the dry period. Greece nor Cyprus mention prohibition periods in dryer periods.

1.1.3. Environmental co-benefits and drawbacks

Closed periods have the potential to have other environmental benefits. Reducing the risk of run-off of organic material (containing pathogens and substances with a high Biochemical Oxygen Demand (BOD)) is a potential secondary benefit of closed periods (Tzilivakis et al., 2021). Prohibiting the application of organic fertilisers at times when overland flow is most likely reduces the chance of organic materials (containing and pathogenic organisms and substances with a high BOD) being transported into surface waters (Pandey et al., 2014).

Reducing the risk of N_2O emissions is also a potential secondary benefit of closed periods (Tzilivakis et al., 2021). The application of N containing fertilisers at times when soil conditions may be prone to waterlogging may result in increased denitrification and emissions of N_2O. These conditions or moments can be covered by the closed periods and as such the closed periods can reduce the risk of N_2O emissions.

A co-benefit could exist, however to a lesser extent, for NH3 emissions. The co-benefits or the combined risk reduction (whether or not N2O or NH3 emissions) depends on the positioning of the closed period, the coincidence of the respective risk periods. These will be regionally different.

A potential drawback of too strict deadlines for manure application is reduced flexibility for farmers to adapt to the current soil conditions. The effect of this will depend on climate zones and soil types. Dryer areas in Europe are less susceptible to soil compaction since wet conditions occur less frequently.

1.1.4. Minimum/threshold or optimum level of implementation

The efficiency of the measure depends on climate conditions, soil type or soil characteristics and land use (cultivated crop and crop uptake). Figure 3 (above) demonstrated that the effect was most pronounced for the shallow soils under high rainfall conditions. The length of the prohibition period is also an important parameter influencing efficiency. Nicholson et al. (2011), however, demonstrated the delicate balance of the length of the prohibition period. Extending the closed periods mentioned in Table 1 by 1 month in spring was predicted to further reduce nitrate losses. However, extending the closed period by 2 months was predicted to increase nitrate losses, compared with the 1-month extension. Moreover, the authors mentioned that a further extension of the 'closed periods' was likely to increase the potential for methane and N_2O emissions during manure storage, because of the requirement to store slurry and poultry manure for longer.

The cost of the closed periods relates to the cost associated with extra storage capacity. The economic benefits can be quantified in terms of reduced chemical fertiliser use, resulting from the improved manure nutrient efficiency, and reductions in ecosystem damage costs resulting from abated ammonia-N and nitrous oxide emissions, nitrate leaching and P losses. The report of Nicholson et al. (2011) mentioned a cost-benefit ratio of 1,4:1 for the closed periods mentioned in Table 1 for the 'current NVZ-AP'. The ratio increased by extending the storage periods, indicating that the additional costs of extending the current NVZ-AP storage periods were not reflected in proportional reductions in manufactured fertiliser use and ecosystem damage costs.

According to Alterra et al. (2011, part D) relevant factors for determining the prohibition period are the length of the growing season, the rainfall surplus outside the growing season, the temperature outside the growing season, the soil type and drainage, and the slope. Differentiation of the closed period for soil type, climate (rainfall) and land use is appropriate.

The principle of a prohibition period is climate robust. The periods as such can be adapted (shifted, extended or shortened) to changing climatic conditions. Member States could revise the prohibition period at regular intervals, e.g. every 5 years considering the climate conditions of the past 5 or 10 years. Climate change, however, increases the risk of more extreme events (e.g. droughts, rains, …) and more unpredictable events. These cannot be countered by a fixed prohibition period.

The effectiveness of fixed prohibition periods will likely be lower due to unexpected/unpredictable weather events. Prohibition periods could be supplemented with warning services or short-term prohibitions based on (longer term) weather forecasts. Such weather forecasts could take into account factors such as:

- Incidence of frost and snow
- Incidence of longer drought periods
- Risk of volatilisation
- Risk of surface runoff due to intense rainfall events
- Incidence of heavy rainfall, risk of flooding
- Incidence of wind in combination with high temperatures and/or drought

In case of short-term prohibitions, the feasibility for the farmers must not be forgotten, this demands a high degree of flexibility. Prohibition periods expressed in function of the vegetative

state of crops or in terms of a maximum period between application and sowing/planting can from that point of view be more "climate robust" than a period defined in terms of fixed dates.

1.2. Restrictions for application on water saturated, flooded, frozen or snow-covered ground.

1.2.1. Background

The restriction for application on water saturated, flooded, frozen or snow-covered ground targets the fertilized land as a potential source of risk because of certain defined states. The relevant risks include surface runoff, leaching and emission of gaseous N.

The term surface runoff covers overland flow, run-off and shallow lateral flow. Waterlogging refers to the saturation of soil with water either temporarily or permanently. Soil is regarded as waterlogged when it is saturated with water to an extent that its air phase is restricted and anaerobic conditions prevail.

1.2.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses.

There is not much scientific literature about nutrient losses through surface runoff and leaching of fertilizer and manure nutrients from water saturated, flooded, frozen or snow-covered soils in Europe. An important reason could be that it is evident that such practices will lead to high nutrient losses. Wherever the evapotranspiration of crops and the water holding capacity of soils are exceeded by natural or anthropogenic additions of water, there is a risk that nutrients will be lost. An imbalance in demand and supply of water on soils tends to occur:

- on soils that are regularly waterlogged due to an impermeable subsoil or a high water table
- when considerable amounts of snow/ice start to melt
- on soils that are impermeable due to their frozen state

Kerebel et al. (2013) stated that the risk of pollution is partly related to the soil water status during and after spreading. **Waterlogged or saturated soils** can trigger leaching, runoff or denitrification with associated gaseous losses. Wet soils have greater risk of runoff. An increase in soil moisture diminishes the hydraulic gradient and decreases infiltration into the soil.

The "infiltration capacity" or the potential infiltration rate of a soil is the maximal rate at which the soil surface can absorb water. Therefore, when the water supply exceeds the infiltration capacity, only part of it infiltrates and the remaining part remains on the soil surface or runs off according to local topography. Soil infiltration rate is a key variable in soil particle and sediment delivery processes, and it has an impact on fertilization efficiency, environmental quality, and water conservation (Assouline, 2013).

Motarjemi et al. (2023) studied the impact of different drainage conditions in Denmark. They found that N losses of poorly drained soils were 14 % higher compared to those of well-drained soils. Greater losses of nitrogen through leaching from drainage and other pathways were measured at the poorly drained soils (109 kg N ha^{-}1 ya^{-1}) compared to the well-drained soils (95 kg N ha^{-1} ya^{-1}). At the same time, denitrification in topsoil was also higher under poor drainage conditions (see also section 1.2.3 below).

Soils with **frozen** soil layers have low water infiltration rate and hydrological conductivity. These elements, even when the frozen soil layer is below the soil surface, can trigger superficial run-off and enhance the risk of overland flow. Srinivasan et al. (2006) referred to Hensler et al. (1970), who applied fresh dairy manure on frozen soils for two consecutive winters and found that the runoff losses were variable. During the first year of observation, more N and P losses were noted in runoff than occurred during the second year. They observed that the dry winter conditions during the second year resulted in less nutrient losses. Williams et al. (2012) mentioned the infiltration of water into the soil varied according to soil temperature during precipitation. They observed a 56 % increase in runoff volume for frozen soils compared to non-frozen soils and referred at that point to Zuzel and Pikul (1987) and Gray et al. (2001) who also mentioned an increase in runoff volume on frozen soils.

Young et al. (2022) measured nutrient losses after dairy manure was applied on top of an established **snowpack**. The results indicated that applying manure on top of snow resulted in high nutrient losses when runoff occurred, regardless of manure solids content. They concluded that liquid manure application on top of an existing snowpack resulted in high N and P losses in snowmelt runoff and was potentially a high-risk surface water quality condition depending on runoff hydrology and stream proximity.

Williams et al. (2011) examined manure application under winter conditions using laboratory methods (Table 3). They studied the influence of manure position within the snowpack on surface and subsurface losses of N and P. For one of the treatments, manure was applied on frozen ground, so this study can give evidence for fertilisation on frozen ground and snow-covered ground and the possible loss. Manure application on frozen ground or on top of a snow cover resulted in higher N and P losses. (All soils were at field capacity at the time of soil freezing, influencing the volume of surface runoff.)

Table 3 Summary of nitrogen and phosphorus losses in surface runoff and subsurface leachate (Williams et al., 2011).

	Runoff and Leachate Losses (μg cm^{-2})					
	NH_4-N		NO_3-N		Total N	
Treatment	Snowmelt	Rainfall[b]	Snowmelt	Rainfall[b]	Snowmelt	Rainfall[b]
Control (C)	n/a	0.9 ±0.4	n/a	0.5 ±0.1	n/a	4.3 ±1.3 b
Manure on frozen soil (MF)	n/a	8.9 ±7.1	n/a	0.4 ±0.3	n/a	39.2 ±33.1 a
Snow-covered control (SC)	0.8 ±0.3	0.8 ±0.3	<0.1	0.3 ±0.6	3.6 ±1.2 c	7.5 ±5.4 b
Manure on top of snow (MTS)	76.4 ±22.1	3.3 ±1.6	<0.1	0.3 ±0.3	254.5 ±14.8 b	12.1 ±4.6 ab
Manure between snow (MBS)	113.8 ±46.1	2.7 ±0.5	<0.1	0.3 ±0.2	230.6 ±56.8 b	11.1 ±1.3 ab
Manure under snow (MUS)	205.3 ±36.6	5.9 ±2.7	<0.1	<0.1	362.4 ±66.5 a	18.3 ±5.1 ab
	DRP				Total P	
	Snowmelt	Rainfall[b]			Snowmelt	Rainfall[b]
Control (C)	n/a	0.1 ±0.1			n/a	0.8 ±0.2 b
Manure on frozen soil (MF)	n/a	1.0 ±0.7			n/a	4.0 ±2.9 ab
Snow-covered control (SC)	0.1 ±0.1	0.1 ±0.1			2.2 ±0.8 c	1.6 ±1.1 ab
Manure on top of snow (MTS)	2.4 ±0.7	1.1 ±0.3			10.9 ±0.8 a	2.9 ±0.7 ab
Manure between snow (MBS)	1.5 ±0.6	1.2 ±0.3			8.5 ±1.5 b	2.8 ±0.3 ab
Manure under snow (MUS)	0.7 ±0.2	2.8 ±0.7			9.1 ±1.5 ab	4.5 ±1.3 a

[a] Values are means ± standard deviation (n/a denotes not applicable).
[b] Rainfall values are sums of surface runoff and subsurface leachate losses.

Alterra (2011-partB) confirmed the necessity of this measure and stated that the application of fertilizers and manures to water-saturated, flooded, frozen or snow-covered ground is associated with very high risk for surface run-off/leaching of N and P, possibly resulting in water pollution.

Moreover, they point out that such applications of fertilizers and manures are not effective as in these situations there are no growing crops and, consequently, no demand for nutrients (Alterra, 2011-part B).

1.2.3. Environmental co-benefits and drawbacks

Waterlogging can create anaerobic conditions which can cause denitrification. Denitrification is the process of anaerobic bacteria in soil converting nitrate-N into gaseous forms like nitric oxide, nitrous oxide and di-nitrogen. Nitrous oxide (N_2O) is a potent greenhouse gas. The primary N loss mechanism from saturated, fine-textured soils may be denitrification. Many studies have observed denitrification increasing when water filled pore space is above 60%. Denitrification will only occur if microbes have access to a food source in the form of soil organic matter, crop residues, or manure. Adding N fertilizers to soils that are already saturated may cause gaseous N losses. In contrast, waiting for the upper few centimeters of soils to dry reduces the risk of losing applied N through denitrification. Soil water content and soil N availability were found to be co-required for high N_2O emissions (Abdalla et al., 2011).

Fertilisation on waterlogged or water saturated soils is not generally expected of farmers, since they rather prefer frozen soils for their carrying capacity. However, the prohibition will certainly contribute to the maintenance of soil structure, avoiding heavy machinery being operated on wet soil.

1.2.4. Minimum/threshold or optimum level of implementation

Although this restriction is an effective measure, the restriction will not be equally relevant everywhere, as pedo-climatic zones vary in rainfall, monthly temperature and periods with frost and snow and also in the relative areas used for agriculture. Alterra et al. (2011-part B) provided an indication of environmental zones with a serious risk of nutrient emissions due to thawing. The indication for the risk of nutrient emissions due to thawing was derived from databases giving information on frost and precipitation: without frost there will be no thawing and generation of water.

The cost of this measure relates to the cost associated with sufficient storage capacity. This cost coincides, however, with the storage cost related to the closed periods, so this measure may not be experienced as a significant extra cost when considered in relation to the closed periods as a whole.

The measure as such is clear, effective, efficient and climate robust. The importance of the measure can change depending on climate change. Global climate change causes waterlogging events to be more frequent, severe, and unpredictable. The change of importance can differ between regions.

The measure can be experienced by farmers as contradictory to good agricultural practices, as they often appreciate frozen soils for their carrying capacity allowing land spreading of manures without negatively affecting the soil structure. European scientific analysis, even in expected low risk situations, could be convincing and boost willingness to comply with this measure. A clear and well underpinned rationale contributes to the respect of the measure.

Williams et al. (2011) referred to Zuzel and Pikul observing that high soil moisture contents at the time of soil freezing can significantly decrease the final infiltration rate (Zuzel and Pikul, 1987 in Williams 2011). From that point of view, fertilisation on frozen soil could be considered

under certain conditions. However, the conditions would be very specific and not easy to define. Control and enforcement would be very difficult.

1.3. The capacity and construction of storage vessels for livestock manures.

1.3.1. Background

During specific periods of the year nutrients in manure cannot be utilized efficiently and pose a significant risk of water pollution. During these periods, manure must be stored.

1.3.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses.

Sommer and Knudsen (2021) referred to the so-called Harmony Rules in the late 1980s in Denmark, which introduced mandatory stipulations on manure storage capacity, application of manure during the growing season, and limitation on the number of animals per hectare agricultural land. Very high local surpluses of N and phosphorus were prevented. The authors stated that the ban on direct discharge of manure and the ban of application of manure in periods without or with limited plant nutrient uptake, were the two most important regulations that were implemented. Also in Denmark, Petersen et al. (2021), who analyzed three decades of trends in NO_3^--concentration in five agricultural catchments, revealed the importance of the manure storage capacity for decreasing stream NO_3^--concentrations.The mandatory storage capacity, being in line with these regulations, can be assessed as an effective measure, in combination with the prohibition periods. It is an effective, but also a costly measure. Construction of storages so as to prevent leakage and ensure impermeability is essential in order to avoid point losses and leaching. The risk of airborne emissions should also be considered.

1.3.3. Environmental co-benefits and drawbacks

Environmental co-benefits

Storage of manure allows to apply nutrients at the right time for crop uptake. The regulation of nutrient application to crops via manure application, by storing it during periods in which soil application should be avoided, allows to optimize crop production while decreasing nutrient leaching.

Environmental drawbacks

The storage of manure has other environmental consequences. Nutrient losses from manure storage facilities are mainly linked to emissions of ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4), the latter two being greenhouse gases. The level of emissions from manure storage facilities depends on the type of manure storage (manure as a solid, liquid, or slurry) and whether or not the manure storage facility is covered (Table 4).

Table 4 Manure N loss (%) from different storage systems (Yang et al., 2011).

Storage systems *m*	Housing N loss (%)[z]	Storage N loss (%)[y]	Total N loss (%)	References
Liquid system				
1. Unlined lagoon	N/A	70	70	Lagoon, Table 3–8 (USEPA 2004)
2. Lined lagoon	N/A	50	50	70% of unlined lagoon
3. Open tank	5	24	28.5	Flush barn, Table 3–8 (USEPA 2004)
4. Tank below slatted floor	5	17	21.5	70% of open tank
5. Sealed covered tank	5	7	11.6	Tanks, Table 3–8 (USEPA 2004)
6. Other	5	17	21.5	The same as tank below slatted floor
Solid system				
1. An open pile on the ground without a roof	5	20	25	Stockpile, Table 3–8 (USEPA 2004)
2. An open pile on the ground with a roof	5	15	20	Solid fraction manure-cattle, Table 2 (Hutchings et al. 2001)
3. Manure pack in barns, pens or corrals	5	10	15	75% of an open pile on ground without a roof
4. An open pad without runoff containment	5	15	20	Solid fraction manure-cattle, Table 2 (Hutchings et al. 2001)
5. An open pad with runoff containment	5	8	13	Outdoor confinement areas, Table 3–8 (USEPA 2004)
6. A covered storage pad	5	4	9	50% of an open pad without run off containment
7. Other[x]	5	15	20	The same as an open pad without run off containment

[z]5% N loss from housing is used in this paper due to the lack of measured data.
[y]Storage N loss rates were based on literature.
[x]Compost was grouped with "other manure" in the survey.

The ammonia emission rate is a function of the ammonia N concentration in the manure, ambient temperature, manure pH, manure moisture content, the exposed manure surface area and wind velocity near the surface. As many of these factors involve the storage surface, a common ammonia reduction strategy is to use a storage cover. According to Brusselman et al. (2016) reduction of the ammonia emission during manure storage is based on the following principles:

- Reduce the free surface of the manure storage;
- Reduce the ammonia source strength (by lowering the pH and the ammonium concentration);
- Leave the manure undisturbed as much as possible

So, lowering the pH of the slurry can be another way to reduce ammonia emissions from storage. With a system decreasing slurry pH to 5.5 by adding 4-6 kg concentrated sulfuric acid per ton of manure, the ammonia emissions were reduced by 70% (Pedersen, 2004). Finally, considering the three possible sources of emissions: manure management from livestock, manure applied to soils and excreta deposited by grazing livestock, manure management almost always predominates as the main emitter of ammonia, followed by manure applied to soils (Malherbe et al., 2022). When manure is stored as a liquid, it decomposes anaerobically. The combination of anaerobic conditions and degradable organic matter results in the production of a significant quantity of methane. The temperature and the retention time in the storage unit greatly affect the amount of methane produced. When manure is stored as a solid, it tends to decompose under more aerobic conditions and less methane is produced.

Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment. Nitrification is likely to occur in stored animal manures provided there is a sufficient supply of oxygen, it does not occur under anaerobic conditions. Nitrites and nitrates are transformed to N_2O and dinitrogen (N_2) by denitrification, an anaerobic process. Nawara et al. (2021) concluded based on a literature study that an aerobic storage of solid and liquid manure would reduce the greenhouse gas emissions. Aeration would decrease methane emission, increase the N_2O emission but result in a net decrease of total greenhouse gas emission.

1.3.4. Minimum/threshold or optimum level of implementation

This measure is an easily controlled measure, supportive of the prohibition periods. Up to date N-excretion values for livestock with a clearly defined calculation and correct quantification of the required storage capacity will support the commitment of the farmers for this measure. The measure demands an investment of the farmers. Regarding the situation or state of art at the average farms and the efforts that generally still have to be made, a financial support measure can be considered. It will increase the ability and motivation of the farmers.

Adequate requirements for the construction of manure storages can reduce losses by volatile emissions. A minimum of prescriptions is necessary and should be included in legislation. The prescriptions enhance the efficiency of this measure to reduce N losses.

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2. CLUSTER II - SLOPING GROUND, WATER COURSES

2.1. Restrictions for application on steeply sloping ground

2.1.1. Background

A sizeable portion of agricultural activities takes place on sloping lands, with estimated 0.62 million hectare on slopes > 25% and 1.78 million ha on slopes between 15 and 25% within nitrate leaching vulnerable zones in the EU-27 (Velthof et al., 2014). On these lands, nutrient loss to surface waters can occur due to both overland-flow and soil erosion. In Flanders, about 25% of the agricultural area is vulnerable to erosion (Departement Leefmilieu, Natuur en Energie, 2011). The Nutrient Emission Model of the Flemish Environmental Agency (NEMO; Van Opstal et al., 2014) estimates the total yearly N-losses due to runoff to be 600 ton N, which equals to 2.5% of the total N losses from agricultural fields to the surface waters. In the Mediterranean area, soil erosion is one of the biggest environmental threats. The areas subjected to soil erosion in the Mediterranean area cover 1,309,000 km², equal to 15% of the land of Mediterranean countries (Cosentino et al., 2015). Globally, 20% of cropland is estimated to be affected by soil erosion (Prăvălie et al., 2021).

The impact of slope on average risk of soil erosion can be calculated with the S-factor within the Revised Universal Soil Loss Equation (RUSLE), which shows an increased risk of soil erosion starting from a slope of 9% (McCool et al., 1987; McCool et al., 1989). Zhang et al., (2015) found a similar relation between sediment yield and slope for farmland and fallow land in Southern China, concluding that starting from a slope of 7-15% erosion on farmland and fallow land became most severe, whereas forests and orchards showed smaller degrees of erosion at these slopes. Based on calculations of the RUSLE model, Alterra Wageningen UR (2011, the Netherlands) considered a full ban on fertiliser application on land with slopes of 8-15% or more to be judicious from a precautionary perspective, with the lower value of 8% referring to arable land, which is more vulnerable to soil erosion, and the upper value of 15% referring to permanent grasslands. Deviation from this rule could be made possible for direct injection of fertiliser and slurries into the soil. In the EU member states in general, restrictions for the spreading of fertilizers on sloping ground are applied to slopes as from >10% to >30%. Practical restrictions vary between member states, regions, etc. and include the following types of measures:

- total prohibition of any fertilizer application on any ground with slopes higher than a limit value,
- prohibition of fertilizer application on sloping ground along watercourses (with varying distances and in some cases depending on the presence of a grassy or perennial unfertilized buffer strip),
- limitation of the applied N-doses on sloping ground and/or obligation of splitting the fertilizer in several doses,
- prohibition of fertilizer application in certain periods (autumn-winter),
- obligation of measures to prevent runoff and erosion, e.g. injection or incorporation of fertilisers within 12 or 24h, terraces, intercropping, conservation tillage, tillage perpendicular to the line of maximum slope.

In addition, restrictions can be different depending on the application technique, the application of measures to prevent runoff and erosion, the applied fertilizer type (mineral or organic, liquid or

solid, rapid release N fertilizers, etc.), the crop type (permanent grassland vs. arable crops), specific geomorphological and soil conditions, predicted rainfall, and the size of the field.

2.1.2. Assessment of the effectiveness and efficiency in terms of preventing and reducing nutrient losses

Generally, nutrient losses through erosion on sloping ground can be reduced by restrictions regarding the application of nutrients on the one hand, or by measures to avoid/reduce runoff and erosion on the other hand. Two main strategies to avoid erosion can be distinguished: (1) make the soil more resilient to erosion and (2) break the force of rain and runoff. This translates into some basic rules that can be used to limit erosion: maintain organic matter content and pH; avoid soil compaction so that water can penetrate the soil properly; keep the soil covered as much as possible with crops, e.g. green cover crops or crops with good (and fast) ground cover; keep crop residues/green cover residues on the surface by not ploughing; leave more clods in the seedbed; avoid preferential lines along which water flows more quickly, e.g. by installing "speed bumps" between ridges and erasing tire tracks.

In the following paragraphs, the effectiveness and efficiency of the most common practical measures to reduce nutrient losses on sloping grounds are reviewed.

2.1.2.1. *Limit fertilizer application on slopes*

Nutrient pollution caused by agricultural fertilizers can be directly controlled by limiting the amount of fertilizer applied. However, it should be kept in mind that this does not directly affect the pollution caused by the nutrients that are naturally present in the soil (Wang et al., 2023). Therefore, in many cases efforts still have to be made to reduce soil and water erosion even when reducing fertilizer application on the slopes. On the other hand, the application of organic fertilizer or manure can have a positive effect in reducing soil erosion by changing the physicochemical properties of the soil, such as the presence of macro aggregates, the soil organic carbon content, and exchangeable cations (Cui et al., 2023). Therefore, more emphasis should be put on reducing mineral fertilizer application than on organic fertilizer application.

As for the quantitative impact of reducing fertilizer application rates on slopes, results from peer-reviewed scientific studies within the EU are scarce. Rodríguez Sousa et al. (2022) found that on olive groves in Portugal, conventionally managed intensive and highly intensive groves used greater amounts of NPK fertilizers, which ultimately led to a higher risk of diffuse pollution. Intensive and highly intensive farms showed both higher erosion (up to 48 t/ha/year) and nitrate concentration (11-16 ppm) than integrated and organic farms (erosion up to 20 ton/ha/year and nitrate concentration up to 5-6 ppm), with part of this difference being attributed to the higher amounts of NPK fertilizer application on intensive farms. In this case, the organic farms had on average 60% less risk on diffuse pollution.

2.1.2.2. Effect of reduced tillage

Both non-inversion tillage and no tillage (no-till) have well documented effects on the reduction of soil erosion, often in combination with mulching of the soil (e.g. in Volker, 2012; Choudhary et al., 1997; Leys et al., 2007; Chalise et al., 2019; Keesstra et al., 2016; Tebrürrge & Düring, 1999). These reductions can in principle also result in reduced nitrogen and phosphorus losses, however, this reduction is certainly not guaranteed. Stevens and Quinton (2009) conclude that the effect of no-tillage on leaching losses is unclear, with no-tillage assumed to be the most extreme application of reduced tillage. Cooper et al. (2017) reported no effect of shallow non-inversion tillage and direct drilling on soil water NO_3-N and P concentrations compared to

conventional ploughing. Furthermore, even when erosion and/or run-off of N and P is reduced, care should be taken, especially for nitrogen, that these nutrients are not lost due to other pathways such as deep percolation or subsurface runoff (Xia et al., 2014).

2.1.2.3. Contour tillage

With contour tillage, tilling and sometimes planting is carried out along the contour lines of the land instead of up and down the slopes. In this way, water runoff is slowed down and infiltration is increased. This practice is effective on slopes with gradients between 2% and 10% (NRCS, 2007). Contour cultivation, especially in combination with the addition of organic matter and the mulching of straw, has been shown to reduce runoff depths as well as soil erodibility, resulting in a reduction of total N-losses by 33 to 63% (Zhang et al., 2016).

2.1.2.4. Contour vegetative barriers

Contour vegetative barriers are grass strips, hedges, or other vegetative barriers that are located within fields and act as barriers to overland flow (Stevens and Quinton, 2009). The effect on sediment losses is well established, with the effectiveness of contour grass strips reported as 15-79%, depending on both grass type and flow rate (Ligdi and Morgan 1995; Dabney et al., 1995). The effect on nutrient losses are expected to be similar to riparian buffer zones (Stevens and Quinton, 2009). Xia et al. (2014) reported significant effects on P but not on N using *Vetiveria zizanioides* and alfalfa contour hedgerows, with reductions of 31-47% in sediment P losses, 28-45% in surface runoff total P losses.

2.1.2.5. Mulching and use of crop residues

Crop residues can be retained on the soil surfaces to act as mulch and help in controlling wind and water erosion. Steven and Quinton (2009) report an average reduction in soil loss of 78% (with range of 40- 100%) from the use of crop residues. Crop residues will release nutrients as they are decomposed, and the fate of these nutrients is determined by the interplay of processes such as immobilization, mineralization, and plant uptake. Therefore, the use of crop residues has only been moderately successful in the reduction of nitrate and phosphate leaching (Thomsen, 2005; Schreiber, 1999; Stenberg et al., 1999; Sharley and Smith, 1991). On the other hand, crop residues are generally more successful in reducing N and P in overland flow (Mostaghimi et al., 1992; Tiscareno-Lopez, 20024; Torbert et al., 1999; Andraski et al., 2003).

2.1.2.6. Perennial crops

Perennial crops, such as perennial grass, can improve soil structure and stability, soil quality, and biodiversity in comparison to annual crops (Zegada-Lizarazu et al., 2010). This can be especially advantageous in regions where soil erosion is a serious concern. Cosentino et al. (2015) reported higher N losses through leaching with annually tilled crops (0.23-2.21 kg N/ha) compared with perennial crops (0.11-0.66 kg N/ha).

2.1.2.7. Cover crops

Cover crops or catch crops are effective in the reduction of soil erosion and nutrient losses through leaching. Even on non-sloping soils, cover crops reduce nitrate leaching directly by intercepting nitrogen that would otherwise be lost from the plant-soil system. The quantitative impact of these reductions, although widely reported, is very mixed, with a review of literature showing reductions between 0 and 98%, with an average annual value of 48% (Stevens and Quinton, 2009). One example from the UK reports a decrease in nitrate leaching losses in soil water of 75-97% by using an oilseed radish cover crop relative to fallow, but had no impact upon

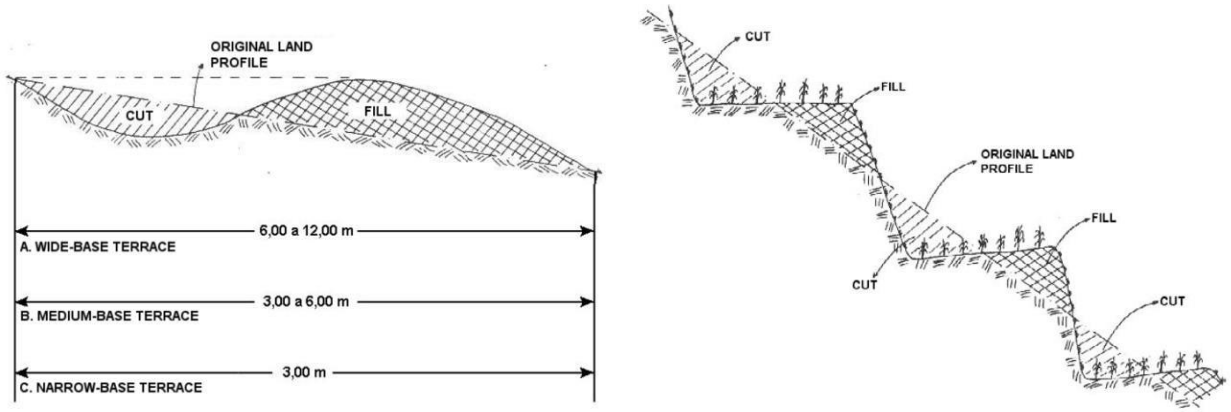
phosphorus (P) losses. Corresponding reductions in riverine NO_3-N concentrations however were not observed (Cooper et al., 2017). On the other hand, the long-term frequent use of cover crops can also increase the risk of nitrate leaching, by increasing the mineralizable nitrogen in the soil. Thus, in years when the catch crop develops poorly, or if the use of catch crops is discontinued, the potential for nitrate leaching is enhanced (Aronson & Torstensson, 1998). Cover crops can also reduce nitrate losses by impacting overland flow. In theory, increased infiltration and evapotranspiration should reduce the volume of overland flow, however in practice both increases and decreases in the nitrate concentration of runoff are reported. When comparing cover crops with bare fallow treatments, a review of Sharpley and Smith (1991) reports the effect of cover crops as ranging from an increase of 31% to a reduction of 87% in nitrate concentration of the runoff. These differences are attributed to site-specific climatic, soil, and crop factors.

2.1.2.8. Terracing

Terracing is one of the oldest measures taken to reduce soil and water losses on sloping ground and are a distinctive feature of the agricultural landscape in Europe (Stanchi et al. 2012). There is a wide variety in the types of terraces, which can be classified according to different criteria (Dorren & Rey, 2004):

1) their main function: *retention* vs. *diversion* of the rainfall runoff
2) the construction process: *channel* (only excavation of soil from uphill side) vs. *ridge* (excavation from both sides of the embankment)
3) the size of the terrace base: *narrow* (soil movement < 3m) vs. *medium* (3-6m) vs. *wide* (6-12m, Figure 5)
4) the terrace shape: *common/normal* (as shown in Figure 5, left) vs. *bench* (Figure 5, right)

Figure 5 Left: diagram of a common terrace form, with illustration of the classification according to difference base sizes. Right: diagram of a typical bench terrace (FAO, 2000).



This classification is relatively detailed, and most publications refer mostly to bench terraces, contour terraces, and parallel terraces; with contour terraces following the contour lines of the terrain, and parallel terraces being constructed parallel to each other (Brown et al. 2021).

The advantages and disadvantages of terracing are summarized in Table 5.

Table 5 Overview of advantages and disadvantages of terracing, based on reviews by Brown et al. (2021), Dorren & Rey (2004), Deng et al. (2021) and Stanchi et al. (2012)

Advantages	Disadvantages
Reduction of runoff and soil loss due to water erosion	Rainwater saturation of the soil can lead to higher storm runoff
Can act as a major store of catchment nutrients	Disturbance of the soil can lead to lower soil quality and fertility in the first few years after construction
Increased soil moisture content and crop yields	Labour cost for construction and maintenance
Conservation of plant biodiversity on a local scale	Large risk of land degradation if management and maintenance are not carried out (sufficiently)

As with many of the measures used to combat soil and water erosion, there is a large amount of research and broad agreement on the effect of the measure on soil and water erosion itself, but the effects on soil nutrient cycling are much less studied, as noted specifically for terracing by the review of Stanchi et al. (2012). These processes are generally more complex, because the nutrients can take different pathways from the soil to the surface- and groundwater and may undergo chemical changes along the way. Generally, and theoretically, however, it can be expected that terracing reduces the risk of N and P losses to surface- and groundwater, because the increased retention of catchment nutrients in the soil will be coupled with increased crop uptake, which will remove (most of) the nutrients from the soil and water cycle. However, this underlines the importance of soil cover during the year, for example with cover crops during the off-season. Additionally, when coarse material is used as filling material for the terraces, rapid water drainage can occur, leading to water stress and increased nutrient losses (Stanchi et al., 2012). This again emphasizes the importance of the design and management of the terraces.

Quantitative figures for the effect on N and P are scarce; however, the effects that are found are in agreement with the expectations stated above: higher nutrient availability on the terraces, and reduction of losses. We have summarized these studies in Table 6.

Table 6 Quantitative effects of terracing on N and P, literature overview

Source	Location	Effect of terraces
Chen et al. (2021)	China (diverse regions)	Increase in soil total nitrogen (TN) of 5, 6 and 43%
Qiang et al. (2020)	Loess plateau of China	Increase in soil organic carbon (SOC) of 50% and soil TN of 75%
Wacha & Giley (2023)	USA (general)	40% decrease in nitrogen (N) and phosphorus (P) loads

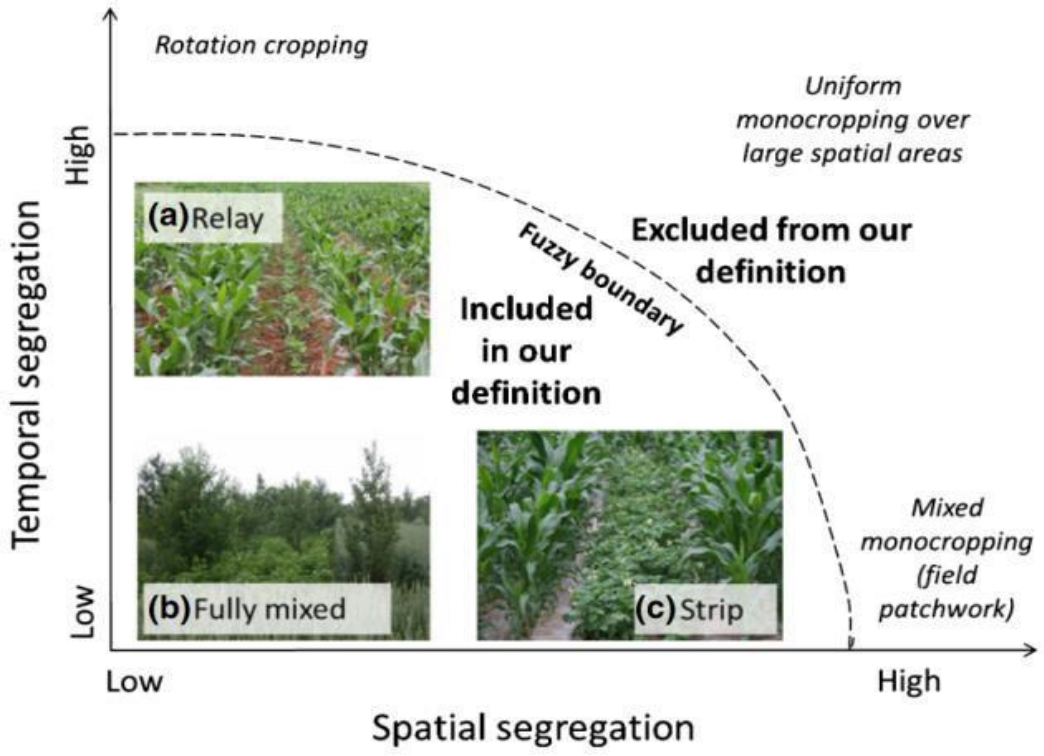
Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, & Iowa State University College of Agriculture and Life Sciences (2013	Iowa, USA	77% decrease in P losses
Bezu & Tezera (2019)	Tigray, Ethiopia	Increase in plant-extractable P of 32% and SOC of 200%

2.1.2.9. Intercropping

Intercropping is the practice of growing multiple crop species at the same time in the same place (Figure 6). Different types of intercropping are distinguished:

- Mixed intercropping: two or more crop species are grown together at the same time in a field without using any particular spatial configuration.
- Strip or row intercropping: two or more crop species are grown in separate, but adjacent, rows at the same time.
- Temporal intercropping: a fast-growing crop is sown together with a slow-growing crop, so that the fast-growing crop is harvested before the slow-growing crop starts to mature.
- Relay cropping: a second crop is sown during the growth, often near the onset of reproductive development or fruiting, of the first crop, so that the first crop is harvested to make room for the full development of the second (overlap with the technique of under-sowing of a grass cover crop, e.g. in maize).

Figure 6 Definition of intercropping based on the temporal and spatial segregation (source: Brooker et al. 2015)



The primary goal of applying intercropping is to obtain complementarity between the different crops: available resources are partitioned and more completely utilized and competition is minimized as a result of different resource acquisition traits: differences in rooting depth, phenology, vegetative architecture, etc. Moreover, one crop species can provide limiting resources or improve environmental conditions for the other species, e.g. a legume crop providing nitrogen or a taller crop providing physical support for the other crop (Bybee-Finley & Ryan, 2018). In practice, farmers also use intercropping to reduce soil erosion, prevent nutrient losses and suppress weeds, as well as provide other ecosystem services such as moisture management, pest reduction, and to increase aggregate yields.

Advantages and disadvantages when compared with monocropping systems are summarized in Table 7.

Table 7 Overview of advantages and disadvantages of intercropping (Brooker et al., 2015; Bybee-Finley & Ryan, 2018; Jørgensen et al., 2000; Blessing et al., 2021; Marques et al. 2010; Jensen et al., 2020)

Advantages	Disadvantages
More complete exploitation of resources (solar radiation, water, soil nutrients, fertilizer)	Not always suitable for mechanization in an intensive farming system
Improved biodiversity, e.g. by providing a habitat for a variety of insects and soil organisms that would not be present in a single-crop environment	Undesirable when a single standard product is required
Pest reduction by increasing predator biodiversity by increasing barriers against biological dispersal of pest organisms through the crop: trap cropping, repellant intercrops, push-pull cropping, etc.	Lack of economies of scale for labour and time management
Weed control	Aggregate yield is not always increased
Reduction of use of N-fertilizer (in case of intercropping with legume crops)	Competition for resources (water) in certain conditions
Pollution mitigation; reduction of nutrient losses	
Input of organic carbon to the soil; improved soil structure	
Similar and even increased aggregate yields	
More stable aggregate yields, decreased risk of crop failure	
Erosion control by continuous soil cover (in time and in space)	

Regarding the reduction of nutrient losses to the environment, intercropping provides a more efficient use of nutrients in the soil and therefore can be useful in reducing nitrate leaching. For instance, a 3-year study in China on strip intercropping with sweet corn and soybean showed a 40% reduction in soil mineral N at the time of harvest compared to the corn monoculture (Tang et al., 2017). During a 2-year experiment in Czech Republic, mixed intercropping of winter wheat and white clover reduced mineral nitrogen losses by 20% compared to sole winter wheat (Kintl et al., 2018).

Finally, in erosion-sensitive crops, such as maize and perennial row crops such as vineyards and orchards, intercropping can provide an efficient soil cover between crop rows, offering a solution against erosion on sloped fields. This effect is reported in several studies regarding the use of

intercrops in row crops to reduce surface runoff and soil erosion (Table 8).

Table 8 Erosion reduction through intercropping

Source	Location	Crop	Soil type	Slope	Reduction of surface runoff	Reduction of soil losses
Biddocu et al. (2017)	Italy	vineyard	clay – clay-loam	15%	50-66%	72-89%
Gomez et al. (2009)	Spain	olive orchard	sandy loam	11%	64%	98%
Kincl et al. (2022)	Czech Republic	maize	Haplic Luvisol	6.6-10.0%	0-66.2%	18-80%
Kabelka et al. (2021)	Canada	hop	Luvic Cambisol	9-17%		9-82%
Marques et al. (2010)	Spain	vineyard	sandy loam	14%	0%	93%
Novara et al. (2011)	Sicily	vineyard	Vertic Haploxerept	15.9%		68%
Wall et al. (1991)	Canada	maize	Luvisol	5%	45-87%	46-78%
Zuazo et al. (2008) (review)	Mediterranean	olive&almond orchards		30-35%	18-78%	51-94%

2.1.3. Environmental co-benefits

- Reducing nitrous oxide (N_2O) losses to atmosphere when using less N fertilizer;
- Reducing loss of fertile soil;
- Reducing risk of mudslides during heavy rainfall.

2.1.4. Minimum/threshold or optimum level of implementation

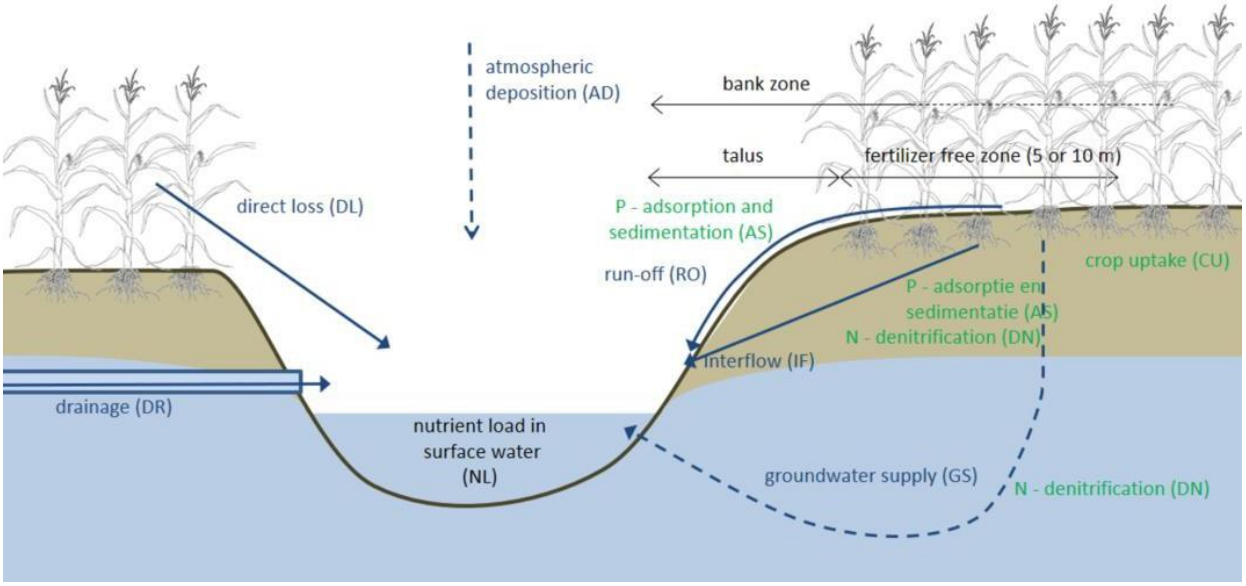
As illustrated in the discussion of the effectiveness of the different measures used to combat nutrient losses on steeply sloping ground, the effectiveness of these measures is in many cases reported as a very wide range. For some measures, not enough research is available to even safely determine this range. While the effect of these measures on reducing soil and water erosion is generally quite well understood and can be modelled using equations such as the RUSLE, the subsequent effect on N and P losses is dependent on relatively complex processes such as immobilization, mineralization, and plant uptake. These processes are in turn dependent on site-specific parameters such as climate, soil type, slope, crop type, and land management. Therefore, the impact on N and P losses is much more variable in results from field studies and is much more difficult to model. Based on this review of existing literature, the use of cover crops and limiting the mineral fertilizer application on slopes show the most well-documented impact on limiting nutrient losses on steeply sloping ground.

2.2. Restrictions for application near watercourses (buffer strips)

2.2.1. Background

As shown in Figure 7, nutrients can end up unintentionally in surface water through various transport routes: deposition during fertilizer application (direct losses), atmospheric deposition, run-off and interflow (subsurface drainage), leaching (groundwater supply), and drainage. During transport as well as in the surface water itself, nutrients are subject to various processes resulting in their retention, conversion and/or removal, including crop uptake, physical processes (adsorption, sedimentation), chemical and microbiological processes (denitrification).

Figure 7 Nutrient loads in surface water: transport routes, processes and factors (Tits et al., 2018).



Nutrient transport via atmospheric deposition and drainage (through drainage pipes) will not be further discussed, since buffer strips along watercourses have little or no influence on these routes.

For Flanders, Tits et al. (2018) calculated that the total amounts of nutrients ending up in watercourses via direct deposition during fertilisation are relatively small, compared to the nutrient loads via other transport routes (runoff, drainage). However, they represent peak loads in surface water that temporarily cause high nutrient concentrations and are therefore important for surface water quality.

In order to reduce nutrient losses to surface water via these transport routes, buffer strips can be implemented along watercourses. A distinction can be made between fertiliser-free buffer strips (i.e. unfertilised zones in which the same crops are grown as in the rest of the field) and vegetated buffer strips (i.e. unfertilised zones in which a permanent cover such as grass is grown). Vegetated buffer strips specifically designed to decrease nutrient transport from agricultural fields to surface water are further discussed under Cluster V (buffers, nature-based solutions).

In the EU, restrictions for the application of fertilizers near surface water apply in most of the Member States. The distance to the waterbody that must be respected in specific conditions vary from 2 to 100 m, depending on a number of factors, such as the slope of the field or of the zone along the watercourse, the application equipment and/or the incorporation of the fertilizer, the surface area and/or width of the field, the type of water body (lake, watercourse, etc.), the type of fertilizer (mineral, organic, liquid, solid, etc.), the presence of a (permanent) plant cover, hedges or wooded bands, the amount of fertilizer applied and the type of crop (row crops or other crops).

2.2.2. Assessment on the effectiveness and efficiency in terms of preventing and reducing nutrient losses

A fertilizer-free zone bordering surface waters can both prevent or reduce direct deposition of

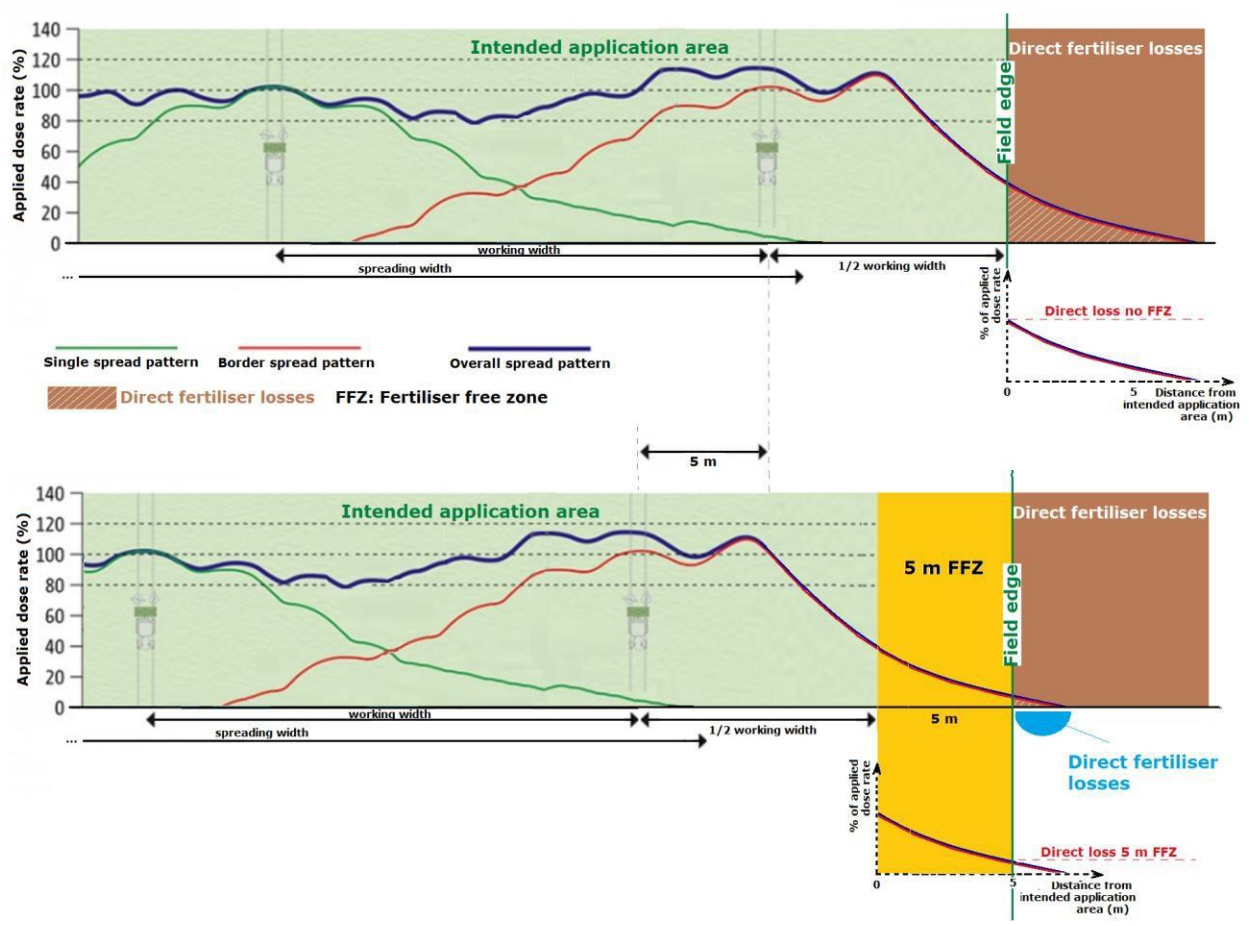
fertilizer in the water. In addition, the reduction of nutrient input near the watercourse reduces the risk of nutrient loss due to overland-flow and soil erosion of the nutrients applied close to the water body.

2.2.2.1. Direct deposition of nutrients during fertilisation

Direct deposition of nutrients in the watercourse during fertilisation can be reduced directly by the implementation of a fertiliser-free zone bordering the surface water (Figure 8). In a study, Tits et al. (2018) calculated that for Flanders, direct deposition of fertilizer in the surface water decreased by a little over 50%, when a fertilizer-free zone of 5 m along all "classified" streams is imposed. This would increase to a little over 80%, when this would also be imposed along all "non-classified" streams. Finally, direct deposition of fertilizer would decrease with 97% when the fertilizer-free zone would increase to 10 m. This measure, however, resulted in a loss of economic revenue for the farmers, due to lower crop yields.

Other efficient measures to reduce or even prevent direct deposition of nutrients in the watercourse during fertilization are the use of precision techniques such as row fertilization, injection of manure, use of border spreaders, etc.

Figure 8 Spread pattern and direct fertilizer losses without (top) of with (bottom) fertilizer free zone (FFZ) (Tits et al., 2018).



2.2.2.2. Surface runoff and subsurface drainage

Tits et al. (2018) showed that the potential loss from N and P applied on the 5-meter strip next to the water body on steeply sloping grounds is 10 to 12 times as large as the direct N deposition in the watercourse and could account for 1% of the total nitrogen transfer from agriculture to surface waters in Flanders (2.6% for P). Surface runoff is influenced by slope (see above), soil texture, soil drainage class and (winter) ground cover. Regarding surface runoff, an unfertilized buffer strip will have an effect on the travel time of the nutrients, because nutrients are deposited at a greater distance from the watercourse and therefore have a longer travel time to migrate to the watercourse. An increase in travel time means that there are more opportunities for other processes to take place during nutrient transport, e.g., denitrification or crop uptake if a crop is present in the unfertilized buffer strip. The increase in travel time is highly dependent on the soil physical properties (mainly moisture balance) and the local slope next to the watercourse. The mechanisms and efficiencies involved here are discussed more in detail in Cluster V.

2.2.2.3. Economic feasibility

Unfertilized buffer strips will likely result in the loss of economic revenue for the farmers, due to lower crop yields in the case of unfertilized strips or due to the loss of arable area in the case of vegetated unfertilised strips. The loss depends on the width of the strip.

2.2.3. Environmental co-benefits (and drawbacks)

2.2.3.1. Co-benefits

- Improved biodiversity
- Increased carbon sequestration
- Creation of attractive landscape elements

2.2.3.2. Environmental drawbacks

- Increased travel time of nitrogen to migrate to the watercourse can lead to increased ammonia volatilization and nitrous oxide emissions. At the same time, ammonia and nitrous-oxide emissions would be reduced because no fertilizer is applied in the buffer strip.

2.2.4. Minimum/threshold or optimum level of implementation

Since the effects of buffer strips on direct deposition of nutrients in the watercourses as well as on surface and subsurface runoff and drainage depend on numerous factors, such as application technique, crop, soil type, slope, etc., thresholds or optimum levels of implementation are difficult to identify.

Thresholds for buffer strip widths in respect to subsurface nitrate removal (groundwater nitrate) are discussed in Cluster V.

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3. CLUSTER III - BALANCED FERTILIZATION, APPLICATION METHODS, FERTILIZER PLANNING AND RECORD KEEPING

3.1. Limitations on fertilisation application rates, including reduced application rates

3.1.1. Background

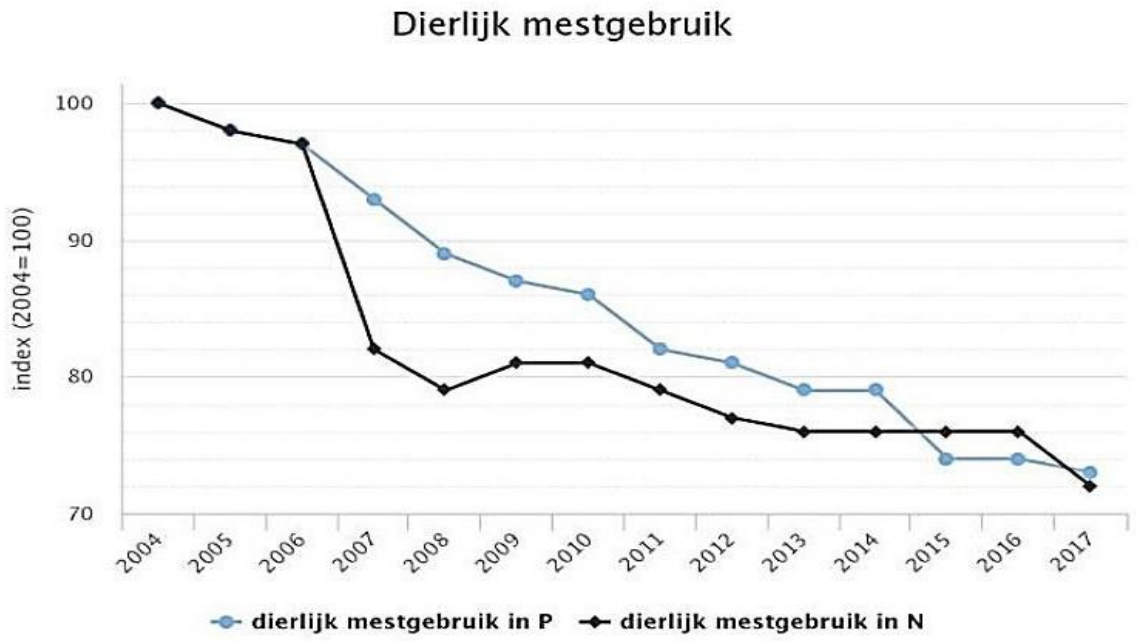
This measure could be simply categorized as a form of supply and demand. Supply should be aligned with crop demand. An oversupply of a nutrient, more than what the crop needs, can sometimes and to a very limited extent lead to higher uptake by plants. But most of the oversupply will accumulate in the soil and will be lost to the environment at a certain moment. From that point of view, limitations of fertiliser application rates are required to protect water and the environment against the loss of the surplus of nutrients. The application rates should be based on the crop requirements, considering all available nitrogen forms.

3.1.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses.

The **limitations on fertilisation application rates** expressed in fertilisation standards, set a clear and explicit limit or line. Without a clear and legally defined limit, fertilisation would certainly be higher. In that respect, this measure has the potential to limit the nitrogen input and to be one of the determinant factors in the reduction of the N-surplus. The N-surplus is an important indicator to evaluate the environmental impact.

The impact of an application standard on the use of a fertiliser and the input of nutrients can be demonstrated in Flanders. Nawara et al. (2021) concluded that a reduced application standards led to a reduced application of manure (Figure 9). Since 2007, the nitrogen application standard for organic manure was limited to 170 kg N ha^{-1}. Before 2007, the application standard was 200-250 kg N ha^{-1} for most common crops.

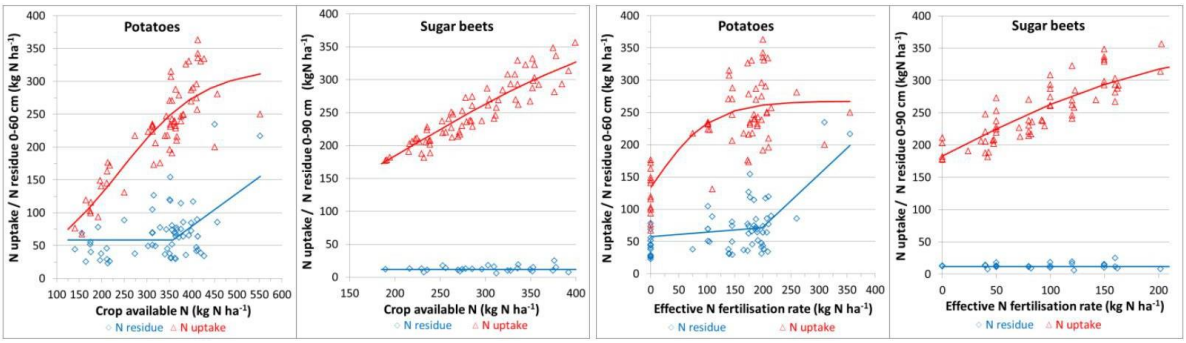
Figure 9 Use of manure since 2004 until 2017 (reference 2004), manure-N= black, manure-P= blue (Nawara et al. (2021) after Vlaamse Milieumaatschappij, 2019).



Van Grinsven et al. (2012) pointed to the limitation of "how much nitrogen in fertiliser and manure can be applied to agricultural land" as a major instrument to reduce nitrogen pollution in waters, together with the restrictions on where and when nitrogen in fertiliser and manure can be applied to agricultural land. They considered that the application limit for nitrogen from animal manure was the most important restriction following from the Nitrate Directive. They also referred to Mikkelsen et al. (2010) who concluded that in Denmark the reduction of N application standards alone contributed 32% of the total reduction of the soil N surplus between 1998 and 2004.

D'Haene et al. (2015) also states that limiting nitrogen (N) fertiliser application rates is one of the best N management measures to minimise N losses. Based on N-dose-response curves and residual soil mineral nitrogen in function of crop available N and applied effective N fertilisation rate for potatoes and sugar beets, they concluded that maximum fertilisation rates can be derived which limit the potential risk of NO_3-leaching during winter (Figure 10). For crops as sugar beets, the effect of a fertilisation standard is less pronounced since the residual soil mineral nitrogen is rather irresponsive for N-fertilisation. The range of N fertilisation evaluated, however, was only the range not negatively affecting tuber quality, an excessive N amount increases impurities and decreases extractable sugar content.

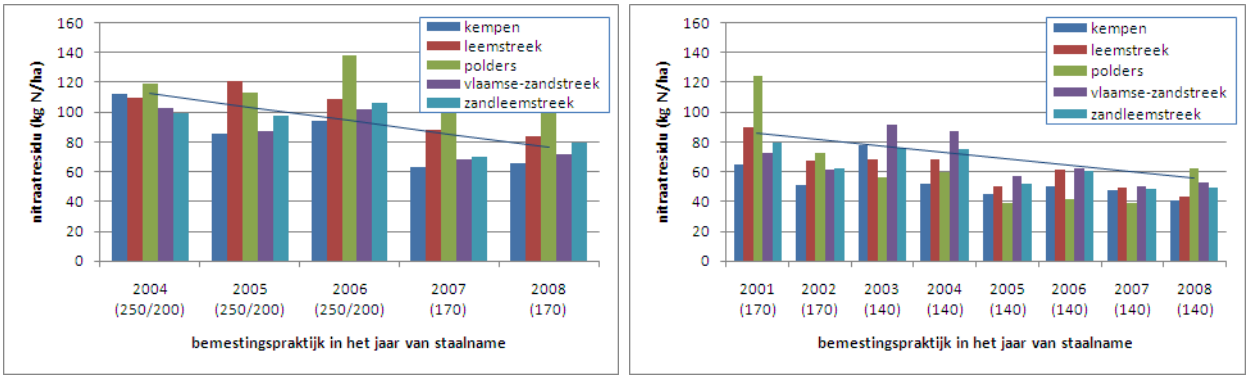
Figure 10 Nitrogen (N) dose-response curves (red triangle) and residual soil mineral nitrogen (rooting depth) (blue circle) in function of crop available N (left) and applied effective N fertilisation rate (right) for potatoes and sugar beets (D'Haene et al., 2015).



Also Van Overtveld et al. (2010) could relate fertilisation practice and by extent the application standards to the residual nitrate-N in Flanders (Figure 11). Fertilisation declined over the years due to stricter fertilisation standards, increasing attention for fertilisation and stricter application periods.

The applicable fertilization standards (standards for total N, manure-N, other organic N and mineral N) appeared all to have a significant effect on the total nitrate residue. However, for some the effect was positive, for others negative. The authors mentioned that fertilization standards were correlated with the year (because of changing standards over the years) and strongly depended on the cultivated crop. The effects found are usually a combination of crop effects and fertilization practices. (Van Overtveld et al., 2010).

Figure 11 Average residual nitrate-N per fertilisation practice/year and agricultural region (Van Overtveld et al., 2010).



Granlund et al. (2007) demonstrated the effect of a decreased N input on N leaching for the Finnish situation using the nutrient leaching model ICECREAM. The model results indicated that it is possible to decrease N leaching by adjusting and decreasing the fertiliser dose, without limiting crop growth and yield. The decrease in N leaching, however, was not linearly related to the reduction in N dose, due to strong annual and regional variation. The effectiveness of limitations on fertilisation application rates depends on the level of the application standards. High application standards based on unrealistically high yield figures will result in nutrient losses and have a negative effect on the environment.

The concrete values need to be properly substantiated and differentiated, then it will be an effective measure. Crops differ in their need and in their capacity to store nutrients ('the plateau' of the nutrient uptake curve). Sandy soils are more vulnerable to leaching than loamy and clay soils. Sandy soils are often characterized by a lower water holding capacity, a limited cation exchange capacity (CEC) and a limited rate of denitrification after leaching. For manure, the timing of the application determines the potential uptake still to be realised, the N needed, and it affects the possible supply of N via mineralization.

Reduced application rates can be beneficial as stated by Granlund et al. (2007). Nawara et al. (2021) noted that lowering N fertilization decreases nutrient leaching but also pointed to the risk of yield losses. The latter is economically disadvantageous and may be resisted by farmers. The possibility and effect of reduced application rates also depends on the 'starting value' on the defined application standards. The application standards are ideally based on a dose response curve. The economically optimal rate is strongly dependent on the economic situation (including the market prices of fertilisers and crops), can be highly variable, is not known at the beginning of the season, and does not necessarily coincide with agriculturally optimal dose. Depending on the crop and the starting point for the application standards, a further reduction might not necessarily result in a reduced residual amount of nitrate-N, prone to leaching (Figure 10), but could rather affect the yield. In literature, results on the extent to which N leaching is influenced by increasing N fertiliser application rates can be contradictory, so the response of N leaching to increasing N application and the dose response curve should be determined for a given environment, i.e., soil-climate-crop.

Nawara et al. (2021) pointed to the possibility of enhancing nitrogen use efficiency, for example by splitting fertilization in several doses. They also stressed the importance of thorough and

long- term field research and a solid scientific and theoretical basis for the application standards.

Regulation of the use of animal manures is important since there are positive relationships between regional livestock densities and N and P concentrations in groundwater and surface water in Europe (Velthof et al., 2009). Animal manure is more difficult to manage than mineral fertilisers. Van der Straeten et al. (2011) referred to the impossibility to predict the exact nutrient availability and uptake as the reason for the precautionary fertilization standard for NVZ's of 170 kg manure-N ha^{-1} $year^{-1}$.

As pointed out in van Grinsven et al. (2015), the fertiliser equivalent (FE) of organic manures is important. Only a correct defined FE can lead to a correct fertilization. Underestimating FE will result in a higher dose as foreseen, maybe in a higher dose than the application standard allows and a higher risk for losses. Overestimating will result in shortage fertilization and loss of production and revenue for farmers. One of the determining factors for the extent to which the N supply from manures and crop demand are synchronised and N supply is utilised, is the ratio of mineral-N (Nm) and organically bound N (Norg) in the manure. One of the major factors determining the Nm:Norg ratio is the housing and storage. N-content depends on animal type, production level, feeding regimes, growth stage, etc. Therefore, values need to be defined regionally or nationally and reviewed at regular basis since production levels and feeding strategies evolve.

3.1.3. Environmental co-benefits and drawbacks

By reducing and regulating the input of nutrients, the surplus of nitrogen and nitrate leaching are reduced. The reduced input implies reduced emissions of ammonia (NH_3) and nitrous oxide (N_2O), the former contributing to air pollution and the latter a potent greenhouse gas.

To the extent the reduction in inputs is achieved through lower use of chemical N fertilisers, this also would reduce the demand for the production of such fertilisers, which is associated with emissions of carbon-dioxide contributing to global warming.

3.1.4. Minimum/threshold or optimum level of implementation

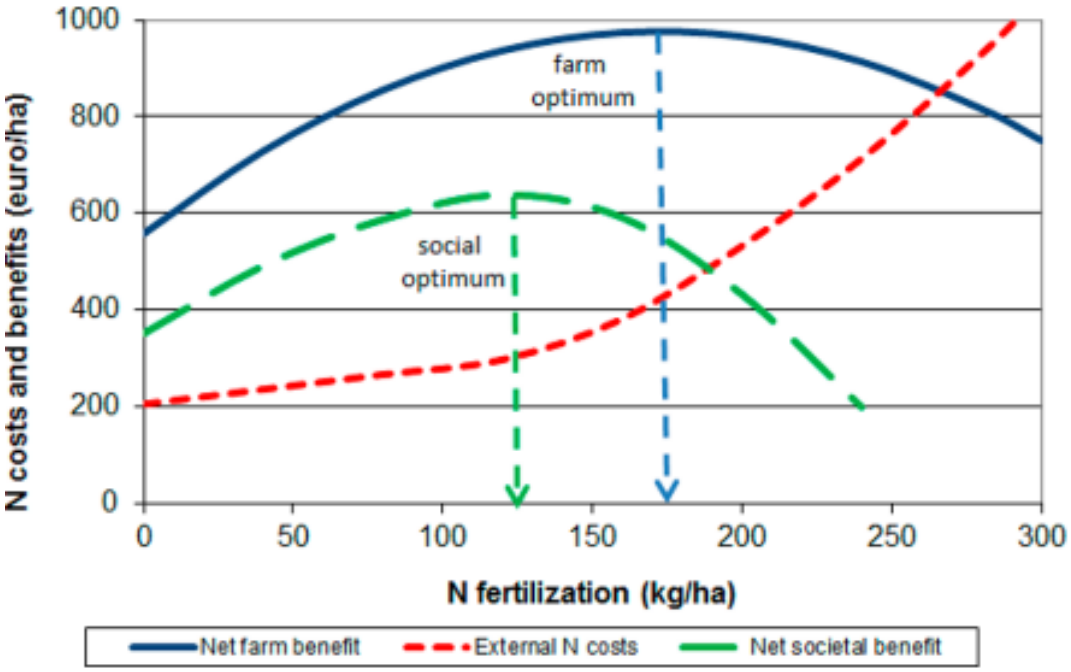
Limitations on fertilisation application rates are an effective measure to reduce the nutrient input, to limit the surplus and to reduce nutrient losses. It will be most effective and efficient if the concrete values are properly targeted and differentiated according to crop, soil type and other relevant factors. The consequence of having a legal system of application standards based on fertiliser equivalent nitrogen is the need of fixed statutory values for the fertiliser equivalency of livestock manures. So, the effectiveness and efficiency of the application standards also depends on the correct valuation of the fertiliser equivalency.

The cost efficiency of the measure depends on the farm type, the standard for mineral or organic fertilisers and the economic situation. If the economically optimal dose exceeds the application standard, the application standards imply yield loss and loss of revenue for the farmer. For arable farms, without livestock production, the application standards will generally limit the input of mineral fertilisers, which reduces costs for the purchasing of such fertilisers. On livestock farms the application limit for manure can imply a need to export manure from the farm and replace it by mineral fertilisers, both of which can be costly for the farmer.

As pointed out in van Grinsven et al (2013), there can be a mismatch between the private economic optimum of the farmer on the one hand and the social economic optimum for society

on the other, due to the externality costs associated with fertilizer use, which fall on society as a whole (see Figure 12).

Figure 12 Mismatch between the economic optimum for the farmer and for society (van Grinsven et al (2013)



The application rates need to be evaluated regularly in a changing climate. A panel of Flemish experts assessed that climate change would impact the effectiveness of the nitrogen application standard negatively. Changing climate conditions, extreme events and longer lasting periods of drought or rain will impact the availability and uptake of nutrients. The effect of the changing climate will be more pronounced at higher doses, creating more uncertainty (Nawara et al., 2011).

3.2. Requirements on application methods to enhance efficiency

3.2.1. Background

Application of manure or fertilisers entails a risk of contamination of soil, water, and air. Not all of the applied nutrient can be recovered by the plants. The low recovery of N is responsible for environmental pollution. Nutrient use efficiency (NUE) is the ratio of the amount of N harvested trough the crop or taken up by the crop relative to the N inputs. A whole series of parameters can influence nutrient use efficiency. For manure, the situation is even more complex than for mineral fertilisers. The nitrogen applied in organic fertilisers will never equal the effect of the same amount of nitrogen applied in mineral fertilisers. This fact is what is referred to by the terms nitrogen fertiliser replacement value (NFRV), N equivalency of manure, or N efficiency of manure. Even when handled according to the best practices, manures have a NFRV smaller than 100%. As for the NUE, measures can be taken to increase the NFRV. This review will cover the measures regarding the application of fertilisers and manure (other factors e.g. affecting the composition of the manure could also influence the NFRV but will not be discussed here).

Ammonium (NH_4^+) contained in manure and fertilisers can be lost as ammonia gas (NH_3). Ammonia is emitted wherever manure is exposed to the atmosphere, also after manure application to fields. Urea-based fertilisers also result in ammonia emissions. Urea is rapidly hydrolysed by the enzyme urease to ammonium carbonate ($(NH_4)_2CO_3$) and ammonium ions provide the main source of ammonia. Ammonia volatilisation occurs when NH_3 in solution is exposed to the atmosphere. The extent to which NH_3 is emitted depends on the chemical composition of the solution (including the concentration of NH_3), the temperature of the solution, the surface area exposed to the atmosphere and the resistance to NH_3 transport in the atmosphere. Surface application of fertiliser involves higher risk.

Ammonia emissions from livestock manures during and after field application depend on:

- properties of the manure, including viscosity, total ammoniacal-N (TAN) content, C content and pH;
- soil properties such as pH, cation exchange capacity, calcium content, water content, buffer capacity and porosity;
- meteorological conditions including precipitation, solar radiation, temperature, humidity and wind speed;
- the method and rate of application of livestock manures, including, for arable land, the time between application and incorporation, and method of incorporation;
- the height and density of any crop present

Ammonia affects air quality but also later results in the deposition of nitrogen compounds on land and water bodies, effectively adding a (more or less) thin layer of fertilizer, which can cause eutrophication of natural ecosystems. Such deposition from the air can also be sufficiently significant that it should be taken into account in fertilizer planning on farms.

Manure and fertiliser applications raise soil nitrate (NO_3) levels. Mineral fertiliser may include nitrate directly (e.g. calcium-ammonium-nitrate (CAN)). Ammonium is converted to nitrate by micro-organisms in the soil through a process called “nitrification”. Over time, organic nitrogen in manure is also gradually released through microbial activity (mineralization) in the form of ammonium, in turn making it available for conversion to nitrate (or release to the air as ammonia). The release of nitrates in the soil should ideally coincide with the demand for nitrates by plants, to limit the risk of losses. This indicates the importance of timing to enhance nutrient use efficiency. In summary, timing of application, application rate, and application method are all crucial for nitrogen use efficiency (Hanif, 2023).

3.2.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses.

Hutchings et al. (2010) subscribed the potential to reduce NH_3 emissions of different **application techniques**. They stated that emissions following application of slurry may be reduced if the slurry is applied in narrow bands (trailing hose), if the slurry is placed beneath the crop canopy (trailing shoe) or placed below the soil surface (injection) (Table 9). It was mentioned that incorporation of slurry and solid manures into tillage land can reduce NH_3 emissions by up to 90 %. The reduction in emission varies according to method of incorporation, interval between manure applications and incorporation and type of manure.

Table 9 Abatement techniques for slurry and solid manure application to land mentioned in Hutchings et al. (2010) (according to UNECE, 2007).

Abatement measure	Type of manure	Land use	Emission reduction (%)	Limits to applicability
Trailing hose	Slurry	Grassland, arable land	30 Emission reduction may be less if applied on grass > 10 cm. Poor reductions on bare land in some situations	Slope of land (< 15 % for tankers; < 25 % for umbilical systems); not for slurry that is viscous or has a large straw content
Trailing shoe	Slurry	Mainly grassland	60**	Slope (< 15 % for tankers; < 25 % for umbilical systems); not viscous slurry, size and shape of the field, grass height should be > 8 cm, difficult when crop residues present
Shallow injection (open slot)	Slurry	Grassland	70**	Slope < 10 %, greater limitations for soil type and conditions, not viscous slurry.
Deep injection (closed slot)	Slurry	Mainly grassland, arable land	80	Slope < 10 %, greater limitations for soil type and conditions, not viscous slurry.
Broadcast application and incorporation by plough in one process	Slurry	Arable land	80	Only for land that can be easily cultivated
Broadcast application and immediate incorporation by plough	Slurry	Arable land	80–90	Only for land that can be easily cultivated
Immediate incorporation by disc			60–80	
Broadcast application and incorporation by plough within 12 h	Slurry	Arable land	30	(according to § 10)
Immediate incorporation by plough	FYM (cattle, pigs)		90	
Immediate incorporation by plough	Poultry manure		95	
Incorporation by plough within 12 h	Solid manure	Arable land	50 for cattle and pig 70 for poultry	
Incorporation by plough within 24 h	Solid manure	Arable land	35 for cattle and pig 55 for poultry	

Notes:
1. */ Emissions reductions are agreed as likely to be achievable across the UNECE.
2. ** revised to incorporate conclusions of recent review.

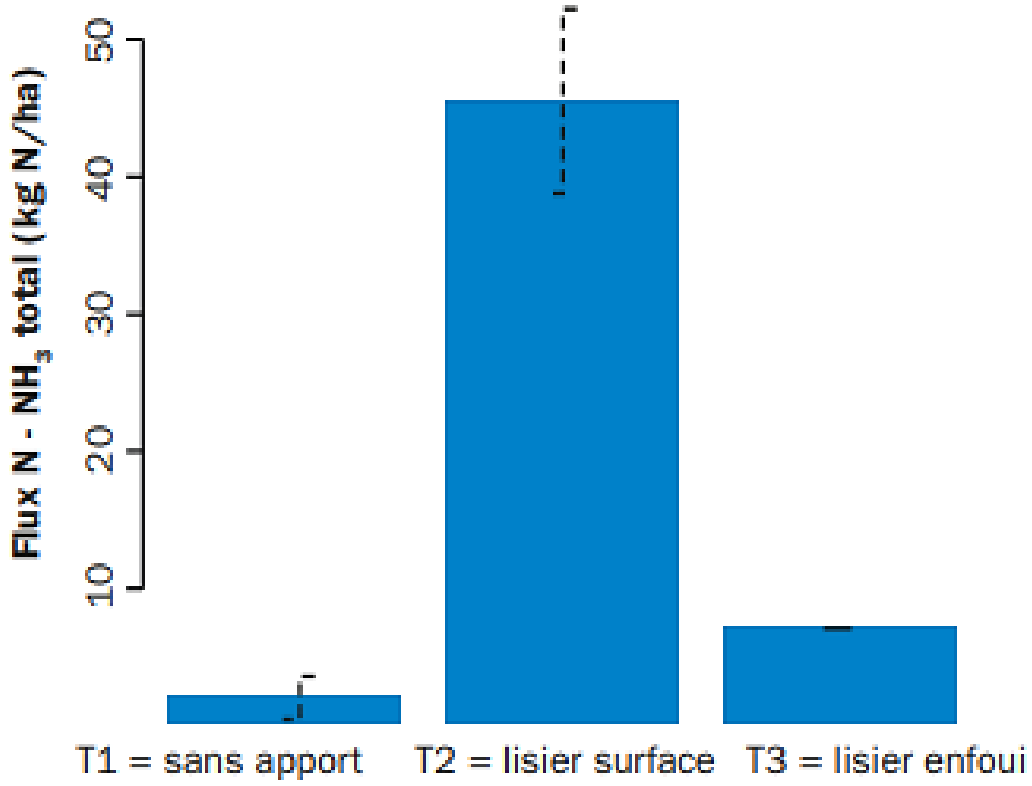
Huijsmans et al. (2008) described low emission application in the Netherlands. They concluded, both for grassland and arable land, that ammonia losses were reduced significantly by low emission application techniques (Table 10), increasing the NFRV of the manure.

Table 10 Ammonia loss (kg NH_3-N per 100 kg total ammoniacal-N applied (TAN) of cattle slurry applied to grassland and arable land, as affected by the application technique (Huijsmans et al., 2008).

Land use	Technique	Loss (kg N/100 kg TAN)
Grassland	Surface spreading	74
	Trailing shoes	26
	Sod injection	19
Arable	Surface spreading	69
	Shallow incorporation (e.g. rigid tine)	22
	Thorough incorporation (e.g. injection, rotavator)	2

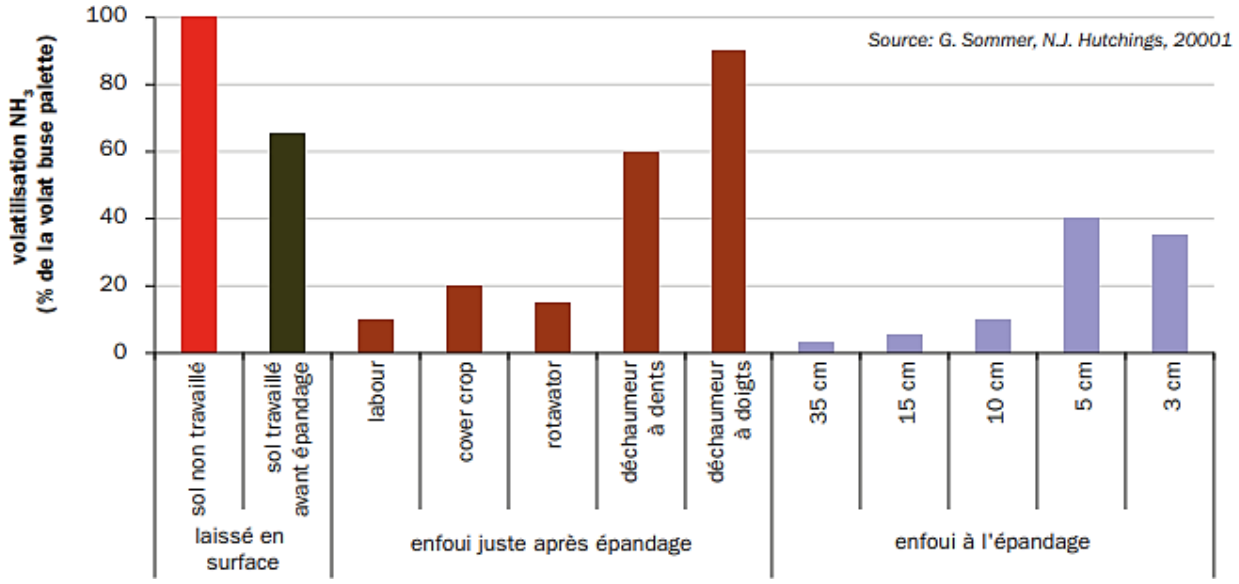
In French field trials a considerable reduction of N emissions was measured by application of pig slurry (Figure 13). If pig slurry was not incorporated 46 kg N of the 71 kg ammonium N was lost, i.e., 64 %. Immediate incorporation reduced the losses to 7 kg N, about 10 % of the applied ammonium N.

Figure 13 Amount of ammonia nitrogen lost by volatilisation on a testimony object without application of manure en two objects with application of pig slurry. Results of the CASDAR VOLAT NH3 project, Essai de Bignan (56), 2011 referred to in Levasseur et al., 2019.



Levasseur et al. (2019) confirmed the importance of the depth of incorporation, which was also mentioned by Huijsmans et al. (2008). They stated that an incorporation technique realising a homogeneous application at a minimal depth of 5-8 cm should be pursued, referring to Sommer and Hutchings (2001) (Figure 14).

Figure 14 Effect of different tillage tools on ammonia volatisation after a broadcast application of pig slurry, in percentage of volatilisation without tillage. Mentioned in Levasseur et al. (2019) referring to Sommer and Hutchings (2001).



Martin and Mathias (2013) analysed the potential of 10 actions to reduce ammonia emissions on French farms. They concluded that incorporation and application techniques showed the highest potential to reduce ammonia losses in France (Figure 15). It needs to be noted, however, that the potential of these measures is partly due to the fact that they cover all animal types and all types of farms.

As mentioned, ammonia losses are most likely in the case of urea fertilisers and manure. The low emission application techniques mentioned for manure application are applicable for mineral fertilisers containing urea. They need incorporation for the same reasons.

In case of row crops, the effect of precise placement of fertilisers on the yield of several crops was demonstrated by Nkebiwe et al. (2016) based on a meta-analysis (Figure 16). Several field studies showed that fertiliser placement resulted in 3.7% higher yield than broadcast and higher nutrient concentrations in different plant parts by 3.7% and nutrient content in above-ground biomass by 11.9% than fertiliser broadcast (Nkebiwe et al., 2016).

Figure 15 Reduction potential (kt. NH3) by 100 % application per practice or practice modality compared to 2010 (Martin and Mathias, 2013).

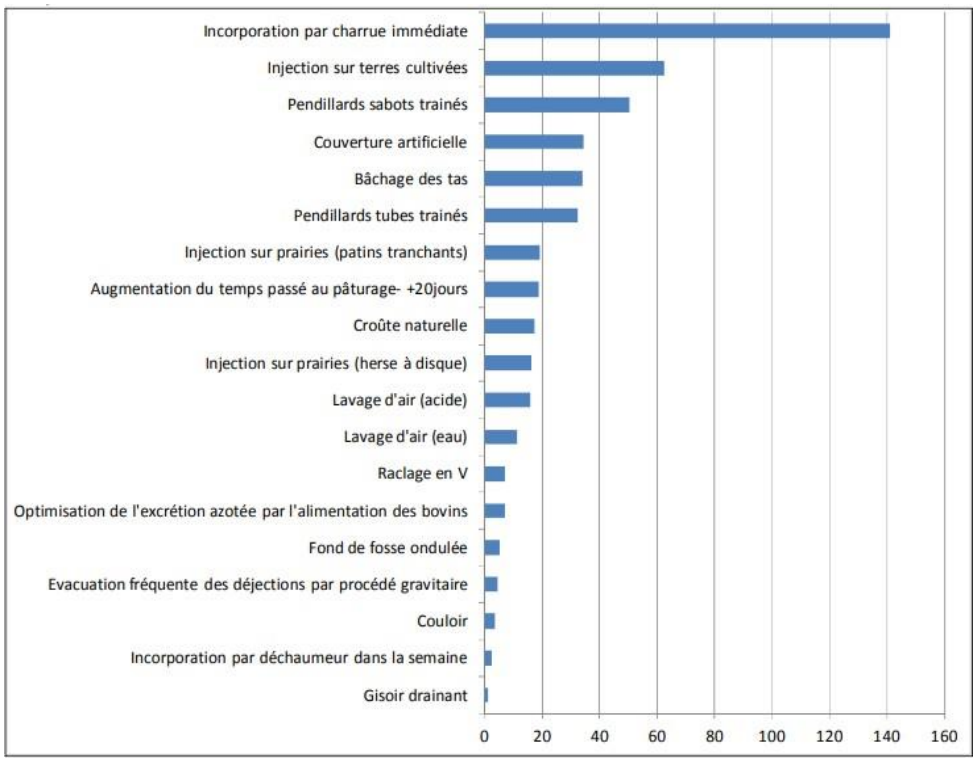
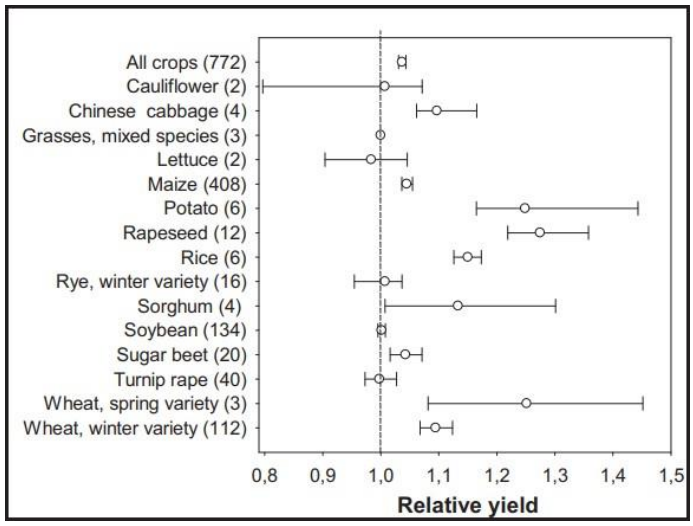


Figure 16 Relative yield of fertiliser placement by crop type. Y-axis: categories and number of datasets per category in brackets; X- axis: relative value of fertiliser placement to fertiliser broadcast; error bars, 95 % confidence intervals; Placement ≠ broadcast, if error bars do not include 1.; Relative values of a pair of categories are different from each other if their 95% confidence intervals do not overlap (Nkebiwe et al., 2016).

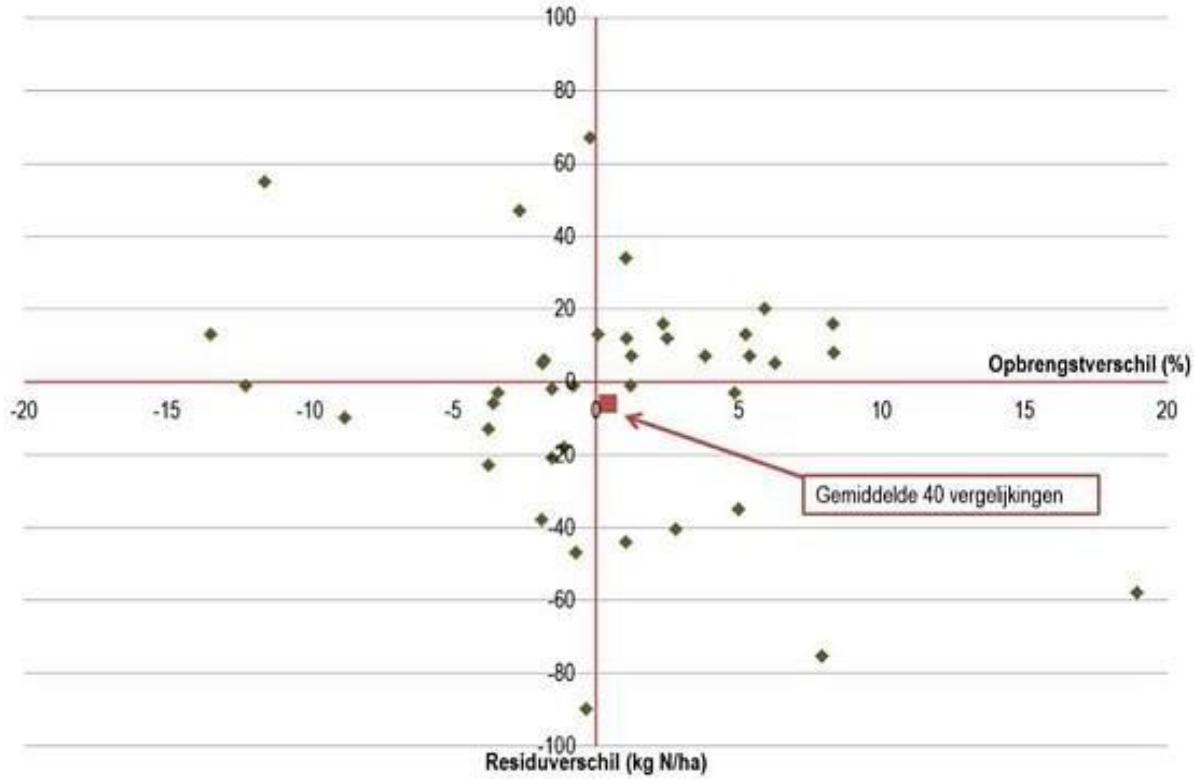


For potatoes, a crop with a relatively high risk of nitrogen losses, the positive effect on yield could not always be confirmed. However, Van Geel (2015) has pointed to the advantage of row application as a low-emission application technique. Maidl et al. (2002) found a positive effect on N recovery of nitrogen placement in the ridge, when the total N amount was applied at planting. In France, Cohan and Laurent (2012) demonstrated an equal yield with less nitrogen input.

In maize, row application is more common. In Flemish field trials it was demonstrated that equal or higher dry matter yields could be realised by row application at 75% of the broadcast dose (Odeurs et al., 2014). As a low emission technique with higher N-recovery in the crop and a possible lower N-input, row application could be an effective measure to limit the surplus and concomitant losses.

Regarding the **time of application**, plant-available N (especially nitrate containing fertilisers) should be applied close to the rapid growth stage of the crop, when N uptake is maximal. Synchronicity of N supply with crop demand is essential in order to ensure adequate uptake (Fageria and Balligar, 2005). In potato, Maidl et al. (2002) found for a broadcast application that fertiliser N recovery was higher when fertilisation was split in several doses as compared with a single application at planting. In Flemish field trials it was demonstrated that split fertilisation can reduce the residual amount of nitrate-N without yield loss (Figure 17). The timely administration of the last fertilisation dose is also important in this case (De Blauwer et al., 2014).

Figure 17 Effect of split fertilisation on the residual nitrate-N and total yield (difference=verschil= split fertilisation versus one application) (De Blauwer et al., 2014).



In maize, the indications on split fertilisation vary in the literature. In Dutch and Flemish research, merely based on yield considerations, it is currently stated that split fertilisation is not to be preferred in maize. In France, on the contrary, Soënen and Bouthier (2015) proposed a split fertilisation for maize to enhance nutrient use efficiency. Davies et al. (2020), in a study from Minnesota, found a higher recovery efficiency of the applied N with split fertilisation. Considering treatments PP100, Sp100 and TSp100, a clear beneficial effect on N-recovery can be noticed (Table 11).

Table 11 Recovery efficiency of applied N fertiliser as affected by treatment and year, averaged across locations (Davies et al., 2020).

Treatment †	2014		2015		2016	
	kg kg^{-1}					
C						
F100	0.433	a‡	0.504	bc	0.213	d
F125	0.403	a	0.423	cd	0.258	cd
PP100	0.383	a	0.363	d	0.418	abc
PP125	0.427	a	0.373	d	0.323	bcd
Sp75	0.388	a	0.644	ab	0.488	ab
Sp100	0.431	a	0.561	bc	0.482	ab
TSp50	0.468	a	0.543	bc	0.562	a
TSp75	0.386	a	0.707	a	0.423	abc
TSp100	0.496	a	0.643	ab	0.503	a

† C, control no N applied; F100, N applied in the fall at 100% of the recommended rate; F125, N applied in the fall at 125% of the recommended rate; PP100, N applied at preplant in the spring at 100% of the recommended rate; PP125, N applied at preplant in the spring at 125% of the recommended rate; Sp75, half of the N applied at preplant in the spring and half at V6 at 75% of the recommended rate; Sp100, half of the N applied at preplant in the spring and half at V6 at 100% of the recommended rate; TSp50, a third of the N applied at preplant in the spring, a third at V6 and a third at R1 at 50% of the recommended rate; TSp75, a third of the N applied at preplant in the spring, a third at V6 and a third at R1 at 75% of the recommended rate; TSp100, a third of the N applied at preplant in the spring, a third at V6 and a third at R1 at 100% of the recommended rate.

‡Means within the column followed by different low case letters are significantly different at $p \leq 0.05$.

F100 en F125, the applications in fall, should not be considered.

Yield was sometimes lower after split fertilisation, but it can still be concluded that yield is generally not negatively influenced by split fertilisation (Table 5). Frerichs et al. (2022) showed in Germany the possibility of a differentiated nitrogen fertilisation strategy in spinach. The strategy of a base N fertilisation and a single top dressing could be further split resulting in a strategy of a base N fertilisation and two top dressings. They concluded that the nitrate concentration at risk of leaching could be considerably reduced by such further splitting of the top dressing. The timing of post-planting nitrogen applications is critical (De Blauwer et al., (2014), Soënen and Bouthier (2015)). One could summarize that the target species must be immature and growing to provide time for the nitrogen to be absorbed and metabolized in order to have the most efficient yield or quality impact.

Table 12 Maize grain yield as affected by treatment, location and year (Davies et al., 2020).

	Becker						Lamberton						Waseca					
Treatment†	2014		2015		2016		2014		2015		2016		2014		2015		2016	
	Mg ha^{-1}																	
C	6.0	e‡	4.9	e	4.9	g	9.5	e	5.0	d	6.3	d	4.5	g	6.9	d	6.1	d
F100	5.7	e	6.8	d	8.0	f	13.8	abc	13.5	a	13.9	ab	8.6	de	15.3	a	11.3	bc
F125	5.8	e	8.2	d	10.2	e	14.5	ab	14.2	a	15.5	a	9.8	bc	14.2	ab	12.1	abc
PP100	7.1	d	10.1	c	12.6	cd	14.4	ab	13.6	a	14.5	ab	10.3	ab	13.5	b	13.4	a
PP125	7.6	d	11.7	b	14.4	ab	14.7	a	14.2	a	14.9	ab	11.2	a	14.0	ab	13.6	a
Sp75	8.9	c	12.0	b	13.6	bc	13.2	bcd	12.0	bc	14.0	ab	9.2	cd	14.0	ab	12.9	ab
Sp100	10.0	bc	15.2	a	14.7	ab	13.9	abc	13.6	a	14.9	ab	9.9	abc	15.3	a	13.0	a
TSp50	9.8	bc	9.9	c	11.1	de	12.2	d	11.0	c	11.3	c	6.6	f	11.6	c	10.8	c
TSp75	10.5	b	12.9	b	13.9	bc	12.8	cd	13.1	ab	13.5	b	7.9	ef	14.1	ab	12.7	ab
TSp100	12.7	a	14.5	a	15.7	a	13.2	bcd	13.3	ab	14.7	ab	9.5	bcd	15.5	a	13.3	a

† C, control no N applied; F100, N applied in the fall at 100% of the recommended rate; F125, N applied in the fall at 125% of the recommended rate; PP100, N applied at preplant in the spring at 100% of the recommended rate; PP125, N applied at preplant in the spring at 125% of the recommended rate; Sp75, half of the N applied at preplant in the spring and half at V6 at 75% of the recommended rate; Sp100, half of the N applied at preplant in the spring and half at V6 at 100% of the recommended rate; TSp50, a third of the N applied at preplant in the spring, a third at V6 and a third at R1 at 50% of the recommended rate; TSp75, a third of the N applied at preplant in the spring, a third at V6 and a third at R1 at 75% of the recommended rate; TSp100, a third of the N applied at preplant in the spring, a third at V6 and a third at R1 at 100% of the recommended rate.

‡Means within the column followed by different lowercase letters are significantly different at $P \leq 0.05$.

According to Vogeler et al. (2020), the potential of **precision agriculture** technologies with site-specific N application rates depends on the N leaching response curve. They studied the marginal nitrate leaching in winter cereals in Denmark. The marginal nitrate leaching is defined as the increase in N leaching as a percentage of an additional unit of N applied. A linear marginal N leaching curve around the optimal rate indicates a situation in which potential N leaching reductions are small. With an exponential response of the marginal N leaching the use of precision agriculture will be more influential on N leaching across the field.

Bongiovanni and Lowenberg-Deboer (2004) did a meta-study in which they gathered data from studies about precision agriculture. The results related to variable N fertilization, as discussed by Bongiovanni and Lowenberg-Deboer (2004), are presented in Table 13.

Table 13 Review of studies cited by Bongiovanni en Lowenberg-Deboer (2004) considering variable N fertilisation as precision technique.

Crop	Input/Factor	Region	Methodology	Results of using VRT
Wang et al. (2003)				
Corn	N	Missouri	Used topsoil depth data to develop recommendations with a simulation model.	*VRT was more profitable than uniform rate in 75% of the cases, with a gain in profits up to \$37.14 ha^{-1} in one of the fields.
Roberts et al. (2001)				
Corn	N	Tennessee	EPIC simulation model to estimate N leaching.	*More N was applied with VRT, but less N was lost to the environment N leaching reduced by 2.24–4.48 kg ha^{-1}.
Delgado et al. (2001)				
Barley Potato	N	South Central Colorado	Field trials and use of information to estimate N leaching as a difference.	*N management practices can potentially be improved to reduce potential N losses and conserve water quality.
Kholsa et al. (2001)				
Corn	N	Colorado	Field trials and use of information to estimate N leaching as a difference.	*VRT-N has the highest NUE and lowest leaching compared to other treatments.
Whitley et al. (2000)				
Potato	N	Washington State	Field trials. Measured N leaching with probes.	*Surface soil had high NO_3–N flux. *Subsurface soil NO_3–N flux stable. *NO_3–N leaching was decreased in vulnerable zones due to a lower N rates in these zones.
Griepentrog and Kyhn (2000)				
Wheat Barley	N	Northern Germany	Field trials. Measured reduced chemical loading.	*VRA reduced N by 36% in low areas while maintaining the high yields.
English et al. (1999)				
Corn	N	West Tennessee	EPIC simulation model to estimate N leaching.	*VRT was more profitable than uniform rate and that it generated less nitrogen loss to the environment in most cases.
Rejesus and Hornbaker (1999)	N	Lake Decatur Illinois	EPIC simulation model to estimate N leaching.	*VRT-N has the potential to reduce the mean and variability of NO_3–N pollution, while improving profitability.
Thrikawala et al. (1999)				
Corn	N	Ontario, Canada	Simulation model (Barry *et al.*, 1993) to estimate N leaching.	*NO_3–N leaching reduced by 13%, average or between 4.2% and 36.3% in high and low fertility areas, respectively.
Watkins et al. (1998)				
Potatoes	N	Idaho	EPIC simulation model and dynamic programming to estimate N leaching.	*No environmental benefits. *No differences in N applied. *No differences in N losses.
Larson et al. (1997)				
Continuous Corn	N	Minnesota	LEACHM simulation model to estimate N leaching.	*No_3–N leaching was decreased in 50%, average, or from 60 to 29 kg ha^{-1}. *Decrease was 0 kg ha^{-1} in the loam, but 99 kg ha^{-1} in a loamy sand.
Leiva et al. (1997)				
Wheat Rapeseed Soybeans	Fertilizers Pesticides	Silsoe England	Measured chemical loading and estimated leaching with simulation.	*PA leads to savings in fertilizers and pesticides, decreasing risk of pollution and energy use, contributing to sustainability.
Hergert et al. (1996)				
Furrow Irrigated Corn	N	Nebraska	Measured after harvest residual soil NO_3–N and estimated N leaching.	*Improves N use efficiency. *Reduces leaching by minimizing high NO_3–N areas in the field.
Redulla et al. (1996)				
Irrigated Corn	N	Central Kansas	Measured after harvest residual soil NO_3–N and estimated N leaching.	*No differences in N use efficiency. *No differences in NO_3–N leaching.
Kitchen et al. (1994)				
Continuous Corn	N	Missouri	Measured grain production, unrecovered N in the crop, and post-harvest NO_3–N.	*The amount of unrecovered N decreased in the least productive soils with VRT. *Gross savings of \$10–\$12 ha^{-1} for using VRT.

Soto et al. (2019) published a study based on a survey of more than 500 farmers and contractors in Belgium, the Netherlands, Germany, France and Greece. The main focus was on arable land, more specifically wheat and potatoes, or cotton in Greece. The effect on yield, fuel and N fertiliser was estimated for a pessimistic, average and optimistic scenario for two precision agriculture techniques: machine guidance (MG) and variable rate nutrient technology (VNRT). Respectively 2.9 and 8.0 % applied N could be saved by machine guidance and variable rate nutrient technology (Table 14). Even without improved yields, the lower N input would lead to a reduced leaching potential.

Table 14 Estimation of the effect of precision agriculture techniques machine guidance (above) and variable rate nutrient technology (under) on yield, fuel use and applied N, according the survey of Soto et al. (2019) in Belgium, the Netherlands, France, Germany and Greece, focussing on wheat and potatoes or cotton in Greece.

	Pessimistic	Average	Optimistic
Yield	-4.0%	0.0%	4.0%
Fuel use	-2.4%	-5.4%	-8.3%
N applied	0.5%	-2.9%	-6.4%

	Pessimistic	Average	Optimistic
Yield	0.8%	4.1%	7.4%
Fuel use	0.6%	-5.4%	-6.3%
N applied	-4.6%	-8.0%	-11.7%

The literature referred to for the comparison in Table 14 is summarised below and it seems to confirms the potential of precision agriculture to improve N efficiency and reduce losses:

Machine guidance

- From the literature survey: Controlled Traffic Farming (CTF) can lead to improved fertiliser
  use efficiency, uptake of fertiliser can be improved by around 15%;
- Presentation Ulrike Kloeble (JRC workshop Sevilla, 2015): parallel tracking and auto- guidance can save 2-5% of N fertiliser and also 2-5% fuel use, based on results from the FutureFarm project;
- Wösten et al. (2016): Fuel consumption can be reduced by 5-10% by using guidance systems

Variable rate nutrient technology

- Koch et al. (2004): Site-specific fertilisation can reduce the total amount of fertiliser used, indicating an increase in Nitrogen Use Efficiency (NUE).
- Raun et al. (2001): average NUE increase of more than 15% in winter wheat in Oklahoma, USA.
- FutureFarm project: variable rate application can save 2-20 kg N per ha;
- Presentation Ulrich Adam (CEMA): 5-30% reduction in fertiliser use due to precision fertilization;
- Presentation from Wilfried Winiwarter (JRC workshop Sevilla, 2015): variable rate application can reduce fertiliser application on average by 24% (range 8-40%), based on several US studies.

The estimated effect of applying these two techniques at EU scale on leaching, NH_3 emissions and N fertiliser use is given in Table 15. The reduction in fertiliser use with the full application of both techniques would be in the order of 5 % of total N fertiliser use in the EU (the total is around 10 million tonnes of N annually). The relative reduction in leaching is in the same order of magnitude.

Table 15 Annual fertiliser, NH3 emission and N leaching and runoff reductions at EU-28 level for different precision agriculture adoption scenarios (Soto et al., 2019).

Adoption scenarios	Fertilizer savings	NH_3 emissions	N leaching and runoff
	kton N	kton N	kton N
Machine guidance >100 ha	72	3	15
Machine guidance >50 ha	88	4	19
Machine guidance full application	120	6	26
VRNT >100 ha	275	13	56
VRNT >50 ha	336	16	70
VRNT full application	457	22	98

3.2.3. Environmental co-benefits and drawbacks

Nawara et al. (2021) noted that the low-emission techniques often represent a trade-off between NH3 and N2O-emissions, as the deeper placement of manures will reduce ammonia losses but can increase N_2O emissions. Depending on the applied manure type and the application method, the increase of N_2O emissions will differ. Split applications in turn require additional rounds to spread fertilisers on the fields, resulting in higher fuel use and related emissions. Precision farming can have added benefits in reducing GHG emissions. Soto et al. (2019) indicated the possible impact of precision agriculture on greenhouse gas emissions (Table 16). They considered the direct soil N_2O emissions from lower fertiliser application, the indirect N_2O emissions resulting from N volatilisation and N leaching and the GHG emissions from fertiliser production and fuel use for field operations.

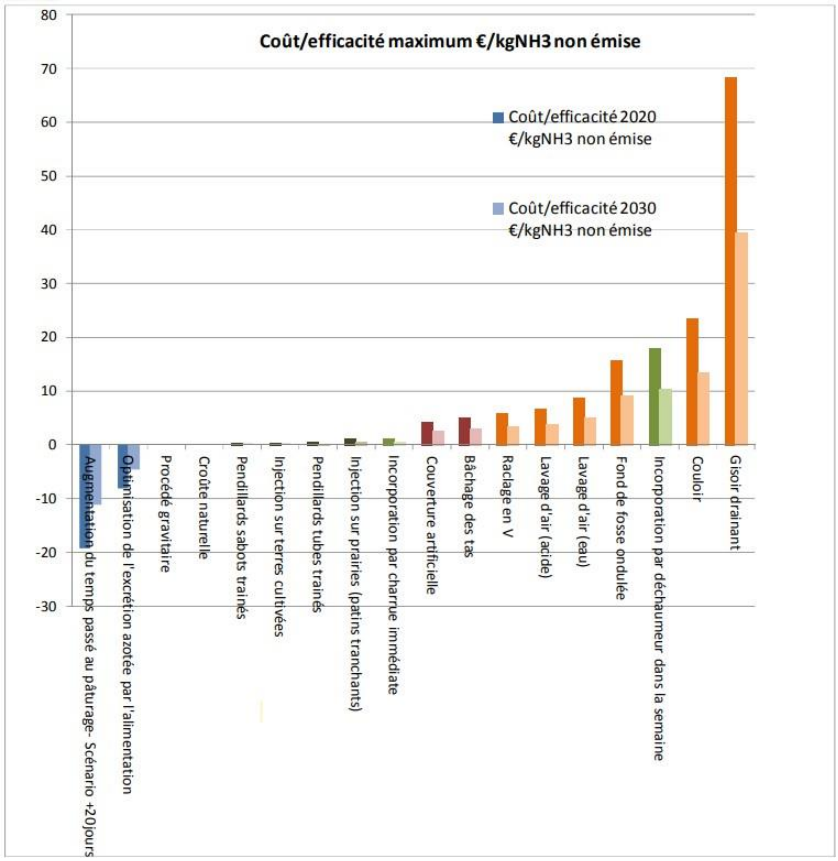
Table 16 Annual greenhouse gas savings at EU-28 level for the MG and VRNT optimistic, average and pessimistic scenarios, based on adoption on farms > 50 ha (Soto et al., 2019).

Savings	MG			VRNT		
[kton CO_2-eq]	Pessimistic	Average	Optimistic	Pessimistic	Average	Optimistic
Direct N_2O	-98	413	1258	904	1572	2299
Indirect N_2O	-21	87	263	190	327	471
Fuel use	363	891	1370	363	891	1370
Fertilizer production	-119	499	1520	1092	1899	2778
Total GHG savings	*125*	*1889*	*4410*	*2549*	*4689*	*6918*

3.2.4. Minimum/threshold or optimum level of implementation

The importance of low emission techniques could increase in a changing climate. More variable weather and extreme weather conditions are likely to limit the number of suitable moments for fertilisation. Every method that can limit the impact of the weather conditions on losses will therefore become more important and more effective in a changing climate. A panel of Flemish experts also did not consider it likely that there would be any negative impact of climate change on the effectiveness of this measure (Nawara et al., 2021). In a study in France, low emission application techniques were also estimated to be a cost-efficient measure with insignificant cost net cost per kg ammonia avoided (grey bars in Figure 18).

Figure 18 Cost-benefit ratio per practice or strategy, all animal categories included, to the horizons of 2020 and 2023, regarding an application rate of 100. (Blue: practices related to feeding, orange: practices related to the buildings, red: practices regarding storage, **gray: practices related to application**, green: post-application practices) (Martin and Mathias, 2013).



Split fertilisation does not necessarily require adapted machinery. Extra costs will concern eventual intermediate soil samples and the extra time that needs to be spent. It can be concluded that split fertilisation is a cost-efficient measure. The addition of an intermediate decision about the need (and level) of any further fertilizer applications makes this measure rather climate robust, even if unforeseen wet conditions may prevent timely treatment or dry conditions can prevent fertiliser from reaching crop roots. In dryer conditions, leaf fertilisation can be considered. However, this is not an option if conditions are too dry or in case of very high doses.

The different forms of precision agriculture (machine guidance, variable rate nutrient technology,

variable irrigation) are often associated with high investment costs. The cost-benefit analysis of these techniques is therefore not always clear, also given that the environmental benefit is not directly felt by the farmer. The size of the farm or the relevant parcels and the diversity of the parcels will partly determine the feasibility and suitability of precision agriculture techniques. These techniques also demand a certain level of IT awareness, which can have a discouraging effect. In conclusion, while is has been demonstrated that precision agriculture can be effective in reducing nutrient losses, economic efficiency is not always clear, especially at the level of the farm. On the other hand, precision agriculture can be seen as a rather climate robust measure, since decisions can be made ad hoc in light of climatic factors.

3.3. Fertilisation plans, records on fertiliser use

3.3.1. Background

This point refers to ANNEX II (B) of the Nitrates Directive where is stated that the Member States may also include in their code(s) of good agricultural the establishment of fertiliser plans on a farm-by-farm basis and the keeping of records on fertiliser use. Focusing on the fertiliser plans and the keeping of records, it's useful to define some terms:

- Fertiliser plan: expected fertilisation practices
- Record keeping (fertilizer register): fertilisation practices actually carried out
- Nutrient balance: calculation of the nitrogen dose based on a nutrient balance.

The fertilisation plan is an overview at parcel level in which the farmer plans the use of animal manure and other fertilisers at the beginning of the fertilization season. The nutrient balance is not asked for in this point of the annex but is rather closely related to the fertiliser plan and could easily be confused with it. The separately effectiveness and efficiency of a fertiliser plan or a fertiliser register is not often scientifically defined or discussed. Nutrient management and fertilisation planning are rather discussed more generally in relation to the nutrient balance.

3.3.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses.

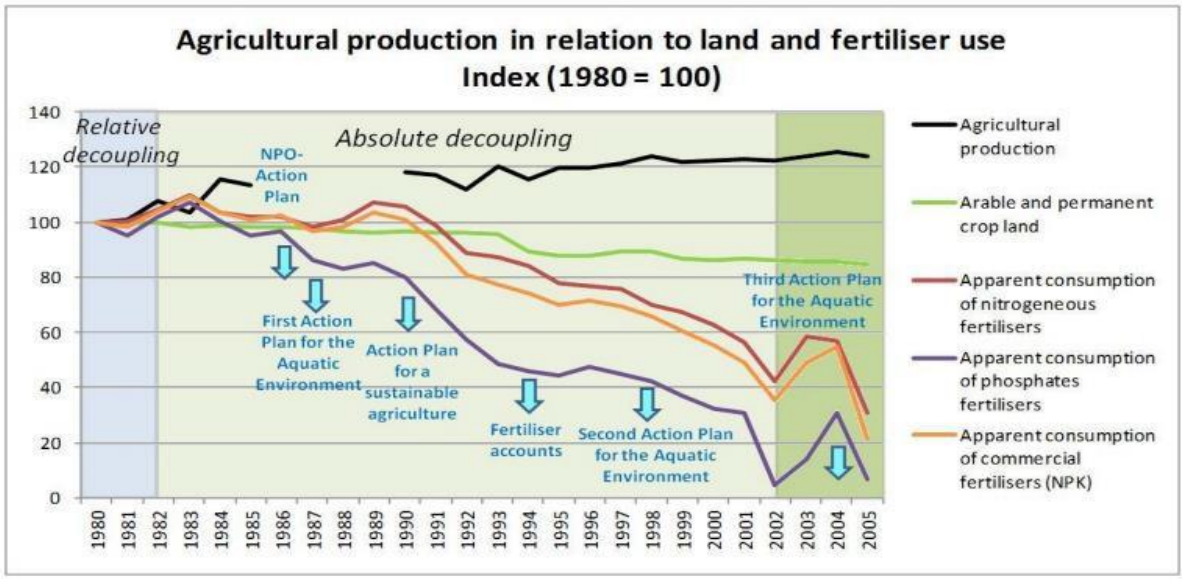
A fertiliser plan provides an overview of the planned use of nutrients on a farm. A fertiliser plan helps the farmers to plan the use of the different fertilisers, gives insight in the flux of fertilisers on the farm and draws the attention on how to apply each fertiliser best. It makes clear which fertiliser should be used for which crop and at which time. In fact, the plan helps to identify and fulfil the 4 R's of fertiliser application (i.e., right source, right rate, right place and right time). Where animals are present, it is necessary to estimate how much manure will be produced and be used and the amount and type (mineral, organic) of N it contains. The application of manure will have to be planned for each crop, as a result of which the need of additional mineral (or other) fertilisers will appear. At farm level, the possible overall shortages or surpluses of N will become apparent in the fertilizer planning. Alterra (2011) stated in a detailed analysis that in many cases, an improvement of the environmental performance of farms can already be achieved by using coarse default values for the various nutrient flows passing the farm gate. The fertilisation plan can be oriented after predetermined and generally applicable application limits or be based on an analysis of the specific need, determined for each crop or parcel at the farm. In either case the fertilisation plan should reduce over-fertilisation and by consequence reduce nitrate leaching.

Determining the input or the fertilisation dose on a specific nutrient balance per crop or at parcel level is the more elaborate and time-consuming exercise. In this case, the estimated need and nitrogen export is based on the production capacity of each crop realised at the farm. The N dose

can be further specified by soil sampling at the start of the growing period. Fertilisation planning based on soil testing, a crop fertilisation plan and a post-hoc nitrogen balance, was evaluated as an effective tool for achieving balanced economic and environmental benefits in crop farming (Popluga et al., 2016). Valkama et al. (2013) indicated that with knowledge of field and crop properties fertilization planning could reduce N input by 20-75 kg/ha for cereals in Finland. The N-balance could be reduced by 10-40 kg/ha/year, indicating a possible reduction of nitrogen losses. Osmond et al. (2015), considering nutrient management planning as the primary tool to reduce nutrient losses from agricultural fields in America, pointed out that the effectiveness of this measure ultimately depends in large measure on its practical implementation by farmers.

The registration of the fertiliser use will encourage the farmers to respect the application standards and reduce nutrient losses. On the one hand, the records on fertiliser use can be used as a control system by governments to control compliance with application standard or N-budget at the farm and to get the closest possible indication of fertiliser use and overall N fluxes at national and regional level. On the other hand, farmers themselves can also use it as a control instrument. They can put the registered use of fertilisers against the fertiliser plan and the results in the field. In that way, it can be used for a post-hoc nitrogen balance and be an element in steering the farm towards more sustainable fertilization practices. The effectiveness of this measure may depend on its enforcement. With outside controls or mandatory registration, it can be a measure to induce farmers to respect the application standards, to reduce over-fertilisation and reduce nutrient losses. Without enforcement, a requirement of fertilizer planning is less likely on its own to help to avoid nutrient losses or lead to a sustainable fertilisation. In Denmark, farmers registered in the Register for Fertilizer Accounts are required to prepare a fertilizer plan, to calculate the nitrogen-quota for the farm and to submit a fertilizer account. The fertilizer plan must be prepared before the growth season begins and the fertilizer account must be submitted after the growing season is over. Fertilisers purchases and manure production and transfers are registered as well as the balance stored. Figure 19 shows that the introduction of the fertiliser account was part of the measures resulting in a reduced use of fertilisers.

Figure 19 Decoupling trends in agricultural use of fertilisers in Denmark. Agricultural production in relation to land and fertiliser use 1980-2005 (Tan and Mudgal, 2013).



In summary, the fertilisation plan encourages the farmer to think about the manure present on the farm, the needs of the different crops, the moment at which N is needed, the need of mineral N and the most suited application method. Since the fertilisation plan will be oriented to a certain application limit, being the application standard or the specifically determined N dose, farmers will have a clear view on the limits and over-fertilisation is discouraged and will be reduced. Reduction of over-fertilisation will result in reduced nitrogen losses. However, the fertilisation plan only reflects an intention. If not implemented, the measure will have no effect. A fertilizer register or record that reflects the actual fertilization practices on the farm can be a useful instrument for both government and the farmer. If planning is also based on soil sampling and determination of the amount of mineral nitrogen, especially nitrate-N, in the soil, the measure can be even more effective but also more costly.

3.3.3. Environmental co-benefits and drawbacks

Popluga et al. (2016) mentioned a reduction of direct N_2O emissions by 47-187 kg CO_2-eq/ha by fertilisation planning and the associated reduced N fertiliser input.

3.3.4. Minimum/threshold or optimum level of implementation

A fertilisation plan and registration of the fertiliser use demands some time of the farmer but is free. A reduction of the fertiliser dose and/or a higher nutrient efficiency by a better planning, can result in savings on fertilizer purchases, so it can be a cost neutral measure in practice. This may be the case even where a more elaborate nutrient management planning with soil sampling is considered.

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4. CLUSTER IV - LAND MANAGEMENT, VEGETATION COVER IN SENSITIVE PERIODS, IRRIGATION SYSTEMS

4.1. Land use management, crop rotation, permanent crops

4.1.1. Background

According to the Nitrates Directive, Annex II, Member States may include in their code(s) of good agricultural practices items regarding "land use management, including the use of crop rotation systems and the proportion of the land area devoted to permanent crops relative to annual tillage crops". Crops differ from each other when it comes to their sensitivity to nitrate leaching. This is partly due to differences in agricultural practice: fertilization, soil preparation, harvest date, crop rotation, etc. In addition, the properties of the crop also play an important role, for example the crop rooting depth, the efficiency of nitrogen uptake and the growing period.

Maize, especially continuous maize cropping (monoculture), is known to be very sensitive to nitrate leaching. In the Netherlands, the median nitrate concentration in soils with maize cropping was observed to be 4 to 8 times higher than in soils with grass (https://www.rivm.nl/landelijk-meetnet-effecten- mestbeleid/nieuwsbrieven/verkenning-gewasspecifieke-nitraatuitspoeling-in-lmm). Maize is more sensitive than grass to nitrate leaching due to a smaller root system, a shorter period of nitrogen uptake and the frequent soil tillage inducing increased mineralisation of soil organic N. In a field experiment in Bulgaria, the losses of nitrate nitrogen out of the root zone were significantly reduced in cereal crops compared to maize (Simeonova, 2024).

Vegetable crops may also lead to considerable N losses through leaching during winter and pose a threat to meeting water quality objectives, due to their often large amounts of crop residue biomass with high N contents (Agneessens et al., 2014). From literature review on nitrate leaching in 40 vegetable crop species, Zemek et al. (2020) concluded that more nitrogen is leached under field vegetable cultivation than under arable and grassland. Specifically cabbage species showed a high N leaching potential, whilst the risk of leaching was considered lower for most leafy vegetable species. Main influencing factors are the amount and N-content of crop residues and the rooting depth.

An illustration of median nitrate concentrations in groundwater and soil moisture for a number of crops in different soil types in the Netherlands is given in Table 1 (van Duijnen, 2020).

Table 17 Median nitrate concentration in groundwater / soil moisture per soil type for a number of crops in 2009-2017 in the Netherlands (based on van Duijnen, 2020)

Crop type	**median nitrate concentration (mg.l^{-1})**			
Soil type:	**Sand**	**Löss**	**Clay**	**Peat**
Grass	7	18	7	6
Maize	62-68	77-99	37	8
Potato	42-45	75		
Leaf & stem vegetables	113			
Barley	48	54		
Temporary grassland	38	17		
Sugar beet	49	52		
Wheat	51	61		

In addition to the differences between crops, it is also essential to look at nitrate leaching at the level of the entire crop rotation. Accurately attributing N leaching to preceding-crops-current crop combinations is often challenging (Beillouin et al., 2021). Based on model simulations,

Rashid et al. (2022) found that rotations with a higher proportion of spring crops are more prone to leaching than rotations having a higher proportion of winter cereals and semi-perennial grass-clover leys. Based on measurements in a small catchment area in northern France, Beaudoin et al. (2005) observed that a sugar beet-wheat rotation gave the lowest nitrate concentration at the end of the winter and a pea-wheat rotation the highest one. The higher was the proportion of spring peas in the crop succession, the greater was the nitrate concentration. De Notaris et al. (2018) tested crop rotations with different annual crops (barley, hemp, pea, wheat, potatoes) and catch crops in Denmark and found that spring wheat and potatoes were the two crops with highest N leaching. Beillouin et al. (2021) simulated 20-year series of N leaching for various cropping sequences and found an impact of the preceding crop on N leaching from the current crop.

Crop rotation and the introduction of alternative and/or (semi-)perennial crops in the rotation as well as the conversion to permanent crops can play an important role in minimizing the risk of nitrate leaching by improving soil N availability, reducing the amount of N fertilizer applied and optimizing nutrient absorption throughout the soil profile as well as throughout the year. According to Beillouin et al. (2021), diversified cropping sequences can reduce N leaching by up to 40%. The effects of land use and crop rotation is illustrated by the literature review given in Table 18, of annual N leaching figures for different crops and crop rotations.

Table 18 Nitrogen leaching in different crop rotations

Reference	**Area**	**Method**	**Crops/Rotations**	**Average N leaching per rotation (kg N.ha^{-1}.year^{-1})**
Beaudoin et al. (2005)	northern France	field measurements; modelling	rapeseed - winter wheat	32 kg N.ha^{-1}
			winter wheat – rapeseed	17 kg N.ha^{-1}
			winter wheat – winter barley	31 kg N.ha^{-1}
			pea – winter wheat	42 kg N.ha^{-1}
			sugar beet – winter wheat	11 kg N.ha^{-1}
			winter barley – cover crop	27 kg N.ha^{-1}
De Notaris et al. (2018)	Denmark	field experiment; field measurements; modelling	barley-hemp-pea-barley-wheat-potatoes without catch crop	51-63 kg N.ha^{-1}
			barley-hemp-pea-barley-wheat-potatoes with catch crop	31-36-39 kg N.ha^{-1}
			barley-green manure crop-barley-wheat without catch crop	54 kg N.ha^{-1}
			barley-green manure crop-barley-wheat without catch crop	24-33 kg N.ha^{-1}
Ferchaud & Mary (2016)	northern France	field experiment; modelling	sorghum-triticale	1.8-5 kg N.ha^{-1}
			switchgrass	0.5 kg N.ha^{-1}
			fescue-alfalfa	0.5-2.3 kg N.ha^{-1}
			miscanthus	2 kg N.ha^{-1}
Hussain et al. (2019)	Michigan, US	field measurements; modelling	continuous maize (corn)	34 kg N.ha^{-1}
			switchgrass	9.2 kg N.ha^{-1}
			miscanthus	7.6 kg N.ha^{-1}
			grasses	4.4 kg N.ha^{-1}
			poplar	7.2 kg N.ha^{-1}
			restored prairie	2.4 kg N.ha^{-1}
Jiang et al. (2022)	Canada	field experiment; modelling	buckwheat-buckwheat-potatoe	135 kg N.ha^{-1}
			buckwheat-red clover-potato	193 kg N.ha^{-1}
			Buckwheat-Timothy-potatoe	86 kg N.ha^{-1}
Kanwar et al. (2005)	Iowa, US	field experiment	maize-soybean-oats strip intercropping	12.6 kg N.ha^{-1}
			alfalfa(3yr)-maize-soybean-oats	11.8 kg N.ha^{-1}
			soybean-maize	13.7 kg N.ha^{-1}
			maize-soybean	13.3 kg N.ha^{-1}

Reference	Area	Method	Crops/Rotations	Average N leaching per rotation (kg $N.ha^{-1}.year^{-1}$)
Kunrath et al. (2015)	France	field experiment	arable rotation: maize-wheat-barley grassland arable + 3 yr grass arable + 6 yr grass	37 kg $N.ha^{-1}$ 70 kg $N.ha^{-1}$ 18 kg $N.ha^{-1}$ 8 kg $N.ha^{-1}$
Masoni et al. (2015)	Italy	field experiment	barley field bean red clover sulla alfalfa italian ryegrass, preceded by: alfalfa (3yr) sulla(2yr) barley(1yr) red clover(2yr) field bean(1yr)	37 kg $N.ha^{-1}$ 47 kg $N.ha^{-1}$ 26 kg $N.ha^{-1}$ 26 kg $N.ha^{-1}$ 18 kg $N.ha^{-1}$ 7 kg $N.ha^{-1}$ 9 kg $N.ha^{-1}$ 22 kg $N.ha^{-1}$ 9 kg $N.ha^{-1}$ 32 kg $N.ha^{-1}$
Olesen & Askegaard (2004)	Denmark	field experiment	barley+ley-grassclover-wheat-lupin barley+ley-grassclover-wheat-lupin+grassclover barley+ley-grassclover-wheat-peas/barley barley+ley-grassclover-wheat+grass-peas/barley+grassclover oat-wheat-cereal-peas/barley oat+clover-wheat+clover-cereal+clover-peas/barley+grassclover	102 kg $N.ha^{-1}$ 68 kg $N.ha^{-1}$ 32-49-95 kg $N.ha^{-1}$ 23-35-63 kg $N.ha^{-1}$ 25-34 kg $N.ha^{-1}$ 24-36 kg $N.ha^{-1}$
Pugesgaard et al. (2015)	Denmark	Field experiment; modelling	winter wheat grass-clover young willow (1-3 yrs after planting) old willow	36-68 kg $N.ha^{-1}$ 3-6 kg $N.ha^{-1}$ 18, 3, 0.3 kg $N.ha^{-1}$ 6-27 kg $N.ha^{-1}$
Randall & Mulla (2001)	US	literature review	continuous maize (corn) maize-soybean, soybean-maize alfalfa grass-alfalfa mix	54 kg $N.ha^{-1}$ 51 kg $N.ha^{-1}$ 50 kg $N.ha^{-1}$ 2 kg $N.ha^{-1}$ 1 kg $N.ha^{-1}$
Simeonova et al. (2024)	Bulgaria	field experiment	maize wheat	5.6-28.5 kg $N.ha^{-1}$ 1.2-6.3 kg $N.ha^{-1}$
Smith et al. (2013)	Illinois (US)	field experiment	maize (corn) soybean miscanthus switchgrass prairie	7-21 kg $N.ha^{-1}$ 10 kg $N.ha^{-1}$ 0.8-22 kg $N.ha^{-1}$ 0.5-8 kg $N.ha^{-1}$ 0.4-9 kg $N.ha^{-1}$

4.1.2. Assessment on the effectiveness and efficiency in terms of preventing and reducing nutrient losses

In the following assessment, the effects of some possible land use and cropping system measures on nitrate leaching are reviewed more in detail, based on literature.

4.1.2.1. Breaking maize monoculture

Growing silage maize on the same field for years has serious disadvantages: yields will decrease, in some cases with up to 20%. Soil organic matter also decreases and nitrate leaching increases.

At the same time, results from the Netherlands show that breaking maize monoculture with grass can result in more nitrate leaching than the continuous and separate cropping of each of these crops, due to the large amount of mineral N released after the ploughing up of the grass (Kayser et al. 2008; Hooijboer et al., 2017). However, trials on experimental farms have shown that nitrate leaching in maize-grass rotations can be reduced with adapted cropping techniques, such as zero N fertilization in the first year of maize after grass and growing of catch crops after maize (Hooijboer et al., 2017).

Based on field experiments in the US (Pasley et al., 2021), rotating maize with soybean allows for a greater environmental buffer than continuous maize with regard to the impact of overfertilization on nitrate leaching. The cropping system plays a significant role in determining the degree to which the fertilizer N rate affects nitrate leaching as well as the rate above which leaching increases significantly.

Including legumes such as soybean or alfalfa, in maize-based rotation systems such crops decrease nitrate-N concentrations in subsurface drainage discharge (Koropeckyj-Cox et al., 2021) and reduces nitrate leaching to aquifers (Singh et al., 2023). From the analysis of field soil samples in Nebraska, Singh et al. (2023) observed that including alfalfa in maize crop rotations effectively reduces the nitrate leaching potential thanks to an improved N uptake (less nitrate-N stock in the soil) and less deep soil water percolation than continuous maize.

4.1.2.2. Introducing break or rest crops in crop rotations

In the context of reducing the risk of nitrate leaching, “break crops” are defined as crops grown to diversify the cropping sequence and reduce N leaching at the rotation due to their contribution to increasing nutrient use efficiency and crop N recovery of the following cereal crop (Beillouin et al., 2021). In the Netherlands, “rest crops” are defined as crops that are less susceptible to nitrate leaching and at the same time have a positive effect on soil quality. Examples are cereals, grass seed, rapeseed, alfalfa and flax (Rijksdienst voor Ondernemend Nederland). In the Netherlands, it is mandatory since 2023 to grow “rest crops” once every 4 years, on all arable fields on sandy and loess soils.

4.1.2.3. Introducing (semi-) perennial crops

Annual crops leak substantially greater amounts of nitrate compared with perennial crops, that have an extended growing period and greater root activity (water and nutrient uptake) and where cycling of N is optimized (Randall et al., 2001; Masoni et al., 2015; Pugesgaard et al., 2015; Ferchaud & Mary, 2016). Deep-rooting crops such as alfalfa are very effective at accessing deep-leached N (Kelner et al., 1997). Therefore, the introduction of perennial crops can contribute substantially to the improvement of the water quality. However, difficulties getting a satisfactory economic return with many perennials may be an obstacle (Randall et al., 2001). Moreover, perennial crops may decrease groundwater recharge in deep soils or dry climates (Ferchaud & Mary, 2016).

In a field experiment in Denmark, significantly lower nitrate leaching compared to winter wheat in grass- clover and willow was attributed to a combination of a longer growing season enabling both willow and grass-clover to take up N during autumn and early spring, higher levels of evapotranspiration and, hence, lower level of drainage from the root zone and minimal soil tillage, resulting in less mineralization (Pugesgaard et al., 2015).

Compared to annual crop production, perennial grasses reduce N losses by exploiting the entire

growing season for several years without re-establishment. In field experiments in Denmark, they reduced nitrate leaching by 70–80% compared to the traditional annual cropping systems (Manevski et al., 2018).

The introduction of perennial mowed grassland sequences into arable crop rotations in a field experiment in France caused a marked reduction in the nitrate levels in groundwater and the greater the proportion of grassland within the rotation the more marked was the reduction in nitrate concentration (Kunrath et al., 2015).

In a field experiment in Minnesota, potential nitrate leaching was estimated to be 77–96% lower under intermediate wheatgrass (perennial grass) than under the annual maize-soybean rotation. The wheatgrass captured a greater proportion of the soil N, which was likely facilitated by its greater root biomass (5.4 times higher than that under the annual crop rotation) (Reilly et al., 2022).

On a yearly basis, nitrate leaching from legumes increases with the decrease in crop cycle length (Masoni et al., 2015). The use of perennial legume crops also reduces nitrate leaching in subsequent grass crops, due to a better synchronisation of their N demand with the N supplied from residue mineralisation. E.g. in a field experiment in Italy, nitrate leaching from Italian ryegrass was higher when cultivated after annual crops than after perennials, attributed to a longer intercrop period following the annual crops (Masoni et al., 2015).

However, perennial crops may leach more nitrate during their establishment phase, in the first few years after planting (Hussain et al., 2019; Ferchaud & Mary, 2016). In their field experiment in Denmark, Pugesgaard et al. (2015) found that nitrate leaching from young willow was higher in the first winter after planting than in the two subsequent winters. The reason is most likely that the willow had not established an extensive root system until after the second growth year after which nutrient uptake is very effective.

4.1.2.4. Permanent crops: orchards

Orchards, like any agricultural system, require nitrogen fertilizers to support plant growth and fruit production. In orchards high value crops are produced and they are often managed in an intensive manner on highly fertile soils. Like all horticultural crops orchards are susceptible to nitrate leaching. A study of the nitrogen dynamics in orchards in Europe has estimated nitrate leaching between 4 and 117 kg N/ha per year (Table 19).

Orchards are often irrigated so an increase of the irrigation efficiency will decrease nitrate leaching out of the root zone. Hydrological studies near in the Jucar river basin near Valencia (Pool et al., 2022, Pérez-Martín and Benedito-Castillo, 2023) estimated for citrus that drip irrigation would reduce the nitrogen leaching fraction from 86% to 18% compared to furrow or flood irrigation. The effect of an improved irrigation management to reduce nitrate leaching is discussed further in the section on *"Prevention of leaching and run-off in irrigation systems"* below.

Table 19 Nitrogen leaching calculated in fruit orchards in Europe.

Author and study period	Crop and location	Fertilization dose	Irrigation	Nitrate leaching per year
Fernández-Escobar et al., 2012 2001-2007	Olive, Cabra, Province of Córdoba, Spain	80-200 kg N/ha	Drip irrigation according to deficit irrigation scheme	14-117 kg N/ha
Lidón et al., 2013 1991-1993	Citrus, Valencia, Spain	150-300 kg N/ha	Yes but no specification of irrigation scheme	40-76 kg N/ha
Nesme et al., 2009 2002-2003	Apple, Nîmes-Montpellier, France	50-150 kg N/ha	Yes, optimal irrigation schedule filling to field capacity after period of water stress.	50-100 kg N/ha
Verellen et al., 2022 2020	Pear, Belgium	65 kg N/ha	Yes, optimal irrigation scheme according to soil water balance	58-75 kg N/ha
Demestihas et al., 2018 2014-2015	Apple, France	18-36 kg N/ha	Yes but no specification of irrigation scheme	4-38 kg N/ha

4.1.3. Environmental co-benefits

Perennial crops can lead to a reduction of N2O emissions (Smith et al., 2013).

Crop diversification contributes to increased biodiversity, improving soil quality, built-up of soil organic matter (SOM).

Perennial crops results in a build-up of soil organic matter and reduces erosion risk.

4.1.4. Minimum/threshold or optimum level of implementation

Not applicable to this measure.

4.2. Vegetation cover in rainy periods, winter (cover crops)

4.2.1. Background

Cover crops are planted/sown to cover the soil during the period between the harvest of a main crop and the sowing of the next main crop (mostly autumn and winter). During these periods, cover crops can “catch” the residual nitrate in the soil after the harvest of the main crop and retain it during winter, releasing it again in spring. In this way, cover crops reduce nitrate leaching and increase the transfer of N to the subsequent crop. Such cover crops are also sometimes referred to as “catch crops”. Their effectiveness depends on soil, climate as well as land and crop management. Globally, the greatest cover crop efficacy is observed in coarse-textured soils, vegetable cropping and tilled soils (Nouri et al., 2022).

4.2.1.1. Cover crop functions

In the literature and in agricultural practice, different names are used for non- (or less) productive crops that are sown after the main crop (cash crop), depending on the intended crop function. For

example, a “cover crop” can be defined as a crop whose function is to keep the soil covered during autumn or winter to reduce the risk of erosion and compaction. The function of a “catch crop” is to capture and retain residual nutrients (N) in the soil in the autumn with the aim of preventing nutrient losses during autumn and winter. A “green manure crop” is a crop that, after dying and incorporation in the soil, provides nutrients for the next main crop. Finally, an “intermediate” crop is a crop that is intended to achieve an additional yield, such as grass after maize.

In practice, there is overlap between these functions. Non-leguminous cover crops also function as catch and green manure crops. Leguminous cover crops mainly function as a green manure and only to a lesser extent as a catch crop. They do absorb some N from the soil, but they do this rather inefficiently. Intermediate crops are (usually) also in the field in autumn-winter, but are harvested (e.g. grass sown after maize, a cutting of which is harvested in the spring). In addition to their yield function, they also function as a catch and cover crop, but not as a green manure. Winter cash crops, such as winter grains, sown in time, can also function as a catch crop (but mainly only after winter) but do not function as a cover or green manure crop.

4.2.1.2. Mechanisms for prevention and reduction of nutrient losses

When a cover crop is sown, the nitrate N content in the soil initially increases slightly, mainly due to a temporary increase in the mineralization of soil organic matter after the seedbed preparation. Once the root system has developed, the cover crop can absorb nitrate from the soil, causing the nitrate content to decrease and remain low during the winter months. In the spring, after the cover crop has been terminated, this absorbed nitrogen will mineralize again and be released in the soil.

A catch crop can also reduce nitrate leaching through a reduction in drainage due to increased transpiration and thus water depletion in the soil (Thapa et al., 2018). On the other hand, Nouri et al. (2022) found that the impact of cover crops on water drainage was non-significant which would imply that nitrate leaching control by cover crops is less likely to be exerted through a reduction in water drainage.

A third mechanism of the reduction of nitrate leaching by cover crops could lie in the microbial immobilization of nitrate due to carbon inputs from cover crop roots into the soil (Thapa et al., 2018).

The effects of cover crops on P losses are less clear. Norberg & Aronsson (2018) conducted a field experiment with oilseed radish in southern Sweden and found no impact on P leaching. A field study review of Aronsson et al. (2016) in southern Scandinavia and Finland, indicated that cover crops do not substantially reduce total P losses by runoff and leaching.

4.2.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses

4.2.2.1. Reduction of nitrate leaching – figures

Based on a global meta-analysis, Thapa et al. (2018) concluded that non-leguminous cover crops reduce nitrate leaching by 56% on average. The potential of the cover crops to reduce nitrate leaching was partially dependent on their sowing date, aboveground biomass and weather conditions (relative precipitation). Early sowing in autumn and higher aboveground biomass in spring are both linked to a longer growth period of the cover crop and therefore a higher nitrogen uptake. The reducing effect on nitrate leaching was higher in relatively drier years (compared to

the long-term average).

Nouri et al. (2022) conducted a similar meta-analysis and found that non-leguminous cover crops reduce nitrate leaching by an average of 69%. Overall, the reduction was greatest with cruciferous (75%) and grassy (52%) cover crops.

In Scandinavian regions, the possibilities of cover crops sown after harvest of the preceding cash crop to reduce nitrate leaching is limited by the poor light and temperature conditions during autumn and winter. For this reason, cover crops are often undersown in the preceding main crop (see below) and the use of cover crops sown at harvest is restricted to southern Scandinavia. Aronsson et al. (2016) summarized the results of field leaching studies at 11 different sites and found an average relative reduction in N leaching of 43%, but it ranged between an increase of 62% (after red clover) to a reduction of 85% to 89% with perennial ryegrass on sandy soils in Denmark. They concluded that, under the climatic conditions of southern Scandinavia and Finland, undersown ryegrass cover crops are robust with respect to growth and reduction of N leaching, while crucifers sown after the main crop are less reliable due to the short time available for growth under cool climate conditions. Valkama et al. (2015) conducted a meta-analysis of studies conducted in Denmark, Sweden, Finland and Norway and found that non-leguminous cover crops, mainly ryegrass species, reduced N leaching loss by 50% on average, whilst leguminous cover crops did not diminish the risk for N leaching.

4.2.2.2. N-uptake and influencing factors

The reduction of nitrate leaching by cover crops is mostly achieved by their N uptake. The N uptake capacity of a crop generally is promoted by the following properties:

- a high leaf growth rate (leaf expansion rate),
- a high radiation conversion efficiency (radiation use efficiency),
- a fast and sufficiently deep root development.

The extent to which these properties are expressed is determined by the weather conditions. In addition, the length of the growing season (sowing time), the soil properties (texture, structure and nutrient availability), the field history, the type of tillage before sowing and the fertilization also have an important impact on the root development and therefore on the efficiency of a cover crop. E.g. Selzer & Schubert (2021) determined the N uptake capacity of different types of cover crops in semi-controlled, non- restrictive growing conditions and found average N uptakes for yellow mustard, Phacelia and ryegrass of 183, 221 and 85 kg N/ha, respectively. Under practical conditions, most studies reported nitrogen uptake rates ranging between 10 and more than 100 kg N/ha.

In a review on the use of catch crops in temperate climates, Thorup-Kristensen et al. (2003) reported N uptakes for non-leguminous catch crops of 10 to 200 kg N/ha and in rare cases even up to 300 kg N/ha. They attributed the variation mainly to weather conditions and N availability.

Cover crop type

Cover crop type is an important factor determining the effect on the reduction of nitrate leaching. An important distinction has to be made between non-legume and legume cover crops.

Non-legume cover crops can be divided into 2 large groups based on their crop growth characteristics and properties:

- Broadleaf cover crops have a rapid and mainly above-ground growth with significant

biomass production and N uptake in late summer and autumn. Typical species are mustard, radish, kale and Phacelia. After winter, these catch crops are incorporated in the soil and, because of their relatively low C:N ratio, they decompose quickly, resulting in an early release of N. Typically, they have little root biomass compared to grasses and leguminous plants. Broadleaf catch crops are generally sensitive to frost, which means that, depending on the climate, they usually freeze in winter and then stop absorbing N.

- Grassy cover crops show a high N uptake, which, however, only starts slowly in the autumn. However, they are not or only moderately sensitive to frost, which means they exhibit stronger growth and N uptake, especially during winter and spring. Typical species are Italian or perennial ryegrass, rye or oats. In contrast to leafy catch crops, grasses have a pronounced root development, which means they make an important contribution to the organic matter in the soil and prevent soil compaction. The higher C:N ratio of these crops ensures a slow decomposition after their termination. As a result, the absorbed N is only released later in the growing season.

When planted early (August-September) and/or no winterkill of broadleaf species takes place, both grasses and non-legume broadleaf species are equally effective in reducing nitrate leaching. When sowing late September-October (after maize, potatoes, sugar beets, etc.), grasses outperform broadleaf species (Thapa et al., 2018). Overall, cover crops from Brassicaceae and Poaceae families show the greatest effect with 75% and 52% reduction in nitrate leaching, respectively (Nouri et al., 2022).

In agricultural practice, the choice of a cover crop depends on various parameters such as the harvest date of the main crop and the weather and soil conditions. In a field trial in northern Germany, Böldt et al. (2021) recorded nitrogen uptakes of 33 to 136 kg N/ha by cover crops. They also measured nitrate leaching and found that it was greater in frost-sensitive winter-killed cover crops, due to the premature mineralization of the crop residues.

Legume cover crops provide a wide range of ecosystem services, including N supply as well as reduction of nitrate leaching (De Notaris et al., 2020). However, they retain less N than non-legume species and therefore are less efficient in reducing nitrate leaching because they meet some of their N demand through atmospheric N fixation (Thapa et al., 2018; Shackelford et al., 2019; White et al., 2017). Numerous studies have also shown that their effectiveness in depletion of soil N is not reliable (Aronsson et al., 2016). Also, high N_2O emissions following the incorporation of monoculture legume cover crops have been reported (reviewed by Jensen et al., 2011).

Non-legume-legume cover crop mixtures can reduce nitrate leaching as effectively as non-legumes, and significantly more than legumes alone (Thapa et al., 2018). Moreover, mixtures of legumes and non- legumes can maximize the provision of ecosystem services, by reducing nitrate leaching and increasing N availability to the following crop, replacing synthetic fertilizer inputs with biologically supplied nitrogen (Kaye et al., 2019) and providing more flexibility to the system and a better ability to adapt to the specific environmental conditions (De Notaris et al., 2020, based on several other sources).

Cover crop species selection and mixture design can substantially mitigate trade-offs between N retention and N supply to cash crops (see also below, 2.2.3.2, Trade-offs), providing a powerful tool for managing N in temperate cropping systems (Kaye et al., 2019). Based on multiple regression analyses with data from on-farm experiments, White et al. (2017) found that potential

nitrate leaching below 30 cm declined as the presence of non-legume species increased in a cover crop.

The C/N ratio of cover crop biomass is positively related to the N retention by cover crops and is negatively related to the N supply to cash crops (Finney et al., 2016). White et al. (2017) used the C:N-ratio as an indicator representing the relative contribution of legume and non-legume (grassy) species to the cover crop biomass. In order to visualise and manage the trade-off between nitrogen supply and retention with cover crop mixtures, they developed a graphical analysis tool to predict relative maize yield and potential nitrate leaching across categories of cover crop type in different environmental conditions in the US (Figure 20 and Figure 21).

Figure 20 The framework of regression models driving the graphical analysis tool (White et al., 2017). Variables that directly predict relative maize yield or potential nitrate leaching are indicated by solid arrows. Variables that are included in the auxiliary regression models to predict fall C:N, spring C:N and fall non-legume biomass N content in legume cover crops are indicated by dashed arrows. Variables that are user inputs to the graphical analysis tool are bounded by the gray box on the left. The graphical output of the tool (gray box on the right) then predicts relative maize yield and potential nitrate leaching across categories of cover crop type and gradients of fractional non-legume seeding rate and spring biomass N content. Because fall C:N, spring C:N and fall non-legume biomass in legume cover crops are predicted by the auxiliary regression models, they are not needed as user inputs to the tool.

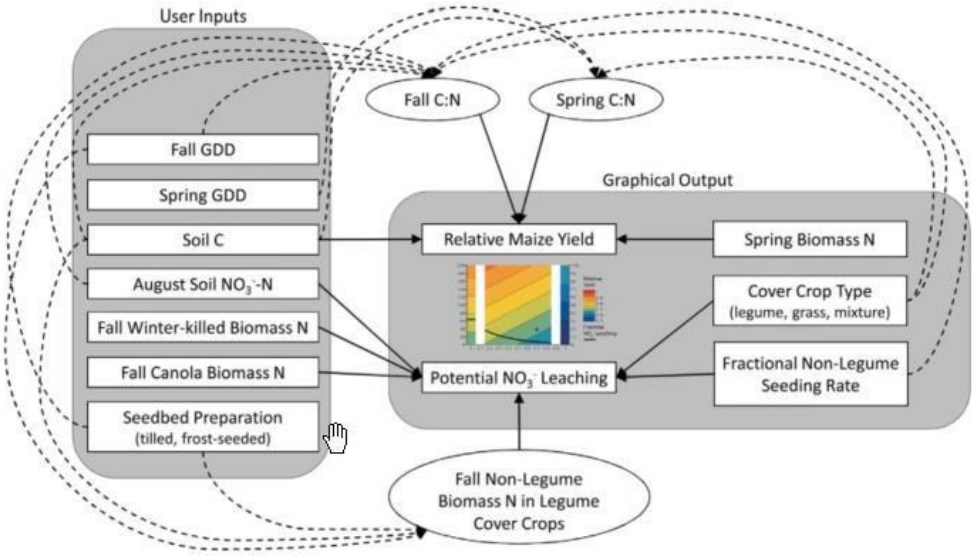
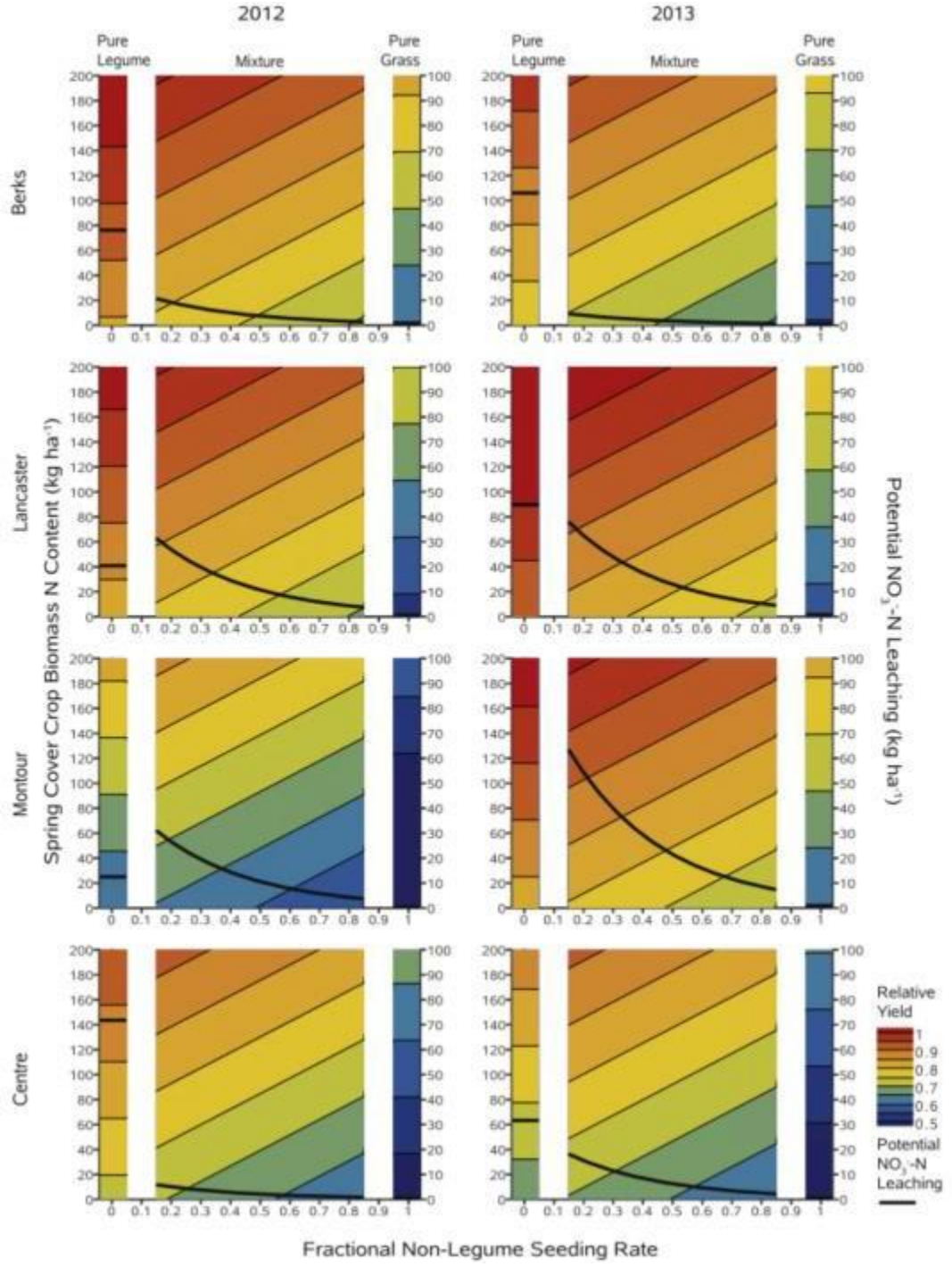


Figure 21 Outputs from the graphical analysis tool predicting potential NO_3^--leaching (black response curves; $kg.ha^{-1}$) and relative maize yield (colored contour plots) in eight site-years based on site-specific environmental conditions and cover crop composition for the 4-species mixture (White et al., 2017). Location on the contour plot for relative maize yield is determined by the fractional non-legume seeding rate (x-axis) and the spring cover crop biomass N content (left y-axis), where the value of each contour interval is defined by the color scale in the legend. Location on the potential NO_3^--leaching response curve is determined by the fractional non-legume seeding rate, with the predicted value read from the second (right-side) y-axis. Each output is divided into three columns on the x-axis, corresponding to the regression models for pure legumes, mixtures, and pure grasses.



Sowing date

The sowing date is an important parameter that determines the total N uptake of a cover crop. With later sowing dates, not only does the total growing season become shorter, but also day length, light intensity and temperature decrease, while the precipitation surplus generally increases. All this ensures that the (total) biomass production and N uptake of a cover crop decrease on average with later sowing dates. Constantin et al. (2015) performed large-scale simulations to determine the optimal emergence and maturity dates of catch crops to reduce nitrate leaching and concluded that cover crops can be very efficient in reducing nitrate leaching if their management, in particular the sowing and termination dates are adjusted to local weather conditions.

Komainda et al. (2018) conducted two field trials in northern Germany with 4 different cover crops, sown between two maize crops on 4 different sowing dates (from September 10 to October 15). Total N uptake by the cover crops varied between 7 and 56 kg N/ha and the latest sowing date yielded an average N uptake reduction of 67% compared to the earliest sowing date. Earlier sowing also resulted in a higher C/N ratio because of the more developed crop during incorporation. Thapa et al. (2018) concluded that a delay in planting till November meant that the cover crop did not induce a significant reduction of nitrate leaching anymore.

Vos (1992) collected data from several empirical studies on N uptake by cover crops. If at least 100 kg/ha of mineral N was initially present, the above-ground N yield at end of November - beginning of December could be approximated using the following equation:

N-uptake = 522 – 1,8 * sowing date

Vos & van der Putten (1997) also demonstrated a linear relationship between the maximum above-ground N uptake and the sowing date for the fertilized catch crops from their study (1991-1996):

N-uptake = 960 – 3.4 * sowing date

(the sowing date is expressed as a day of the calendar year)

However, there is a large variation in the effect of the sowing date, which can be attributed to annual meteorological differences, to the differences between the types of cover crops and to the presence or absence of additional fertilization. Cover crops usually are sown after the harvest of the main crop, but especially in northern regions (at higher latitudes) where light and temperatures during winter are limiting, their growing period can be extended by establishing them already in the growing main crop. This can be done by undersowing in spring or by preharvest broadcasting of seeds later in the growing season (Thomsen & Hansen, 2014).

Constantin et al. (2015) simulated the emergence of catch crops for different regions in France, depending on seedbed conditions with regard to temperature, moisture content, soil structure and crust formation. The results showed that in (Mediterranean) areas with dry summers, early sowing (mid-July) often resulted in poor germination and emergence of the catch crop, while later sowing (mid-September) was usually more successful. They concluded that sowing date is the management factor with the greatest impact and that it must be carefully adjusted to weather conditions to maximize nitrate uptake.

Weather conditions

The effects of sowing date cannot be completely separated from the effect of climate and weather conditions. In general, there is a direct link between the dry matter production of crops and the

captured solar radiation (Vos & van der Putten, 1997). Komainda et al. (2016) found that the temperature (sum) was the determining factor for dry matter production and nitrogen uptake, while solar radiation had no meaningful influence on the underground plant parts. Although dry matter production is directly related to solar radiation as an energy source, leaf development in autumn is mainly controlled by temperature (Bartholomew & Williams, 2005).

Komainda et al. (2016) developed exponential functions based on temperature sums to predict above- and below-ground biomass and N uptake for rye and Italian ryegrass. As a base temperature for the calculation of temperature sums, the best model fit was obtained for a base temperature of 5°C. This way, they calculated for example that for rye a temperature sum of 278 °C is required to achieve a total N uptake of 20 kg N/ha. In northern German conditions, this corresponds to a sowing date at the latest in the middle part of September. In an earlier study by Schröder et al. (1996), a linear relationship was found between above-ground N uptake and temperature sums (with a base temperature of 5°C) for Italian ryegrass.

In addition to solar radiation and temperature, precipitation and drought can also play an important role in the growth and nitrogen uptake of catch crops. Thapa et al. (2018) concluded that the effect of non-leguminous cover crops in reducing nitrate leaching was greater during years of low precipitation (<90% of the long-term normal). Emergence rate is also crucial for cover crop establishment, especially in dry areas and is mostly influenced by water availability and therefore by climatic conditions in the period around the sowing date. Tribouillois et al. (2016) calculated optimal and baseline values for temperature and soil moisture content for the germination of a range of catch crops (basic temperatures for germination ranged from 0.0 to 8.1°C, optimal temperatures from 20.2 to 37.2° C, maximum temperatures from 27.7 to 43.4°C and basic moisture stress values ranged from 0.1 to 2.6 MPa). Based on field trial data and simulations with the STICS model, Tribouillois et al. (2018) proposed a simple statistical model to predict the emergence of catch crops, in which both soil moisture content and precipitation (and irrigation) after sowing were significant predictive parameters:

$$\text{Emergence duration} = 6.9 - 0.29 \times SM + 0.44 \times DWR + 0.03 \times DD_e$$

where SM is soil moisture (%) in the seedbed layer at sowing, DWR is the number of consecutive days without significant water input (daily rainfall or irrigation < 3 mm) after sowing and "DD_e" is the number of degree days required for each species to emerge without stress. The values of DDe for each species are given in Appendix. According to the GLM, DWR, SM and DD_e were significant ($P < 0.001$, $=0.001$ and $=0.05$, respectively) and explained 52%, 6% and 4% of the variability, respectively.

Soil type

Cover cropping on Ultisols, Histosols, and Inceptisols resulted in the greatest reduction in nitrate leaching (77%, 78%, and 77%, respectively). Greater efficacy of cover crops at reducing nitrate leaching was evident with increasing soil sand content (Nouri et al., 2022).

4.2.2.3. Effects on nutrient losses after termination of cover crops

Once terminated, cover crops can also increase the risk of nitrate leaching in spring, if the N released during decomposition is not recaptured by the subsequent cash crop. In other words, leaching during the subsequent cash crop period after termination of cover crops is associated

with the time lag between the N released from cover crop residues and the N demand of the cash crop. Cover crops are typically terminated 2 to 6 weeks before the subsequent cash crop is planted, inducing a relatively long period without living plants absorbing soil N. Therefore, strategies to reduce nitrate leaching should not only focus on growing cover crops but also on the efficient use of the N captured by the cover crops and released after their termination.

The risk of N leaching after cover crop termination depends on the C:N ratio of the cover crop residues, the soil type, and the N uptake by the subsequent cash crop. Typically, legume and other broadleaf cover crops have a lower C:N ratio (see above), with a quick decomposition and an early release of N, whilst grassy cover crops have a C:N ratio that increases with plant maturity (Greenwood et al., 1990), ensuring a slow decomposition after their termination and an N release only later in the growing season. In this perspective, legume-non-legume mixtures have the advantage of having an intermediate C:N-ratio, ensuring a more balanced N mineralization and immobilization turnover, an improved coordination between the N release from cover crop residues and uptake by subsequent cash crops. As a result, they can reduce nitrate leaching in spring and at the same time partially meet the N fertilizer requirements of the subsequent cash crop.

4.2.3. Environmental co-benefits and drawbacks

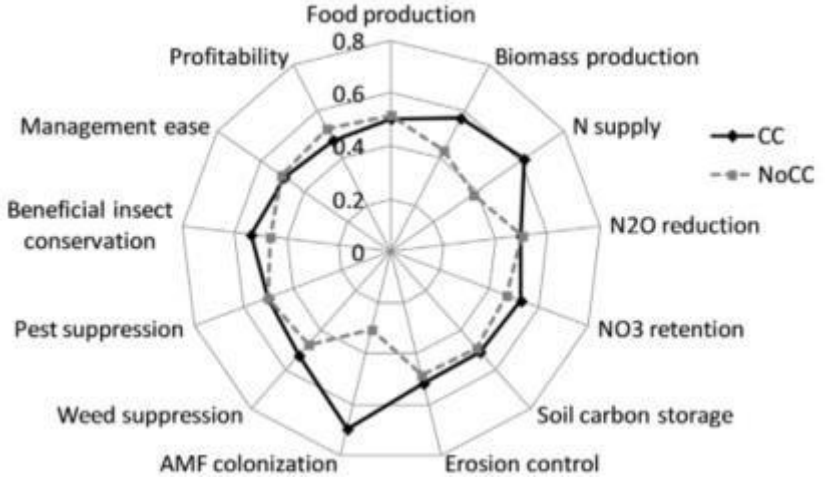
4.2.3.1. Co-benefits

Besides reduction in nitrate leaching, cover crops can enhance numerous other agroecosystem services, including

- Weed suppression (Shackelford et al., 2019; Thapa et al., 2018; Blanco-Canqui et al., 2021) ;
- Increase in soil organic matter and soil microbial biomass (De Notaris et al., 2020 ; Shackelford et al., 2019; Thapa et al., 2018; Blanco-Canqui et al., 2021; McClelland et al., 2021);
- Reduction of soil erosion and soil compaction (Thapa et al., 2018; Rivière et al., 2011; Blanco-Canqui et al., 2021; Lopez-Vincente et al., 2020). Cover crops are used to minimize soil erosion caused by intensive tillage, overuse of herbicides and loss of soil organic matter (Lopez-Vincente et al., 2020; Quintarelli et al., 2022). García-Díaz et al. (2022) observed that the use of cover crops could reduce soil losses by 3.8 to 0.7 Mg/ha in a vineyard. Novara et al. showed that using cover crops reduces by 27% annual water runoff and can be used as an agronomic strategy for improving water use efficiency (see also Task 4: use of cover crops and intercropping to reduce nutrient losses on sloping ground);
- Increase of soil porosity and improved soil-water balance (Quintarelli et al., 2022);
- Increase of biodiversity (Thapa et al., 2018; Rivière et al., 2011; Blanco-Canqui et al., 2021; Quintarelli et al., 2022) ;
- Stimulation of beneficial micro-organisms (Quintarelli et al., 2022);
- In case of legume cover crops, fixation of atmospheric N and reduction of N fertilizer inputs.

Schipanski et al. (2014) integrated a suite of ecosystem services into a unified analytical framework and estimated that cover crops increase 8 of 11 ecosystem services (Figure 3).

Figure 3 Normalized values for 11 ecosystem services and two economic metrics averaged across the 3-year rotation of cropping systems with (CC) and without (NoCC) cover crops (Schipanski et al., 2014)



4.2.3.2. Drawbacks and trade-offs

In general, cover crops do not significantly reduce the yields of the following cash crops (Thapa et al., 2018). Leguminous cover crops can even increase crop yields (depending on fertilisation practices) (Shackelford et al., 2019). However, resource competition (for nutrients and water) with the cash crop can induce lower yields of the cash crop in the short-term (Shackelford et al., 2019; Alonso- Ayuso et al., 2017). This aspect is especially important in Mediterranean regions/climates. Applying management strategies including timely cover crop termination, selection of cover crop species and other strategies can contribute to cover crop success in water-limited environments (Blanco-Canqui et al., 2021; Shackelford et al., 2019). Effects of cover crops on water availability can also be masked by management practices such as irrigation (Shackelford et al., 2018).

In organic systems, cover crops can supply N to subsequent crops and retain nitrate against leaching (Thorup-Kristensen et al., 2012). However, individual cover crop species can often provide optimal levels of only one or the other of these services. Therefore, the use of cover crop mixtures (legume-non-legume) is often more favourable. For example, Engedal et al. (2023) concluded, based on the results of a field trial, that cover crop mixtures showed the highest total carbon input and generally a higher or similar mineral N depletion potential than the average of the pure stands, suggesting that cover crop mixtures offer a realistic means of overcoming trade-offs among ecosystem functions. White et al. (2017) suggested that the trade-off between N retention and N supply could be minimized by managing environmental conditions and cover crop composition. This could be achieved by maintaining low soil nitrate concentrations prior to cover crop planting, not including winter-killed legumes in the mixture, and using non-legume species that are the most efficient at N retention. Finally, trade-offs between ecosystem benefits, production costs, and management risks should be considered (Schipanski et al., 2014).

4.2.4. Minimum/threshold or optimum level of implementation

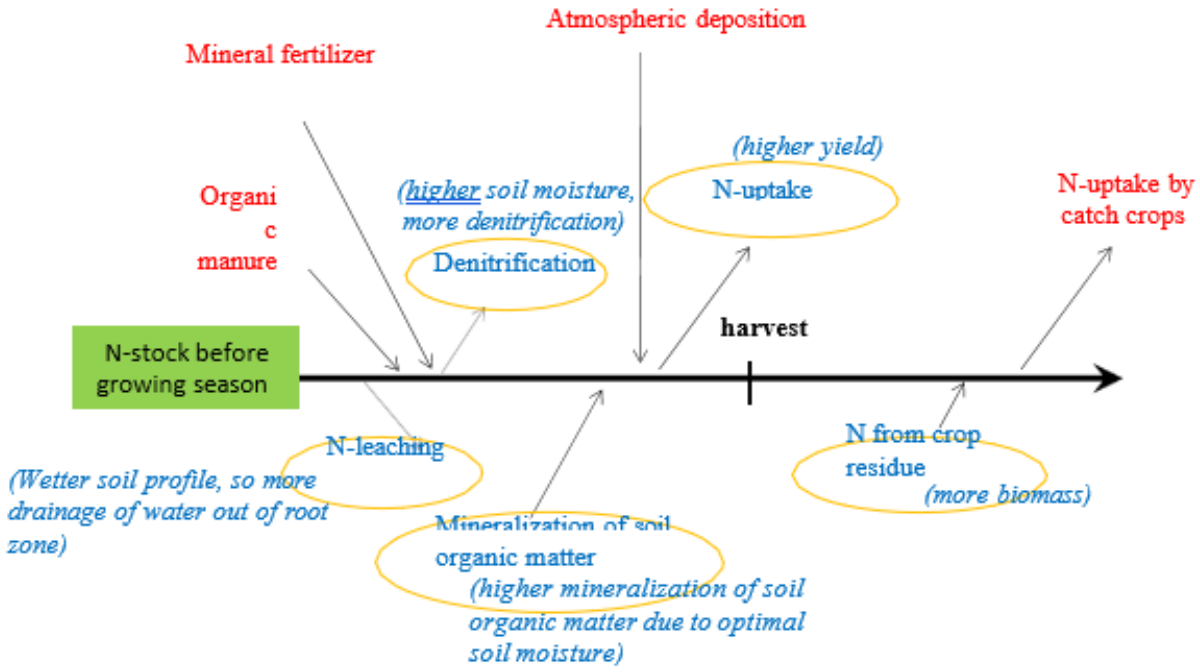
Not relevant for this measure.

4.3. Prevention of leaching and run-off in irrigation systems

4.3.1. Background

Irrigation affects the water status of the soil, which influences the nitrogen cycle (Figure 22). A higher water content in the soil will lead to more rapid drainage and thus possible nitrate leaching. A higher water content will stimulate microbiological activity and mineralisation of organic matter. If the increased water content leads to anaerobic conditions, also the denitrification rate will be higher. Generally, a higher water status in the soil during the growing season leads to more biomass production, higher yields and thus more nitrogen uptake by the crop but also more crop residues at harvest.

Figure 22 All factors that have an influence on the NO_3^--N concentration in agricultural soils; factors that are influenced by the soil water status are indicated in blue.



The effect of irrigation on water quality has been particularly examined for southern Europe (Table 20. Irrigation with water showing low NO3--concentration has been shown to dilute NO3-contaminated groundwater (Andrade and Stigter, 2009; Serra et al., 2021; Ventura et al., 2008). Next to more efficient fertilizer application a better management of irrigation has been suggested to lower NO3--N-losses to aquifers (González Vázquez et al., 2005; Lyra et al., 2022; Malik and Dechmi, 2020; Serra et al., 2021).

Table 20 Overview of studies on the relation between irrigation and NO_3^--N pollution in water bodies in Europe.

Author and study period	**Method used**	**Location and area**	**Relation between NO_3^--N pollution and irrigation**
Andrade and Stigter, 2009 (2000-2002)	Factorial correspondence analysis	Mondego River drainage basin - Central Portugal (51 km²)	Irrigation with water from the river dilutes the NO_3^- concentration in the groundwater.
González Vázquez et al., 2005 (1994-1996)	Multivariate statistical techniques (factor and cluster analysis)	Aquifer Nr 28 Unit Seville-Carmona, Province of Seville, Spain	NO_3^--N pollution is linked to cotton and potato production, due to the type of farming carried out, flood irrigation and excessive fertilizer application.
Isidoro et al., 2006 (1995-1998)	Calculation of the water budget	La Violada Irrigation District (VID) is located in the middle Ebro River basin (North-Eastern Spain)	Irrigated agriculture in was the main source of salt loading in La Violada Gully.
Lyra et al., 2022 (1991-2018)	Integrated Modeling System for agricultural coastal watersheds	Almyros basin located in the Thessaly region, central-eastern Greece (856 km^2)	The results of the study indicate that priority should be placed upon deficit irrigation under reduced fertilization.
Malik and Dechmi, 2020 (2014-2017)	Calculation with a Decision Support System for Agro-technology Transfer model	La Violada Irrigation District (VID) is located in the middle Ebro River basin (northeastern Spain)	Optimum N management could reduce NO_3^--N leaching below the root zone by 51%. These reductions could be improved further by 35%, under the combined N fertilization and irrigation optimum management.
Serra et al., 2021 (1999 and 2009)	Calculation of nitrogen balances	The methodology was applied on a national scale, considering mainland Portugal	Irrigation leads to a higher leaching risk but leads to aquifer recharge and thus also dilutes the NO_3^- concentration in the groundwater when the irrigation source has a low NO_3^- concentration.
Ventura et al., 2008 (2004-2006)	Calculation of nitrogen balance	Valle Volta, located in the eastern Po river valley (Italy)	Irrigation with open surface water that contains little NO_3^--N as a limited contribution to the influx of NO_3^--N in the area.

4.3.2. Effectiveness and efficiency in terms of preventing and reducing nutrient losses

Quemada et al. (2013) reviewed 44 irrigation experiments published between 1981 and 2012 and mainly executed in Europe and North America. The authors concluded that an improved water management has the highest potential to reduce nitrate leaching in irrigated areas. More specifically, a better irrigation scheduling according to crop needs was considered the most effective measure. Moreover, these measures did not result in yield decline. The implementation of deficit irrigation offers additional opportunities to reduce nitrate leaching, although this may be associated with a decrease in yield. Also important is that a reduction in irrigation must be accompanied by a reduction in fertilization dose. In this study, a better water management in irrigated fields was more successful than the improvement of fertilizer management or the use of cover crops to reduce nitrate leaching.

4.3.2.1. Irrigation scheduling

Irrigation scheduling is the practice of determining when and how much water to apply to crops or plants to meet their water needs efficiently. Irrigation scheduling has been closely linked to nitrate leaching and optimal N fertilization (Table 21).

Over-irrigation can cause water to percolate deep into the soil profile, carrying nitrates along with it. If more water is applied than the plants can use, the excess water can push nitrates past the root zone, increasing the risk of leaching. This has been described for irrigated maize in Portugal (Cameira et al., 2003) Spain (Daudén et al., 2004) and Romania (Marinov and Marinov, 2014). Also for open field processing tomato, nitrate leaching has been linked to excessive irrigation both in Italy (Rinaldi et al., 2007) and Spain (Vázquez et al., 2006).

On the other hand, insufficient irrigation may lead to water stress in plants, reducing their ability to take up nitrogen from the soil. This can result in unused nitrogen remaining in the soil, which is then more susceptible to leaching during subsequent rainfall or irrigation events. Especially in northern Europe studies emphasize the link between optimal agricultural production and nitrate leaching (ten Damme et al., 2022, Hack-Ten Broeke, 2001).

Table 21 List of studies in Europe linking irrigation scheduling to NO_3^--N leaching

Author and study period	**Crop(s) and growing conditions**	**Location and soil type**	**Relation between irrigation scheduling and NO_3^- - N leaching**
Cameira et al., 2003 (1996-1997)	maize for grain, silage maize grown in open fields	South of Portugal, Silty loam alluvial soil, with a shallow water table, sandy soil with a very low water retention capacity	Over-irrigation has been linked to NO_3^- - N leaching. Irrigation depths and frequency should be limited to crop demand. In the crop water demand, capillary rise from a shallow groundwater table should be taken into account.
Daudén et al., 2004 (1997)	corn grow in in lysimeters	Zaragoza, Spain, Clay loam soil with an organic matter content of 18 g/kg	It is important to adapt N applications to crop extractions. Improvement of irrigation decreased the amount of irrigation leached.

Diez et al., 2000 (1991-1997)	rotation of corn, wheat and oat grown in open fields	30 km southeast of Madrid, Spain, sandy loam texture in the first 0.5 m with an increasingly sandy texture below. Water table is some 4 m below the soil surface.	Adapting irrigation schedules reduced nitrate discharge to groundwater without impairing grain yields. Discharge of nitrate was related to both irrigation management and fertilizer application.
Marinov and Marinov, 2014	Corn, conclusions only based on model calculations no data	Balta Brailei region of Romania, Chernozem and alluvial loamy sand	Over-irrigation increases the net nitrate leakage to the groundwater, while lowering the nitrate concentration in the root regions and restricting plant growth. An intermediate trade-off between the two is necessary.
Rinaldi et al., 2007 (simulation period 1952-2004, calibration and validation based on data between 2002-2004)	Processing tomato grown in open field	Foggia, Italy, silty-clay vertisol of alluvial origin, organic matter 2.1%	Irrigation applications of 600–800 mm, which are representative of the typical application rates, will results in low WUE and NUE values. Optimal irrigation rates to minimize crop water stress and N leaching should be approximately 400 mm.
ten Damme et al., 2022 (1988-1992)	spring barley, winter oilseed rape grown in open field	Jyndevad Experimental Station in Denmark, coarse sandy soil, classified as an Orthic Haplohumod (USDA Soil Taxonomy)	Irrigation does not need to increase the risk of nitrate leaching, despite it increasing the soil water content and percolation. Synchronised management of irrigation and N-application is key for managing the risk of nitrate leaching.
Hack-Ten Broeke, 2001 (1991-1995)	Grassland grown in open field	Hengelo, The Netherlands. Cambic Podzol, organic matter 3-5%. 89 to 92% sand	Increased irrigation dose did not lead to higher nitrate leaching. In one field more irrigation led to a higher agricultural production and reduced nitrate leaching.
Vázquez et al., 2006 (2001-2002)	processing tomato grown in open field	La Rioja, Ebro Valley, Spain. Eutric Fluvisol	Over-irrigation was linked to nitrate leaching. Treatments receiving water according to 80% of maximal evapotranspiration, showed almost no drainage during the growth period and no reduction in crop yield.
Granados et al., 2013 (2006-2007)	Muskelon, Pepper grown in plastic greenhouse.	El Ejido, Almeria, Spain, an artificial layered soil, 10 cm of coarse sand on top of 30 clay	Better irrigation management by avoiding over-irrigation reduced NO_3^--N leaching by 58% in pepper and by at least 49% in muskmelon.

4.3.2.2. Irrigation technique

With respect to the application of irrigation, farmers in Europe mainly choose drip irrigation or overhead sprinkler or gun irrigation. The acreage in furrow irrigation is declining but still relevant (Lopez-Gunn et al., 2012). Hydrological studies in the Jucar river basin near Valencia (Pool et al., 2022; Pérez-Martín and Benedito-Castillo, 2023) estimated for citrus that drip irrigation would reduce the nitrogen leaching fraction from 86% to 18% compared to furrow or flood irrigation. Quiñones et al. (2007) compared nitrogen use efficiency of low frequency nitrogen applied furrow irrigated citrus trees with the efficiency of high frequency nitrogen applied drip irrigated trees with aid of a lysimeter. Drip irrigation led to a higher nitrogen uptake and a lower residual soil NO_3^--nitrogen.

Poch-Massegú et al. (2014) evaluated furrow irrigation in Girona, Spain, to be less responsible for nitrate leaching since nitrate leached mostly out the soil profile during the fallow period and not during the irrigation season. In the same study the authors point out the risk of irrigation applied for frost protection. These irrigations events are usually applied with a big volume of water during a phase where the crop does not consume a lot of water and thus imply a high risk of nitrate leaching. Next to drip irrigation, overhead irrigation applied by irrigation guns is an important irrigation technique in Europe. Zhou et al. (2018) compared both irrigation techniques in a potato experiment in Denmark. They found that there is no clear advantage of changing gun irrigation to drip irrigation. Yield, nitrogen uptake and nitrogen use efficiency were not improved with drip irrigation.

4.3.2.3. Fertigation

Fertigation is a method of fertilizing plants by applying fertilizer directly to the irrigation water. In this technique, soluble fertilizers are dissolved in water and then applied to plants through the irrigation system, allowing for a precise control over the timing and dosage of fertilizers. Experimental results in fertigation trials in Europe do not unambiguously prove its efficiency (Table 22). Quiñones et al. (2007) concluded that nitrogen use efficiency is 13% higher in citrus trees when applied under high frequency drip irrigation. Rolbiecki et al. (2020) observed a higher yield in fertigated watermelon. The added value of fertigation compared to broad band fertilization was observed to be significant but also rather moderate for arable crops (Żarski and Kuśmierek-Tomaszewska, 2023; Zhou et al. ,2018). Frequent application of nitrogen under moist conditions may entail a risk of nitrate losses to leaching (Rubio-Asensio and Intrigliolo, 2024). The importance of proper irrigation management has already been discussed. It makes sense that a correct irrigation schedule is a crucial requirement for successful fertigation application.

Table 22 Efficiency of fertigation discussed in experiments in Europe

Author and study period	Crop(s) and growing conditions	Location and soil type	Efficiency of fertigation
Arbat et al., 2013 (2009-2010)	Corn grown in open field	Mas Badia, Spain, an alluvial soil, very deep, moderately well drained 28-35% sand, 9-17% clay	70 m³/ha pig slurry (120 kg N) and maximal 75 kg N applied by fertigation in 3 fractions allowed maximal yield. Higher doses did nog increase yield and led to increased nitrate leaching.
Quiñones et al., 2007 (1998)	Citrus grow in lysimeters	Spain Typic Xerofluvent soil (67.4% sand, 10.8% silt, 21. 8% clay; 0.6%)	Whole tree nitrogen use efficiency was significantly higher under high frequency drip irrigation (75.1%) than under low frequency flood irrigation (62.7%).
Rolbiecki et al., 2020 (2021-2015)	Watermelon grown in open field	Krajenski near Bydgoszcz, Poland, slightly loamy sand, 1.5% organic matter	Fertigation lead to a higher yield (20%) compared to broadband fertilization, under the same irrigation treatment.
Rubio-Asensio and Intrigliolo, 2024 (2019-2022)	Lettuce or endive in the fall–winter, and melon in the spring–summer under plastic soil mulching	Torre Pacheco, Murcia, SE Spain, clay- loam texture (36% clay, 36% sand)	The results demonstrated that high frequency fertigation increases shoot fresh weight, but did not improve shoot nutrient uptake or nitrogen nutritional status. High and medium fertigation frequencies decreased nitrate concentration in the root zone, where it may be prone to leaching.
Żarski and Kuśmierek-Tomaszewska, 2023 (2015–2017)	Maize grown in open field	Bydgoszcz, Poland, Sandy soil 82% sand	The application 180 kg N trough fertigation resulted in a significant increase in the yield of grain maize compared to the traditional method of nitrogen fertilization (3% increase).
Zhou et al., 2018 (2013-2015)	Potato grown in open field	Jyndevad Research Station, Denmark soil 93% sand	Simulations with a crop model and observations showed more nitrate leaching in the gun irrigation treatment although yield between the fertigated and gun irrigated treatment was similar.

4.3.3. Environmental co-benefits

A better water management by more careful irrigation scheduling or a better water application reduces the risk of nitrate leaching. Primarily a better water management will contribute to a lower water use. Water savings reported in Portugal, Spain and Italy vary between 10 and 80% (Table 23). In Denmark, a better irrigation management led to a higher water use. Irrigation leads to higher emissions since energy is needed to bring the water to the field. However, expressed per kg of biomass irrigation, the environmental impact of food production decreases, provided irrigation is carefully scheduled. This has been documented by Abrahão et al. (2017) for irrigated corn in North West Spain and by Rogy et al. (2022) in France. Haverkort and Hillier (2011) calculated that 40 mm of irrigation in Denmark is responsible for 1.4% of the CO_2 emission

of potato production while this amount increases potato production by 8%.

Table 23 Water savings realized by a better water management when irrigating

Author	Water saved
Water savings due to improved irrigation scheduling	
Cameira et al., 2003	45% (157 mm/year) of the water applied drained to the root zone; this could be prevented by better irrigation scheduling.
Diez et al., 2000	12% less water (43 mm/year) was applied in an improved irrigation schedule.
Rinaldi et al., 2007	33% (200 mm/year) or 50% (400 mm/year) less irrigation should be possible form an economic point of view when carefully scheduled.
Vázquez et al., 2006	Irrigation scheduled according to 80% of the maximal crop evapotranspiration did not result in any yield loss.
Granados et al., 2013	Irrigation volume was reduced by 17% in pepper and by 20% in muskmelon.
ten Damme et al., 2022	20 to 150 mm more irrigation applied led to higher yield and lower nitrate leaching.
Water savings due to a better irrigation application	
Pool et al., 2022	Water leakage out of flood-irrigated orchards (230 mm/year) was 1.3 times higher than the annual recharge in drip-irrigated orchards (174 mm/year).
Pérez-Martín and Benedito-Castillo, 2023	A reduction of 60% in irrigation volume was assumed (223 mm/year).

4.3.3. Minimum/threshold or optimum level of implementation

Due to the differences between regions, thresholds or optimum levels of implementation need to be judged in function of the specific field and crop conditions.

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5. CLUSTER V – BUFFER STRIPS, NATURE-BASED SOLUTIONS

5.1. Targeted establishment of buffer areas

5.1.1. Introduction

Buffer areas can be defined as areas between agricultural fields and watercourses or other protected zones, i.e., nature protection areas or surface water wells. Buffer areas are designed to reduce losses of nutrients (nitrogen and phosphorus, but also pesticides) from the agricultural fields into watercourses and drinking water abstraction locations. Buffer areas for nature protection can be defined as a certain area of land that is necessary to protect the natural protected area from anthropogenic pressures. These anthropogenic pressures can differ, but in the scope of this assessment, we will focus on nutrient losses from agricultural land use surrounding the protected area. The buffer areas are not protected sites themselves but help to reach the goals in the protected sites.

Nutrients are transported from agricultural fields towards watercourses and other protected zones either sorbed onto soil particles or dissolved in water by different routes or via the atmosphere. These transport routes are i) erosion of soil particles, ii) surface runoff of precipitation, iii) superficial subsurface runoff, iv) leaching to groundwater, v) artificial drainage, vi) atmospheric volatilization and subsequent deposition and vii) direct losses during application of fertilizers. Buffer areas can be effective in mitigating all these types of transport processes, often tackling multiple of them, depending on the local conditions. The effect of buffer areas to the latter two transport processes, i.e., atmospheric deposition and direct losses, lies in physically separating sensitive zones from the source of nutrients (i.e., the application of fertilisers and manure on agricultural fields).

The effect of buffer areas on direct losses is not discussed here, as it was already covered above in Cluster II (sloping ground, water courses). After arrival to the buffer area, immobilization or removal of nutrients within the buffer areas further reduce the risk of re-release of nutrients from the buffer areas into watercourses and other protected zones. Mechanisms involved here are the settling of soil particles and infiltration of excess water into the soil of the buffer area allowing for i) uptake of transported nutrients by vegetation, ii) sorption of phosphorus on soil particles and iii) denitrification of nitrate (Carstensen et al., 2020; Hill, 2019; Mancuso et al., 2021; Owenius & Van Der Nat, 2011; Pistocchi, 2022; Rizzo et al., 2023; Robotham et al., 2023; Walton et al., 2020; Zhu et al., 2020).

In the following, buffer areas to protect water quality are discussed separately from buffer areas to protect natural areas.

5.1.2. Buffer areas to protect water quality

Usually, buffer areas are vegetated, as the vegetation slows down incoming runoff and has a function in immobilizing incoming nutrients into the buffer area. In addition, buffer areas are often not fertilized and not treated with pesticides. To be effective, buffer areas occupy critical positions in the landscape where they can prevent the transport of nutrients and pesticides towards the sensitive zones (Hill, 2019; Owenius & Van Der Nat, 2011).

The vegetation of the buffer areas can be herbaceous, with grass or mixtures of grass and other plants, or with the addition of woody plants, i.e., shrubs and trees. A third type of buffer areas are wetland buffer areas, where the vegetation can also be herbaceous or woody, but where the soil of the buffer area is water saturated. A wetland buffer area can also be a shallow water body

between the terrestrial and the aquatic system (Owenius & Van Der Nat, 2011; Walton et al., 2020).

In the following sections, herbaceous and woody buffer areas are assessed separately from wetland buffer areas, with the implicit assumption that the former type of buffer zones are not under wetland conditions.

5.1.2.1. Herbaceous and/or woody buffer area

In the design of herbaceous and/or woody buffer areas to protect water quality, the local hydrogeological system needs to be well understood. Furthermore, buffer areas need maintenance to ensure a dense vegetation cover. Harvesting could be necessary to remove immobilized nutrient loads taken up in plants. Nutrient losses from adjacent agricultural fields may still bypass buffer areas due to deeper water flow pathways, or in the case of strong surface runoff. The presence of tile drainage can also diminish the effectiveness a buffer area in the riparian zone of a watercourse, as water flowing through the drainage system can bypass the buffer area (Hill, 2019; Owenius & Van Der Nat, 2011). Finally, the risk of flooding may need to be considered due to the increased roughness of the river section (Pistocchi, 2022).

Efficiency in terms of preventing and reducing nutrient losses to watercourses

A recent meta-analysis (Rizzo et al., 2023) showed that buffer strips can reduce nitrogen losses to water from 7 to 98% and total phosphorus from -40 to 98%, when designed to intercept run-off, while buffer strips designed to remove groundwater nitrate have removal efficiencies ranging from -500 to 100% for nitrate. A negative removal efficiency indicates that the buffer area is a source rather than a sink of nutrients.

The median values presented in this meta-analysis for these two types of buffer strips are presented in Table 24 and show that overall, herbaceous and woody buffer areas along watercourses can be effective in decreasing nutrient loads towards the aquatic environment. However, the variation in their effectiveness can be large, and in a worst-case-scenario, buffer areas can be a net source of nutrient losses to the watercourse. As discussed above, proper design considering the local hydrogeology and proper management can be essential in this respect.

Table 24 Median values of nitrogen and phosphorus removal in herbaceous and woody buffer areas along watercourses in the global meta-analysis of Rizzo et al. (2023).

Type	Study area	Efficiency	Remarks	Reference
Buffer strips designed to intercept **run-off** towards watercourses	Global, studies with climate relevant for EU	72% for TN 64% for nitrate 74% for TP	Meta-analysis, 34 studies, n = 52 for TN, n = 51 for nitrate, n = 47 for TP.	Rizzo et al. (2023)
Buffer strips designed to intercept **groundwater flows** of nitrate to watercourses	Global, studies with climate relevant for EU	58% for nitrate	Meta-analysis, 43 studies, n=111 for nitrate	Rizzo et al. (2023)

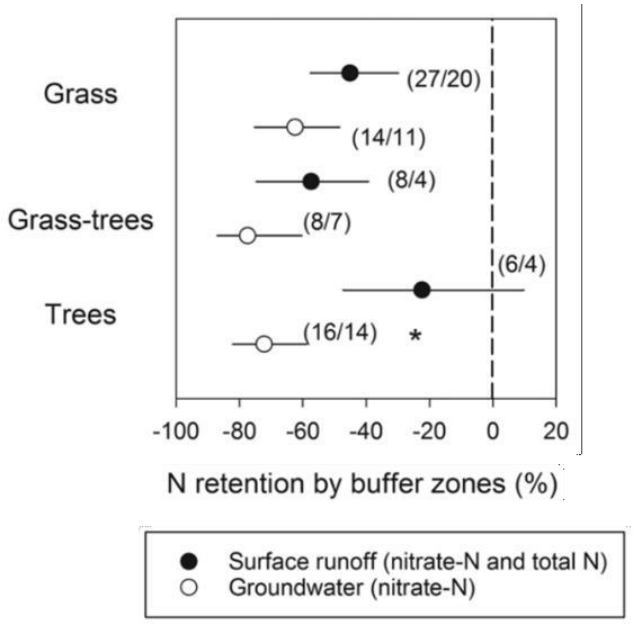
N=nitrogen, P=phosphorus, T=total, n=number of data points

Similar results were found in older meta-analyses, for example, the mean removal efficiency of nitrate was 54% in herbaceous buffer strips (n=32), 72 % in forested buffer strips (n=31) and 80% in mixed buffer strips (n=11) in a meta-analysis by Mayer et al. (2007). The results of this meta-analysis suggest that buffer strips with woody vegetation perform better than without, and that combining both herbaceous and woody vegetation therefore provides the highest nutrient removal efficiency.

This pattern could be explained by the fact that mixed vegetation buffers combine the different characteristics of both type of vegetation, i.e., herbaceous vegetation can be more effective in intercepting runoff as it provides a dense soil cover, while woody vegetation can be more effective in intercepting subsurface transport of nutrients due to deeper root systems.

Such an interpretation is corroborated by another meta-analysis (Valkama et al. (2019)), shown in Figure 23, which indicates that mixed vegetation buffer strips are most efficient in reducing both surface runoff and groundwater N, while grass buffer strips are more efficient than tree buffer strips in reducing surface runoff, and tree buffer strips are more efficient than grass buffer strips in reducing groundwater N.

Figure 23 N retention by buffer strips with different vegetation types. N retention by buffer strips targeting surface runoff and by buffer strips targeting groundwater N is presented separately. Figure from Valkama et al. (2019).



For herbaceous and woody buffer strips designed to reduce runoff to watercourses, climate variables and soil types are not found to significantly affect N-reduction efficiency. In contrast, the P-reduction efficiency in this type of buffer strips is significantly higher in regions with higher temperature, lower precipitation or soil types with more clay content. This can be partly explained by the fact that these buffer strips aim to reduce soil particle transport, which is important for phosphorus due to strong association of phosphorus with soil particles. Hence also the higher efficiency on soil types with more clay, as these soil types are more prone to erosion (Rizzo et al., 2023).

Because buffer strips intercept runoff soil particles more than runoff water, they are more efficient at removing total N and P (including N and P associated to sediments and N and P in organic matter), compared to dissolved N and P alone. Indeed, the ability to remove nitrate (dissolved) is lower in buffer strips designed to capture runoff compared to the efficiency to remove total N (Table 1). This picture is also corroborated in another meta-analysis (Valkama et al. (2019)), where it is shown that buffer strips can achieve a 17-48% reduction in nitrate N from runoff, while the reduction is 43-68% for total N from runoff. For phosphorus, the difference between the retention of dissolved and total P is less clear, due to the large ranges in the literature consulted. Based on two review studies, the efficiency of buffer strips for P can be estimated at -57 to 93% for dissolved P and -64 to 98% for total P (Dorioz et al., 2006; Roberts et al., 2012).

This shows that buffer strips can be a source of P (negative removal = release of P), although this depends very much on the local situation: the meta-analysis of Prosser et al. (2020), which included 38 studies for P, reports no negative efficiencies, whilst in the studies of Dorioz et al. (2006) and Roberts et al. (2012), 4 out of 19 studies report negative efficiencies. Net release of P can be explained by re-mobilization of previously fixed particulate P, by desorption of dissolved P whenever the top layer in the buffer strip becomes P saturated, by mineralisation of P fixed in organic material and by the reductive dissolution of iron hydroxides (Roberts et al. , 2012). Iron hydroxides are the most important P-binding minerals in the soil, but under anaerobic conditions they are unstable, they dissolve and release the bound P. Anaerobic conditions occur in wet, water-saturated soils where sufficient organic matter is present, which can therefore certainly be relevant in buffer strips along waterways.

As a conclusion, buffer strips can be effective in reducing nutrient loads to surface water, as many studies show removal efficiencies higher than 50% for N and for P. Overall, buffer strips with woody vegetation perform better than without, and combining both herbaceous and woody vegetation provides the highest nutrient removal efficiency. High variability of the efficiency is reported in literature, stressing that proper design that considers the local hydrogeology and proper management of the buffer strip is essential for a good functioning of the buffer zone. In addition, care needs to be taken to ensure no P re-release occurs under anaerobic conditions in the buffer zone.

Socio-economic consequences

The implementation of herbaceous and/or woody buffer strips is not very expensive. However, sufficient design work needs to be performed beforehand, the maintenance of buffer strips can be time consuming and an inevitable consequence of establishing buffer strips is the loss of productive farmland and related income losses for farmers (Owenius & Van Der Nat, 2011).

Environmental co-benefits and trade offs

Natural development of the buffer strips can contribute to biodiversity in agricultural landscapes. To keep a diverse vegetation, cutting and removing the herbaceous vegetation at least yearly will be necessary. This leads to a secondary co-benefit when the harvested vegetation can be reused as green manure or after composting as organic soil amendment, hereby contributing to closing the nutrient cycle within the agricultural system (Owenius & Van Der Nat, 2011). Buffer strips can also increase faunal biodiversity and can increase aquatic biodiversity as well, for example in the case where shrubs and trees provide shade over an adjacent watercourse. Depending on rules regarding public access, buffer strips may also be used for recreation (Owenius & Van Der Nat, 2011), and they will contribute to some extent to carbon sequestration in agricultural landscapes.

A potential environmental tradeoff is the risk of shifting from a water quality problem to a greenhouse gas problem. This can be an issue in cases where the buffer strip is designed to remove nitrogen through denitrification, an unavoidable by-product of which is the creation of N_2O, an important greenhouse gas.

Threshold level of implementation

Thresholds for buffer strips width in respect of subsurface nitrate removal (groundwater nitrate) depend on sediment texture and depth to a confining layer. Buffer strips need to be wider when sediments are coarse (gravel to sand) and when the permeable sediment is deeper. Buffer strips on fine textured (loam/silt/clay) and shallow permeable sediment can be more narrow. Buffers with less than 4 m depths of sand and gravel sediments in sloping landscapes often achieve 90% nitrate removal efficiency within widths of 30–60 m, whereas many buffers with less than 4 m depths of fine-grained sediments reach a 90% efficiency in 10–20 m. Conversely, studies report considerable increases in required buffer widths (up to 100-200 m) for 90% nitrate removal when permeable sediment depths increase to more than 4 m of sand or gravel layers and in some cases deep flow paths bypass the buffer (Hill, 2019).

5.1.2.2. Wetland buffer areas

Different types of wetlands can be considered to reduce nutrient input to watercourses. In the concept of a buffer area, a wetland buffer area is in this assessment considered to be water saturated soil or shallow aquatic areas located between agricultural fields and a watercourse, designed to capture diffuse nutrient pollution by draining water from the agricultural fields towards the watercourse. Wetlands constructed for manure or wastewater treatment (i.e., point sources) are not considered in this assessment.

Efficiency in terms of preventing and reducing nutrient losses

A recent meta-analysis (Rizzo et al., 2023) showed that removal efficiencies of free water surface wetland buffer areas (i.e., shallow aquatic areas) ranged between -43 and >99% for nitrate, -45 and 90% for total N and -101% and 80% for total P. A negative removal efficiency indicates that the buffer area is a source rather than a sink of nutrients. The median values reported in this meta-analysis for wetland buffer areas are presented in Table 2 and show that wetland buffer areas along watercourses can have an effect on decreasing nutrient loads towards the aquatic environment. As with the unsaturated buffer strips, the variation in their effectiveness can be large and, in a worst-case-scenario, wetland buffer areas can be a source of nutrients.

Another meta-analysis (Land et al., 2016) on wetland buffers tackling agricultural runoff reported 95% confidence intervals of 25 – 46 % total N removal and 31 – 54% total P removal. Median values reported in that study are also presented in Table 2, and show very similar results as the previous one for free water surface wetlands. Average retention values for different types of wetlands from a third meta-analysis are also included in Table 25, reporting similar summarized values with a large variation and no significant differences between the different types of wetlands.

Table 25 Median values of nitrogen and phosphorus removal in wetland buffer areas.

Type	Study area	Efficiency	Remarks	Reference
Open surface water wetland buffer areas	Global, studies with climate relevant for EU	Median values of 31% for TN, 44% for nitrate, 34% for TP	Meta-analysis, 35 studies, n = 57 for TN, n = 40 for nitrate, n = 33 for TP.	Rizzo et al. (2023, note, data were retrieved fro m Supporting Material)
Unspecified wetland buffer areas	Global	Median values of 36% for TN and 44 % of TP	Meta-analysis, n = 18 for TN, n= 35 for TP	Land et al. (2016)
Riperian mineral soil wetlands, peat-accumulating wetlands, floodplains	Global, 67% of studies were in the EU	Average with standard deviation between brackets of 51(31)% for nitrate, 43(30)% for TN and 21(72)% for TP. Efficiencies did not differ significantly between the different types of wetlands	Meta-analysis, n=56 for nitrate, n=58 for TN, n=55 for TP.	Walton et al., (2020)

N=nitrogen, P=phosphorus, T=total, n=number of datapoints

The variation in removal efficiency can be explained by several physical, biological and chemical variables, highlighting the importance of proper design and proper management of wetland buffer areas (Owenius & Van Der Nat, 2011). With low nitrate load into the wetland, no effect of soil type (organic vs mineral soil) was found on nitrate removal efficiency, while with high nitrate loads, organic soils had a higher nitrate removal efficiency (Walton et al., 2020), which could be explained by carbon-limitation in a mineral soil hampering denitrification of a higher nitrate load.

In the meta-analysis of Rizzo et al. (2023), statistical analysis of the effects of climate and occurrence of clay soil was done, combining results of wetland buffer areas and vegetated drainage ditches, where similar mechanisms are driving nutrient removal. The results indicate that increased annual precipitation increases total N removal, likely caused by a greater input of N, while a higher number of months with low temperature decreased nitrate removal, due to the negative effect of low temperature on denitrification. Increased potential for evapotranspiration resulted in a decrease in both total nitrogen and total phosphorus removal, which could however be due to evaporation of water from the wetland or drainage ditch, resulting in higher a concentration of nutrients in the outflow water and reducing the measured decrease compared to inflow water. No effect was found of clayey soil on nitrogen or phosphorus removal. As climate change will impact precipitation and evapotranspiration, the efficiency of wetlands to remove nutrients will likely change depending on the climate.

Socio-economic consequences

The costs of designing and establishing a wetland depends on its size, construction method and technical requirements and can be significant. In addition, maintenance can be time consuming. Finally, loss of productive farmland will have a negative impact on the local farmers' income.

Environmental co-benefits and tradeoffs

Wetland buffer areas can provide multiple ecosystem services, such as biodiversity enhancement, carbon sequestration, reservoirs for water and recreation (Land et al., 2016). An environmental tradeoff related to wetland buffer areas is that to some extent it shifts a water quality problem to a greenhouse gas problem, as the main nitrogen removal process relied on in wetlands is denitrification, a microbial process converting nitrate NO_3 to nitrogen gas N_2, an unavoidable by-product of which is the production of nitrous oxide N_2O, which is an important greenhouse gas.

Threshold level of implementation

To have a continuous water supply for a free water surface wetland, a sufficiently large catchment is a necessary precondition for this measure. Up to 200 ha of utilized agricultural land is needed per ha of established wetland, so that the wetland corresponds to about 0.5 – 4% of the total drainage area (Owenius & Van Der Nat, 2011). The exact location of the wetland and the local hydrogeological conditions will have an important impact on the efficiency of the wetland in capturing agricultural nitrates and acting as an effective buffer. A recent study based on modelling concluded that restoring 27% of wetlands historically drained for agriculture in the EU (3% of the EU land area), targeted in high nitrogen input areas, could reduce current nitrogen loads to the sea by 36%, but would have potential costs to agricultural productivity. A more efficient strategy targeting wetland restoration on farmlands projected to be abandoned by 2040 would yield a 22% load reduction and could enable major rivers such as the Rhine, Elbe and Vistula to meet water quality targets with minimal agricultural impact (Bertassello et al, 2025).

5.1.2.3. Specific case for surface drinking water abstraction points

For buffer areas to protect surface drinking water abstraction points, in theory, the above description of buffer areas along watercourses is still relevant, i.e., the design to have a good efficiency of reduction of nutrients will depend on the local hydrogeological conditions in the catchment that is draining into the surface drinking water abstraction point. Thus, buffer areas can be effective in protecting surface water abstraction points, however, they need to be properly designed to reach the desired level of protection (EPA (IE), 2011). In the Fontaine du Theil catchment, in Brittany, France in the early 2000's (Basilico & Domange, 2011), the use of buffer strips was combined with increasing erosion prevention and incremental use of mechanical pest control instead of chemical pest control to protect surface water quality. No results of nutrient reduction were documented, but the combined approach successfully reduced the presence of pesticides in water samples. Obviously, in large catchments with large scale farming that drain into surface water abstraction points, this will be increasingly more challenging, as many farmers will need to be engaged and adapt to new practices. Finally, monitoring of achieved results needs to be executed in action plans to improve the water quality of drinking water abstractions, in order to assess the true effectiveness of the measures taken (Basilico & Domange, 2011).

The discussion of socio-economic consequences, potential synergies/offsets, environmental co-benefits and threshold level of implementation of the previous sections of buffer areas, applies also for the use of buffer areas to protect surface drinking water abstraction points.

5.1.3. Buffer areas to protect natural areas

Transport routes of nutrients into protected natural areas via watercourses that flow through an area with low water quality due to agricultural pressures or by direct runoff or subsurface water flow, could be tackled by buffer areas as described above. In theory, such buffer areas can be effective in reducing nutrient pressures into the natural area. Similarly to the protection of a surface drinking water abstraction point, the size of the greater area surrounding the protected area will need to be determined, and buffers will need to be designed according to the local hydrogeological conditions.

There is little quantitative data available to assess the efficiency of buffer zones for the protection of a protected natural area against nutrient inflows. The atmospheric transport of volatile nitrogen compounds will likely not be abated sufficiently with these types of buffer areas. As some natural protected sites are very sensitive to atmospheric deposition of nitrogen, additional measures will need to be taken to ensure nutrient pressure does not jeopardize the nature protection goals of the protected area (Van Dasselaar, 2000). These additional measures could be to decrease the ammonia emissions from livestock farms in a buffer zone around the protected natural site. A scenario-analysis for Denmark showed that decreasing emissions on farms that fall within in a 250 m wide buffer zone around different types of protected natural sites certainly decreases total ammonia emissions to nearby protected natural sites (Schou et al., 2006). However, the effectiveness of a buffer zone in which ammonia emissions are reduced will depend on the type of sources that contribute to the atmospheric nitrogen deposition on a specific natural area. In case the sources are mainly local, decreasing the emissions locally can have high efficiency on the total atmospheric deposition in that area. However, when non-local sources affecting a natural area are significant, the effect of establishing a buffer zone will be lower. In that case, emission reduction measures need to be taken on a larger regional basis, to decrease "background" nitrogen deposition rates (Erisman et al., 2023; van Pul et al., 2004). A possible alternative to a buffer zone directly adjacent to natural areas could be a "targeted emission reduction plan". A study from the Netherlands (Erisman & Brouwer, 2021) estimated the effect of applying more emission reduction measures in certain areas throughout the country which had the highest contributions to total ammonia deposition in all Natura 2000 areas, and less emission reduction measures in the rest of the country. The results were compared to a generic reduction emission plan, in which the same emission reduction measures were applied to all areas. Only the ammonia emissions from stables was included in the calculation. This modelling exercise indicated that with the same percentage reduction of the total agricultural ammonia emissions in the Netherlands, the "targeted emission reduction approach" could reduce the total ammonia deposition in all Natura 2000 areas by almost 50%, while this was only 26% with the generic approach. This shows that a targeted approach based on emission and deposition modelling could be more efficient than a buffer zone approach, defining an area specifically surrounding the natural sites.

Socio-economic consequences

Buffer areas are used to protect natural areas can incur costs in terms of reduced agricultural production due to restrictions on agricultural activities within the buffer. Requirements on the reduction of ammonia emissions can require significant investments.

Environmental co-benefits

Depending on the specific measures introduced, buffer areas to protect natural areas can contribute more generally to reducing nitrogen losses.

5.2. Other nature-based solutions

5.2.1. Introduction

Nature-based solutions are actions or measures to protect, manage or restore natural ecosystems, inspired and supported by natural processes (Pistocchi, 2022). In the framework of this assessment, we focused on nature-based solution to decrease nutrient losses from agricultural fields into the natural ecosystems surrounding agricultural areas, which are not discussed yet in any of the other tasks in this assessment. In the next sections several nature-based solutions to tackle nutrient losses will be discussed, namely agroforestry, drainage mitigation measures, enhanced in-stream retention by two-stage channels and vegetated drainage ditches.

5.2.2. Agroforestry

Agroforestry is a type of farming practice wherein trees are combined with arable crops (silvoarable) or pastures (silvopasture), in a wide variety of possible combinations. Nutrient losses from agroforestry systems are lower than in a conventional farming system mainly due to decreased soil erosion due to the formation of a litter layer from leaves and stabilization of soils by tree roots, as well as the absorption of nutrients below the crop rootzone by relative deep tree roots (Zhu et al., 2020).

Efficiency in terms of preventing and reducing nutrient losses

A recent meta-analysis (Zhu et al., 2020) shows that silvoarable agroforestry systems can reduce nitrogen losses by -193 – 100% and phosphorus losses by 2 – 100%. Silvopastural agroforestry systems can reduce nitrogen losses by -48 – 91% and phosphorus losses by 0 – 38%. Linear tree plantings at field edges can reduce nitrogen losses by -114 – 98% and phosphorus losses by 0 – 50%. A negative removal efficiency indicates that the agroforestry system has higher nutrient losses compared to the conventional system. The median values reported in this meta-analysis are presented in Table 26 and show that agroforestry systems have generally lower nutrient losses compared to conventional farming systems. However, as shown above, the variation in effectiveness can be large, and in some cases, they can also lead to higher nutrient losses.

Table 26 Median values of reduction in nitrogen and phosphorus losses of agroforestry systems compared to conventional farming systems in the global meta-analysis of Zhu et al. (2020).

Type of agroforestry system	Study area	Efficiency	Remarks	Reference
Silvoarable	Global	Median values of 58% for TN, 68% for TP	Meta-analysis, 38 studies	Zhu et al. (2020)
Silvopastural	Global	Median values of 55% for TN, 57% for TP	Meta-analysis, 6 studies	Zhu et al. (2020)
Linear tree plantings	Global	Median values of 55% for TN, 18% for TP	Meta-analysis, 6 studies	Zhu et al. (2020)

N=nitrogen, P=phosphorus, T=total

Socio-economic consequences

Changing from conventional agriculture to agroforestry in arable and pasture systems can be challenging for farmers due to high costs of implementation, lack of financial incentives, limited agroforestry product marketing, lack of education and awareness and lack of field demonstrations (Sollen-Norrlin et al., 2020).

In temperate regions, yield losses of summer arable crops (i.e., potato, maize) grown in combination with older (large) trees will potentially impact the farmers' income negatively. A smart selection of crops and trees, taking the development of the trees into account by changing the crop type, could address this. In addition, proper selection and management of the tree species could have a positive effect on the farmer's income (Pardon et al., 2018).

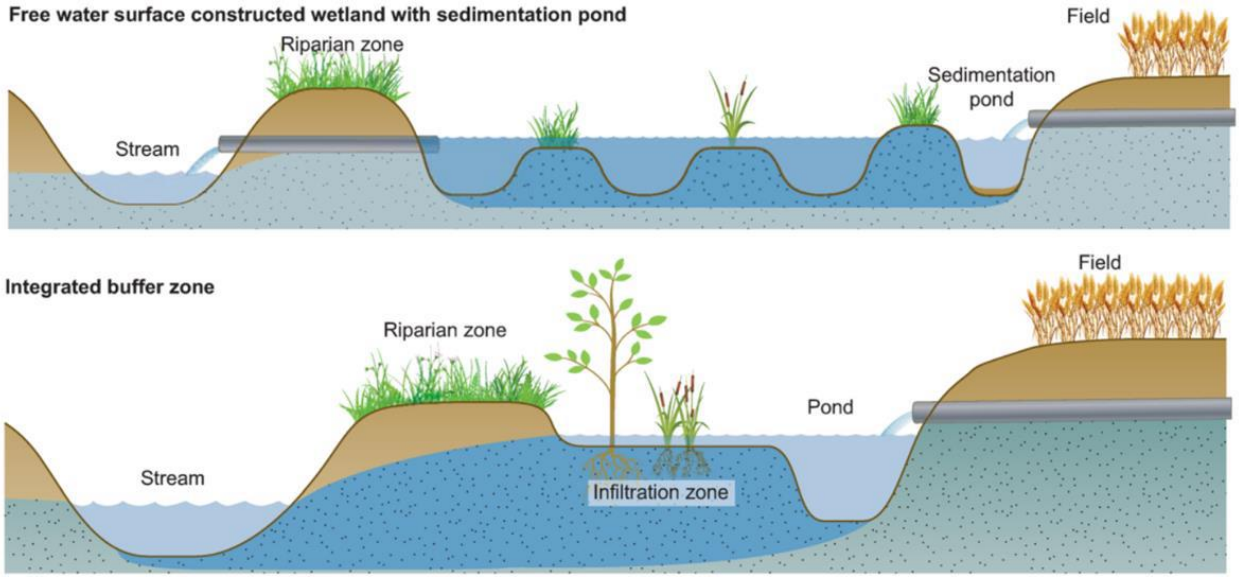
Environmental co-benefits

Agroforestry systems provide multiple ecosystem services, such as enhanced carbon sequestration in agricultural landscapes, greater biodiversity and wind erosion control (Zhu et al., 2020).

5.2.3. Drainage mitigation measures

When agricultural fields are drained with artificial drainage systems, direct transport of nutrients to watercourses is further enabled. This effect could be mitigated by a combination of rerouting the drainage outflow and natural-based solutions similar to wetland systems as in Figure 24 below. Drainage water of the agricultural field flows first into an area that lies between the field and the stream, similar to wetland buffer areas described above. This area could be designed as a sedimentation pond, followed by a free water surface wetland area or as a simple pond with an infiltration zone. The latter option is named an "integrated buffer zone", and has recently developed and tested in northwestern Europe to improve the nutrient reduction capacity of traditional riparian buffer zones. The nutrient removal process in such systems is similar to buffer areas, mainly sedimentation, uptake by vegetation and denitrification of nitrate (Carstensen et al., 2020).

Figure 24 Conceptual scheme of natural-based solutions for mitigation of nutrient losses via drainage, figure adapted from Carstensen et al. (2020).



Efficiency in terms of preventing and reducing nutrient losses

Results from a recent meta-analysis (Carstensen et al., 2020) shows that rerouting drainage outflow in combination with free water surface wetlands reduces nitrate loading with -8% – 63% and total phosphorus with -103 – 68%. A negative removal efficiency indicates the system is rather a source than a sink of nutrients. Fewer data are available regarding nutrient removal efficiencies for integrated buffer zones to mitigate nutrient losses via drainage systems, the mean removal efficiency for nitrate was 26% (standard deviation of 4%, based on only 2 studies), while it was 48% for total phosphorus (standard deviation of 6%, based on only 2 studies). The weighted averages reported in this meta-analysis are presented in Table 27 and show that overall, nature-based solutions to mitigate drainage nutrient losses can be efficient. However, as shown above, the variation in their effectiveness can be large and in a worst-case scenario even be a source of nutrients rather than a sink.

Table 27 Meta-analysis weighted average nutrient removal efficiencies of nature-based solutions to mitigate drainage nutrient losses reported in the global meta-analysis of Carstensen et al. (2020).

Type	Study area	Efficiency	Remarks	Reference
Drainage + free water surface wetland	Global	41% (standard deviation 21%) for nitrate, 33% (standard deviation 28%) for TP	Meta-analysis, 14 studies for nitrate, 15 studies for TP	Carstensen et al. (2020)

P=phosphorus, T=total

For the drainage + free water surface wetland systems, the variability in removal efficiencies can be explained by the different local conditions of the included studies, such as hydraulic retention time or carbon availability, similar as discussed for wetlands. Optimal designing, implementation and management is important and will depend on the local hydrogeological and geochemical conditions.

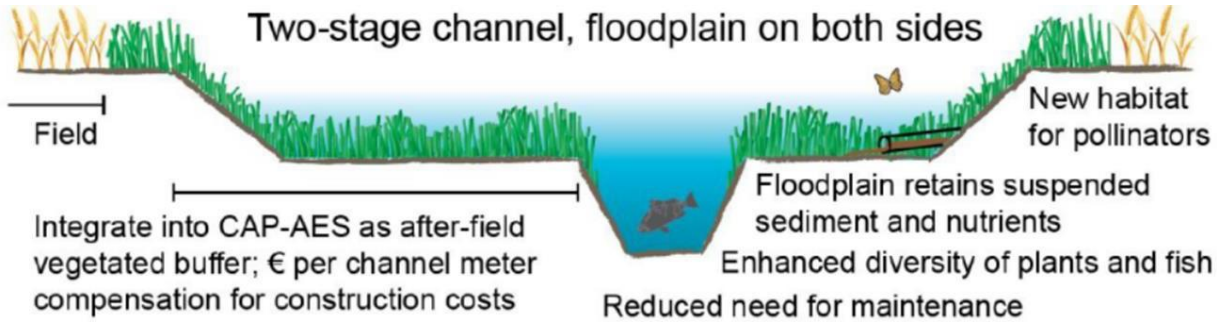
For the drainage + integrated buffer zones, few data were available and no meta-analysis weighted- average could be calculated. The nitrate removal efficiency was relatively low in the 2 studies included, likely due to suboptimal design of the system. In addition, the riparian zone after the integrated buffer zone could further remove nitrate before it reaches the stream. More studies of this type of mitigation measure for drainage nutrient losses are needed (Carstensen et al., 2020).

The discussion of socio-economic consequences, potential synergies/offsets, environmental co-benefits and threshold level of implementation of wetlands applies also here, as the drainage mitigation systems of nature-based solutions are an extension of wetland buffer areas.

5.2.4. Enhanced in-stream retention

With adaptions to the geometry or vegetation in streams, increased retention of nutrients within the stream itself (i.e., after losses from agricultural fields) could be achieved. Two examples are the two-stage channel design and vegetated drainage ditches. The two-stage channel design consist of a constructed floodplain on one or both sides of the existing main channel (Figure 25). This channel design optimizes transport of water and sediment, requires less maintenance than traditional channels (dredging) and is expected to enhance ecological functioning and biodiversity (Pistocchi (2022)).

Figure 25 Conceptual figure of a two-stage channel. Figure from Pistocchi (2022).



Vegetated drainage ditches are agricultural drainage ditches that are properly vegetated and shaped to provide the same physical and biological processes occurring in wetlands (Rizzo et al., 2023).

Efficiency in terms of preventing and reducing nutrient losses

Few studies of the effect on water quality in the EU of two-stage channels are available. A study in Finland showed a net retention (both in the floodplain and low-flow channel) of 2.1% for suspended sediment and 3.5% for total phosphorus per km of channel length (Pistocchi, 2022). However, the authors note that this study was done on a newly installed two-stage channel and they expect lower resuspension rates from the sediment in the low flow channel with time, as the loose deposits originating from the last conventional dredging have been flushed away. A study conducted in the US (Indiana, Hodaj et al. (2017)) showed that a two-stage channel decreased total phosphorus, soluble reactive phosphorus, total suspended sediment and nitrate concentrations in the water. By taking the water discharge rate into account, the study concluded that the two-stage channel also decreased the total phosphorus load (by 40%), the soluble reactive phosphorus load (by 11%) and the total suspended sediment load (by 22-40%), while no significant reduction in nitrate load was achieved. A recent meta-analysis (Rizzo et al., 2023) showed that vegetated drainage ditches have removal efficiencies of nitrate ranging from 1 – 93%, of total nitrogen ranging 9 – 92% and of total phosphorus ranging 14 – 100%. The median values reported in this meta-analysis are presented in Table 28 and show that overall vegetated drainage ditches can be efficient in removing nutrients, however, as shown above, the variation in their effectiveness can be large.

The effects of climatic and soil variables discussed for wetlands are also applicable for vegetated drainage ditches, due to similar mechanisms of nutrient removal.

Table 28 Median values of reduction in nitrogen and phosphorus in vegetated drainage ditches in the global meta-analysis of Rizzo et al. (2023).

Type	Study area	Efficiency	Remarks	Reference
Vegetated drainage ditches	Global, but only including studies with climate relevant for EU	54% for nitrate, 53% for TN, 57% for TP	Meta-analysis, n=13 for nitrate, n=16 for TN, n=10 for TP	Rizzo et al. (2023, note, data were retrieved from Supporting Material)

N=nitrogen, P=phosphorus, T=total, n=number of data points

Socio-economic consequences

Two-stage channels can either be implemented by changing the current geometry of the stream or by lower the adjacent riparian area next to the stream. The installment of two-stage channels will have a significant cost, but maintenance costs will be lower compared to the traditional channel, due to lower dredging requirements. The installment of two-stage channels can be disruptive to local farmers and could possibly result in area losses (when adjacent riparian area next to the stream needed would be productive area). Fear for increased risk of flooding outside of the stream could hinder adoption rates by locals. Proper design of the two-stage channels and communication towards the local stakeholders of the area could improve this. Vegetated drainage ditches do not need changes in geometry, but do require periodic removing of excessive vegetation. Ditches that are essential for water discharge of a flooding prone area are not a good candidate for the installment of vegetated drainage ditches (Hodaj et al., 2017; Pistocchi, 2022).

Environmental co-benefits

Two-stage channels have positive effects on plant biodiversity and improve riparian and instream habitat quality. In addition, these types of channel improve water conveyance with lower management requirements. This is beneficial in light of climate change, which may increase the need for efficient drainage and water flow conveyance (Hodaj et al., 2017; Pistocchi, 2022).

An important environmental offset of enhanced in-stream retention of nutrients is the possibility to shift a water quality problem to a greenhouse gas problem, when the main nitrogen removal process is denitrification of nitrate to N_2-gas, where N_2O is an unavoidable byproduct.

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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XII. MEMBER STATES' APPROACH TO THE IMPLEMENTATION OF MEASURES IN ANNEX II AND III OF THE NITRATES DIRECTIVE

This annex offers an overview of how the measures of Annex II and III of the Nitrates Directive are implemented in the Member States in Nitrate Vulnerable Zones and whether the flexibility linked to the national implementations has an effect on the effectiveness of the directive. It first examines what measures have been implemented in which Member State and then provides examples of how the implementation varies between Member States. To the extent possible, it also describes if the variation is linked with the flexibility to adapt to local circumstances and whether this flexibility increases the risk of losses to the environment and thus has a potential impact on the effectiveness of the measures. Three measures are analysed in more detail: closed periods, balanced fertilisation, including manure application, and the manure application limit. Finally, the annex examines how measures on phosphorus are covered in the national nitrates action programmes, and whether this has had an impact on the effectiveness of the directive.

This annex is based on several studies and scientific articles[1],[2],[3] as well as scientific support from the JRC[4] and from other sources[5].

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[1] Tzivilakis et al, Identification of approaches and measures in action programmes under Directive 91/676/EEC, 2020, Ref. ENV.D.1/SER/2018/0017

[2] J. Tzilivakis et al, A broad-scale spatial analysis of the environmental benefits of fertiliser closed periods implemented under the Nitrates Directive in Europe, 2021. https://doi.org/10.1016/j.jenvman.2021.113674

[3] Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources, 2011, Contract number N° 07 0307/2010/580551/ETU/B1

[4] Grizetti et al, Assessing the effectiveness of the Nitrates Directive: implications for agriculture and for water, soil and air quality (2025)

[5] Scientific Support for the Implementation of the Nitrates Directive (Directive 91/676/EEC) and for an integrated nutrient management, Service Contract number: 09.0201/2022/881726/ENV.D.1

1. Requirements under the Nitrates Directive

The measures of Annex II and III are implemented in the Member States in accordance to Articles 4 and 5:

Article 4 of the Nitrates Directive requires that Member States establish a code or codes of good agricultural practice. These are to be implemented by farmers on a voluntary basis and should contain provisions covering at least the items mentioned in Annex II A. Article 4 also requires MS to set up where necessary a programme, including the provision of training and information for farmers, promoting the application of the code(s) of good agricultural practice.

Article 5 of the Nitrates Directive requires that Member States establish action programmes in respect of designated vulnerable zones, which shall consist of the following mandatory measures: (a) the measures in Annex III; (b) those measures which Member States have prescribed in the code(s) of good agricultural practice, except those which have been superseded by the measures in Annex III.

The Nitrates Directive leaves a lot of flexibility to the Member States in the implementation of articles 4 and 5. The Nitrates Directive is not a blanket set of prescriptions and nitrate action programmes (NAP) can vary from one Member State or region to another. Consequently, there is scope for differences in NAPs across the EU.

The NAPs (and the codes of good agriculture practices) may relate to all vulnerable zones in the country, or may differ for different vulnerable zones or parts of zones. They also have to take into account the environmental conditions in the relevant regions of the Member State. In practice, while some Member States have one NAP for the whole territory with a limited number of regional variations, other have one national NAP which is complemented or superseded by a number of regional action programmes, managed by the regional authorities. In their study Tzilivakis et al., (2020) created an inventory of NAP measures and identified differences in approaches between Member States and regions (Tzilivakis et al., 2020). The project identified 76 different NAPs across the 27 Member States, with regional NAPs for example in Belgium (2), Finland (2), France (12), Greece (7)[6], Italy (18) and Spain (14). Germany has one national NAP, and then the Lander can implement a certain number of options variations, while Belgium has two disconnected action programmes, one for Flanders and one for Wallonia, but no programme at federal level.

Annex II and III specify the type of measure that is required, but it is up to the Member State to prescribe how each of the measures will be applied throughout its territory. Annexes II and III of the Nitrates Directive outline the minimum measures to be included in NAPs, but Member States have scope to tailor and build upon these to account for national and regional circumstances. This flexibility to adapt to local circumstances is indispensable for Member States to ensure that the measures are the most appropriate and effective to reduce and prevent pollution. The local circumstances include (1) geo-physical characteristics such as hydrology, geography, soil and climate and their associated risk of pollution (2) sensitivity of the waters to nutrients, current levels of

[6] Note that Greece has a national action programme since 2020. This illustrates changes implemented as a result of enforcement actions.

water pollution and water quality objectives; (3) type of farming activity and level of intensity of farming. The flexibility further allows to take into account other environmental objectives such as nature protection, air quality objectives or GHG reduction.

2. Overview of variations and extent of implementation of NAP measures in all Member States

The Tzilivakis et al. (2020) study aforementioned prepared an overview of the NAP measures as implemented in the Member States[7]. It identified more than 70 different measures as declinations of the requirements set out in Annex II and Annex III, detailing or complementing the requirements, as illustrated in the following table:

Table 1 National measures implementing Annex II and Annex III requirements

Category	Sub-category	Measure
Planning	Risk assessment	1. Risk map
		2. Field risk assessment
	Cropping and grazing	3. Prohibited or required cropping*
		74. Prohibited and permitted grazing
		19. Grazing closed periods
	Nutrient balancing	4. Farm nutrient balance*
		5. Field nutrient balance*
	Fertiliser planning	61. Fertilisation plan for nitrogen*
		62. Fertilisation plan for phosphorus*
		6. Soil sampling
		65. Foliar analysis
		71. Analysis of the nutrient content of organic manures
		57. Irrigation water analysis
		47. Education and training
	Record keeping	17. Farm records*
		18. Field records*
Fertiliser storage	Manure storage - permanent	72. Processing of livestock manures
		20. Manure, slurry and effluent storage period and capacity*
		66. Maximum duration of manure storage in permanent stores*
		73. Export of manure from the farm
		51. Distance between permanent manure stores and surface water*
		54. Distance between permanent manure stores and groundwater sources*
		76. Distance between permanent manure stores and other features
		45. Design and construction of storage for manure, slurry and dirty

[7] The authors warn that the overview is not fully exhaustive as they did not have access to the detailed implementations in all Member States, nor could the overviews be verified with all MS. Therefore, the absence of a measure in the table does not mean that it is not implemented in the MS. It is important to acknowledge that some of the measures in the inventory are implemented by other regulations in some MSs/regions, notably in Denmark and France, and these measures are not reflected in the implementation statistics for the NAPs or the characterisation. The tables also include updates from 2022.

Category	Sub-category	Measure
		water*
		46. Design and construction of farmyard buildings and infrastructure
	Manure storage - temporary field	22. Conditions for field manure heaps*
		59. Minimum storage time before storage in temporary heap
		50. Temporary manure heap closed periods
		40. Duration of temporary manure heaps*
		7. Minimum time before a site can be used again for a temporary manure heap
		41. Covering temporary manure heaps*
		43. Distance between temporary manure heaps and surface water*
		42. Distance between temporary manure heaps and groundwater sources*
		44. Distance between temporary manure heaps and exposed cavernous or karstified limestone features*
		69. Distance between temporary manure heaps and other features
	Inorganic fertiliser storage	52. Distance between inorganic fertiliser stores and surface water
		53. Distance between an inorganic fertiliser stores and groundwater sources
		49. Design and construction of stores for inorganic fertilisers
		70. Requirements for fertiliser containers
Application	Conditions	23. Climate and soil conditions that prohibit the use of fertilisers*
		82. Prohibition of fertilisers on sloping land*

Based on this categorisation of measures, the Tzivilakis et al 2020 study prepared a table showing whether the measure is implemented in a way or another in a Member State. This is illustrated in the table below. Noteworthy are the entries in bright yellow which directly correspond to the requirements in Annex II and Annex III, while the other measures are variations and detailed measures around the same requirements. Lighter green colours are used for BE, IT, FR and ES to indicate that there are regional action programmes, with further variations. The study includes detailed tables for the regional NAPs in these countries.

Table 2 Overview of measures in NAP per Member State (period 2016-2019)

	M	AT	BE	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PO	PT	RO	SK	SI	ES	SE
	1												SR															
	2																											
	3																											
	74																											
	19																										SR	
	4																											
	5																										SR	
Annex II B 9 Fertilsation plans	61															SR											SR	
	62															SR												
	6																										SR	
	65																											
	71																										SR	
	57															SR												
	47																										SR	
Annex II B 9 Record keeping	17																											
Annex II B 9 Record keeping	18																											
	72															SR												
Annex II A 5 & Annex III 1.2 Manure storage & capacity	20																											
	66																											
	73															SR												
	51															SR												
	54																											
	76															SR												
	45																											
	46																											
	22																										SR	
	59																											
	50																											
	40																										SR	
	7																											
	41																										SR	
	43																										SR	
	42																										SR	
	44																											
	69															SR											SR	
	52																											
	53																											
	49																											
	70															SR												
Annex II A 3 No fertiliser vs soil conditions	23																										SR	
Annex II A 2 No fertiliser on	82																										SR	

	M	AT	BE	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PO	PT	RO	SK	SI	ES	SE
slopes																												
	83																											
	84															SR											SR	
Annex III 2 Limit on manure application	24																											
	75																											
	81																											
	77																											
	78																											
	25																											
Annex III 1.3 Balanced fertilisation – N field limit	26																											
	27																											
	28																											
	29																											
Annex III 1.1 & Annex II A 1 Closing periods	30																										SR	
	67																											
	31																											
Annex II A 4 Buffer strips (chemical)	32																											
	33																											
	55																											
Annex II A 4 Buffer strips (organic)	34																											
	35																										SR	
	36																											
	80															SR											SR	
	63																											
	64																										SR	
Annex II A 6 Application techniques	37																										SR	
	38															SR												
	56																										SR	
Annex II B 8 Cover crops	39															SR											SR	
	85																										SR	
	60																											
	86																											
	79		*																									

The table shows that mandatory requirements from Annex II and III are implemented in all Member States (occasional blanks are rather missing information than absence of measures) and that voluntary requirements from Annex II B such as fertilisation plans and record keeping are implemented in nearly all Member States, whereas cover crops and land management measures are implemented in a majority of Member States. The

table also shows that there are many additional measures beyond the main requirements of Annex II and Annex III with variable presence in the national or regional implementations. Some are implemented in many Member States, such as soil sampling, design guidance for manure storage, conditions for field manure heaps, while others can be found only in a few Member States, such as maximum duration for manure storage or foliar analysis.

The study also looked at the variation and extent of implementation for individual measures. Among the key measures there is a lot of variation as explained in the table below:

measure	**variation**
61. Fertilisation plan	Variable details for what is required to be included within the N fertilisation plan
17 & 18. Record keeping	Items that need to be recorded vary
M23. Climate and soil conditions that prohibit the use of fertilisers	The conditions that prohibit application vary
M82. Prohibition of fertilisers on sloping land	Typically prohibited on slopes >10-15%, but ranges from 6 to 30%
M26. Field limit for total nitrogen	Limits vary with crops and multiple other variables
M30. Closed periods when the application of fertilisers is prohibited:	Very often MSs/regions have multiple closed periods for different combinations of variables (e.g. precipitation, crop, soil type, etc.). Consequently, the coverage of risk periods for leaching and run-off is highly variable
M32. Distance between the application of inorganic fertilisers and surface water	Buffer distances are typically around 5m, ranging from 0.5 to 200m
M34. Distance between the application of organic fertilisers and surface water	Buffer distances are typically around 10m, ranging from 0 to 500m
M39. Ground cover and land management	Ground cover requirements are variable both in terms of the conditions required and the dates, with the latter being variable in relation to coverage of risk periods for leaching and run-off

The study reveals that there is significant variability between NAPs with respect to the measures that have been implemented and the details of how the measures have been implemented. This variation is expected to tailor measures to regional circumstances, but there are NAPs that implement measures more extensively than others. The study further assessed the extent of implementation based on potential for enhancement as shown in the tables below for MS (in summary, the darker the shading the higher the extent of the implementation)[8]. The regional action programmes are not shown in this table but give a very similar picture.

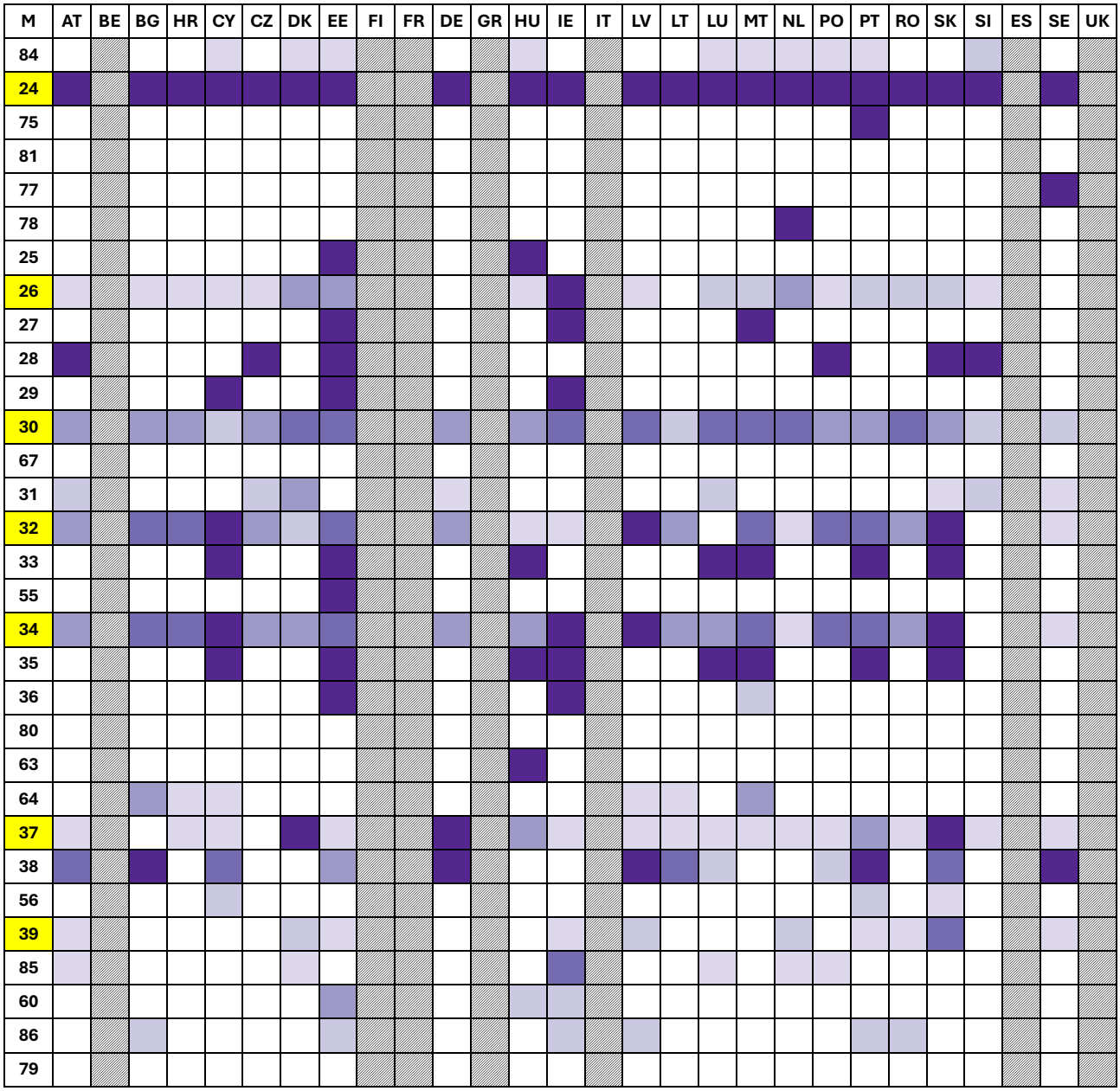
	Implementation extent		**Implementation extent**		

[8] The study used the risk characterisation for each NAP to determine the scope for enhancement (i.e. to further increase the risk mitigation potential for nitrate). This was done by comparing the current NAP measure to moderate and full implementation scenarios for that measure in each Member State. These findings have not been validated with Member States, and cannot be considered as exhaustive or fully accurate on the extent of implementation.

	None (N)		Moderate (M)	M	Requirement from Annex II and III
	Low (L)		Moderate to High (MH)		Regional AP (see study for details)
	Moderate to Low (ML)		High (H)		

Table 3 Assessment of extent of implementation based on potential for enhancement: MS

M	AT	BE	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PO	PT	RO	SK	SI	ES	SE	UK
1																												
2																												
3																												
74																												
19																												
4																												
5																												
61																												
62																												
6																												
65																												
71																												
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22																												
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50																												
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7																												
41																												
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42																												
44																												
69																												
52																												
53																												
49																												
70																												
23																												
82																												
83																												



The analysis shows different scenarios for the implementation of the Annex II and III measures in the Member States nitrates action programmes:

I. Mandatory measure, implemented in all Member States, low variation, strong implementation:

e.g. M24 – manure application limit; M20 – manure storage

II. Mandatory measure, implemented in all Member States, high variation, moderate to strong implementation:

e.g. M30 – closed or prohibition periods when the application of fertilisers is prohibited; M32 - Distance between the application of inorganic fertilisers and surface water; M34 - Distance between the application of organic fertilisers and surface water

III. Mandatory measure, implemented in all Member States, high variation, weak to moderate implementation:

e.g. M26 – balanced fertilisation – Nitrogen field limit; M23. Climate and soil conditions that prohibit the use of fertilisers

IV. Voluntary measure, not implemented in all Member States, high variation, weak to moderate implementation:

e.g.M 61 – Fertilisation plan; M17 &18 – Record Keeping

The study therefore concludes that high variation does not necessary correlate with variation in the risk of nitrate loss, as some of the variation will be due to tailoring to regional circumstances. The study recognises that there is scope for MS/regions to learn from each other on the implementation of measures and how to improve their effectiveness, especially where regional circumstances are similar and where there are differences in the measures implemented.

3. Analysis of variation and risk coverage of closed periods

The above finding is further corroborated by a scientific article[9] analysing the implementation of closed periods in the Member States. This article shows that there is very high variation, including at regional level, in the implementation of closed periods which may be linked to maximal use of flexibility to adapt to local climate, agronomic and environmental conditions, and that this flexibility may rather help to maximise the risk coverage of the closing periods, thus minimising nitrates leaching and run-off, and may further have benefits on reducing other nitrogen emissions such as ammonia and nitrous oxide.

This article confirms the high variability in the implementation of closed periods between NAPs, in terms of different closed periods for different fertilisers, crops, conditions, etc. The study identifies 1155 different closed periods across 69 NAPs, ranging from a single closed period for all fertilisers (e. g. Malta) to multiple closed period dates depending on, for example, fertiliser type and crop (e.g. 109 different closed periods in Nouvelle Aquitaine, France) and shows that land use/crop and fertiliser type are the most common parameters used to vary closed periods, followed by region, and then soil type; all of which will vary spatially.

The study analyses the coverage of leaching and run-off risks for nitrates across the Member States, and further whether there are benefits for other emissions like ammonia (NH3) or nitrous oxide (N2O). The study finds that

- Each Member State takes account of the regional circumstances to determine how measures, such as closed periods, are implemented.
- There are many areas within different Member States that have a relatively high coverage of risk periods. These areas tend to be where closed periods cover the highest risk periods and apply to crops that are widely grown.
- Further, those Member States and regions which have highly tailored closed periods appear to provide higher coverage of risk periods, where closed periods are resulting in risk reduction across all the impact categories.
- There are also a few Member States and regions where coverage of risk periods is relatively low across many of the impact categories. For example, some Member States only have closed periods for organic fertilisers. This results in a lower coverage of risk periods especially for NO3 leaching, NO3 run-off and N2O emissions, where closed periods for inorganic fertilisers (with high readily available N) are of more importance.

[9] J. Tzilivakis et al, A broad-scale spatial analysis of the environmental benefits of fertiliser closed periods implemented under the Nitrates Directive in Europe, 2021. https://doi.org/10.1016/j.jenvman.2021.113674

The study further finds that risk reduction is spatially variable across all the impact categories and the scope for synergy is also variable. For example, it cannot be assumed that high coverage of risk periods for nitrate loss will always correlate with high coverage N2O and NH3 risk periods. It will depend on the specific combination of climatic, soil and agronomic factors within each region. There may be scope to explore how closed periods can be better used to tackle N2O and NH3 emissions, by exploring where closed periods in similar zones have resulted in higher coverage of risk periods.

4. Temporal evolution of nitrogen fertiliser input across the EU and analysis of variation and risk coverage of the implementation of balanced fertilisation

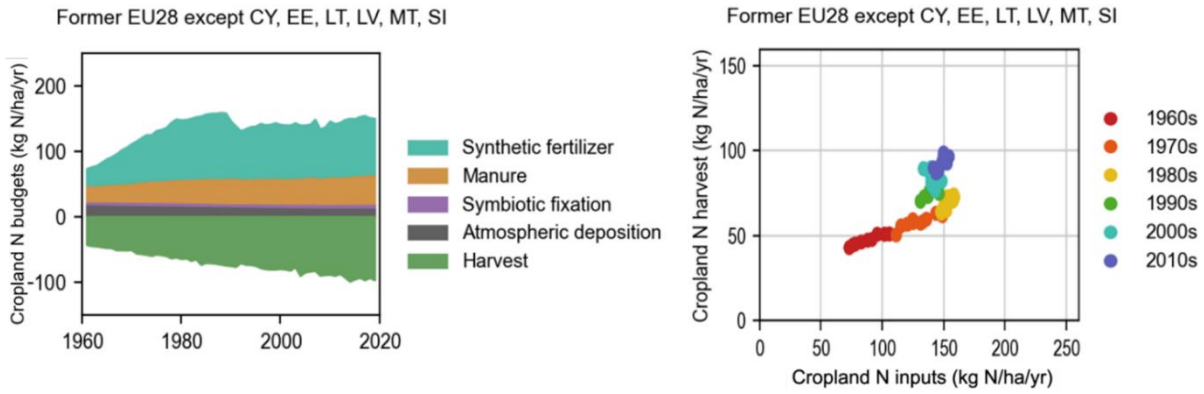
Growing plants requires relatively high concentrations of available N and P and that is why farmers add N and P to soil, via animal manure, fertilizers, composts, residues and wastes. However, the response of the crops decreases with increasing N and P availability, which is known as the law of diminishing returns (also called the law of diminishing marginal returns). Conversely, the risks of nitrate pollution of groundwater and surface waters and of eutrophication of surface waters increase with increasing N and P availability. Note, that the uptake efficiency by crops is always less than 100%, because of the heterogeneous distribution of available N in the soil and the heterogeneous distribution of the root system. Also, uptake of nutrients requires energy and at low nutrients concentrations the uptake of soil nutrients is less effective. Hence, some losses are inevitable, and therefore the purpose of balanced fertilisation is to ensure sufficient nutrients for plant growth while limiting those losses.

4.1 Temporal evolution of nitrogen fertiliser application in EU compared to other regions of the World

Over the past few decades, while global food production and fertilizer use in agriculture have increased, EU environmental legislation has limited the application of fertilizers in agricultural fields. Before the implementation of the Nitrates Directive, there was a significant increase in the application of synthetic fertilisers in the former EU28 with decreasing efficiency of N uptake by crops (between 1961 and the 1980s). This was followed by a break in the increase of nitrogen application in synthetic fertilisers around the 1990s and remains somewhat stable until 2010s. This is accompanied by increased efficiency of N uptake by crops, which resulted in higher harvest and thus minimises surplus N[10].

[10] Einarsson et al., 2021

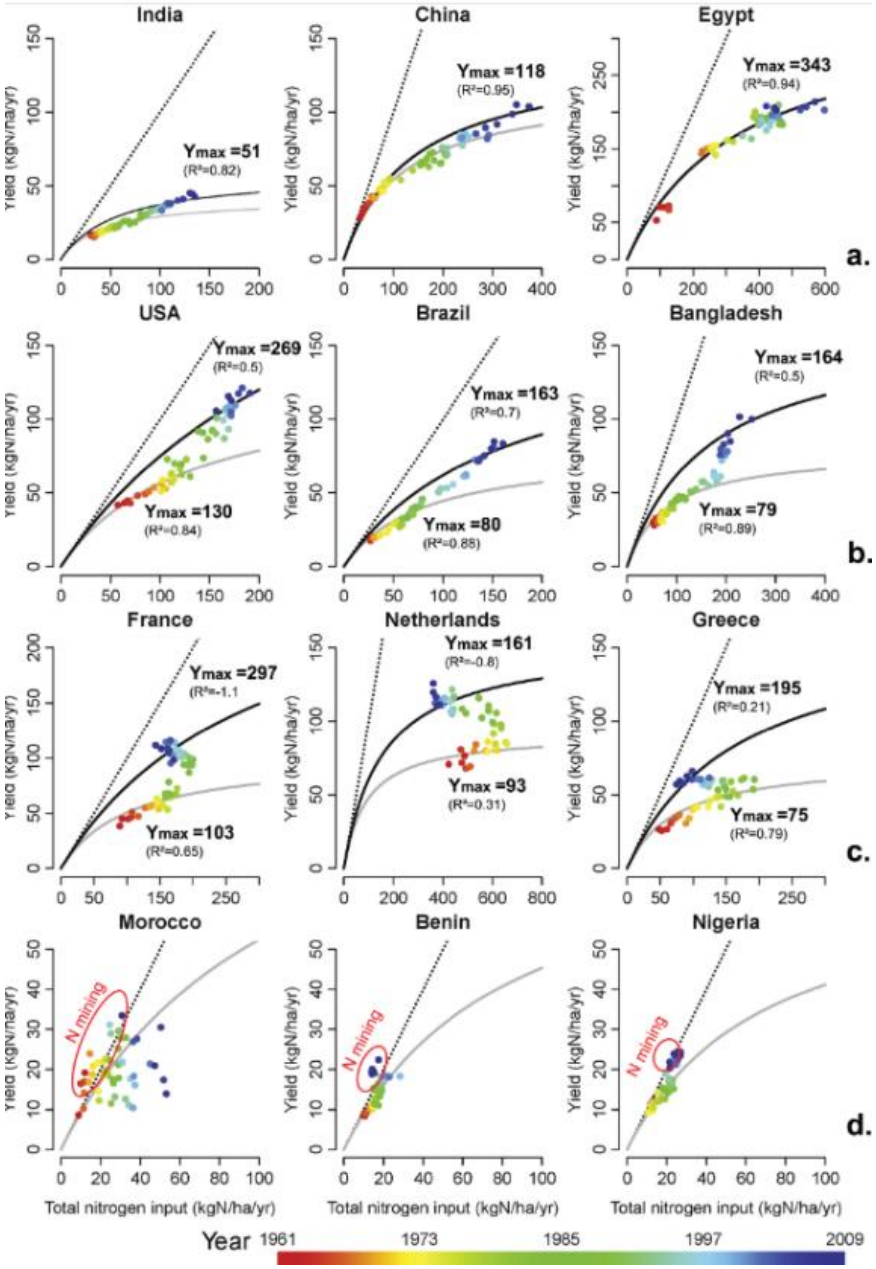
Figure 1 The left panel shows the cropland N budget in kg N/ha/year for the former EU28 countries, except Cyprus, Estonia, Lithuania, Latvia, Malta and Slovenia, between 1961 and 2019. The right panel shows the trajectory regarding total cropland N harvest and total N input rate to cropland (synthetic fertiliser, manure, symbiotic fixation, and atmospheric deposition) during the same period.



Lassaletta et al. (2014)[11] also analysed the long-term relationship (1961-2009) between crop yields and nitrogen input in cropland. In most European countries, they observed a trend towards increased yields without corresponding increases in fertilization, and in some cases, even decreases in fertilization rates. This shift can be attributed to the impact of EU environmental legislation, in particular the requirement of balanced fertilisation in the Nitrates Directive. In contrast, other regions of the world, such as the USA, China, India, and Brazil, have seen rising nitrogen fertilization rates. The graphs below show the relationship between the yields (y axis) and the nitrogen application rate (x axis), with dots representing years from 1961 to 2009. The graphs show a characteristic backwards curve in EU MS, indicating a reduction in fertiliser inputs but continued increase in yields.

[11] Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., Garnier, J., 2014. 50 year trends in nitrogen use efficiency of world cropping systems: The relationship between yield and nitrogen input to cropland. Environ. Res. Lett. 9. https://doi.org/10.1088/1748-9326/9/10/105011

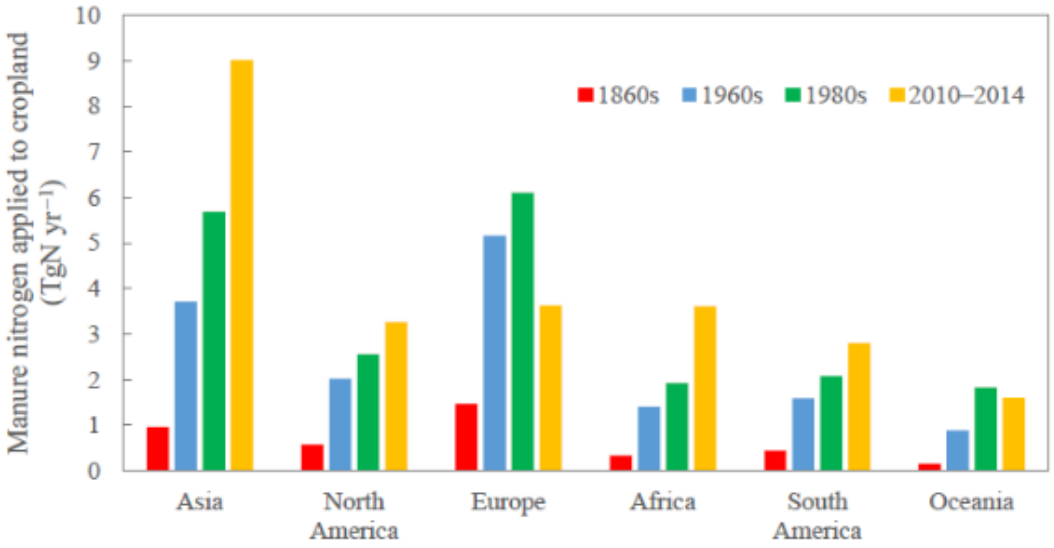
Figure 2 Temporal evolution of nitrogen fertiliser application in EU compared to other regions of the World



Moreover, Europe is the only region, apart from Oceania, where the application of manure nitrogen to cropland has decreased significantly between 2010-2014 compared to the 1980s, with Oceania experiencing a slight decline (Zhang et al., 2017). The graph below shows changes in manure nitrogen amount applied to cropland at the continental level (source Zhang et al. 2017)[12].

Figure 3 Evolution of manure nitrogen applied to cropland at the continental level

[12] Zhang, B., Tian, H., Lu, C., Dangal, S.R.S., Yang, J., Pan, S., 2017. Global manure nitrogen production and application in cropland during 1860–2014: a 5 arcmin gridded global dataset for Earth system modeling. Earth Syst. Sci. Data 9, 667–678. https://doi.org/10.5194/essd-9-667-2017



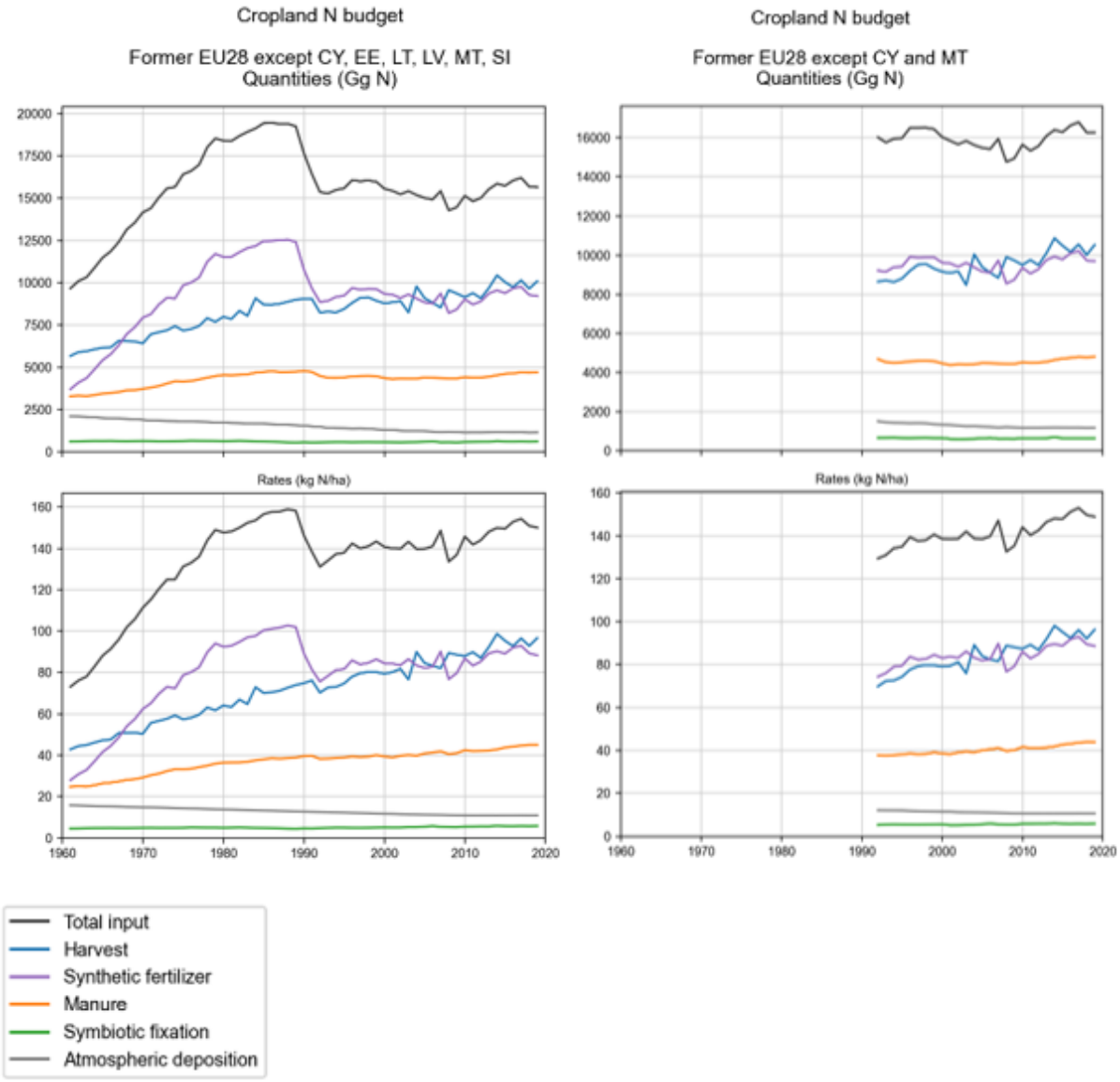
4.2 Temporal evolution of nitrogen input in EU considering political and economic changes (1961-2019)

Einarsson et al. (2021)[13] present a comprehensive overview of crop production and nitrogen use in European cropland and grassland, covering the period from 1961 to 2019, based on official statistical data.

Overall, in the EU28, the total production of manure (in terms of nitrogen content) increased from the 1960s to the 1990s, and then remained relatively stable, although a slight uptrend can be observed after 2010. However, the trend in nitrogen input from synthetic fertilizers and manure varied across countries and was influenced by a range of factors, including political and socio-economic conditions, as well as the development of the Common Agricultural Policy (CAP) and EU environmental legislation.

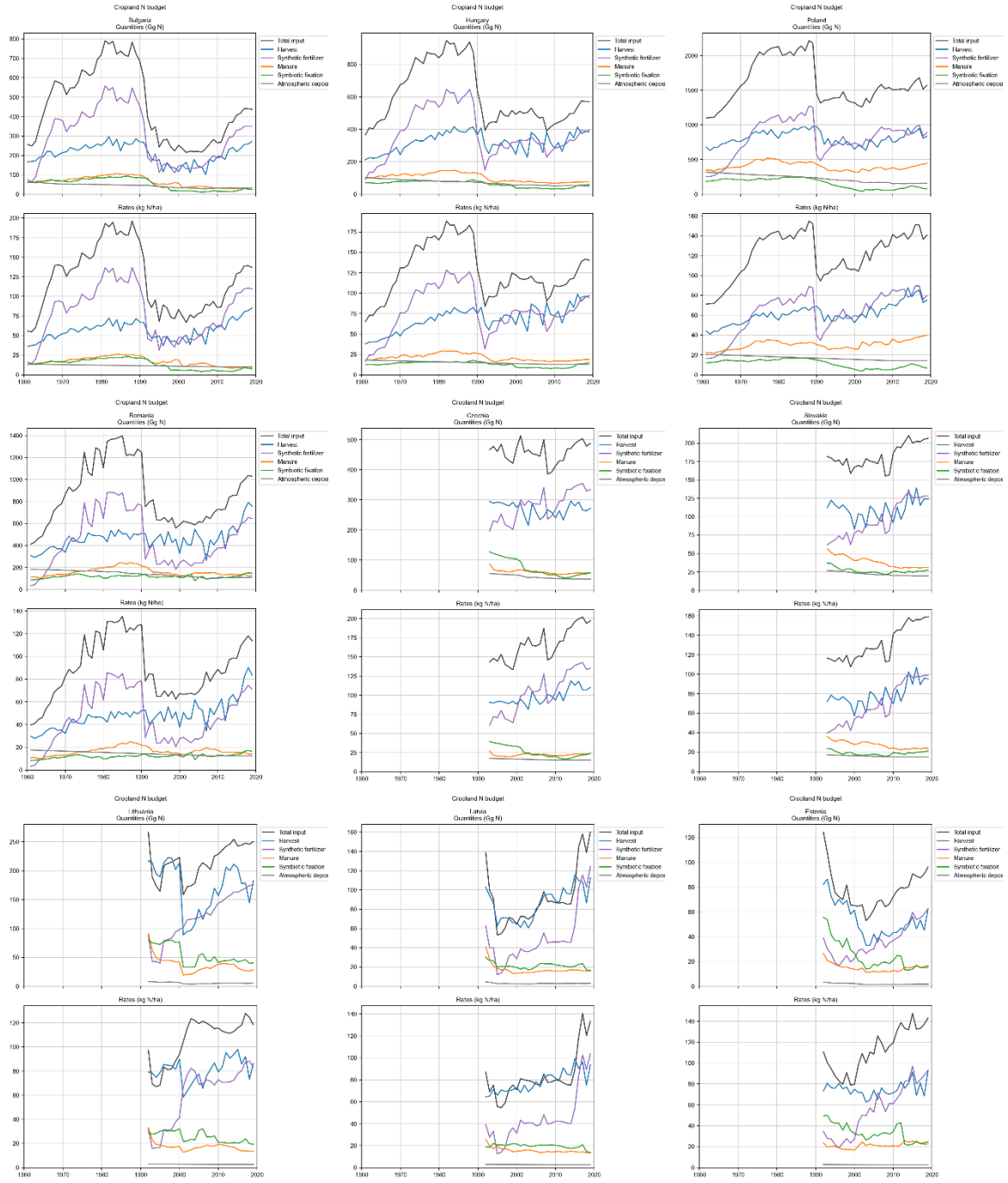
[13] Einarsson, R., Sanz-Cobena, A., Aguilera, E., Billen, G., Garnier, J., van Grinsven, H.J.M., Lassaletta, L., 2021. Crop production and nitrogen use in European cropland and grassland 1961–2019. Sci. Data 8, 288. https://doi.org/10.1038/s41597-021-01061-z

Figure 4 Cropland nitrogen budget (quantities (Gg N) and rates (kg N/ha)) in the former EU28



Countries that were formerly part of the Soviet bloc experienced a decline in manure production around 1990, coinciding with the Eastern European revolutions of 1989 and the collapse of the Soviet Union. Subsequently, manure production generally stabilized following the accession of these countries to the European Union, with the first wave of accession occurring in 2004 (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia) and a second wave in 2007 (Bulgaria and Romania). However, Poland and Estonia were exceptions to this trend, as they experienced a slight increase in manure production after 2010. The use of synthetic nitrogen fertilisers have increased in all countries since 1990s.

Figure 5 Cropland nitrogen budget (quantities (Gg N) and rates (kg N/ha)) in Member States, who joined the EU in 2004 and 2007 (Bulgaria, Hungary, Poland, Romania, Czechia, Slovakia, Lithuania, Latvia and Estonia)



In Western Europe, since the 1990s the use of nitrogen mineral fertilizers has been decreasing or remaining stable. The use of nitrogen from manure has remained relatively stable in Sweden, Finland, and Greece, while increasing in the Netherlands, Denmark, Austria, Spain, and Italy.

Figure 6 Cropland nitrogen budget (quantities (Gg N) and rates (kg N/ha)) in Western Europe (Sweden, Finland, Greece, Netherlands, Denmark, Austria, Spain and Italy)



In France, Belgium, and Luxembourg, mineral fertilization has been relatively stable, while manure application peaked in the 1990s. In Portugal, the total amount of manure has decreased since the 1990s, but the application rate per hectare has increased, indicating an intensification of agricultural practices. In Germany, mineral fertilization has decreased since 2010, while manure application has slightly increased. In Ireland, trends in nitrogen fertilisers have been influenced by the economic crisis of 2008. Additionally, several European countries have seen a decrease in the use of synthetic fertilizers in 2008 and 2022, largely due to peak fertilizer prices (Snapp et al. 2023)[14].

[14] Snapp, S., Sapkota, T.B., Chamberlin, J., Cox, C.M., Gameda, S., Jat, M.L., Marenya, P., Mottaleb, K.A., Negra, C., Senthilkumar, K., Sida, T.S., Singh, U., Stewart, Z.P., Tesfaye, K., Govaerts, B., 2023. Spatially differentiated nitrogen supply is key in a global food–fertilizer price crisis. Nat. Sustain. 6, 1268–1278. https://doi.org/10.1038/s41893-023-01166-w

The evolution of the Common Agricultural Policy (CAP) and the implementation of the EU environmental legislation (in particular the Nitrates Directive established in 1991 as well as the Water Framework Directive introduced in 2000) has also influenced the application of synthetic and manure nitrogen fertilisers.

Major reforms of the CAP:

- 1962 the CAP is established. Increase productivity, support the market price
- 1984 Milk Quota introduction
- 1992 MacSharry Reform, shift to producer support, direct income to farmers, set-aside
- 2003 Fischler Reform, income support, decoupling subsidies and production
- 2013 CAP reform, greening of the CAP, sustainable farming and innovation, rural development
- 2015 Milk Quota abolished
- 2018 New CAP legislation proposal, 2021-2022 transitional period
- 2023 CAP Reform, CAP 2023-2027 entered into force, CAP Strategic Plans
- 2025 First performance review of each CAP Strategic Plans

Figure 7 Cropland nitrogen budget (quantities (Gg N) and rates (kg N/ha)) in Western Europe (France, Belgium and Luxembourg, Portugal, Germany and Ireland)



4.3 Analysis of variation and risk coverage of the implementation of balanced fertilisation

The study of Tzilivakis et al. of 2020 showed that balanced fertilisation as a mandatory measure is implemented in all Member States, that there are large variations in the national implementation and that there seems to be overall an important potential for enhancement.

The large variation in implementation is further confirmed by an analysis done in 2022 comparing the ranges or maximum fertilisation rates for a set of crops across the NAPs in a number of Member States[15] in similar climatic zones, and comparing those to the recommendations for establishing action programmes from 2011[16].

The analysis found that N application levels included in the NAPs of the different Member States/Regions investigated in this study are following different methodologies. First, some MS/Regions do not regulate N application via fixed N-field limits, but have other methodologies, where farmers need to, for example, calculate fertilisation rates according to the N nutrient balance and some indicative average N requirements for a certain yield. This is the case for example in Germany, several Regions (and for differing crop groups) in France and in Poland for large farms. Second, in other regions, for example Wallonia in Belgium, no differentiation of field N limits for different crop groups is made, only field N limits for arable and grassland exist. Similarly, in Romania, field N limits differentiate for different crops for mineral fertilizer only, for animal manure a blanket threshold of 170 kg NT/ha exists. Third, in Ireland, field N limits per crop are differentiated based on the ability of soil to supply N, defined by a soil N index. Fourth, for example in the Denmark, Netherlands, Bulgaria and Belgium (Flanders) field N limits per crop are differentiated per soil type. In a few Member States field N limits per crop are further differentiated in function of water quality. Fifth and final, for example in Denmark, Luxembourg, Austria, Czech Republic, Slovakia and Hungary, field N limits are differing per crop and per estimated yield of the respective crop.

The difference in yield is either defined in categories (Austria, Czech Republic, Slovakia and Hungary) or with a yield adjustment factor per unit yield difference (Luxembourg, Denmark). Additionally, the yield differences are estimated according to soil type (Denmark), soil type and the ability of the soil to supply N (Hungary) and soil type and climate (Czech Republic).

The 2011 Recommendations for the measures of Annexes II and III of the Nitrates Directive[17] have been made specific for thirteen pedo-climatic (sub) zones in the European Union. Pedo-climatic zones have specific ranges for crop growth potential, surface runoff risk potential and leaching risk potentials. Pedo-climatic zones are based on climate, landform and soil type characteristics, as illustrated in the three figures below.

Figure 8 Environmental Stratification of Europe

[15] In Austria, Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Hungary, Ireland, Luxembourg, Netherlands, Romania, Slovakia.

[16] Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources, 2011, Contract number N° 07 0307/2010/580551/ETU/B1

[17] idem

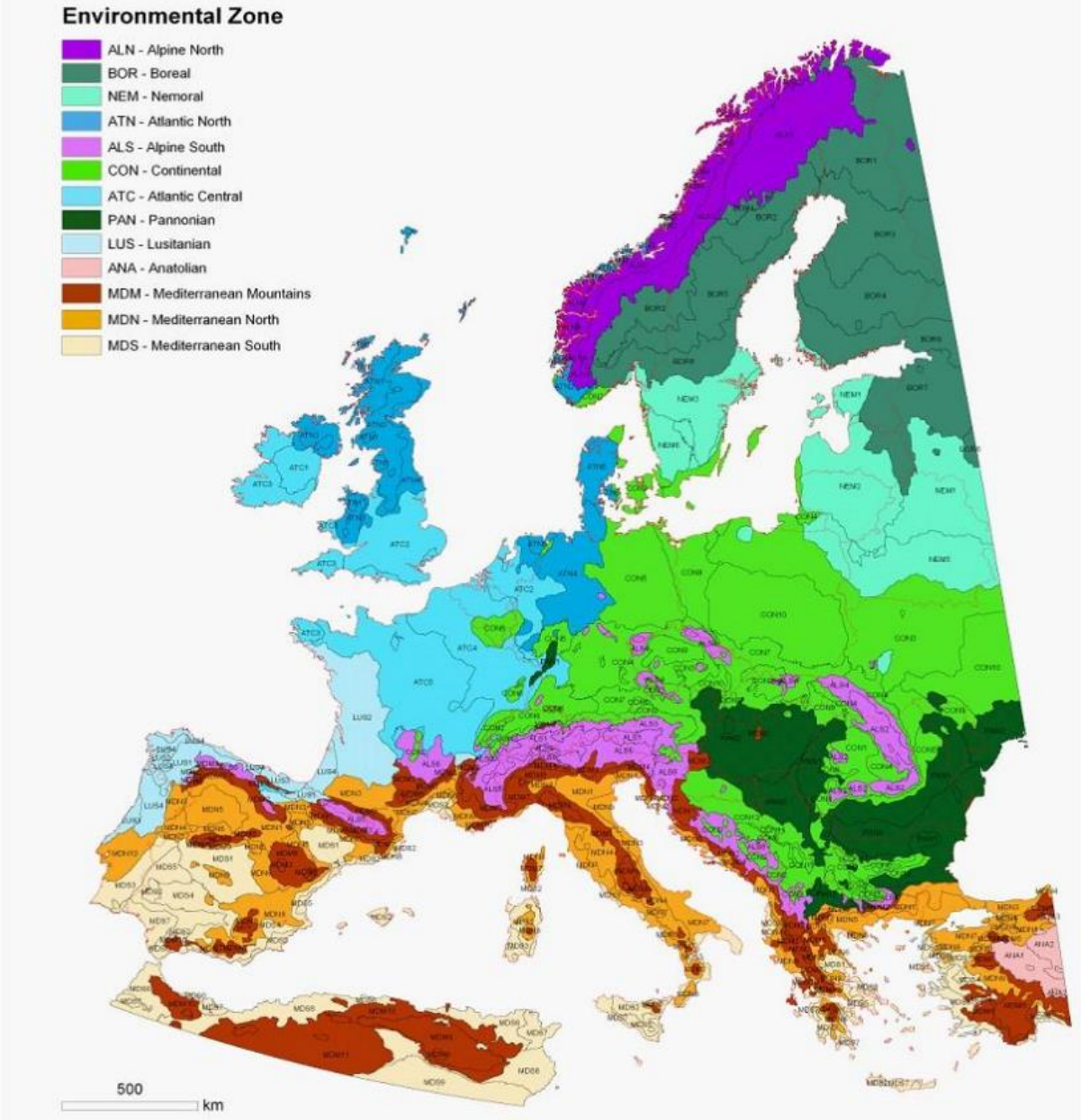
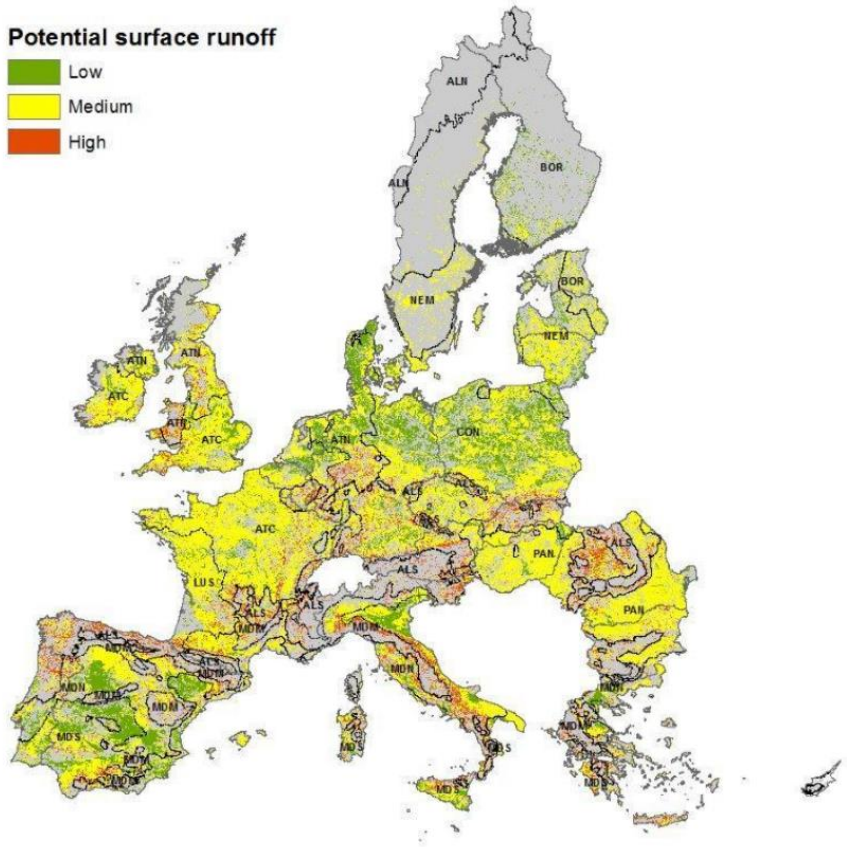
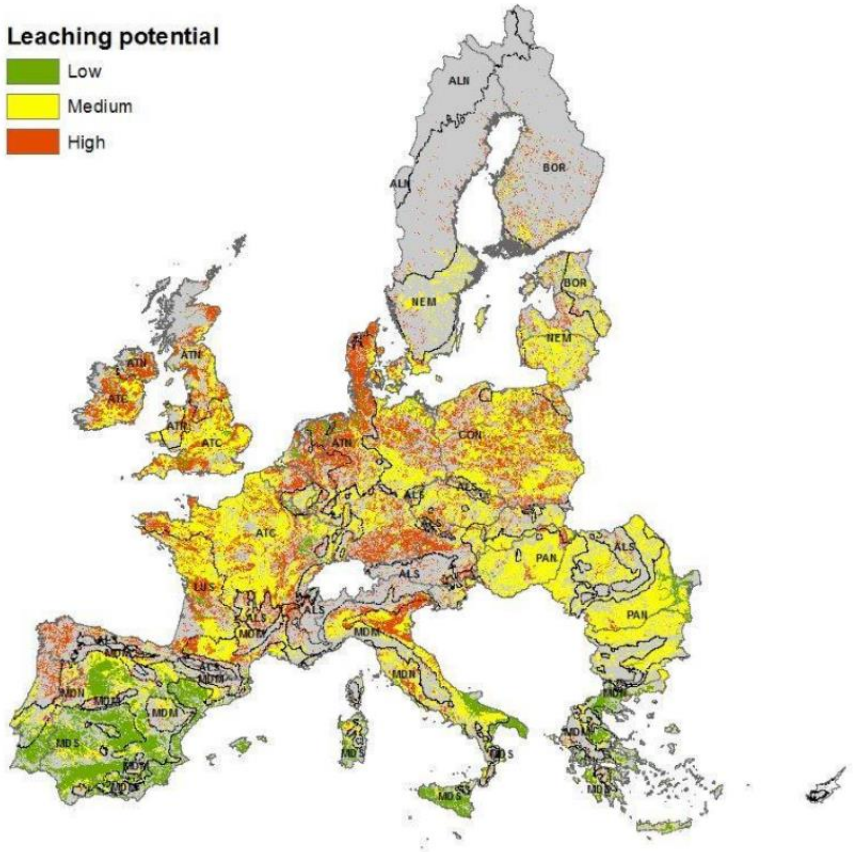


Figure 9 Map showing potential runoff risk for agricultural land within the Environmental Zones in the EU27



Note: grey areas indicate non-agricultural areas.

Figure 10 Map show leaching risk potential for agricultural land within the Environmental Zones in the EU27



The 2011 Recommendations have established recommendations for balanced fertilisation in relation to the risks of leaching and run-off and provided indicative N

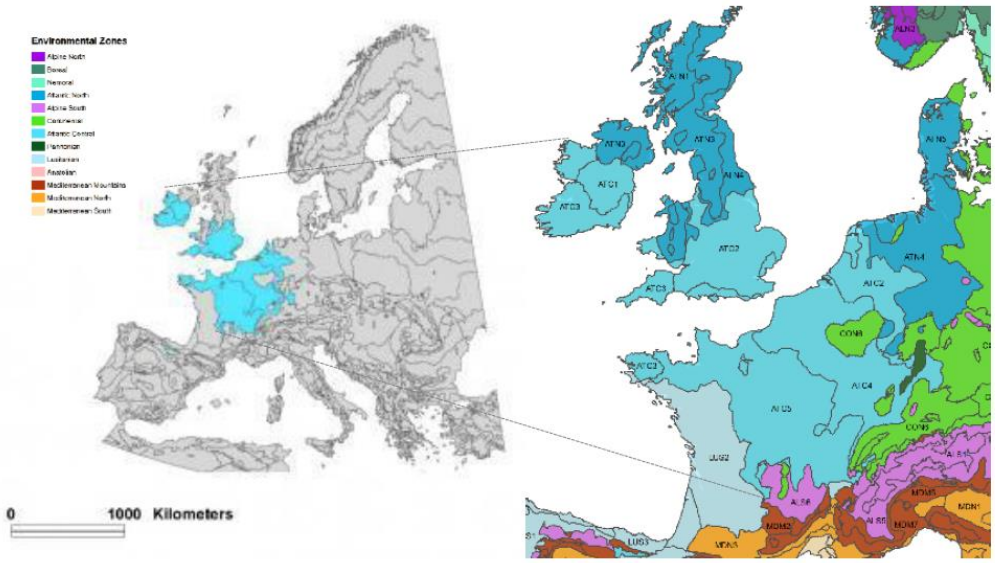
recommendations (kg N per ha per year) for major crop species per environmental zone. These recommendations are based on statistical records of crops yields. For each zone there are three ranges of N recommendations per crop in function of the risk of leaching and run-off (low/medium/high). The study notes that indicative N applications for the areas with medium and high risks for leaching and surface runoff may lead to a decrease in crop yield and quality, and that lower application rates may be needed in case receiving water bodies are very polluted.

For the purpose of the ND evaluation, we have selected two major EU agriculture production zones as examples to illustrate both the variation and the extent of risk coverage: the Atlantic Central Zone and the Continental Zone.

Atlantic Central Zone

The Atlantic Central Zone (ATC) includes the south west and south of the British Isles, Northern France and the Low countries. The ENZ-ATC covers 10% of Germany, 68% of the Netherlands, 89% of Ireland, 58% of Luxembourg, 66% of Belgium, and 49% of France.

Figure 11 Map of Atlantic Central Zone



Common crops are cereals, maize, potatoes, rapeseed, sugar beet, grasslands and vegetables. Potential crop yields and N demand by the crop are relatively high, due to the relatively long growing season, with on average sufficient rainfall. Indicative N application rates are presented below for the dominant crops as function of the leaching risk potential (in kg per ha per year). Note that the indicative N applications for the areas with medium and high risks for leaching and surface runoff may lead to a decrease in crop yield and quality. Lower application rates may be needed in case receiving water bodies are very polluted.

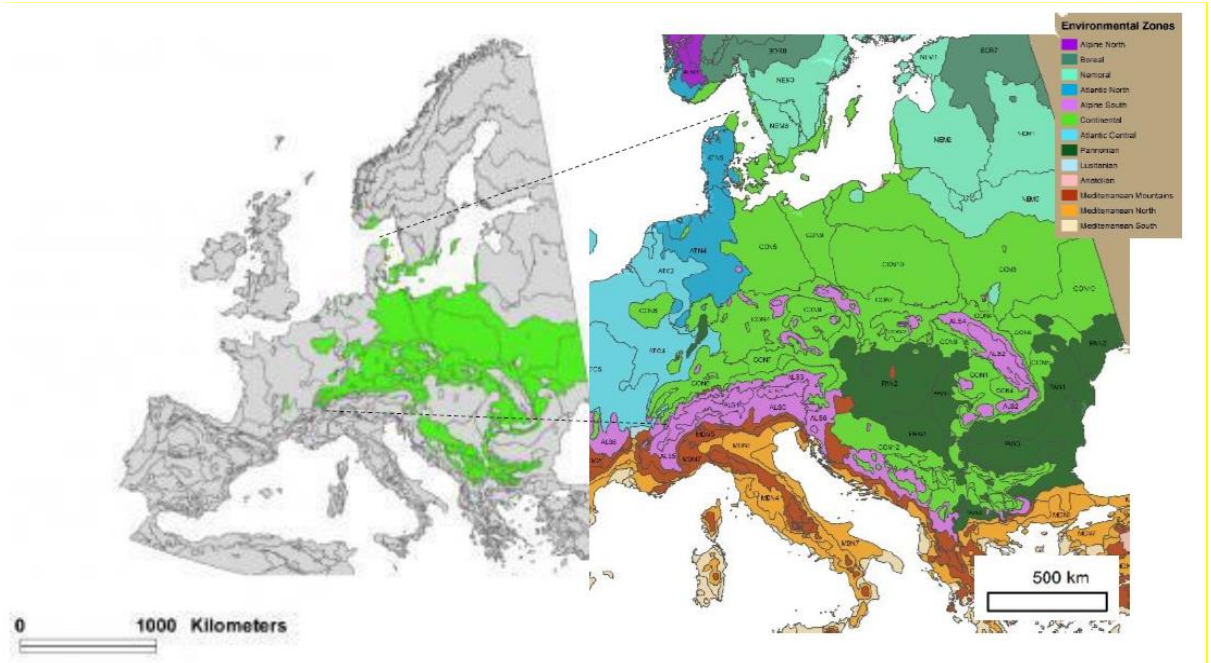
Risk	Wheat	Grain maize	Other cereals	Rapeseed	Potatoes	Sugar beets	Vegetables	*Grass land*	Silage maize
Low	130-220	140-230	100-170	100-160	200-250	130-200	130-210	*150-250*	150-250
Medium	80-130	80-130	50-90	50-90	120-200	130-200	70-110	*140-230*	90-150
High	50-80	50-80	30-50	30-50	80-130	90-150	40-70	*100-170*	60-90

Continental Environmental zone.

It covers vast areas in Central Europe: 82% of Czech Republic, 63% of Germany, 93% of Poland, 34% of Denmark, 70% of Slovakia, 42% of Austria, 8% of Hungary, 45% of Switzerland, 35 % of Romania, 31% of Bulgaria, 34% of Belgium, 42% of Luxembourg,

3% of France (Figure 12). The relevant European Member states/regions in this area are Austria, Belgium (Wallonia), Bulgaria, Czech Republic, Denmark, France (Grand Est, Auvergne - Rhône-Alpes and Bourgogne - Franche-Comté), Germany, Hungary, Luxembourg, Poland, Romania and Slovakia. Among those Member States, Austria, Bulgaria, Czech Republic, Denmark, Hungary, Luxembourg, Poland, Romania and Slovakia define clear field limits.

Figure 12 Map of Continental Environmental Zone



Common crops are cereals, maize, sunflowers, sugar beet, grasslands and vegetables. Potential crop yields and N demand by the crop are relatively high, due to the relatively long growing season, but with temporary droughts. Irrigation is therefore quite common, especially in high-value crops. Indicative N application rates are presented below for the dominant crops as function of the leaching risk potential (in kg per ha per year). Note that the indicative N applications for the areas with medium and high-risks for leaching and surface runoff may lead to a decrease in crop yield and quality. Lower application rates may be needed in case receiving water bodies are very polluted. Note that the recommended rates are usually lower in the Continental Zone compared to the Central Atlantic.

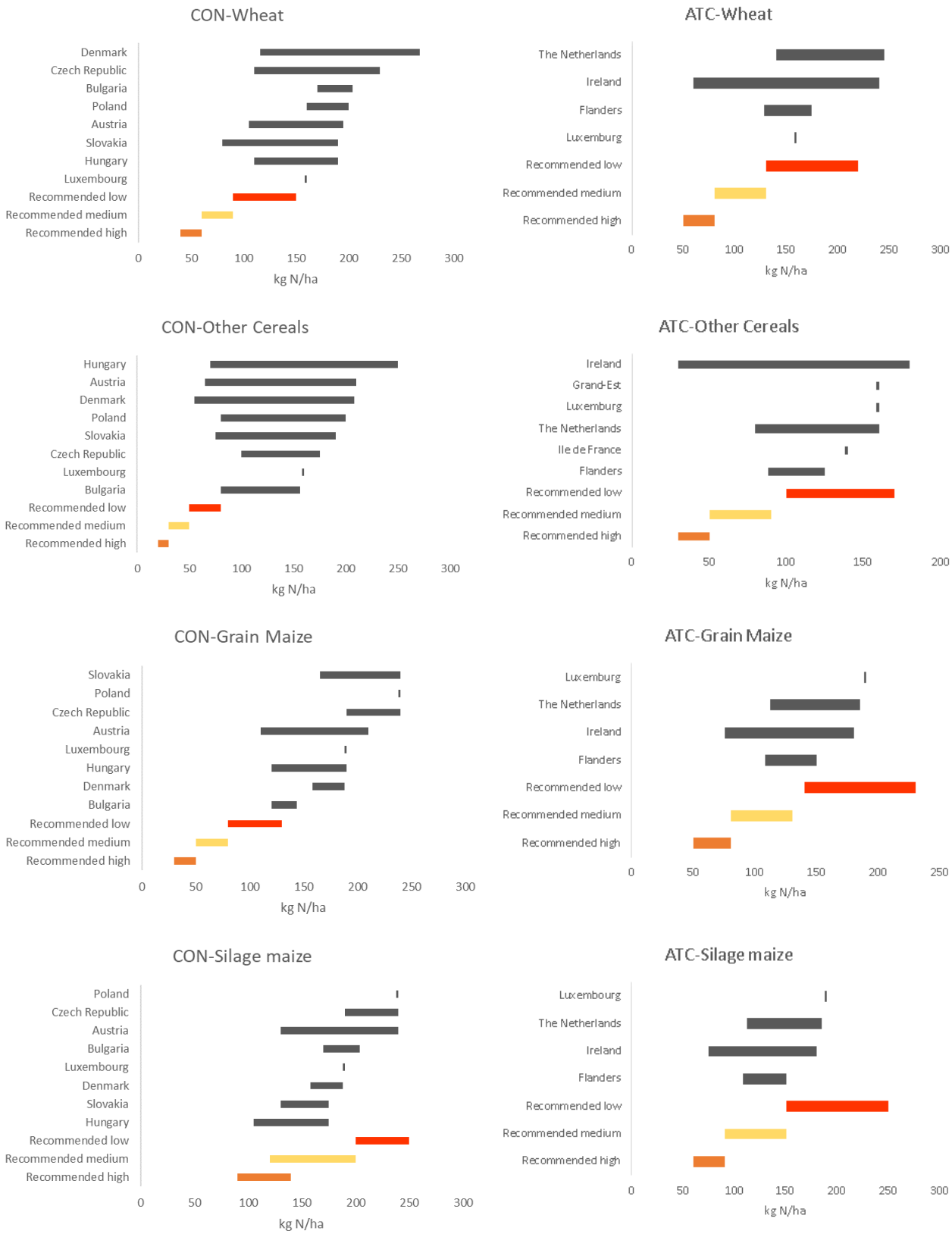
Risk	Wheat	Grain maize	Other cereals	Sun flower	Potatoes	Sugar beets	Vegetables	*Grassland*	Silage maize
Low	90-150	80-130	50-80	40-60	90-150	130-200	100-170	*80-140*	200-250
Medium	60-90	50-80	30-50	20-30	50-90	100-160	60-100	*50-80*	120-200
High	40-60	30-50	20-30	10-20	30-60	70-120	40-70	*30-60*	90-140

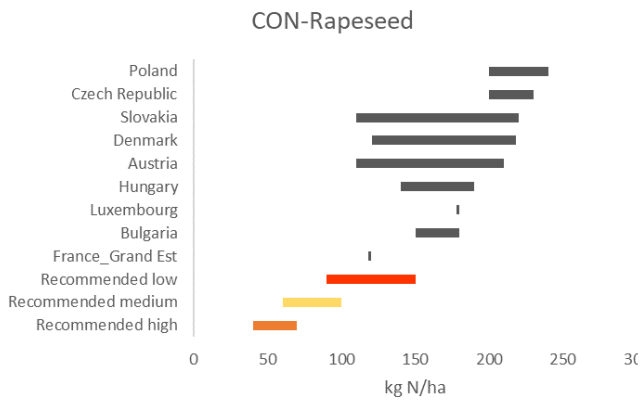
Comparisons

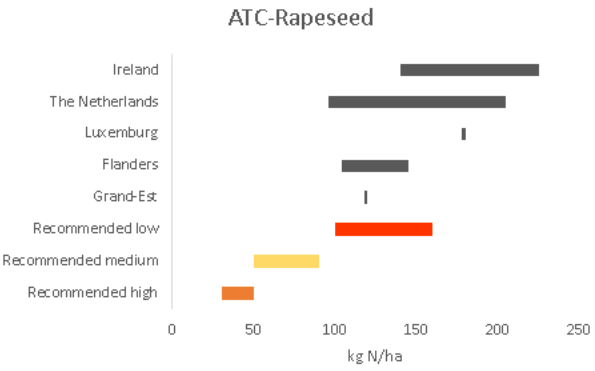
In 2022, a comparison was made of the main fertilisation rates for the main crops among Member States in the Continental and Atlantic central pedo-climatic zones and with the

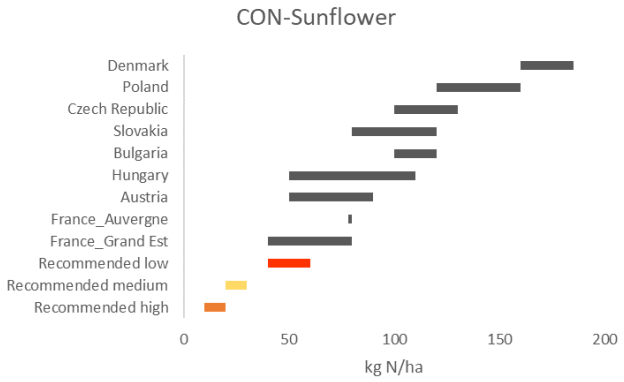
2011 recommendations. It is important to note that this is given as an illustration of the implementation in the Member States based on the available information in the national and regional action programmes but does not intend to be exhaustive or reflect all the specific situations and exceptions of the action programmes.

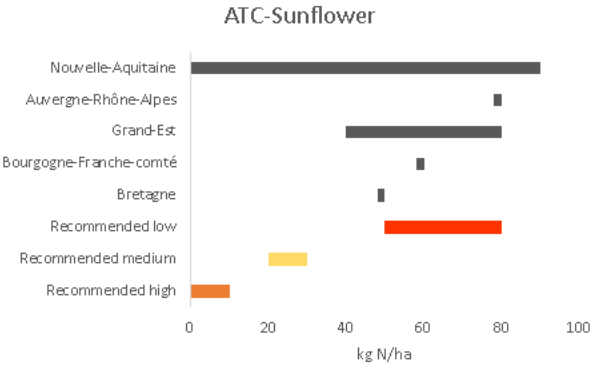
Figure 13 Schematic comparison of the Member states' of regional ranges of field limits together with the recommended limits for the Continental and the Atlantic central zone.

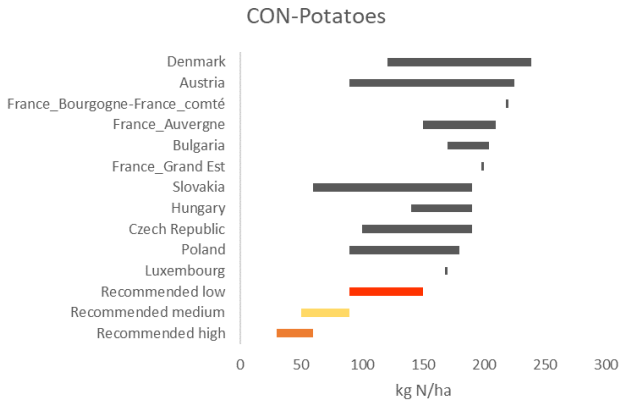


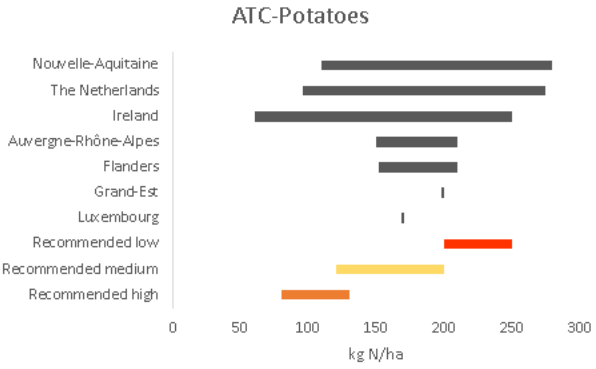

CON-Rapeseed
Poland
Czech Republic
Slovakia
Denmark
Austria
Hungary
Luxembourg
Bulgaria
France_Grand Est
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
250
kg N/ha

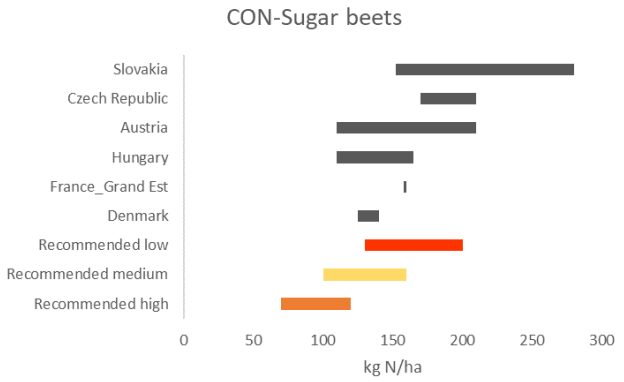

ATC-Rapeseed
Ireland
The Netherlands
Luxemburg
Flanders
Grand-Est
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
250
kg N/ha

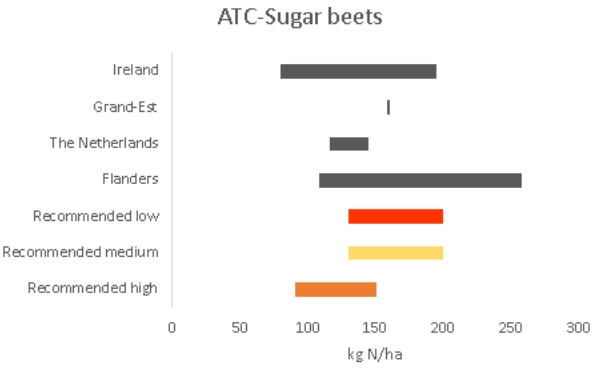

CON-Sunflower
Denmark
Poland
Czech Republic
Slovakia
Bulgaria
Hungary
Austria
France_Auvergne
France_Grand Est
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
kg N/ha

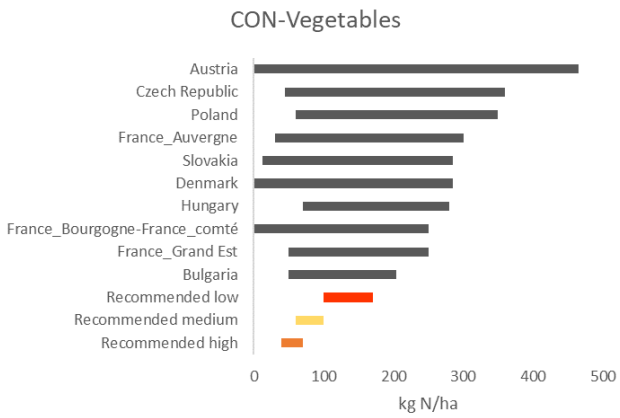

ATC-Sunflower
Nouvelle-Aquitaine
Auvergne-Rhône-Alpes
Grand-Est
Bourgogne-Franche-comté
Bretagne
Recommended low
Recommended medium
Recommended high
0
20
40
60
80
100
kg N/ha

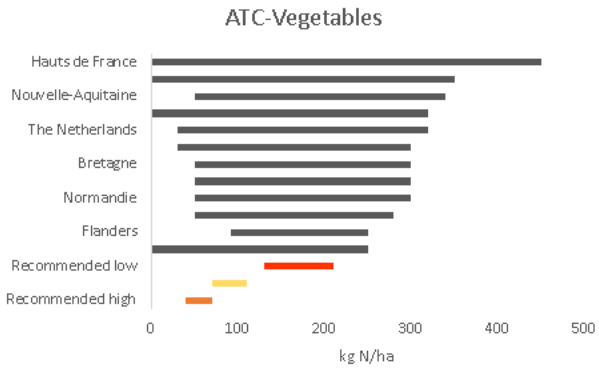

CON-Potatoes
Denmark
Austria
France_Bourgogne-France_comté
France_Auvergne
Bulgaria
France_Grand Est
Slovakia
Hungary
Czech Republic
Poland
Luxembourg
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
250
300
kg N/ha

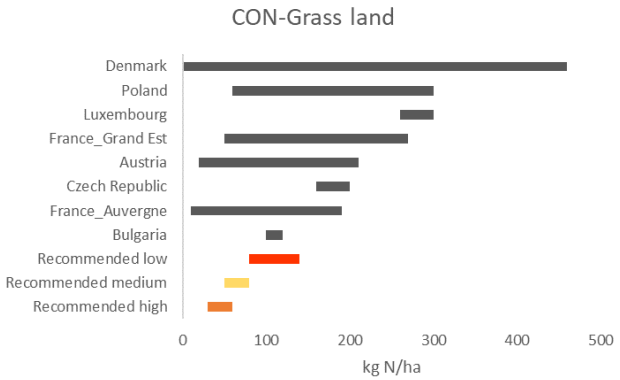

ATC-Potatoes
Nouvelle-Aquitaine
The Netherlands
Ireland
Auvergne-Rhône-Alpes
Flanders
Grand-Est
Luxembourg
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
250
300
kg N/ha

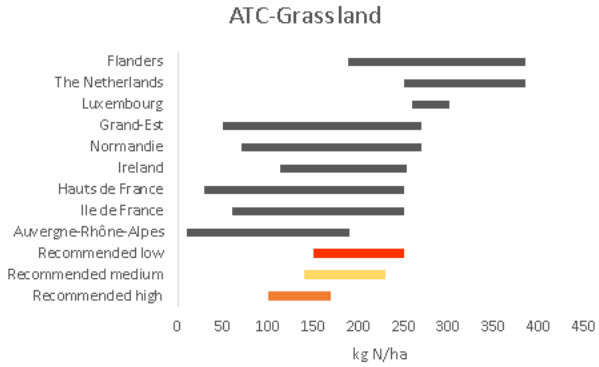

CON-Sugar beets
Slovakia
Czech Republic
Austria
Hungary
France_Grand Est
Denmark
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
250
300
kg N/ha


ATC-Sugar beets
Ireland
Grand-Est
The Netherlands
Flanders
Recommended low
Recommended medium
Recommended high
0
50
100
150
200
250
300
kg N/ha









From this comparison, it appears that the

- fertilisation rates vary (sometimes significantly) between Member States, even in the same pedo-climatic zone.
- For many crops the fertilisation ranges in Member States would correspond to the *low risk* range recommendation, even when the Member State or part of it would be in a *high or medium risk* range
- In the continental zone, for many crops the fertilisation ranges in the Member States are significantly higher than the *low risk* range recommendation. It also needs to be noted that the 2011 recommendations are generally lower for the continental pedo-climatic zone, so that the ranges implemented in practice are not in effect always so different between the zones.

Analysis

These examples illustrate how MS are using the flexibility provided by the Directive in setting limits on the application of fertilisers in line with the balanced fertilisation as required in Annex III. Echoing the findings in the Tzilivakis et al. study, the examples illustrate that the fertilisation application limits set by the MS often overshoot the recommended limits for low risk areas, and that in many cases the ranges do not seem to encompass the higher risk of nitrogen losses in high and medium risk areas, which would according to the 2011 recommendations require a lowering of the fertilisation limits. In this case, it appears that the flexibility given by the directive is not only used as an adaptation to local conditions but that other factors are influencing. In particular, the

market pressure for high yields and production often overweigh the precautionary approach which would be required in areas with medium to high risks of leaching or run-off while MS do not sufficiently take into account the water quality objectives in areas with already very polluted waters. Consultations with the MS confirmed that in most cases the fertilisation rates were set so as to optimise yields based on economic calculations. This is also illustrated by the cost analysis which found that the cost of implementing the balanced fertilisation requirement is negligeable (see section 4).

Applying lower rates, which in some areas would be more effective for reducing water pollution or in line with the precautionary principle, entails the risk of lower yields or lower quality (e.g. lower protein content). The JRC study[18] has found that in some regions of the EU with high nutrient balances (mainly as a result of high livestock concentration and manure application) a reduction of up to 25% of mineral fertilisers would have a negligeable impact on yields for green and grain maize.

The choice of keeping high fertilisation rates in high-risk areas does not necessarily mean that the NAP will not be effective as a whole, but it has impacts on the design of the NAP if it needs to remain effective in reducing and preventing pollution. To avoid a reduced effectiveness of the NAP in the longer term, once the low hanging fruits have been picked, it can become necessary for Member States to strengthen other measures or adopt additional measures outside the NAP, in order to be able to maintain high fertilisation rates in high-risk areas. At the same time, reduced fertilisation rates have been implemented in a number of Member States with intensive agriculture, often targeting the most polluted areas (e.g. Germany and the Netherlands). Some of the measures have been imposed as a result of enforcement action by the Commission, and reduced fertilisation rates are unpopular with farmers.

5. Variation and risk coverage in the implementation of the manure application limit

The manure application limit is set at EU level and applies throughout the EU in all nitrate vulnerable zones. As shown in Tzilivakis et Al (2020), the measure is implemented in all Member States and the extent of implementation is considered overall strong. However, there remain important flexibilities linked to its implementation, which may impact its effectiveness.

It is for the Member States to specify the formulas for determining the **content of nitrogen and phosphorous in each type of manure**, at production, storage and application. The underestimation of nitrogen content of manure could lead to a systemic over fertilisation by manure and affect the effectiveness of the Directive. Such figures therefore need to be regularly updated based on empirical evidence. For example, livestock breeding aiming to increase productivity tends to increase excretion over time and changes in stable and storage technology may alter the level of ammonia emissions from farm buildings, leading to higher nitrogen content in the manure applied to fields.

[18] (Pacifico et al., 2024) as summarised in the JRC study Assessing the effectiveness of the Nitrates Directive: implications for agriculture and for water, soil and air quality (2025),

Another aspect is the assessment of the share of nitrogen in manure that is made available for the crop during the growing season. Such estimates will not affect the calculation in relation to the 170 kg/ha limit, but it will affect the calculation in relation to the overall amount of fertiliser that can be applied. If the fertiliser equivalence for the manure estimate is too low, there is a higher risk of leaching, as the overall the crop will be overfertilised.

As the limit applies at farm level, MS have the possibility to impose **limits at field level**. For example, some Member States impose a maximum percentage of exceedance per field, as they have found that the flexibility has sometimes led to large overapplication of manure on a limited number of fields of the farm, thereby increasing the risk of N and P losses.

MS are also free to impose lower limits for manure, for example in relation to the risk of eutrophication due to the imbalance of nitrogen vs **phosphorous in manure**. Long term high levels of manure application may result in phosphorous saturation of the soils, which is a major cause of eutrophication due to erosion or hydrology. The Nitrates Directive indirectly limits P application by manure, due to the limit of N application from manure, which is 170 kg ha^{-1} $year^{-1}$. However, using estimates of N-P ratios in different manure types, the nitrogen application rates may be higher than the required P inputs, especially in livestock dense regions where there tends to be a high accumulation of P. Limit values on manure application based on P requirements, would generally result in lower N application limits than what is currently allowed in the Nitrates Directive. (see below measures on P). Imposing limits on phosphorus in manure can be an effective way to implement the manure limit, addressing the risks of nitrogen and phosphorus pollution at the same time. Some Member States use this approach.

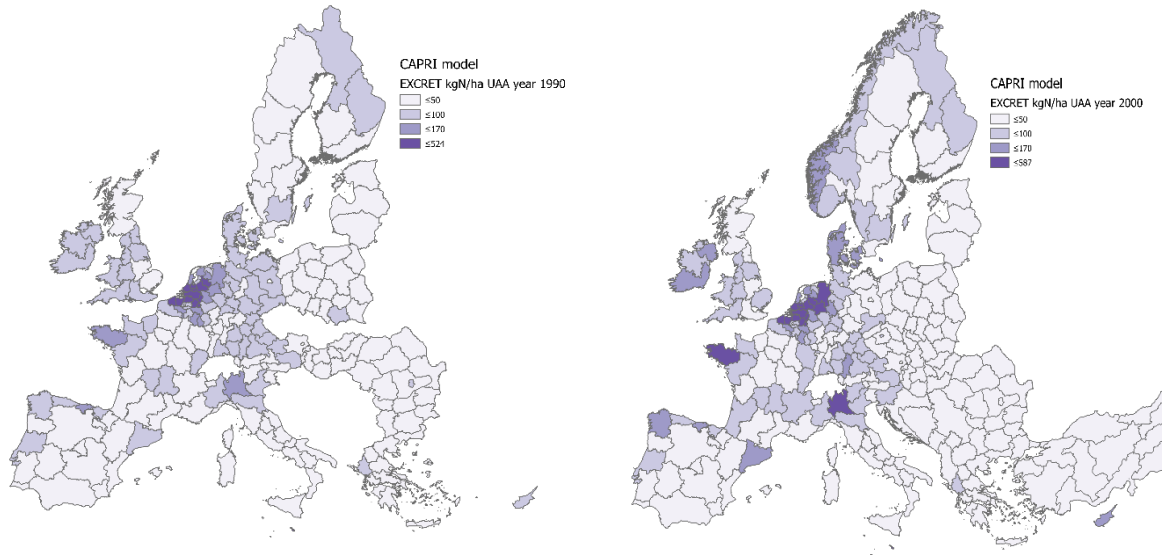
As the Nitrates Directive does not impose a limit on **manure production** per farm, there is also the flexibility for Member States to allow that farms produce more manure than they can apply on land. When a farm produces more manure than it can apply, the excess manure needs to be disposed of. The most economic way with least environmental impacts is when the excess manure can be used as fertiliser on crop fields from another farm nearby. Local biogas or manure processing plants can also serve as local hubs that allow redistribution of the processed manure among farms in the region. As long as the cumulative amount of manure produced on the farms in a given region remains well below the amount of manure that can be easily transported and applied on land in the same region in line with the manure application limit and balanced fertilisation limits, the flexibility profits all farms in the region (both those in need of disposing of excess manure and those receiving it) and the risks of nitrogen losses associated with this flexibility remain relatively low. However when the cumulative manure production on the farms in a given region exceeds the total amount of manure that can be easily transported and applied on land in the same region in line with the manure application limit and balanced fertilisation limits, both the costs for farmers to dispose of the manure and the risks of nitrogen losses (nitrates in water, ammonia in the air) increase, due to the high total concentration of nitrogen from manure in the same region. The mismatch between manure production and potential for manure application at regional level can have a negative impact on the effectiveness of the Nitrates Directive. In the long term,

nutrient pollution hotspots can develop with high nitrogen losses to the air, soil and water with cascading pollution impacts on all waters, on nature and human health[19].

The JRC study shows the evolution of manure production per NUTS 2 region in the EU in 1990, 2000, 2010 and 2018. While the maps clearly show that the majority of regions in the EU have maintained a manure production level far below the Nitrates Directive limit, there are a number of NUTS2 regions where the average manure production remains high between 100 and 170 kg N/ha UAA, and the maps also show the nutrient hotspots in the EU with average production at NUTS2 level above 170 kg N/ha of UAA. Even though most regions remain well below the established limit, the Nitrates Directive plays a crucial role in maintaining this status and in identifying nutrient hotspots where targeted measures should be implemented to prevent water pollution. The manure limit set by the directive has been effective in reducing nitrate pollution, eutrophication, and, to some extent, ammonia emissions. The manure limit aims to address high concentrations of livestock in certain regions as well as individual farms, which lead to excessive manure application and pose an additional risk of nitrogen losses.

The graphs below show the evolution of manure production over time for a selected number of countries and regions.

Figure 14 Nitrogen in manure production (EXCRET: Nitrogen in excretion of animals) per hectare of Utilised Agricultural Area (UAA) for NUTS2 regions in 1990, 2000, 2010 and 2018, as estimated by the CAPRI model.



[19] 2022 Medium-term EU Agricultural Outlook (EC, 2022, Chapter 7) explores scenarios limiting the livestock density to 2 LSU/ha UAA at NUTS2 level and at 10km x 10km grid level. In such scenarios nitrates leaching and run-off would be overall reduced between 4 % to 10%. However, in hotspots regions, the reductions could reach up to 50%. (Source JRC study 2025)

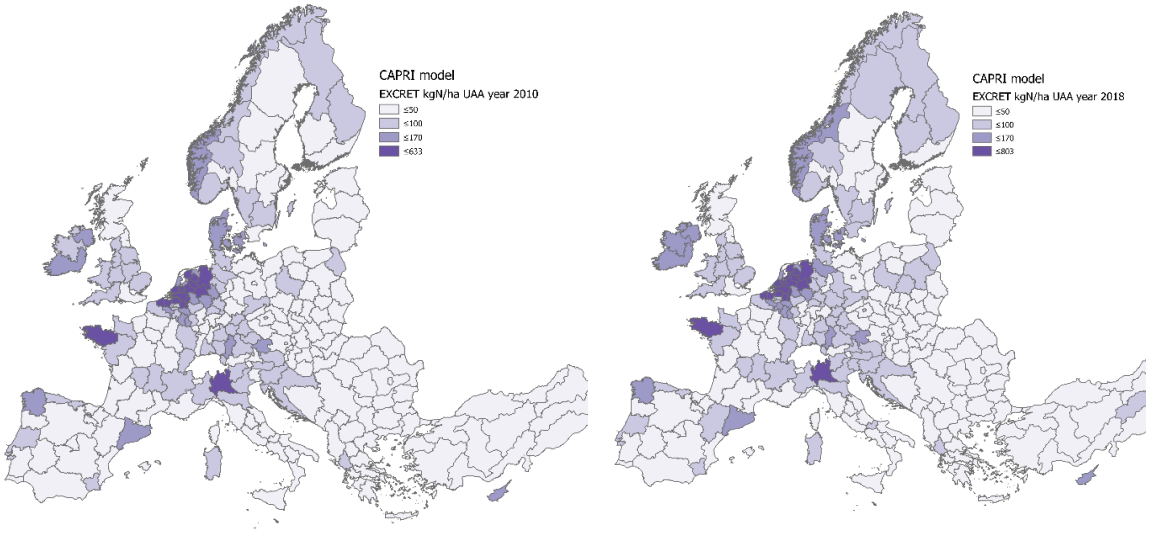
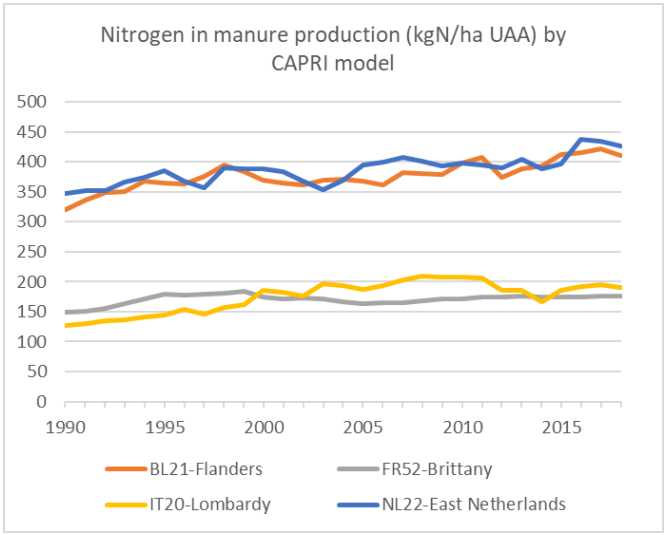
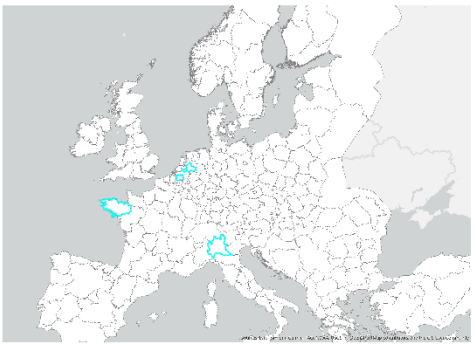
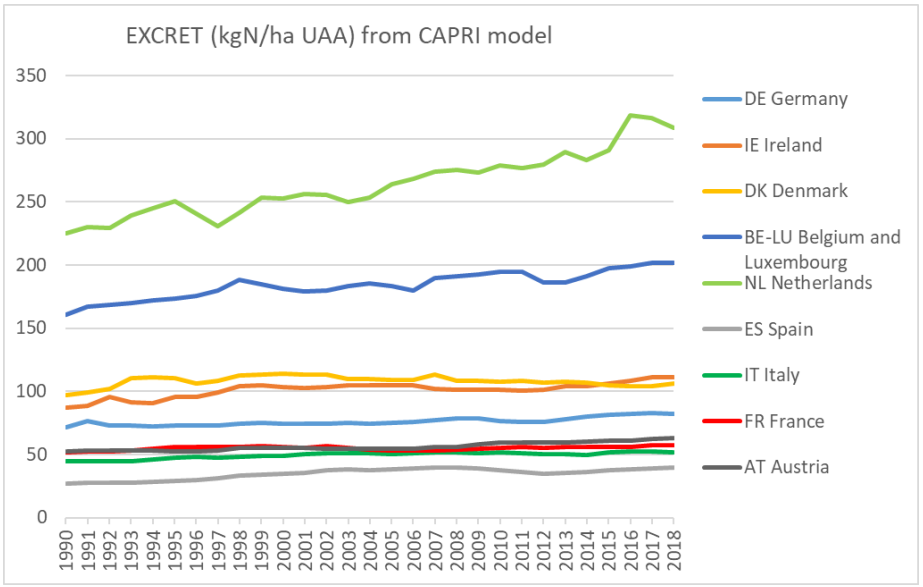


Figure 15 Nitrogen in manure production (EXCRET: Nitrogen in excretion of animals) per hectare of Utilised Agricultural Area (UAA) for selected NUTS2 regions and selected countries as estimated by the CAPRI model.



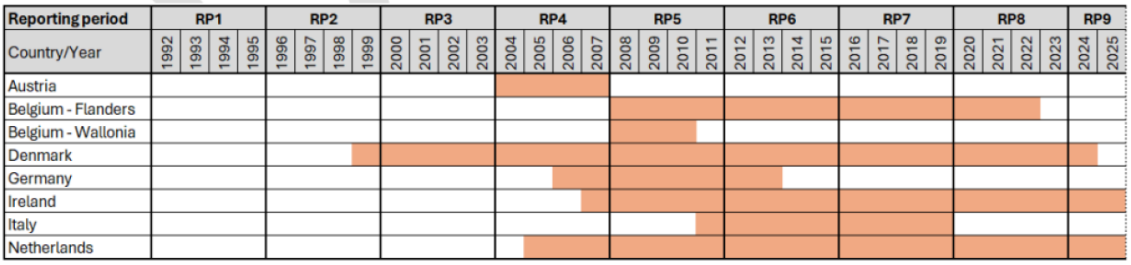




An additional flexibility to the manure application limit is that MS can also request **derogations to apply higher amounts of manure** in nitrate vulnerable zones if objective criteria show that the amount of nitrogen fixed and the other conditions will not lead to increased nitrate water pollution. Derogations to the manure limit are granted to Member States for 4 years by the Commission after obtaining the support of a qualified majority of Member States in the Nitrates Committee. The consultation and support of the other Member States on derogation decision is consistent with the requirement to protect the level playing field as minimum protection standard provided by the harmonized manure application limit. Seven Member States have requested derogations since the entry into force of the directive. The aim was to allow applying higher amounts of manure under different circumstances such as farms with long growing seasons and crops with high nitrogen uptake. In their requests for derogations, Member States have had to justify their requests based on their national conditions (soil type, climatic conditions etc.) and ensure that the use of higher amounts would not impact water quality. For each request, the Commission carefully considers scientific justifications, confirming that the higher amount of manure applied does not lead to additional pollution. The Commission also considers the status of water quality, the need to take reinforced measures in the Nitrate Action Programme and if needed the effectiveness of these reinforced measures and the revised action programme. The Figure 16 gives an overview of the derogations granted to the Member States over time. Some of the derogations were regional, such Belgium – Flanders and Wallonia, and for Italy - Lombardia, Piemonte, Emilia Romagna, Veneto. Comparing to the earlier maps and graphs on manure production, one can see that derogations have been granted in Member States and regions with high to very high manure production, which is natural as these are the regions that would require a derogation. However, as mentioned, the derogations are always based on objective criteria and strict conditions to ensure that they do not undermine the objectives of the directive.

While the Nitrates Directive provides considerable flexibility by enabling Member States to request and implement derogations, it should always be considered that such derogations risk having an influence on the directive's overall effectiveness. Livestock intensification in areas where derogations are in place has led the Commission to conduct closer assessments of how these derogations are applied. More importantly, it has prompted a stricter evaluation of the conditions that might justify the granting of such derogations.

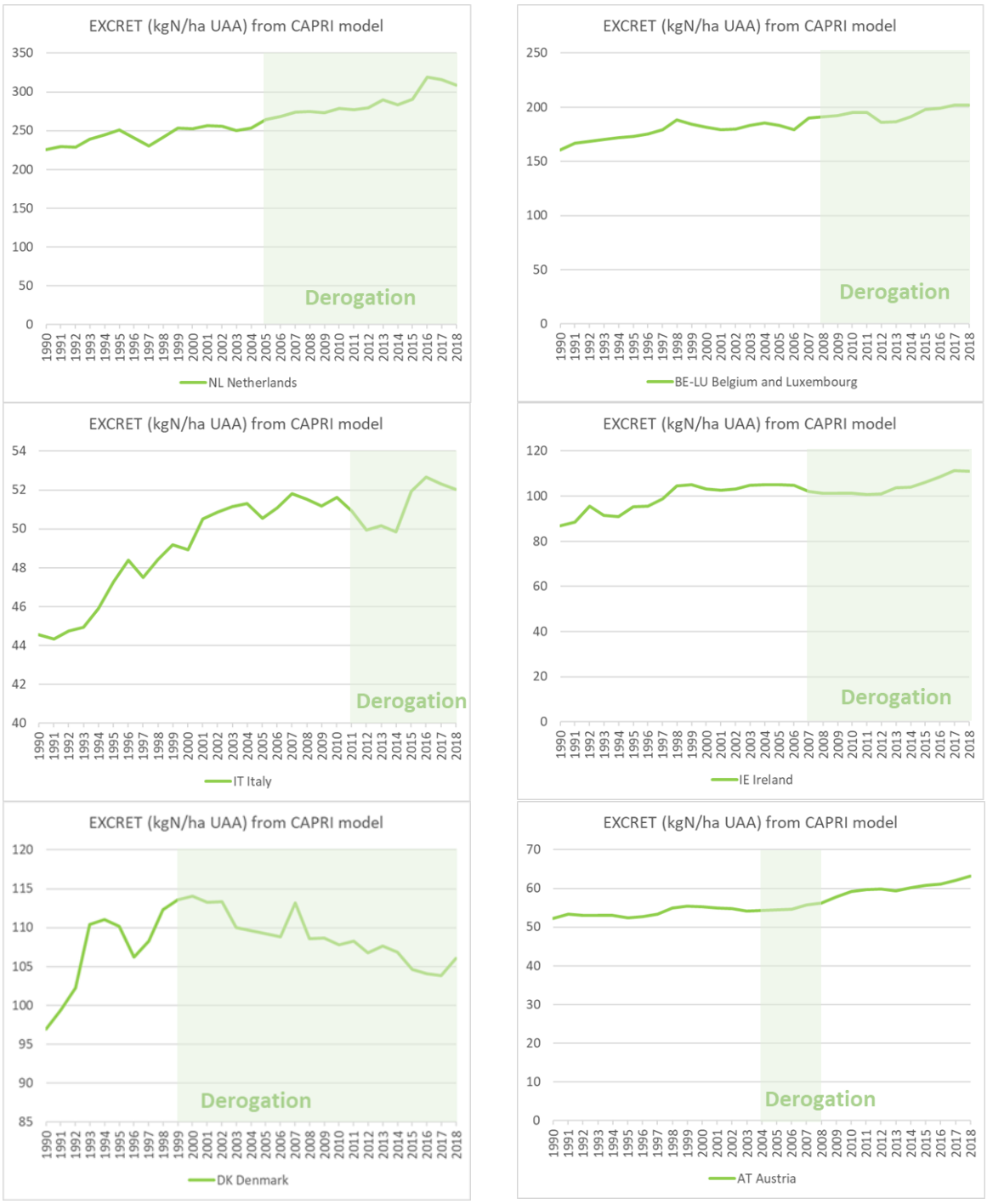
Figure 16 Overview of derogations granted to Member States[20]



[20] End of 2025, Ireland was granted a derogation for 2026-2028.

Except Denmark, Member States with long-term derogations have maintained or even increased the manure production over time, as shown in the graphs below.

Figure 17 Nitrogen in manure production (EXCRET: Nitrogen in excretion of animals) per hectare of Utilised Agricultural Area (UAA) for countries with derogation as estimated by the CAPRI model.



Derogation decisions granted to Member States have always included additional measures for farms with a derogation (e.g. percentage of grassland, buffer strips, chemical fertilisation, soil samplings, phosphorous measures) to mitigate the additional risk of leaching and run-offs from the farms with derogations. However it is not possible to affirm that the derogations have had no negative impact on the achievement of the objectives to reduce and prevent further water pollution. Derogations in Germany, Italy

and Belgium-Flanders have been discontinued following the start of infringement proceedings initiated by the Commission for failure to implement sufficiently effective measures under the directive. In 2024, Denmark decided not to request a new derogation following concerns about increasing eutrophication in coastal waters. A report from the European Court of Auditors in 2023[21] concluded that "As regards the application of the Nitrates Directive provisions relating to manure, we found that policy decisions such as the abolition of milk quotas led to an increase in the herd size in farms benefiting from a derogation from the nitrogen limits, which were constraining the application of manure. As a result, the derogation limited the achievement of the Directive's objective." The European Court of Auditors therefore recommended that when deciding whether to grant derogations, the Commission should ensure that they only apply to those areas already achieving the Nitrates Directive objective, and include in its assessment a review of potential conflicting objectives arising in other EU policy areas.

6. Measures to address phosphorus losses

Eutrophication can be caused both by nitrogen (N) and phosphorus (P), but the Nitrates Directive does not mention P explicitly. The evaluation therefore examined whether the fact that the Directive does not explicitly cover phosphorus has had an impact on the achievement of the objectives regarding eutrophication.

Section 3 and Annex XV on the interlinking between the Nitrates Directive and the WFD already examines more generally the absence of parameters or thresholds for N and P for defining eutrophication under the Nitrates Directive. This issue has led to delays in implementation, monitoring and reporting of eutrophication. The WFD however provides a legal context and a work strand for a scientifically validated methodology for setting ranges and thresholds for N & P in relation to eutrophication and good ecological status. Not all Member States have yet defined such thresholds for all waters, nor use the WFD approach to define the trophic status under the Nitrates Directive. This issue is also addressed further under coherence and simplification.

This section further examines whether the absence of *explicit measures to address P losses to water* in Annex II and III affected the achievement of the objectives.

Reducing P losses and eutrophication is regulated under several EU directives, including the Nitrates Directive, WFD, IED, UWWTD, MSFD and under international conventions (e.g. HELCOM, OSPAR) (see also table below with a list of relevant EU legislation). The Member States have implemented measures to address P losses under these various legal frameworks and there is no uniform approach across Member states. However, the WFD remains the overall coherent and encompassing framework to address eutrophication in fresh and coastal waters.

Nitrates Directive: measures to address P losses

When the Nitrates Directive (ND) and the UWWTD were adopted, P pollution was mostly caused by urban wastewater and this was considered as the main priority[22]. Nevertheless, the ND implicitly covers measures to reduce P losses to water.

[21] European Court of Auditors, Special report 19/2023, EU efforts for sustainable soil management.
[22] Wastewaters remain a very significant source for P and can also have local impacts as these are point source contributions.

The ND does not set limits to the application of P in fertilisers. The limit on livestock manure applying in all NVZ expressed in relation to nitrogen plays an important role in this respect, as livestock manure is a significant source of P. The phosphorus content varies depending on the animal type, but generally the 170 kg limit for nitrogen tends to result in an amount of P that exceeds crop needs in most cases, especially in regions with high legacy P content in agricultural soils. Manure generally has a N/P ratio between 2 and 8, in contrast to the N/P ratio of 7 – 11 required by crops. When the crop's N requirement is applied by using solely manure, this results in an excess of P[23]. Member States can impose lower limits under the ND where needed.

The good agricultural practices of Annex II and III to reduce nitrate leaching and run-off from fields are also effective measures in reducing P losses to water. P can be lost from the soil via erosion, surface runoff, subsurface runoff, leaching and tile drainage. In the consultations, Member States experts confirmed that the measures in Annex II and III are considered effective in addressing P losses and rated their effectiveness as follows from 1 (not effective) to 5 (very effective).

Table 4 Effectiveness of the measures to address P losses from agriculture based on Member States experts' consultations

How effective are the measures to address P losses from agriculture 1 (not effective) to 5 (very effective)	**Average score**
Requirements on capacity and construction of storage vessels	**4.3**
Restrictions on water-saturated, flooded, frozen and snow-covered ground	**4.2**
Restrictions near water courses	**4.1**
Requirements on land application methods and limits (balanced fertilisation)	**4.0**
Restrictions on steeply sloping ground	**3.9**
Requirements on fertiliser planning and record keeping	**3.6**
Closing periods for the application of fertilisers	**3.4**
Requirements on minimum land cover	**3.4**
Limit on manure application (170 kg N/ha) – without derogation	**3.4**
Requirements on land use management (crop rotation etc.)	**2.9**
Limit on manure application - with derogation and related conditions	**2.8**
Requirements related to irrigation	**2.8**

Moreover, in 2000, the CJEU highlighted with regard to Article 3(1) on the identification of polluted waters that 'restricting the scope of the ND to exclude certain categories of waters owing to the supposedly fundamental role of phosphorus in the pollution of those waters is incompatible with both the logic and the objective of the ND' (Case 258/00 Commission v France). Therefore, the CJEU clarified that Member States are required to identify waters as polluted also if P is the main controlling factor for eutrophication. This further means as a direct consequence once waters are identified as polluted that Member States should take measures to reduce and prevent such eutrophication and may imply the necessity to take action on addressing P losses from agriculture.

A study of 2014, after explicit requests to Member States on the measures to address P losses from agriculture found that the consulted Member States considered that the measures under the Nitrates Directive were addressing P losses from agriculture, and in addition at least 9 MS had explicit limits on application of P fertilisers depending on crop

[23] Study: Amery, F. and O.F. Schoumans, 2014. Agricultural phosphorus legislation in Europe. ILVO.

and/or soil conditions. (although the extent, form and the amounts of these limits vary a lot from one MS to another)[24].

A check on the NAP and ND reporting from MS in 2024 found that at least 14 MS implement explicit limitations on the application of P as fertiliser. The table below illustrates these findings[25].

Table 5 Limitations on the application of P as fertiliser

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
Austria		N	Y	For implementing SMR 1 obligation (as part of the conditionality of CAP Strategic Plan 2023-2027) in terms of controlling diffuse sources of phosphorus, an additional GAEC standard (GAEC 10) has been specified at the national level. Requirements include compliance with recommendations (guidelines) for proper fertilisation with regard to P fertilisation and the verification of P-requirement by soil test as well as the documentation of applications of additional mineral P-fertilisation exceeding a given threshold.
Belgium	Flanders	Y		Limitation on the application of phosphorus depending on the crop type, the soil phosphorus content (4 different classes) and the location in soil phosphorus saturated areas.
Belgium	Wallonia	N		
Bulgaria		N		
Croatia		N	Y	The Croatian Nitrates Action Programme does not include specific measures on phosphorus fertilisation as a standalone element. However, restrictions on the use of phosphorus are laid down in the Regulation on Conditionality and Social Conditionality, Official Gazette

[24] Study: Amery, F. and O.F. Schoumans, 2014. Agricultural phosphorus legislation in Europe. ILVO.
[25] The table is based on information provided by Member states authorities in December 2025.

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
				No. 71/2025. In particular, Annex IV of the Regulation defines maximum permissible application rates of phosphorus for different agricultural crops, expressed in kg/ha. These crop-specific limits constitute binding restrictions aimed at preventing excessive phosphorus inputs to soils. Furthermore, under SMR 1, phosphorus fertilisation must be carried out on the basis of soil chemical analysis, which must be performed at least once every four years per production parcel.
Cyprus		N		
Czech Republic		N	Y	The CZ AP does not include measures on phosphorus fertilisation. However, in 2025, the P (and N) balance on arable land has been incorporated into the conditions of the new eco-scheme supporting sustainable nutrient management (Government Regulation No. 83/2023 Coll.). The eco-payment is annual, so the balance result is evaluated each year, with a balance surplus limit for phosphorus on farm level of max. 10 kg P/ha. The need for phosphorus recovery to the soil depends on crop yields and on extractable phosphorus content in soils. Soil testing for available nutrient content (P, K, Mg, …) is provided nationwide in the Czech Republic as part of the Agrochemical Testing of Agricultural Soils.
Denmark		Y		Legislation limiting the application of phosphorus has entered into force in August 2017, although restrictions linked to P surplus from manure were

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
				already in place. Phosphorus ceilings are set for the different fertilisers. The phosphorus regulation covers both organic and chemical fertilizers. Stricter phosphorus ceilings apply in catchments for lakes in the river basin management plans where additional protection is needed.
Estonia		Y		Legislation provides a limit of P-application by manure. Manure may be applied up to 25 kilograms of phosphorus per hectare (on average over five years). The limit of 25 kilograms of phosphorus per hectare by manure does not apply if a valid soil analysis indicates that the need for phosphorus absorbed by plants in the soil is high or very high. A “total” P-limit, regarding both mineral and organic P-fertilisation is not present. The exemption from the 25 kg P/ha limit is subject to mandatory soil sampling and classification of soil phosphorus demand in accordance with national legislation. This is regulated by a ministerial regulation establishing soil phosphorus demand classes, which defines the soil phosphorus classes and the accredited analytical methods used for determining plant-available phosphorus in soil.
Finland		N	Y	The AP of Finland does not include measures on phosphorus fertilisation. However, this is set out in another regulation. The Government Decree on regulating the use of phosphorus in agriculture and horticulture and in green and environmental construction (64/2023) lays down provisions on restrictions on the

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
				use of phosphorus (e.g. fertilisation restrictions). It includes for example maximum rates of phosphorus fertilization in Annex I.
France		N		
Germany		Y	Y	Germany has a number of rules specifically regarding phosphorus fertilisation including a prohibition period, prohibition of fertilisation in certain circumstances, the need for a fertiliser requirement calculation, determination of soil phosphorus content, limitation of the P2O5-fertilisation, requirements for buffer distances to water bodies when applying phosphorus fertilisers and extended buffer distances on fields with a certain slope gradient. In addition, there are record-keeping obligations to document fertilisation measures carried out. Furthermore, the federal states are required to designate eutrophicated areas in which additional measures apply and must be complied with. Finally, outside the scope of the NAP, requirements under GAEC 5 of the Common Agricultural Policy apply with regard to soil cover, particularly in erosion-prone areas. These areas are designated under the erosion protection regulations.
Greece		N		
Hungary		N	Y	In the measures of Conditionality under the CAP in SMR1 P application with slurry is limited. Legislation for the application of sludge reducing eutrophication.
Italy	national	N		

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
	Emilia-Romagna	Y		Soil analyses must be carried out in areas with the highest density of livestock farms and/or with specific local conditions. A limit on soil P concentration is set (200 mg P/kg soil) and if this threshold is exceeded, it shall be prohibited to apply all fertilisers containing P.
	Lombardia	Y		Prohibition to use synthetic phosphate fertilisers when the phosphorus requirements of the crops are already met by the use of manure and/or agro-livestock digestate and agro-industrial digestate containing livestock P.
	other regions	N		
Latvia		N		
Lithuania		N		
Luxembourg		N		
Ireland		Y		Ireland requires farmers to comply with limits for both N and P application as part of the balanced fertilisation requirement. On arable land the maximum fertilisation rates depend on the P status of the soils as well as on the crop. On grassland the maximum P fertilisation rates depend on the stocking rate as well.
Malta		Y?		The Maltese Progress Report of January 2025 mentions attention for phosphorus in the fertiliser plan. The analyses include the amount of phosphorus which is also taken into consideration in the fertiliser plan. Where phosphorus surplus is identified, fertilisers with low phosphorus content will be applied. (Progress Report 5.2).
Poland		N		Currently, there are no legally

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
				binding measures limiting the amount of phosphorus fertilisers applied by farmers. However, assumptions for introducing such measures are included in planning documents developed under the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD), and recommendations and good practice guidelines are in place.
Portugal		Y	Y	The AP of mainland Portugal does not include rules on phosphorus fertilisation. However, the Code of Good Agricultural Practice (2018) is mandatory in the NVZ and includes some rules concerning the application of phosphorus fertilisation, while it is optional outside these zones. Additionally, Ordinance no. 79/2022, of February 3, which defines the regime applicable to the management of livestock effluents, also contains measures for the application of livestock effluents (manure and slurry) in fertilization according to the crop's needs for nitrogen and phosphorus for the expected production. The AP's of the vulnerable zones in the Autonomous Region of the Azores provide application limits for phosphorus depending on the P-content of the soil. Also in the Autonomous Regions of the Azores, certified laboratories will recommend the most appropriate fertilisation, including the amount and form of nitrogen and phosphorus. In the scope of WFD, threshold values have been set for

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
				phosphorus in groundwater and surface water. In addition, certain measures have been defined for cases where the status of water bodies is less than good due to agricultural practices, including livestock farming
Romania		N		
Slovakia		N		No rules on phosphorus fertilisation included. However, regarding phosphorus the Act provides the nutrient need of individual crops per unit of production is given (Annex 3 of the Act), and the proportion of phosphorus usable from applied agricultural fertilisers or organic fertilisers (Annexes No. 5 and 6 of the Act). A maximum dose to which the applied amount of phosphorus has to be limited is not provided.
Slovenia		N		
Spain		N		
	Aragón	N	N	The Fifth AP of Aragon sets out recommendations on phosphorus fertilisation.
	Madrid	Y	N	
	Murcia	Y	Y	
Sweden		Y		The fertilisation rate of organic fertilisers in the nitrate vulnerable zones is limited both by N and P. Regarding phosphorus, manure and other organic fertilisers must not be applied in greater amounts over a five-year period than the equivalent of 22 kg total phosphorus per hectare of application area per year. There is also a maximum amount of total phosphorus per hectare that may be added to arable land via

Member State	Region	Measure in the NAP	Measure outside the NAP *	Info
				sewage sludge. This amount is differentiated regarding the soil phosphorus class. The phosphorus regulations apply throughout the country and not just in the nitrate vulnerable zones.
Netherlands		Y		Phosphate usage standards are included in the regulations. These may vary depending on the phosphate status of the soil (based on combination of P-CaCl2- and P-AL values), type of fertilising product and whether it is applied on grassland and arable land. The standard limit is 75 kg of phosphate per hectare for grassland and 40 kg of phosphate per hectare for arable land. Extra P can be given from specific fertilising products with high effective organic matter content, in order to maintain soil organic matter content. Higher P-amounts are allowed (up to 120 kg P2O5/ha) for soils with poor P status (P-CaCl2 <3,4 and P-AL < 45).

Note: * WFD, CAP, etc.

Reporting on P concentrations or on P specific measures has not been part of the reporting guidelines under the Nitrates Directive. A number of Member States monitor and report P concentrations as part of their national reporting under the Nitrates Directive, but this is not systematic and the Commission has not integrated this aspect in its 4 yearly reporting to the European Parliament and the Council.

Water Framework Directive and P pollution

The WFD requires that Member States address eutrophication and pollution from N and P if these are a pressure responsible for deterioration of the status of a water body or if it is an obstacle in the water body achieving good ecological status. P and N are both supporting elements for assessing the ecological status. The WFD also provides an encompassing approach to P pollution as P is considered as a main pollutant and Member States have an obligation to control it as part of the basic measures in the programme of measures under the RBPM. Member States should address the different sources of the pollutant in a combined approach for point sources and diffuse sources. It is for Member States to determine the necessary load reduction from the different sources of P pollution,

being urban waste water, agriculture or industry and take effective measures for each sector to reduce the pollution so as to reach the water quality objectives. (see also Annex XV on links between ND and WFD).

Common Agriculture Policy and P pollution

The CAP Regulation[26] also plays a role in reducing P losses from agriculture through the cross compliance by reenforcing the obligation under the WFD:

SMR 1: Directive 2000/60/EC of 23 October 2000 of the European Parliament and of the Council establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000, p. 1): Article 11(3), point (e), and point (h), *as regards mandatory requirements to control diffuse sources of pollution by phosphates*

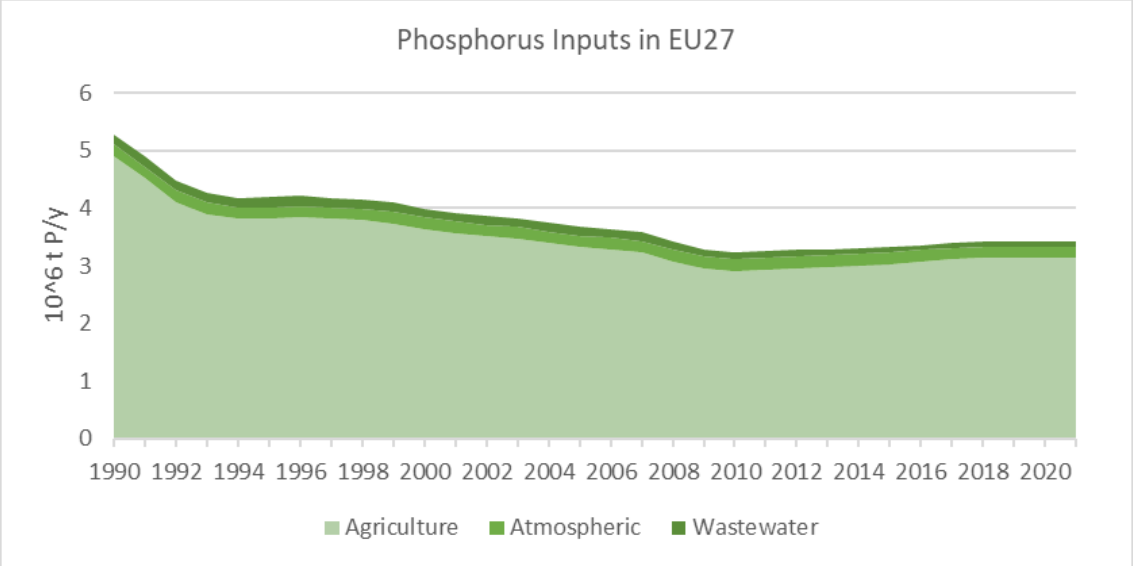
Moreover GAEC 4 (buffer strips), GAEC 5 (Tillage management, reducing the risk of soil degradation and erosion, including consideration of the slope gradient) and GAEC 6 (Minimum soil cover to avoid bare soil in periods that are most sensitive) further contribute to reducing P pollution. These obligations complement the Annex II measures under the Nitrates Directive, in particular outside NVZ.

Additional voluntary measures and financial incentives are also available in many Member States to address P pollution.

Evolution of P inputs from agriculture

The Figure 18 shows the evolution of P inputs from different sources: agriculture and wastewater discharges from domestic and industrial sources. The figure shows a clear reduction of P inputs from agriculture since 1990, with a renewed increase since 2010.

Figure 18 Development of the phosphorus inputs in the EU27 between 1990 and 2021

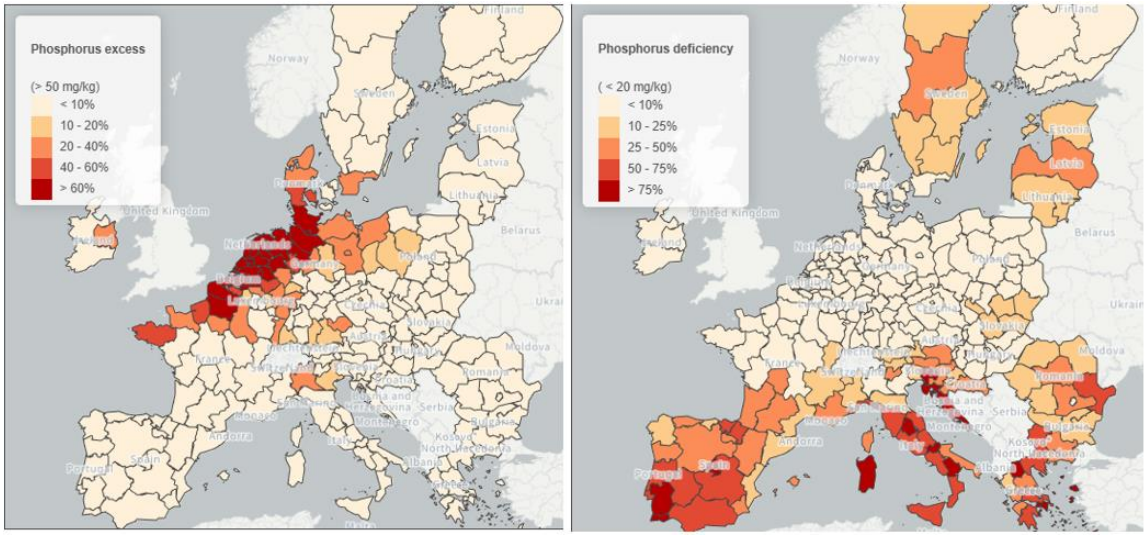


High P surpluses remain common in the EU, although they have reduced considerably since 1980. P inputs have peaked above 30 kg ha^{-1} around 1980, while P inputs are on average 16 kg ha^{-1} in the EU+UK (data available in 2022).

Due to the lower mobility and high retention of P in soils, the positive budgets of the past have resulted in a build-up of soil P pools representing a large soil P legacy in certain areas of EU. (source JRC study) On the other hand there are areas, mainly in the southern part of the EU, where there is a risk of phosphorus deficiency for crop production.

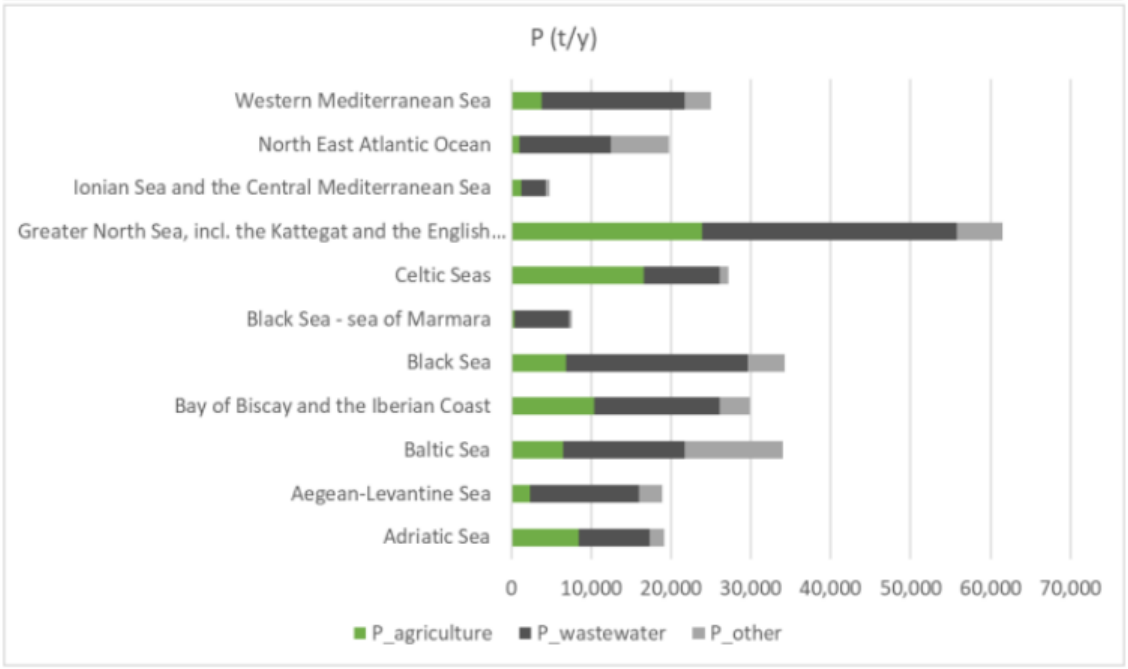
[26] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2115

Figure 19 Phosphorus excess (left) and deficiency (right) in soils



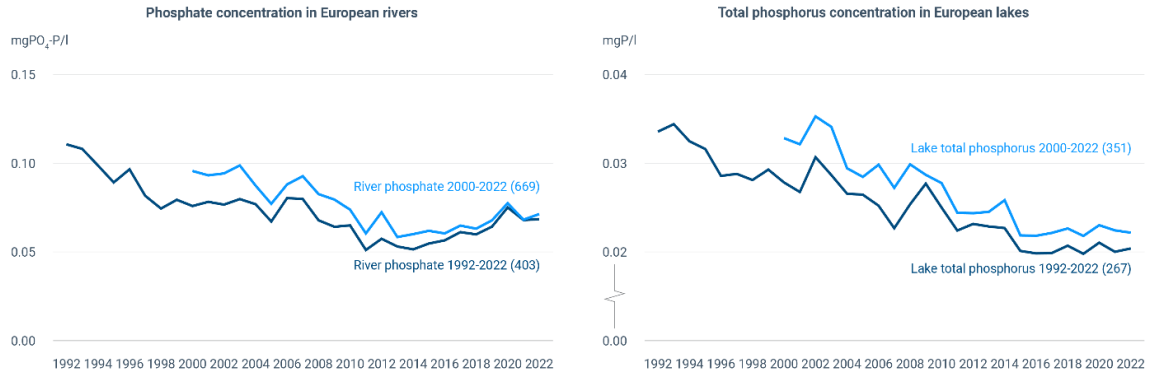
The Figure 20 shows the estimated P loads from different sources in European seas, which can be seen as the ultimate end point. Wastewaters remain the most important contributor at this level. The difference in the balance between agriculture and wastewater between this figure and Figure 18 above reflects the fact that most of the agricultural inputs are retained in agricultural soils and in sediments of small watercourses upstream, whereas discharges of wastewater tend to have a more direct route downstream towards the sea.

Figure 20 Estimated P loads from different sources in European seas



In terms of impacts to water, the following figure reproduced also in section 3 shows the evolution of P concentrations in rivers and lakes. The EEA explains that the bulk of the reduction is the result of UWW treatment and phosphate free detergents.

Figure 21 Evolution of concentrations of phosphates in rivers (left) and phosphorus in lakes (right).



Source: EEA, 2025, 'Nutrients in freshwater in Europe', European Environment Agency. (https://www.eea.europa.eu/en/analysis/indicators/nutrients-in-freshwater-in-europe) accessed 13 May 2025.

Conclusion

Requirements to address phosphorus pollution in water from agriculture are covered in several EU Directives. The Nitrates Directive does not mention phosphorus explicitly but the agricultural measures in Annex II and III also contribute to some extent to address phosphorus pollution. An CJEU ruling in 2000 clarified that Member States should identify polluted waters and thus take measures under the Nitrates Directive to reduce and prevent eutrophication, even where phosphorus is the main factor causing eutrophication.

The obligation under the WFD to address diffuse phosphorus pollution from agriculture in the programme of measures wherever phosphorus losses from agriculture has been identified as a pressure on a waterbody complements the obligation to take action under the Nitrates Directive, the measures taken under the latter constituting basic measures under the WFD. Therefore, when designing the programme of measures under the WFD, Member States can rely exclusively on the measures of the Nitrates Directive to address phosphorus pollution from agriculture but, if this proves insufficient to reach the overall objective of reducing phosphorus concentrations, they should add further measures. At least one third of the Member States have added measures to limit phosphorus fertiliser application in their national legislation. The obligation to address phosphorus pollution from agriculture is further reinforced through cross-compliance, GAEC requirements and voluntary measures under the CAP.

Consultations with Member States experts confirmed that national measures to address phosphorus pollution from agriculture are often a mix of mandatory and voluntary measures under different legal instruments. However, phosphorus concentrations and specific measures on phosphorus are not part of the reporting under the Nitrates Directive, creating a blind spot in terms of causes of the eutrophication, which is not filled by the WFD reporting.

While originally it was decided not to include requirements to limit phosphorus fertilisation in the Nitrates Directive, the question as to whether this should be done today remains valid. When consulted, Member States experts were divided on whether rules on addressing emissions of phosphorus were sufficiently well covered. Overall, measures taken under the Nitrates Directive in combination with the WFD have contributed to reducing phosphorus inputs from agriculture as well as run-off and erosion of phosphorus from soils and thus contributed to reduce phosphorus concentrations in water. Therefore the measures have allowed progressing towards the reduction and prevention of eutrophication, and achievement of water protection goals and the pertinence of including specific rules on phosphorus in the Nitrates Directive would need to be weighed against the risk of excessive regulation. Urban wastewater remains a

major source of phosphorus, even though the reduced concentrations in rivers and lakes that has taken place since the 1990s can mostly be attributed to progress in wastewater treatment.

Table 6 EU legislation that tackles phosphate pollution.

Legislation	Phosphate control
Urban Waste Water Treatment Directive (UWWTD)	• Requires more stringent removal of nutrients like phosphorus from urban wastewater, particularly in sensitive areas identified as eutrophic or at risk of becoming so.
Water Framework Directive (WFD)	• Sets the overarching objective for all water bodies to achieve "good status," which includes managing nutrient levels to prevent eutrophication. • Member States must take remedial action for waters that are eutrophic or have the potential to become so.
Marine Strategy Framework Directive (2008/56/EC)	• Aims to protect the marine environment across Europe and requires member states to develop strategies for their marine waters with the goal of achieving "Good Environmental Status" by addressing sources of pollution, including nutrients such as phosphates.
Industrial Emissions Directive (IED)	• Mandates the use of Best Available Techniques (BAT) for industries, which increasingly includes phosphorus recovery from waste streams. • Examples include recovering phosphorus as struvite from wastewater in the "Food, Drink and Milk" industry.
Common Agricultural Policy (CAP)	• the CAP includes measures and incentives for sustainable agricultural practices, which help reduce nutrient runoff (including phosphates) into water bodies
EU Action Plan: Towards Zero Pollution for Air, Water and Soil	• Includes a 2030 target to reduce nutrient losses by 50%. • Encourages pollution prevention across various policies and promotes synergies to reduce environmental damage from pollutants like phosphate.
EU fertilising products regulations	• Includes rules on the composition of fertilising products, allowing for the use of recycled materials like struvite, which contributes to a circular economy for phosphorus.
Detergents regulations	• This regulation controls the use of phosphates in detergents, contributing to the reduction of phosphate pollution in water bodies. Amendments have been made to restrict the use of phosphates in consumer laundry and dishwasher detergents

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SWD(2026) 234 final

PART 5/11

COMMISSION STAFF WORKING DOCUMENT

EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

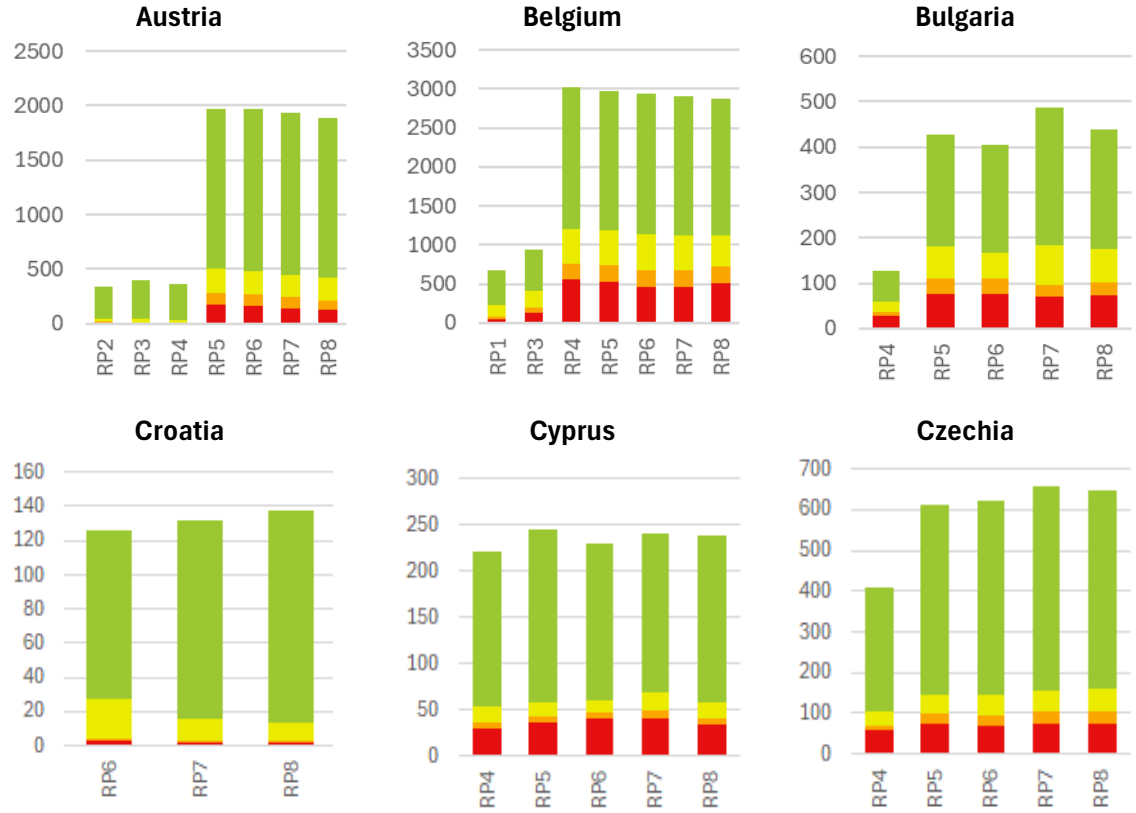
{SWD(2026) 235 final}

ANNEX XIII. TEMPORAL DISTRIBUTION OF NITRATES CONCENTRATIONS AND TROPHIC STATUS OF WATERS IN MEMBER STATES FROM 1992 TO 2023

This annex complements the section 3.3 describing the impacts of the Nitrates Directive on the evolution of water quality. It first provides the graphic evolution across the 8 reporting periods (RP) [1] of nitrates concentrations in groundwater, surface water and eutrophication per Member State, complementing the EU level graphs presented in sections 3.3.1, 3.3.2 and 3.3.3. In the second part, it provides the full set of maps of long-term trend analysis of nitrate concentration in surface and groundwater 2008-2023 prepared by the JRC, complementing the maps on trends in ground and surface waters nitrate concentrations in sections 3.3.1 and 3.3.2.

Nitrates pollution in groundwaters

Figure 1 - Evolution in nitrate concentration classes in groundwater between 1992 – 2023



Legend:

Nitrates concentration classes: < 25 mg/l | 25 - 39.99 mg/l | 40 - 49.99 mg/l | ≥50 mg/l

X axis – reporting period, Y axis – number of groundwater monitoring points

[1] RP1: period 1992-1995, RP2: period 1996-1999, RP3: period 2000-2023, RP4: period 2004-2007, RP5: period 2008-2011, RP6: period 2012-2015, RP7: period 2016-2019, RP8: period 2020-2023.



Legend:

Nitrates concentration classes: < 25 mg/l | 25 - 39.99 mg/l | 40 - 49.99 mg/l | ≥50 mg/l

X axis – reporting period, Y axis – number of groundwater monitoring points



Legend:

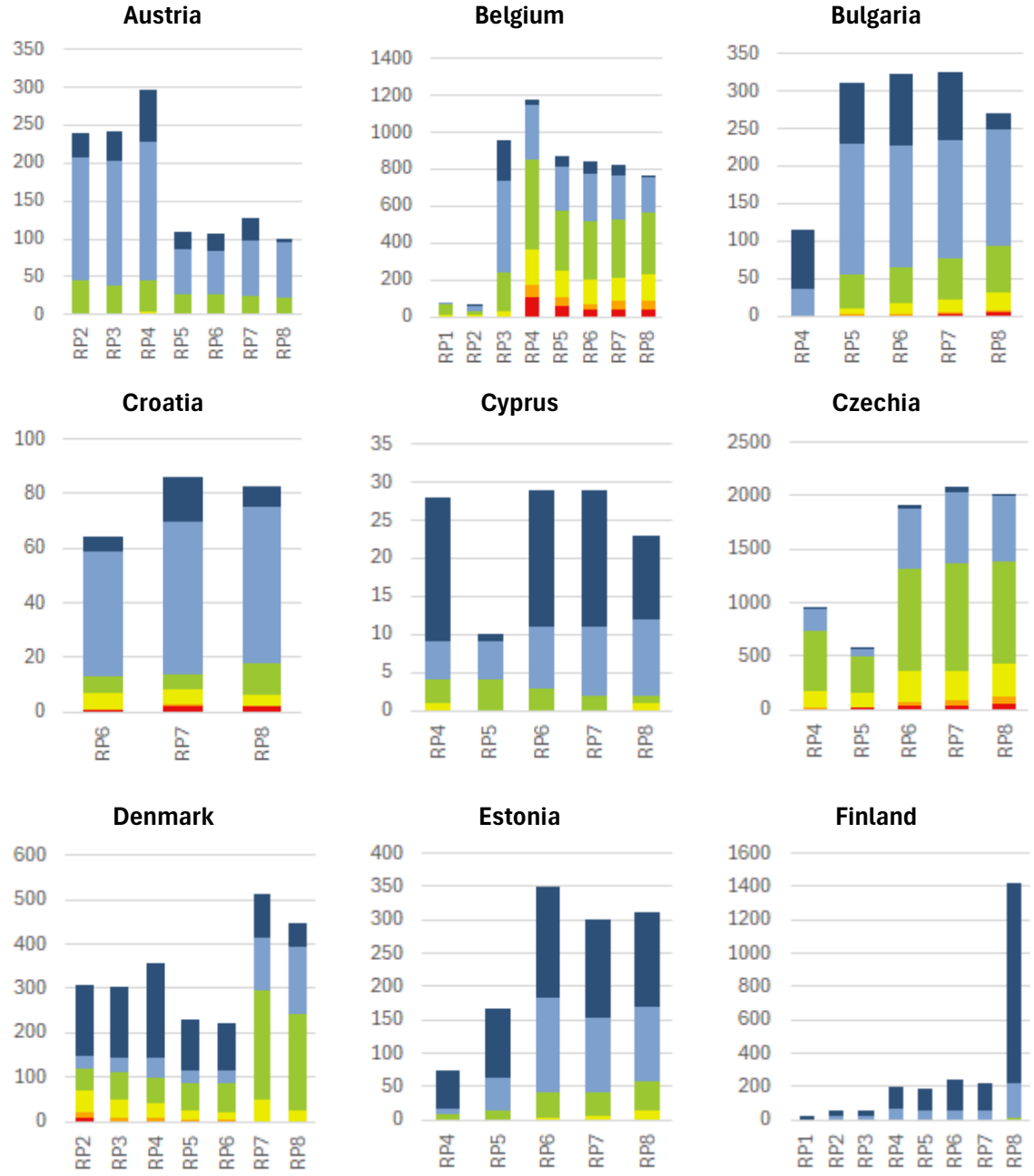
Nitrates concentration classes: < 25 mg/l | 25 - 39.99 mg/l | 40 - 49.99 mg/l | ≥50 mg/l

X axis – reporting period, Y axis – number of groundwater monitoring points

[2] Stations for the reporting periods 2008-2011 and 2012-2015 contain previous errors in reporting. Although these reporting errors were resolved thereupon, it was not possible to include the new data in the subsequent reports.

Nitrates pollution in surface waters

Figure 2 - Evolution in nitrate concentration classes in surface waters between 1992 – 2023



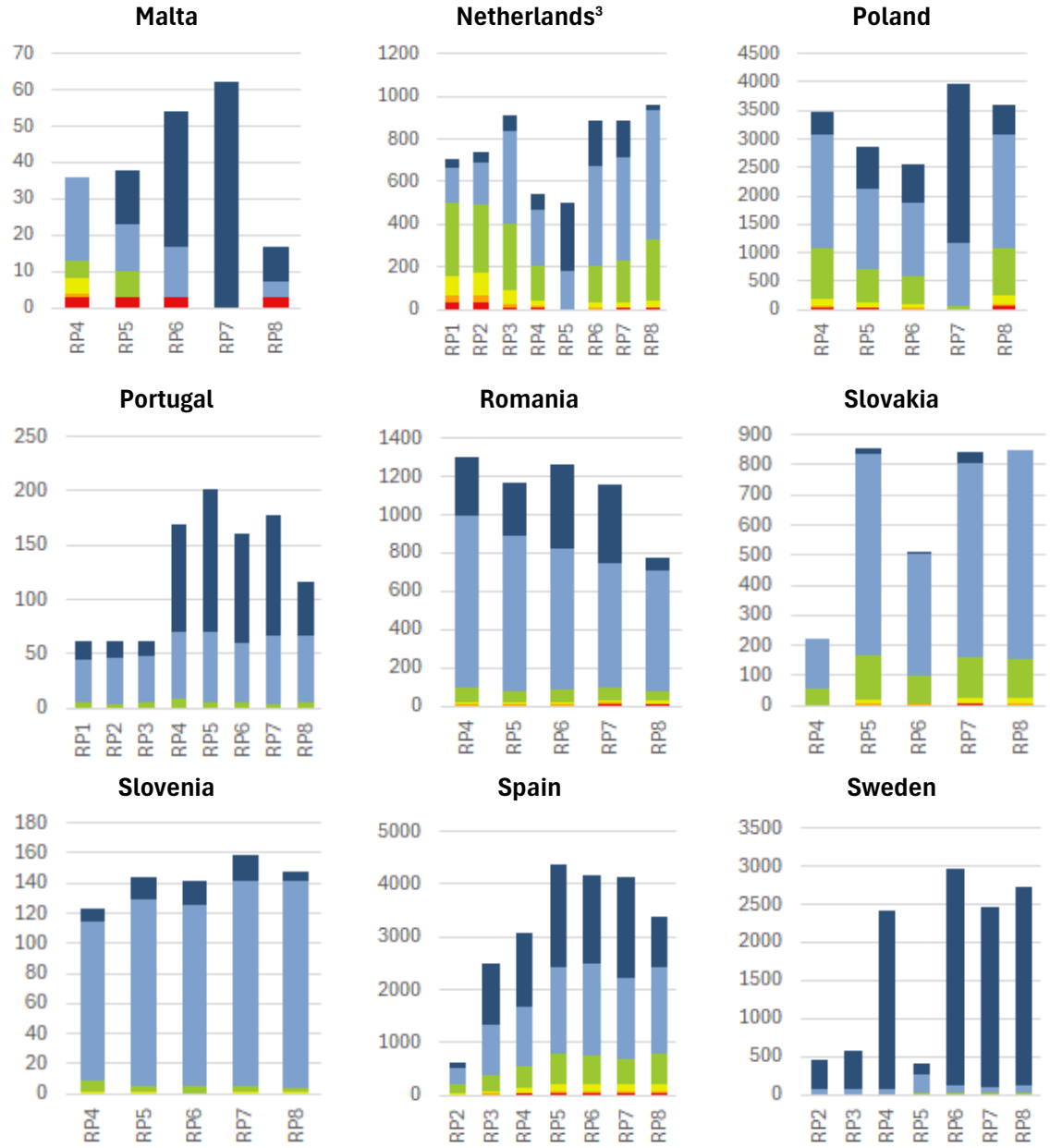
X axis – reporting period, Y axis – number of surface waters monitoring points



Legend

Nitrates concentration classes: < 2 mg/l; 2 - 9.99 mg/l; 10 - 24.99 mg/l; 25 - 39.99 mg/l; 40 - 49.99 mg/l; ≥50 mg/l

X axis – reporting period, Y axis – number of surface water monitoring points



Legend

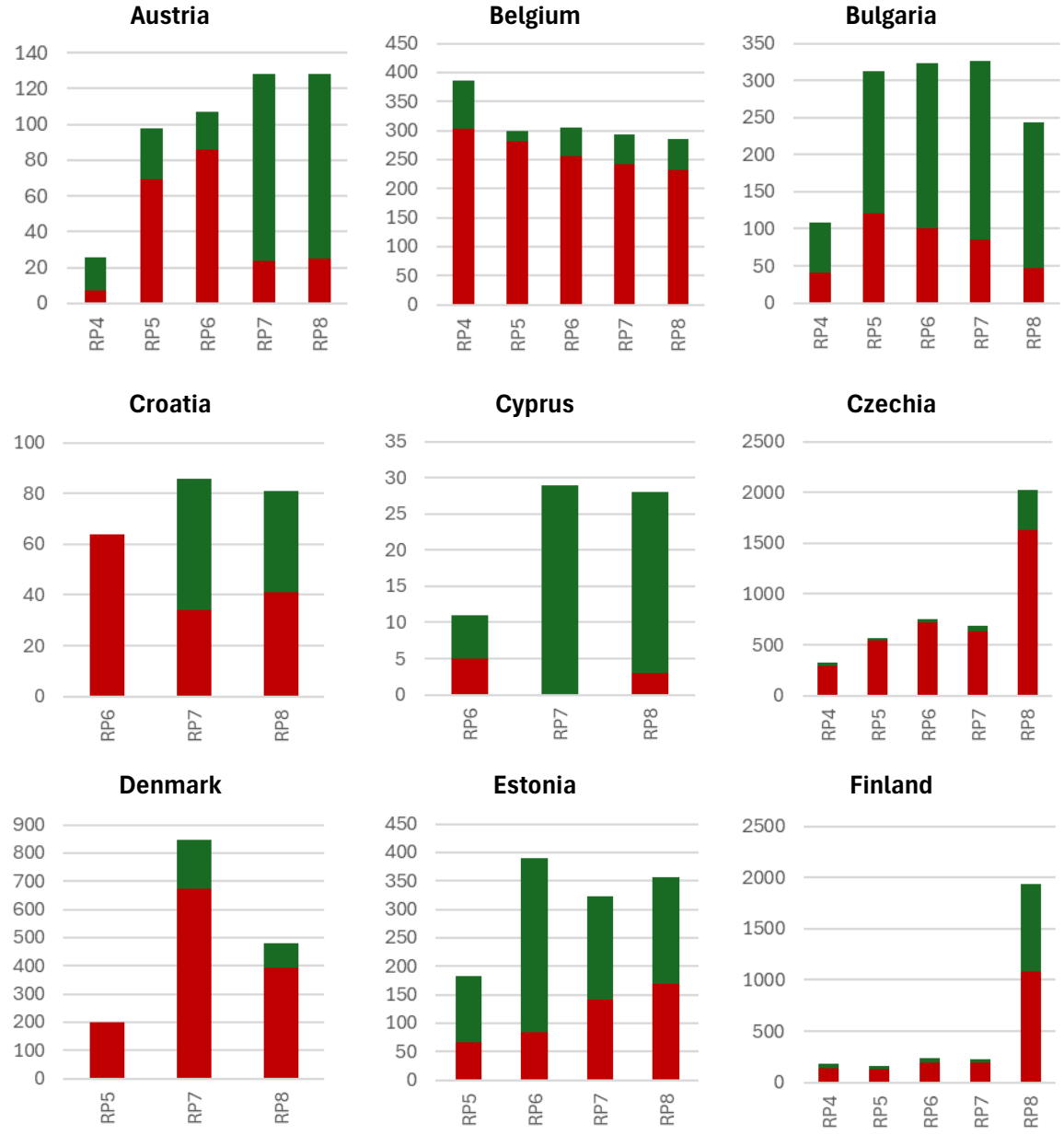
Nitrates concentration classes: < 2 mg/l; 2 - 9.99 mg/l; 10 - 24.99 mg/l; 25 - 39.99 mg/l; 40 - 49.99 mg/l; ≥50 mg/l

X axis – reporting period, Y axis – number of surface water monitoring points

[3] Stations for the reporting periods 2008-2011 and 2012-2015 contain previous errors in reporting. Although these reporting errors were resolved thereupon, it was not possible to include the new data in the subsequent reports.

Eutrophication in surface waters

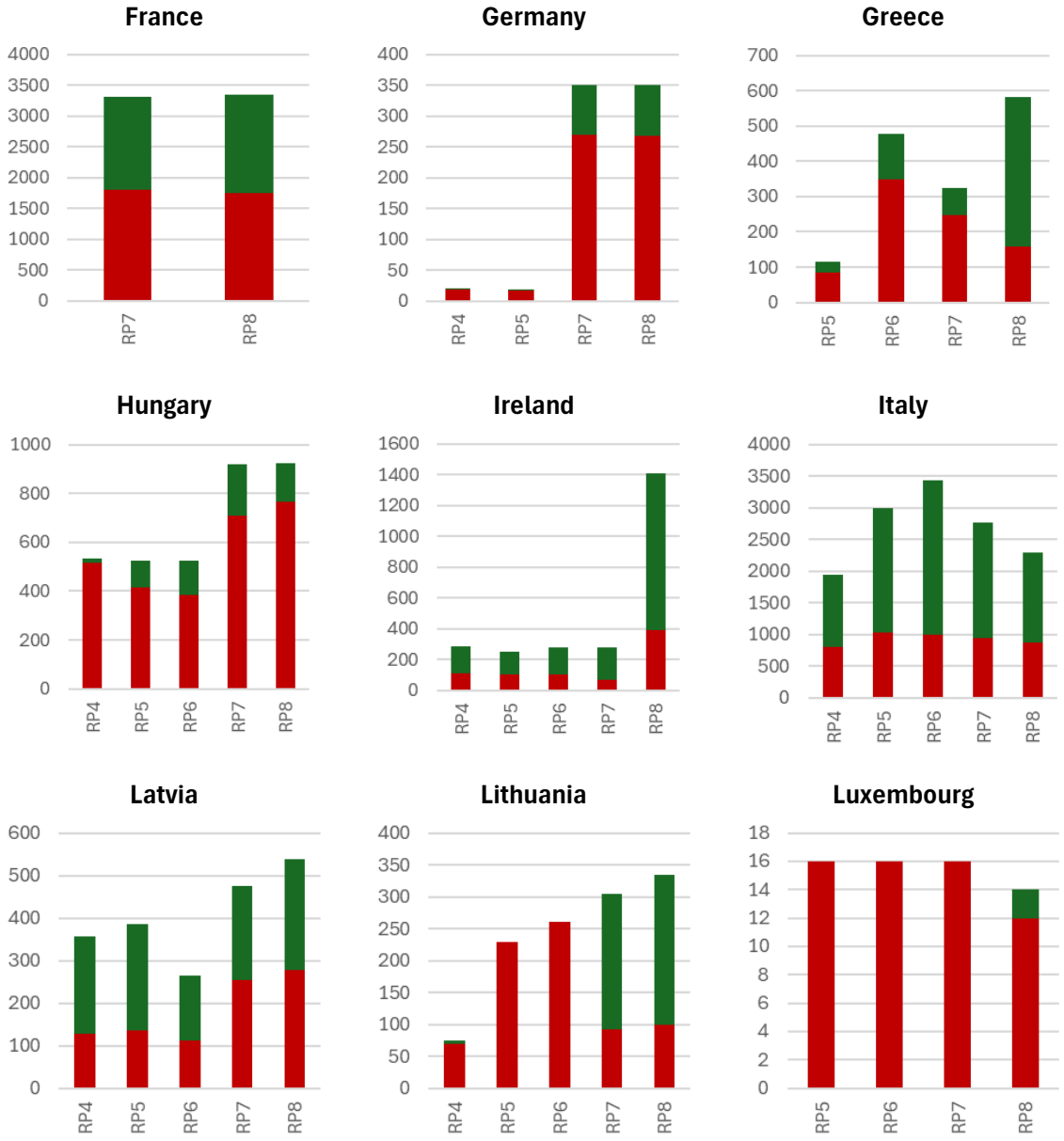
Figure 3 - Evolution of trophic status in surface waters between 2004 – 2023



Legend:

Nitrates concentration classes: Non-eutrophic Eutrophic/could become eutrophic

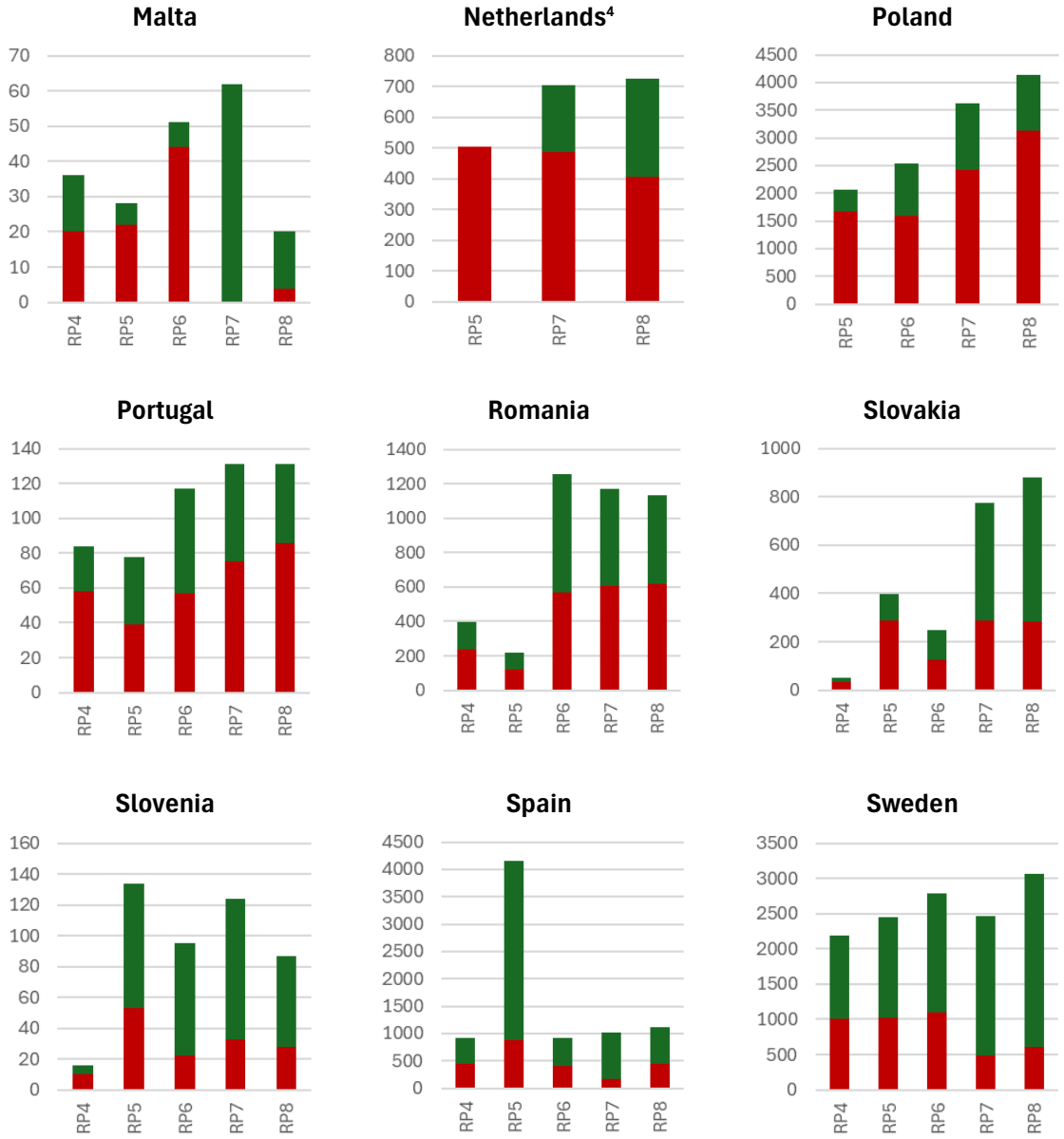
X axis – reporting period, Y axis – number of monitoring points with data on trophic status



Legend:

Nitrates concentration classes: Non-eutrophic Eutrophic/could become eutrophic

X axis – reporting period, Y axis – number of monitoring points with data on trophic status



Legend:

Nitrates concentration classes: Non-eutrophic Eutrophic/could become eutrophic

X axis – reporting period, Y axis – number of monitoring points with data on trophic status

[4] Stations for the reporting periods 2008-2011 and 2012-2015 contain previous errors in reporting. Although these reporting errors were resolved thereupon, it was not possible to include the new data in the subsequent reports.

Long-term trend analysis of nitrate concentration in surface and groundwater 2008-2023

Initially, the analysis below aimed to assess **long-term trends in nitrate concentrations** using the official monitoring points reported by the Member States. However, it proved technically challenging to reconstruct a consistent time series for each individual station. This difficulty stemmed from common data management issues, including:

- **Turnover of monitoring points** (stations being discontinued and new ones opened),
- **Changes in station names** or codes over time,
- **Slight shifts in reported coordinates**, which complicated the matching of sites across reporting cycles.

Because of these inconsistencies, using single monitoring points risked producing fragmented time series that would not reliably reflect the underlying dynamics.

To overcome this, the data was aggregated at **NUTS3 region,** and the **average nitrate concentration** was calculated at this scale, which was then used to construct continuous time series for trend analysis.

Although this approach involves a level of spatial aggregation, it remains **pertinent and robust** for several reasons:

1. **Preserves comparability over time** – averaging across all available points in each NUTS3 region ensures that the effects of turnover or minor changes in stations are reduced or evened out in most cases[5].
2. **Reflects regional water quality status** – the NUTS3 scale aligns with a policy-relevant level of analysis, offering insights into regional patterns rather than site-specific noise.
3. **Reduces bias from station changes** – the aggregation minimizes the artificial variability introduced by name/coordinate changes, allowing the focus to remain on genuine water quality trends.
4. **Enables consistent trend detection** – statistical analyses of average values are still valid for assessing whether nitrate concentrations are rising, stable, or declining over time.

In sum, while the ideal method would rely on continuous individual monitoring records, the aggregated NUTS3 approach is a **methodologically sound and policy-relevant alternative**, ensuring that the analysis captures meaningful temporal trends despite technical constraints in the raw monitoring dataset.

[5] There may still be exceptions in cases where the density of monitoring stations is very low.

Figure 4 Trend analysis of NUTS3 average annual concentration in **groundwater** for the period 2008-2023

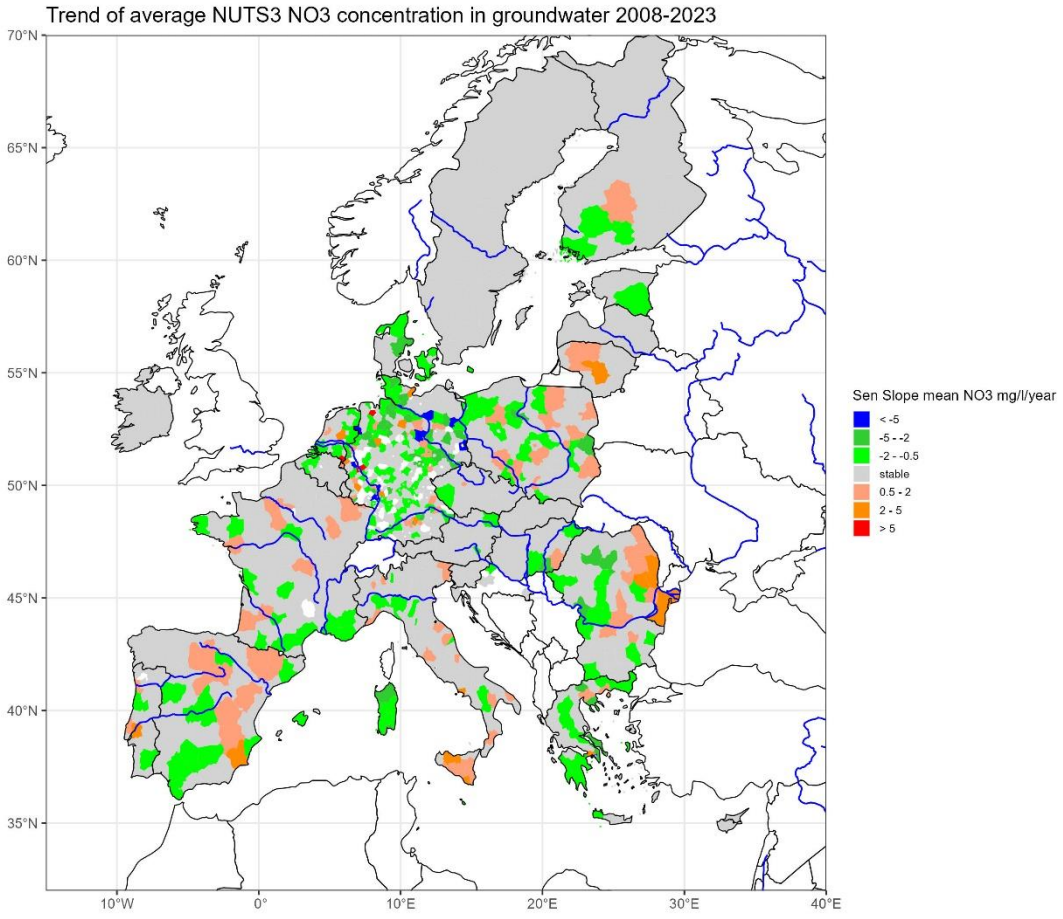


Figure 5 Trend analysis of NUTS3 average annual concentration in **surface water** for the period 2008-2023

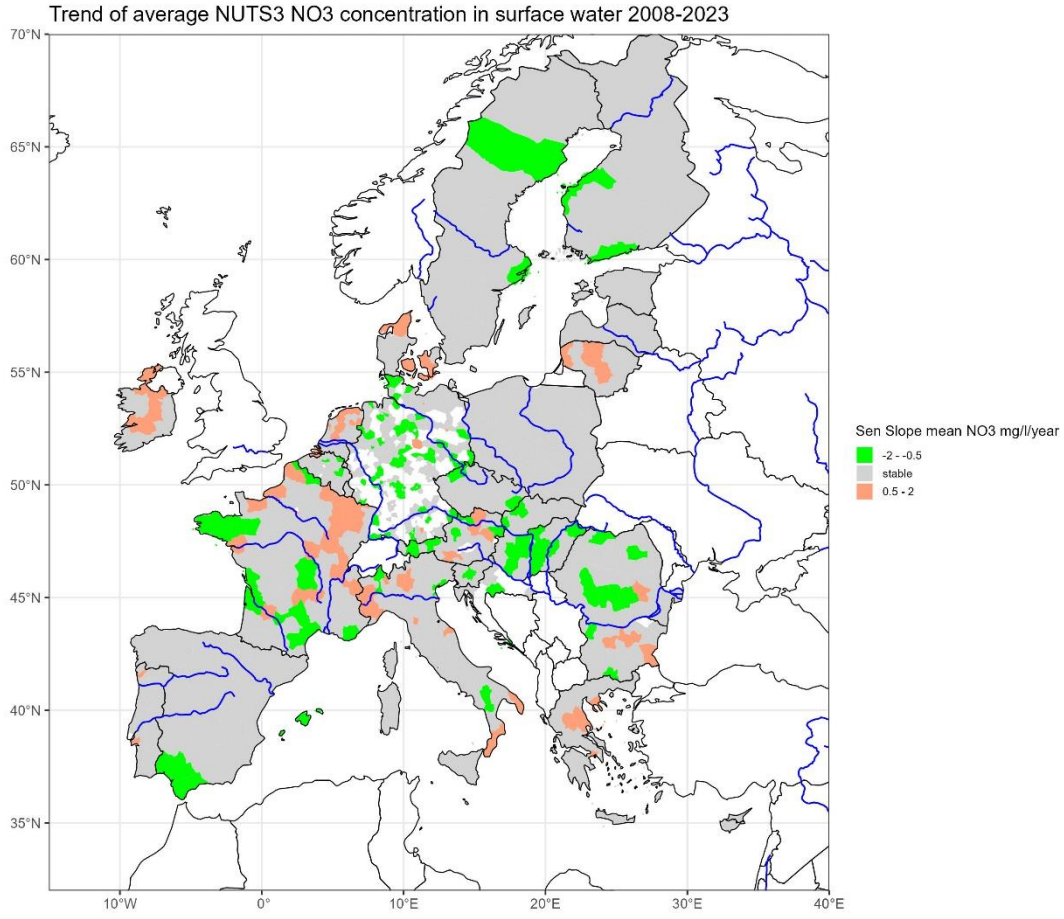


Figure 6 Latest reported NUTS3 average annual concentration in groundwater in the period 2008-2023 for regions with decreasing trends

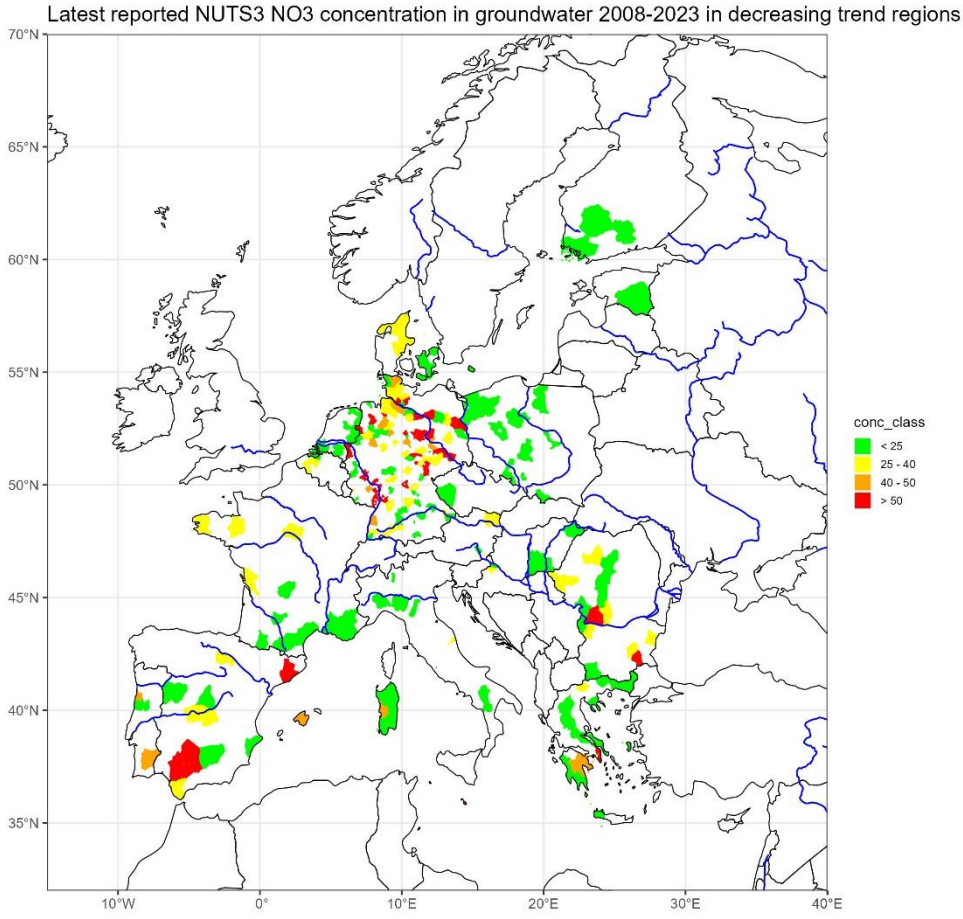


Figure 7 Latest reported NUTS3 average annual concentration in groundwater in the period 2008-2023 for regions with stable concentrations

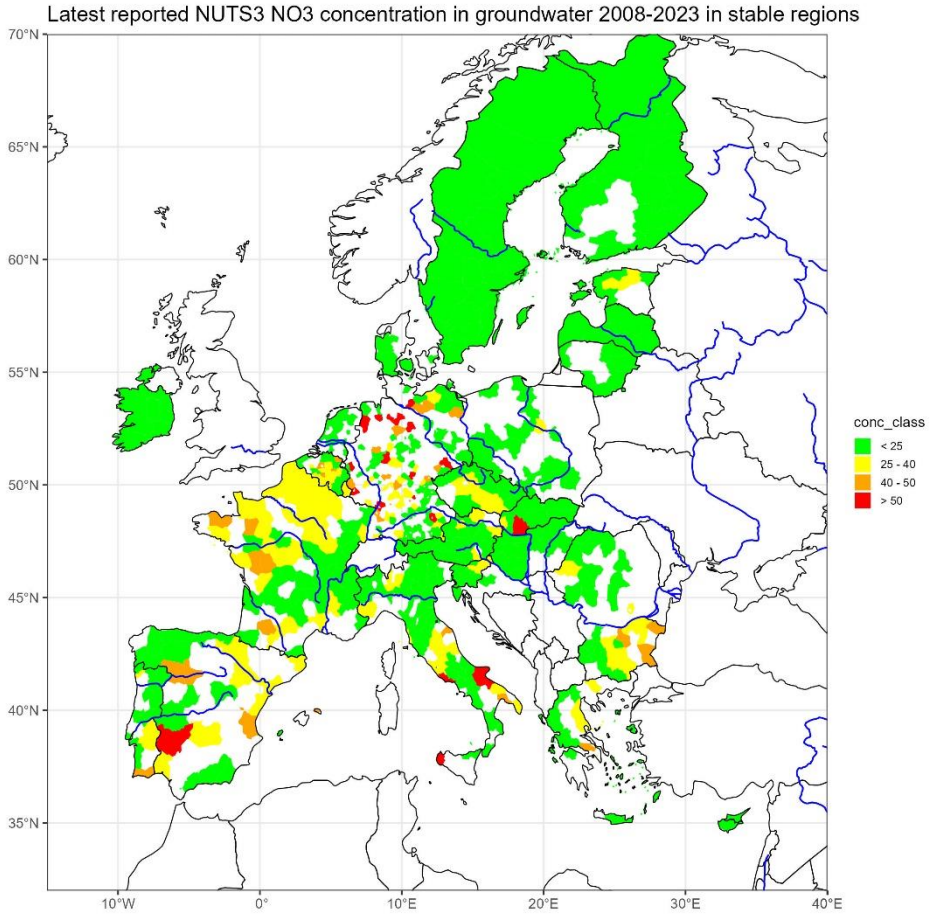


Figure 8 Latest reported NUTS3 average annual concentration in groundwater in the period 2008-2023 for regions with increasing trends

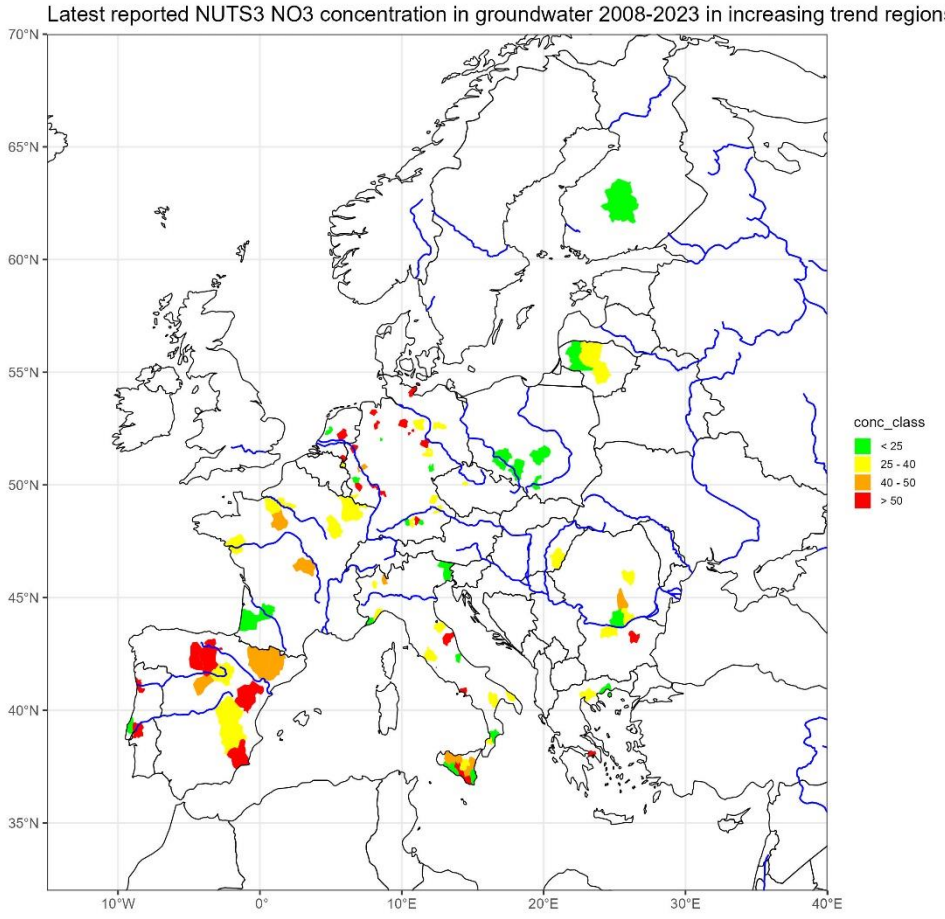


Figure 9 Latest reported NUTS3 average annual concentration in surface water in the period 2008-2023 for regions with decreasing trends

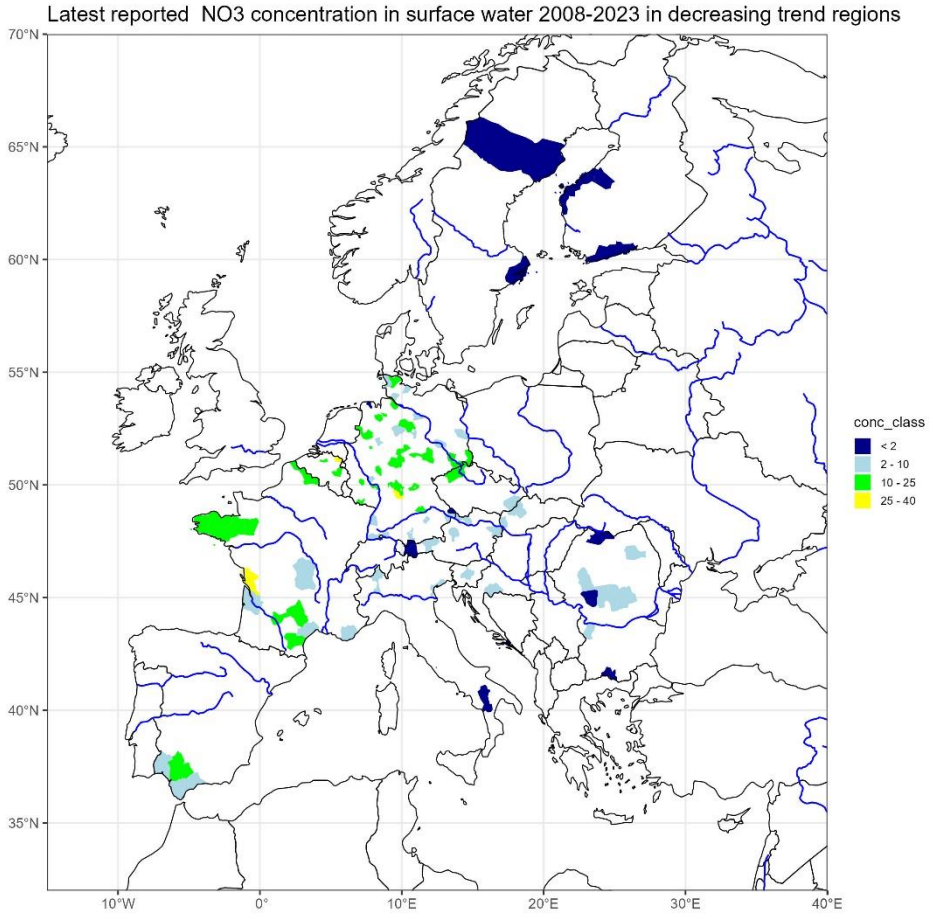


Figure 10 Latest reported NUTS3 average annual concentration in surface water in the period 2008-2023 for regions with stable concentrations

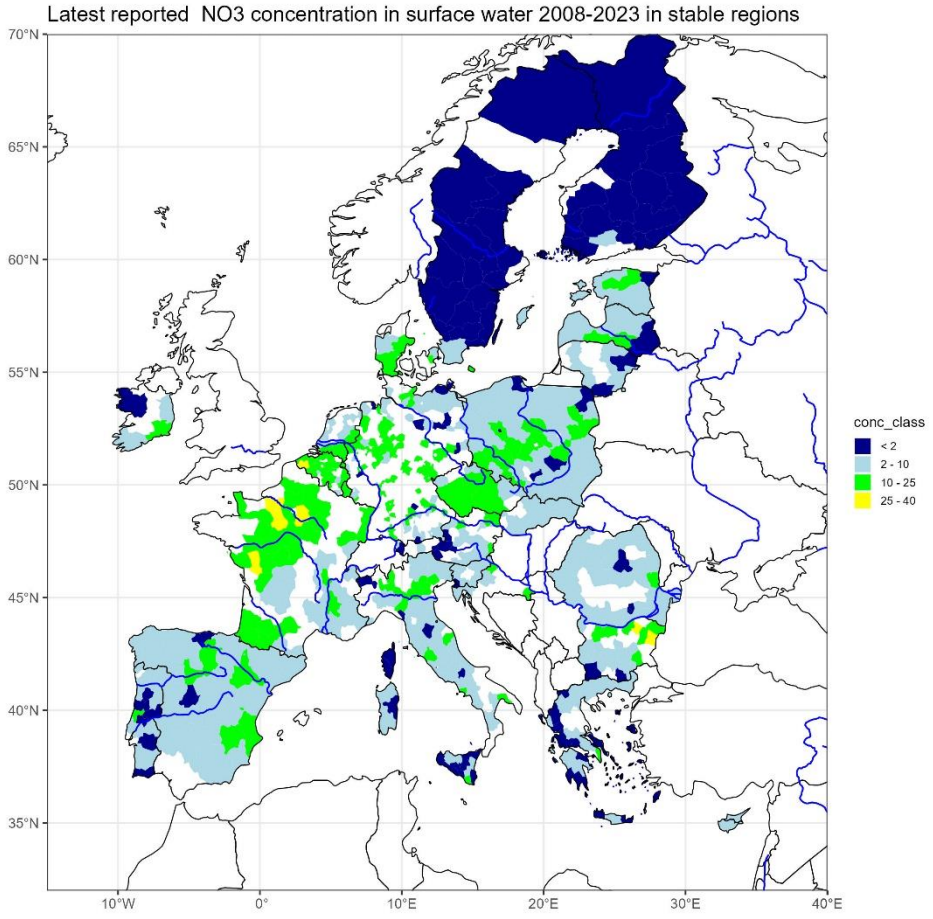
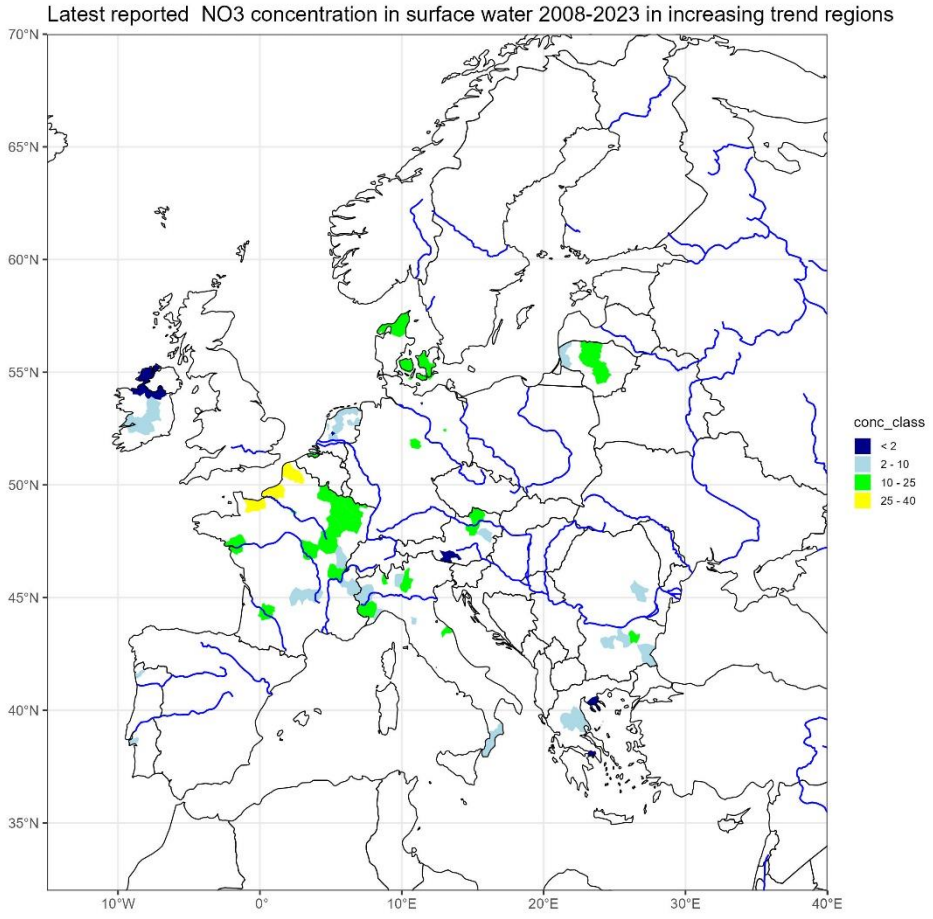


Figure 11 Latest reported NUTS3 average annual concentration in surface water in the period 2008-2023 for regions with increasing trends



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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XIV. THE ROLE OF THE NITRATES DIRECTIVE IN REDUCING NITRATE LEVELS IN THE MEMBER STATES

This annex illustrates the impact of the Nitrates Directive (ND), in terms of reducing nitrates pollution, through examples from Member States based on national and EU reporting, and scientific publications. It includes a set of illustrative examples of impacts in nitrate levels across the EU Member States and regions which can be linked to the implementation of the Nitrates Directive. The following criteria were used for the selection of examples to present a variety of relevant aspects, such as: (i) the long-term development of nitrate concentrations in groundwater, root zones, and surface waters; (ii) the lag time between changes in agricultural practices and their impact on nitrate concentrations; (iii) the parallel evolution of the nitrogen balance in agricultural soils and nitrate concentrations in groundwater; (iv) the long-term development of phosphorus concentrations in surface waters; and (v) the development of water quality in geographically diverse regions across the EU27.

The first **four examples cover the whole period of implementation of the Nitrates Directive from 1991 to 2023** and highlight cases of increasing trends that have been reversed as well as of significant reductions in nitrates concentrations during the first two decades of implementation of the directive:

1. Temporal evolution of the groundwater nitrate concentrations in Denmark between 1940s and 2020: the example shows the parallel evolution of the nitrogen balance for agricultural soils and nitrate concentrations in groundwater, as well as the lag time between changes in agriculture practices and their impact on nitrates concentrations.
2. Development of the nitrate load and concentration in surface waters in France between 1990 and 2022: this example shows the impact of changed agricultural practices in reducing nitrates concentrations in surface waters and discusses the lag time between changes in agriculture practices and their impact on nitrates concentrations.
3. Temporal evolution of nitrate concentrations in the root zone and upper oxic groundwater as well as leaching between 1990 and 2023 in a limited number of catchments in Denmark chosen to be representative of the country in general: this example shows the effect of measures taken under the ND in terms of the evolution of nitrates concentrations in the root zone and upper oxic groundwater and modelled leaching.
4. Temporal evolution of nitrate concentrations in the root zone and surface waters in the Netherlands between 1992 and 2023, based on a specific monitoring network: this example shows the effect of measures taken under the ND in terms of the evolution of nitrates concentrations in the root zone, as well as the evolution of average surface water nitrate concentrations in agricultural areas.

The next **three examples focus on the years 2008-2023 corresponding to the last 15 years of the period examined in this evaluation** and are based on the data reported by the Member States under the ND. These examples aim to provide a more nuanced view of nitrate concentration trends in surface and groundwaters across the EU from 2016 to

2023 as reported in section 3 of the evaluation report. While the evolution at EU level shows stagnation of results or even increasing concentrations for surface waters, the picture is not the same in all Member States, as shown in these examples:

5. Temporal evolution of the nitrate concentrations in Austria with a focus on the evolution in the last 15 years studied in the evaluation.
6. Temporal evolution of the nitrate concentrations in Romania with a focus on the evolution in the last 15 years studied in the evaluation.
7. Temporal evolution of the nitrate concentrations in surface waters in Slovakia with a focus on the evolution in the last 15 years studied in the evaluation.

A last example illustrates the interplay between the Nitrates Directive and the UWWTD in the Danube River between 1996 and 2021. It shows the rapid improvements resulting from the UWWTD implementation especially in P reductions, and the effects, albeit slower and less significant, of the Nitrates Directive in continuous reduction of nitrates concentrations. This is despite a continuous contribution of legacy nitrogen (accumulated nitrogen in soil, saturated zone and groundwater before 1991) and the fact that agricultural inputs in the lower Danube region have increased significantly since 1991.

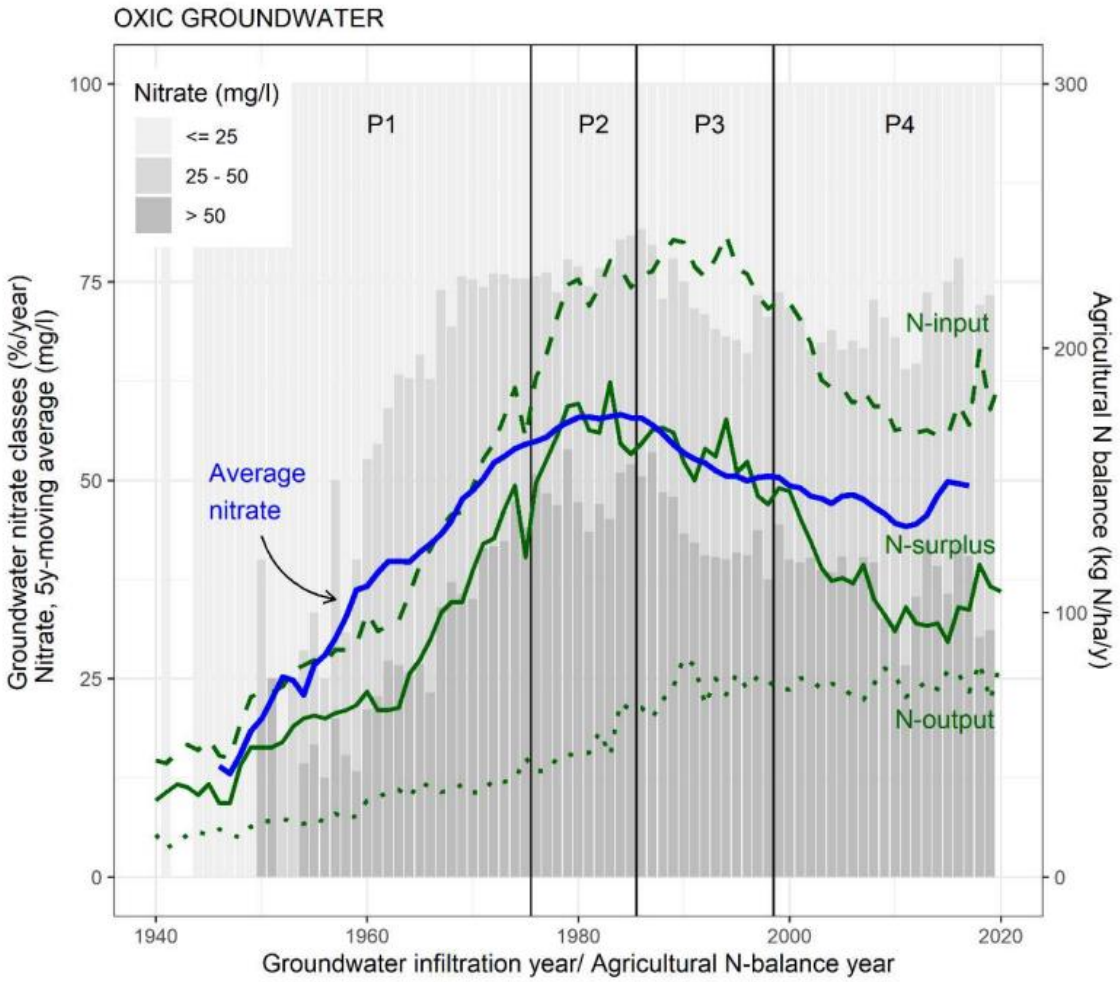
8. Trends in nitrogen and phosphorus dynamics along the Danube River between 1996 and 2021

1. Development of nitrates in Denmark groundwater between 1940s and 2020

Denmark measured nitrate concentrations in a sample of groundwater points dated according to the year of infiltration. The Figure 1 also shows the evolution of nitrogen inputs, offtake in crops and the nitrogen balance. (Source: Report of Denmark under Article 10 of the Nitrates Directive for the period 2020-2023.)[1]

Groundwater age determination allows a relationship to concentrations of nitrate with "time of recharge" instead of "time of sampling". In this way, direct comparison between nitrate in groundwater and N loss from agriculture is possible.

Figure 1 Long-term evolution of nitrates in groundwater in Denmark



According to the Danish Report, statistical nitrate trend analyses at a national level using CFC dating (using CFC gasses dissolved in groundwater as a dating method) gave a strong indication of a trend reversal of nitrate in Danish oxic groundwater since the 1980s due to reduced nitrogen leaching in Danish agriculture (Hansen et al., 2011). A recent assessment by Hansen & Larsen (2016) and Hansen et al. (2017) using both CFC and tritium/helium dating, support these earlier findings showing significant correlation between nitrate in oxic groundwater and nitrogen surplus in agriculture at the overall Danish national level (Figure 1).

[1] See also Hansen et al 2017 "Groundwater nitrate response to sustainable nitrogen management" (DOI:10.1038/s41598-017-07147-2)

In the period 1940-1985, nitrate concentrations in groundwater were increasing in wells monitoring recharged groundwater due to the development of Danish agriculture with increasing input of N fertilizers and N surplus. Since then, a decreasing trend in the oxic groundwater has been observed from 1985 – 2012. The age of groundwater in the oxic groundwater monitoring points is up to 50 years. Thus, an increase in nitrate concentrations still takes place in many monitoring points due to the high input of nitrogen in agriculture in the period from 1940-1985. Figure 1 also shows that in the last decade or so, the decrease in nitrogen surplus has halted, and instead a minor increase can be detected, probably due to changes in regulatory practices.

To underpin these conclusions, the development in the nitrate concentration in individual monitoring points, i.e. screens, in the national groundwater monitoring network with oxic groundwater has been investigated with a linear regression analysis of nitrate time series from the individual monitoring points, as published in Hansen et al. (2017). Figure 2 shows the accumulated result of the 665 calculated nitrate trends for the individual monitoring points distributed over the four (infiltration) periods with both statistically significant and non-significant trends at a 95% confidence level. Figure 2 shows a clear trend towards a declining nitrate content in oxic groundwater, both when only the development in the statistically significant trends is considered and when both significant and non-significant trends are examined. It also shows that there has not been any major change in the nitrate trends from the 1986-1996 period to the 1999-2020 period.

Figure 2 Long-term evolution of nitrate concentration trends in groundwater in Denmark

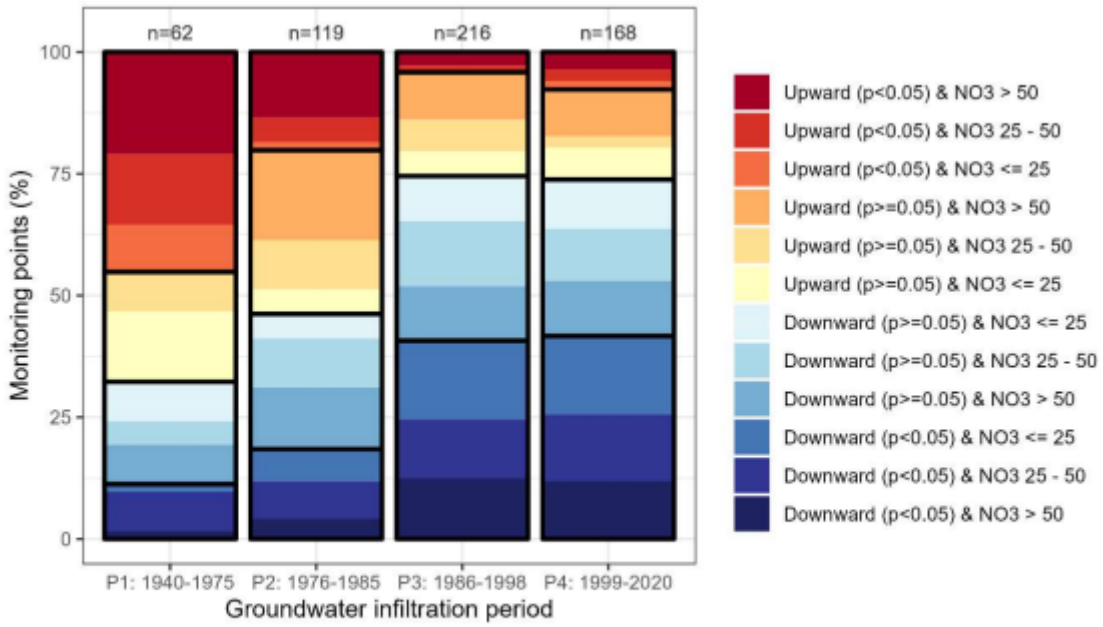


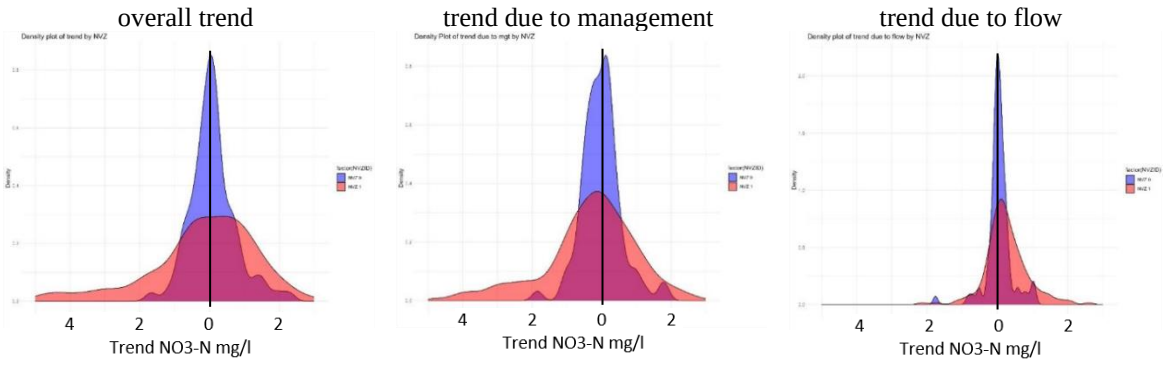
Figure 3.27. National groundwater monitoring network: Oxic groundwater only: 665 nitrate trends in in oxic groundwater for 4 periods based on the year of groundwater formation. The analysis includes a total of 6,193 samples from 364 screens, where the time series cover at least 8 years. At the top of each column is the number of monitoring points with trends for the period. Both statistically significant and non-significant nitrate trends are shown at 95% confidence levels. The figure is based on data collected from 1988-2012 (Thorling et al., 2024).

2. Development of the nitrate load and concentration in surface waters in France between 1990 and 2022

A scientific publication from the Joint Research Centre "30 years of nitrate load and concentration in French rivers: environmental and policy impacts"[2] examines three decades of nitrate trends in France's surface waters, focusing on the effectiveness of the EU Nitrates Directive (91/676/EEC) and related nutrient management strategies. Excess nitrates from agriculture remain a key water quality issue across Europe, with France among those affected. Additionally, France alone represents more than 17 % of all utilised agricultural area in the EU. Using long-term data (1990–2022), Weighted Regressions on Time, Discharge, and Season (WRTDS) a statistical model was applied to distinguish between changes driven by management practices (e.g., fertilizer regulation, manure control, wastewater treatment) and those caused by hydrological variability (e.g., rainfall and flow changes).

The study analysed 268 monitoring stations across France and nine major river basins (Adour, Dordogne, Garonne, Loire, Meuse, Rhine, Rhône, Seine, Vilaine), covering nearly half the French territory. Results show that management measures under the Nitrates Directive have significantly reduced nitrate loads, particularly in Nitrate Vulnerable Zones (NVZs), where mandatory best practices were implemented. Across France, nitrate loads decreased by roughly 30,000 tons of nitrate nitrogen since the 1990s. Within NVZs, management-driven nitrate reductions averaged –0.6 mg NO_3-N L^{-1} yr^{-1}, while outside NVZs the effect was significantly lower. This also translated to trend in the nitrate concentrations, where one of the findings was that the beneficial impact of management, in terms of reducing nitrate levels, was significantly more pronounced within NVZ areas. Hydrological factors, however, often counteracted these gains, with flow-related changes increasing nitrate concentrations at many sites (Figure **3**).

Figure 3 Trend in NO3-N concentrations in mg/l (blue – outside NVZs, red – inside NVZs)



[2] Bouraoui F., Udias A., Vigiak O., Grizzetti B., 2026. "30 years of Nitrates Directive in a changing climate: Environmental and policy impacts on nutrient pollution of French rivers". Journal of Hydrology: Regional Studies. Vol.65, 103445, ISSN 2214-5818, https://doi.org/10.1016/j.ejrh.2026.103445.

In NVZs, which are typically regions of intensive agriculture, showed higher absolute nitrate concentrations than non-NVZ areas, but also stronger improvement trends.

Furthermore, temporal analyses revealed an approximately five-year lag time between reductions in agricultural nitrogen inputs and observable water quality improvements, exceeding the Directive's four-year reporting cycle. This lag suggests that assessments of policy effectiveness may underestimate long-term progress.

At the river basin scale, six of the nine major basins (Adour, Garonne, Dordogne, Rhine, Seine, and Vilaine) exhibited clear declines in nitrate loads and concentration in surface waters linked to management, while others such as the Rhône and Meuse showed persistent increases, likely due to legacy nitrate sources in soils and groundwater. The overall nitrate export from the nine major rivers fell by nearly 19% (≈61 million kg N) between 2003 and 2022, with about half of this decline attributed to nutrient management measures and half to hydrological changes.

Figure 4 Annual nitrate concentration for no flow impact (window 15) and no flow interannual variability (window 7) for the most downstream part of the large French river basins.

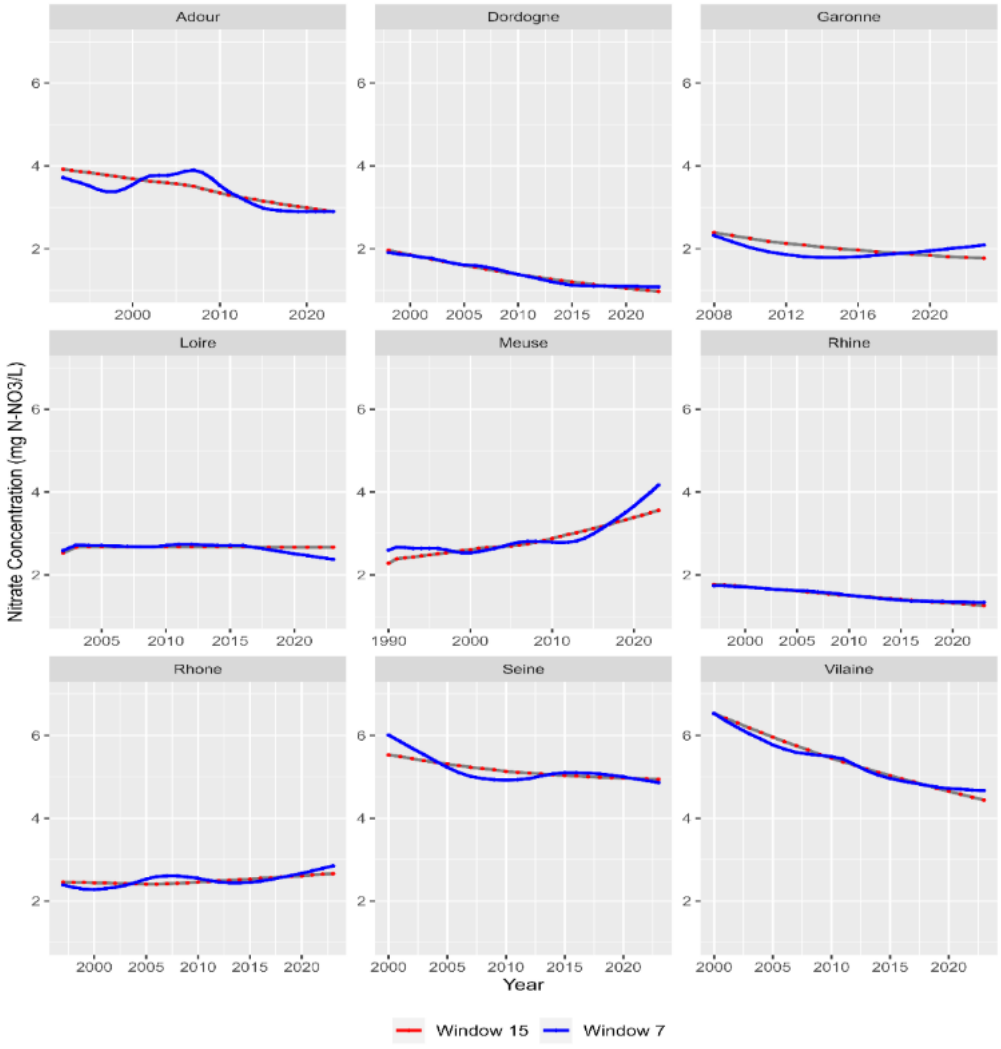
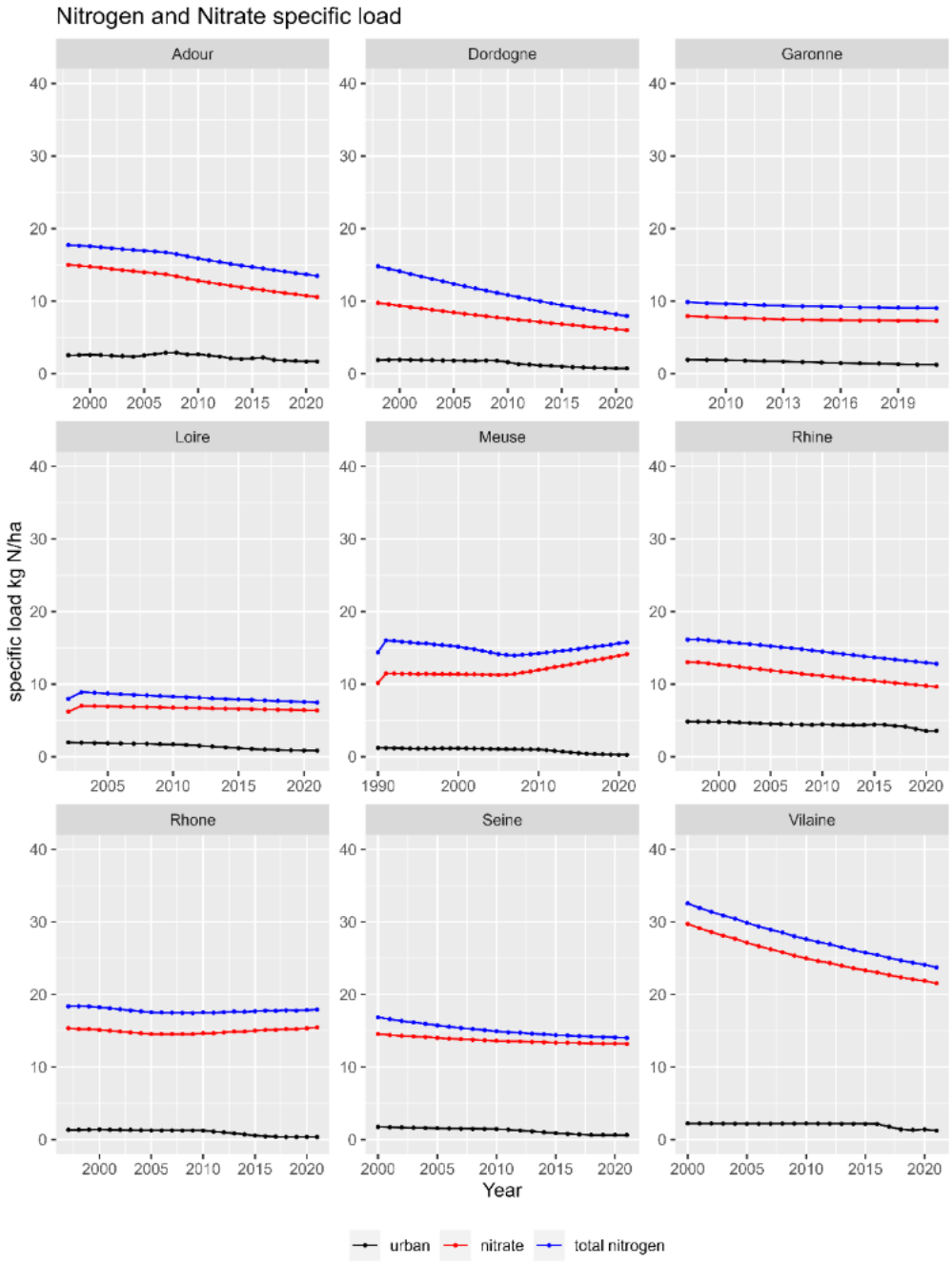


Figure 5 Specific nitrate loads attributable to management (no-flow impact)



Despite these improvements, nitrate reductions have been smaller than those observed for phosphorus, resulting in a rising nitrogen-to-phosphorus ratio that risks destabilizing aquatic ecosystems and promoting eutrophication.

The study emphasizes that nitrate management is complicated by diffuse agricultural sources, groundwater legacy effects, and climate-driven hydrological changes. The study argues for integrated nutrient management, combining stricter enforcement of the Nitrates Directive with complementary measures such as precision farming, and floodplain restoration.

3. Evolution of nitrate leaching and nitrate concentrations in Denmark between 1990-2023

To evaluate the effects of the measures of the nitrates action programme, Denmark has implemented a specific monitoring programme (Agricultural Catchment Monitoring Programme) in 6 small agricultural catchments measuring nitrate concentrations in root zone water (1m below ground level) and concentrations in upper oxic groundwater (1.5-5m below ground level)-. Contrary to measuring impact on overall groundwaters which may take several decades to become visible, this type of monitoring will very rapidly show the effect of the measures on nitrates leaching. Denmark has monitoring data going back to the start of the implementation of the Nitrates Directive and has further developed modelling of the effects of measures on the evolution of nitrate leaching from 1991 to 2023. [3]

Measurements of nitrate in water leaving the root zone and in upper oxic groundwater

Based on data from the Agricultural Catchment Monitoring Programme of Denmark, the development of nitrate concentrations in the root zone (flow-weighted) and upper oxic groundwater are shown as annual average values for loamy and sandy soils in, respectively, for the period 1990/91 to 2022/23 (see Figure 6). The figures clearly show that nitrates concentrations have decreased in the period 1991-2015.

In the loamy catchments, the measured nitrate concentrations in root zone water decreased from 61-155 mg/1 in the 5-year period 1990/91-1994/95 to 37-66 mg/1 in the 5-year period 2011/12-2015/16. In the latest 5-year period 2018/19-2022/23 the nitrate concentrations have varied from 66 to 116 mg/l. In the sandy catchments, the nitrate concentration decreased from 73-192 mg/l in the 5-year period 1990/91-1994/95 to 54-73 mg/l in the 5-year period 2011/12-2015/16. In the latest 5-year period 2018/19-2022/23 the concentrations have varied from 61 to 113 mg/l.

In the upper oxic groundwater (1.5-5.0 m below ground level), nitrate concentrations were lower than in the root zone water, especially in loamy catchments, indicating nitrate reduction between the bottom of the root zone and the uppermost groundwater.

In the oxic groundwater, the largest decrease in nitrate concentrations is observed in the first half of the monitoring period. For the loamy catchments, the average nitrate concentration is below the groundwater limit value of 50 mg/l in the whole monitoring period. For the sandy catchments, the average nitrate concentration in the oxic groundwater is above the limit value of 50 mg/l for most of the monitoring period. In 2023, the average nitrate content is 72 mg/l and 36 mg/l in the sand and loamy catchments, respectively. In contrast to the early years, there appears to be a trend of increasing nitrate concentrations since around 2015 in the loamy catchments and since around 2007 or 2012 in the sandy catchments.

[3] Source: Danish Ministry for the Green Transition (2024) Report on the implementation of the Nitrates Directive in Denmark for 2020-2023.

Figure 6 Development of nitrate concentrations in the root zone (flow-weighted) and upper oxic groundwater in Denmark

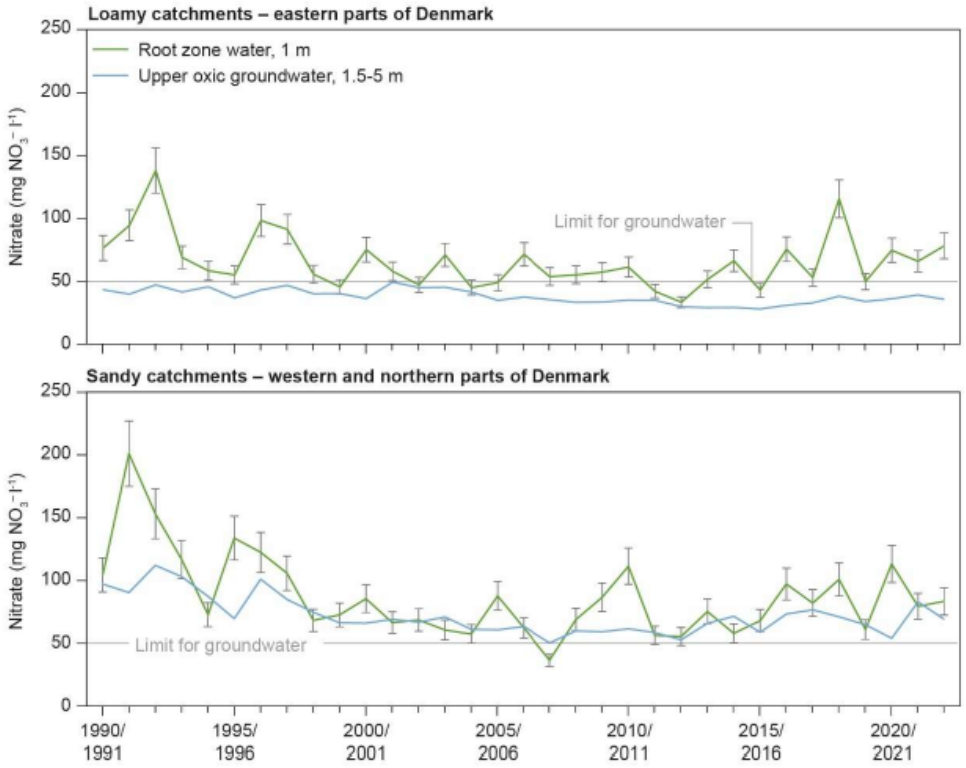


FIGURE 4.8 Annual flow-weighted nitrate concentrations measured in root zone water (1 m below ground level) and annual average nitrate concentrations measured in upper oxic groundwater (1.5-5 m below ground level), in the Agricultural Catchment Monitoring Programme 1990/91 to 2022/23. Error bars on the root zone data indicate variation in percolation as precipitation varied on local scale within a DMI 10 x 10 km^2 precipitation grid. Further details om the variation in data, i.e. standard deviations on measured groundwater concentrations, are presented in the annual report for the Agricultural Monitoring Programme (Blicher-Mathiesen et al., 2024).

Evolution in nitrate leaching 1990-2023

The modelled nitrate leaching from the agricultural areas in the monitored catchments in Denmark was calculated using collected data for crops and fertilization for the period 1990 to 2023 (representing the hydrological years 1990/91 to 2023/24). The modelling[4] shows the effects on nitrate leaching of measures introduced to mitigate nutrient losses from agriculture. The modelled leaching is shown in Figure 7 below as an average for sandy and loamy catchments, respectively.

[4] The modelling is carried out for climate normalised growth conditions, i.e. averaging the model output for a 20-year period: The model is run for each year in the 20-year period and model outputs are then averaged for the period. The climatic data used cover the period 1990-2010. Actual measurements of nitrate leaching will show higher annual variations than the climatic average of the modelled values as the measurements depend on the actual climate. The period 1990-2010 covers a period where the Danish precipitation data were measured using the same method. From 2011, there was a change in both the measurement method and the number of stations available, which may influence the modelled water balance, and thereby influence the modelled nitrate leaching

Figure 7 Simulation of the nitrate leaching in Denmark

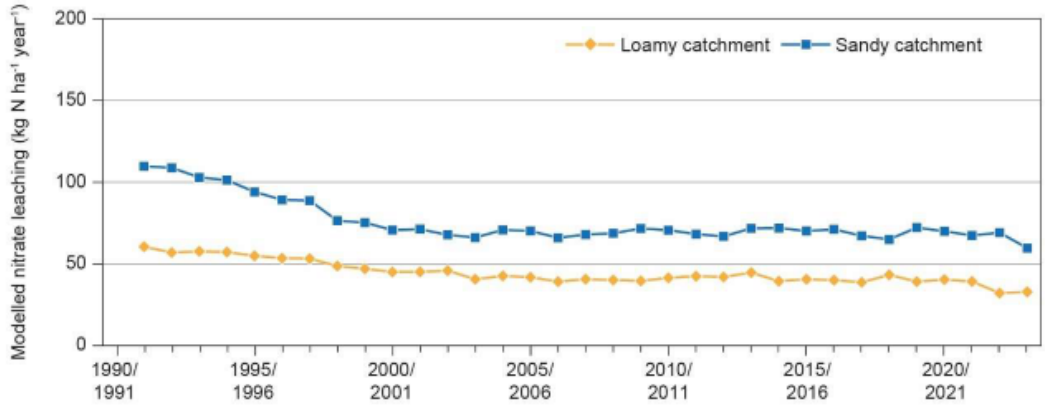


FIGURE 4.7 Simulation of the nitrate leaching using the NLES5 model in a standard climate for the fields of three loamy and two sandy catchments within the Agricultural Catchment Monitoring Programme 1990/91-2023/24.

The Danish Report explains that overall, a decrease in the modelled nitrate leaching of 46 % has been achieved for the entire period 1991 to 2023. The decrease in nitrate leaching is particularly marked in the first period of implementation of the Nitrates Directive, with a 37% decrease from 1991 to 2003.

For the loamy catchments, modelled annual nitrate leaching was relatively stable around 40 kg N ha-1 during the period 2003-2014 decreasing to a level below 40 kg N ha-1 in the period 2015-2022. In 2022/23 and 2023/24 the simulated leaching decreased to 32-33 kg N ha-1 for the loamy catchments, which are the lowest values simulated for the entire period 1991-2023, which is caused by the modelled effect of an increased area with catch crops. For the sandy catchments, the modelled annual nitrate leaching was relatively stable around 70 kg N ha-1 during the period 2003-2022. In 2023/24, the simulated leaching decreased to 60 kg N ha-1 for the sandy catchments. The lower modelled leaching after 2013 is mainly due to more cover crops after cereals and maize.[5]

[5] The trends in nitrate concentrations are not everywhere reflected in similar trends in the nitrate leaching, especially since 2015. The Danish report explains that this may be related to the development in the water balance.

4. Development of the nitrate concentrations in root zone and surface waters in the Netherlands between 1990s and 2023[6]

To evaluate the effects of the measures of the nitrates action programme, the Netherlands has implemented a specific monitoring programme measuring nitrate concentrations in root zone water and in surface waters near a small number of farms in each of the regions representing the different soil types[7]. Contrary to measuring impact on overall groundwaters which may take several decades to become visible, this type of monitoring will very rapidly show the effect of the measures on nitrates leaching. The Netherlands has monitoring data going back to the start of the implementation of the Nitrates Directive for the sandy soil regions and since 1998 for the other regions. Figure 8 provides the evolution of the average root zone nitrate concentration per soil type.

Figure 8 Nitrate concentration in leachate from agricultural parcels in the Netherlands

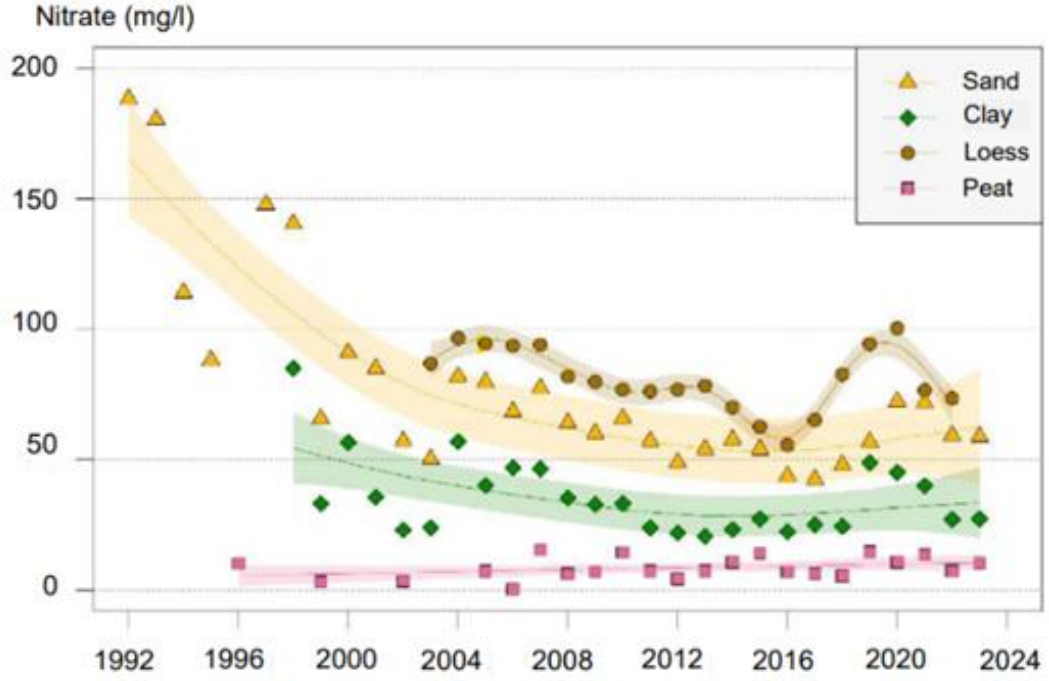


Figure S2 Nitrate concentration (as NO_3 in mg/l) in leachate from agricultural parcels per region in the period 1992–2023. The average concentration over the year is given. The band represents the 95% confidence interval of the fitted trend line.

The nitrate concentrations in leachate from agricultural parcels decreased in the Sand, Loess and Clay region during the period 1992–2012 (see Figure 8). In the Peat region, concentrations were low from the start of the period and did not show a trend. In the period 2012–2017, the decline in nitrate concentrations in the Sand, Clay and Peat

[6] NL report
[7] https://www.rivm.nl/landelijk-meetnet-effecten-mestbeleid

region stagnated. From 2017 onwards, concentrations increased, but from 2020–2021 onwards, nitrate concentrations decreased again in all regions.

As regards surface waters, it is reported that **since the introduction of the Fertilisers Act in 1986 and the entry into force of the European Nitrates Directive, there has been a clear reduction in average nitrate concentrations in winter (the leaching season).** This is illustrated by the following graph reproducing all three types of surface waters (agriculture-specific waters, regional WFD waters and national WFD waters)[8] (see Figure 9).

Figure 9 Average nitrate concentrations in winter (mg/l) in fresh surface waters in the Netherlands, distinguishing between national WFD water, regional WFD waters and agriculture-specific waters

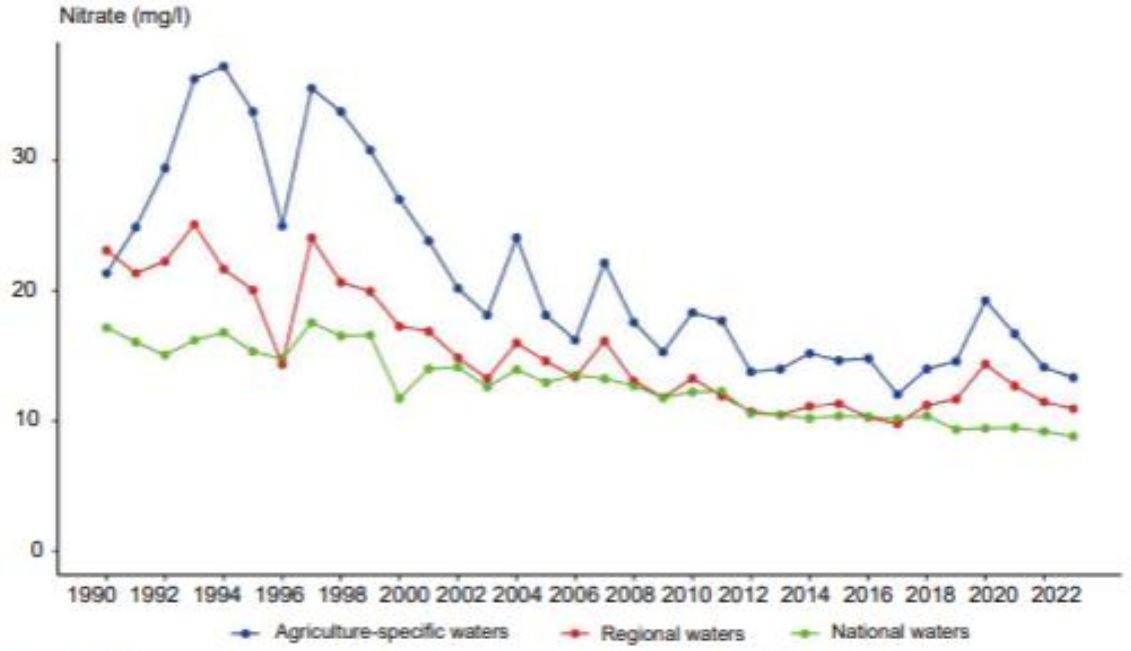


Figure S4 Average nitrate concentrations in winter (in mg NO_3/l) in fresh surface waters in the period 1990–2023, distinguishing between national WFD waters, regional WFD waters and agriculture-specific waters.

The sharpest decline occurred from 1994 until 2012.

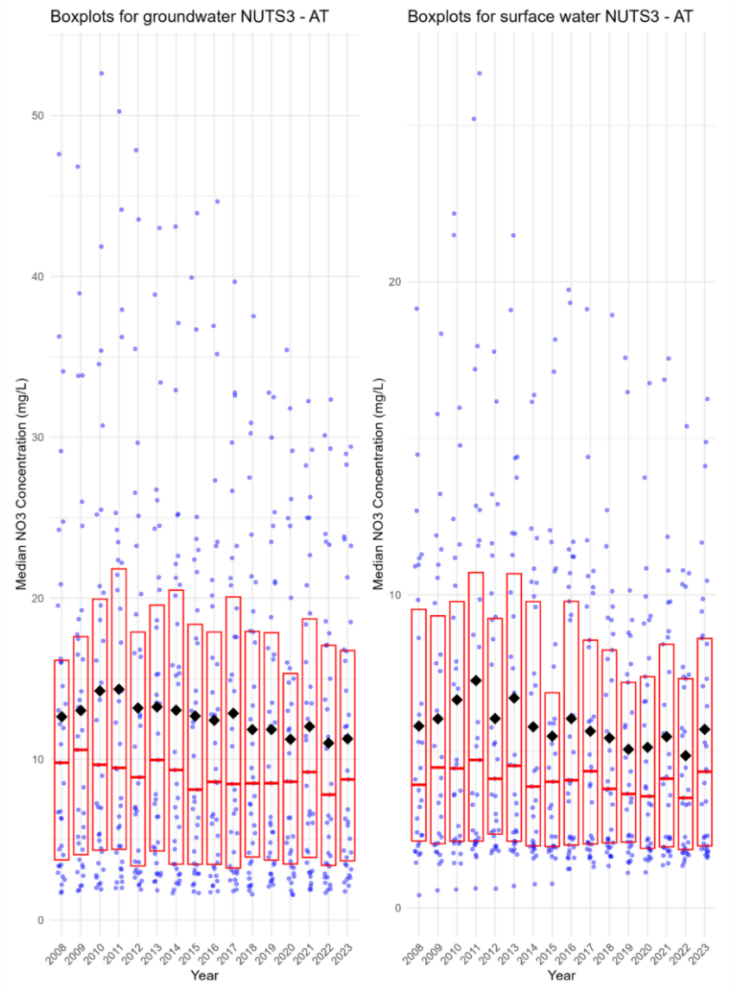
The picture changes when looking at the most recent period. In almost half of the agriculture-specific locations, the average nitrate concentration in winter increased in the period 2020–2023 compared to the period 2016–2019.

[8] Meetnet Nutriënten Landbouw Specifiek Oppervlaktewater (MNLSO)

5. Development of the nitrate concentrations in Austria between 2008 and 2023

There has been a positive evolution with decreasing average nitrates concentrations at NUTS3 regional level for groundwater and surface waters between 2011 and 2019, while the decreasing pattern may be less visible in the average for the whole country. This decrease is particularly prominent in NUTS3 regions with high levels of nitrate concentrations: in groundwaters, the highest average concentrations at NUTS 3 level decreased by more than 20 mg/l between 2010 and 2023 and in surface waters, the highest average concentration decreased by more than 10 mg/l between 2011 and 2023. The graphs below display the groundwater and surface water nitrate concentration at NUTS3 level for the entire country on an annual basis. Each blue dot is the average concentration of a NUTS3 for a specific date. The black dots represent the average concentration for the whole country. Red lines represent the 25% quantiles[9].

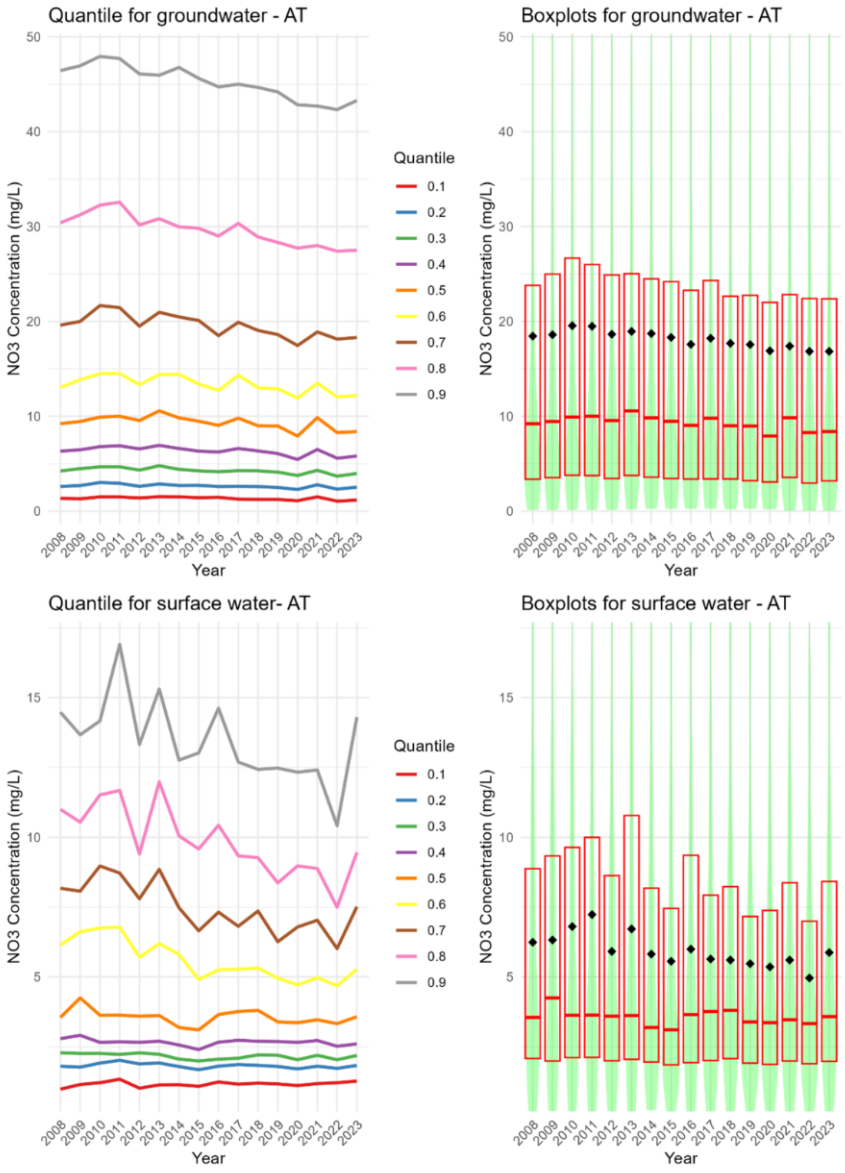
Figure 10 Distribution of annual Nitrate concentration levels (mg/L) in groundwater and surface water in NUTS3-regions in Austria from 2008-2023



[9] scales for groundwater and surface water are different.

This positive evolution is also observed at monitoring point level (Figure 11).[10] The graphs below display the groundwater and surface water nitrate concentration for all monitoring points for the entire country. The left plots show the time series of the quantiles, while the right graphs represent the annual box plots of the concentration. The black dots represent the mean concentration for a specific date. Red lines represent the quartiles. Average nitrate concentration in groundwater has been decreasing since 2010 and levels of nitrate in surface waters are currently lower than decade ago. The decrease in concentrations is particularly noticeable for monitoring points with higher concentrations, specifically within the 0.5 to 0.9 quantiles, while the lower quantiles (0.4 to 0.1) rather show stable concentration levels (left graph).[11]

Figure 11 Distribution of Annual Nitrate Concentrations in mg/L for monitoring points in Austria from 2008 to 2023, Divided into 10 Quantiles



[10] The green shade is a violin plot (fit illustrates the distribution of the points, the fatter the violin the more points there are). Be careful the scales for groundwater and surface water are different.

[11] Note that all groundwater and surface water quantiles for individual monitoring stations demonstrate an increase in 2023. The cause of this development remains unclear and requires further observations.

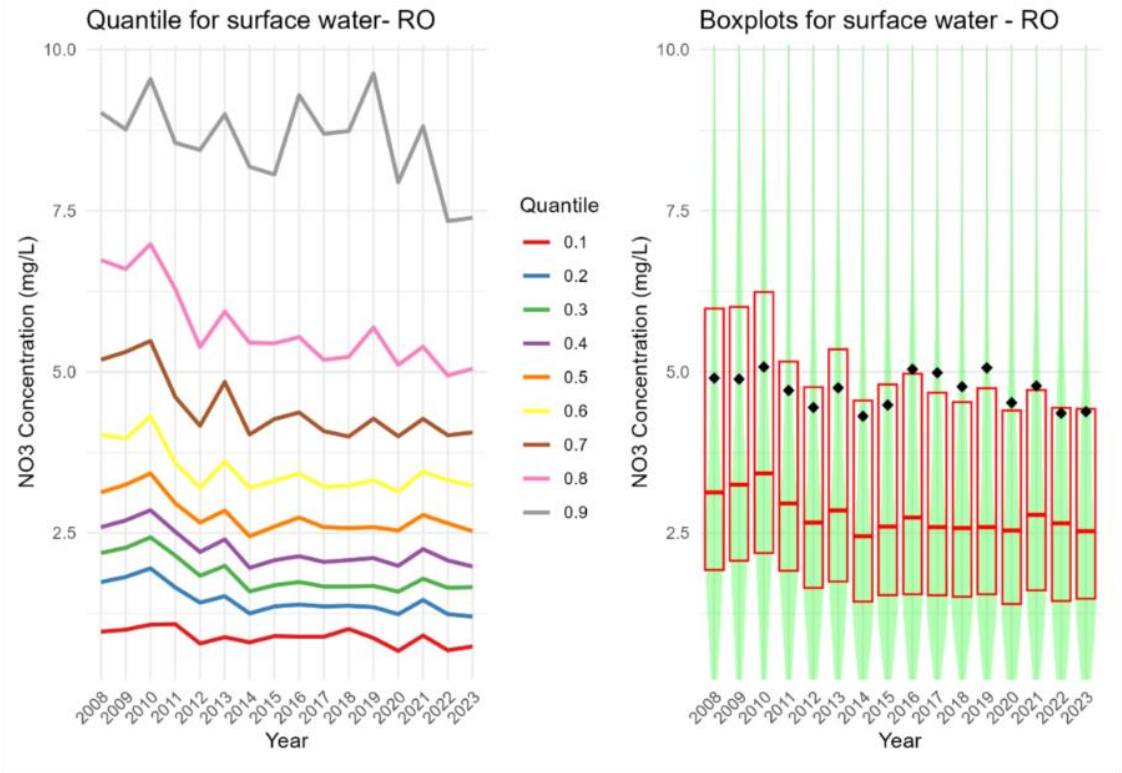
6. Development of the nitrate concentrations in Romania between 2008 and 2023

There has been a positive evolution in surface waters and groundwater in Romania between 2008 and 2023.

An average and median nitrate concentration in surface waters has overall decreased since 2008 (right graph). Most prominent decrease in concentrations is observed in monitoring points with the highest concentrations, but it is seen even in monitoring points with lower nitrates concentration (left graph).

The graphs display the surface water nitrate concentration for all monitoring points for the entire country. The left plots show the time series of the quantiles, while the right graphs represent the annual box plots of the concentration. The black dots represent the mean concentration for a specific date. Red lines represent the quartiles.

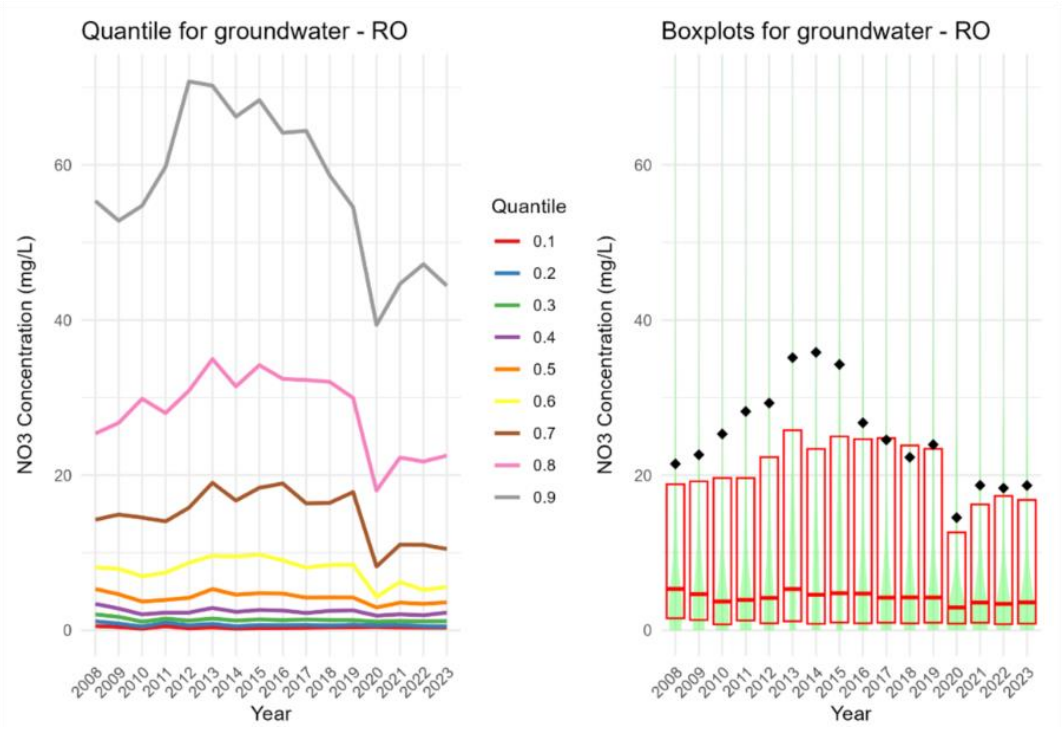
Figure 12 Distribution of Annual Nitrate Concentrations in mg/L for monitoring points in Romania from 2008 to 2023, Divided into 10 Quantiles



Also, in groundwater an average and median nitrate concentration in groundwater has decreased since 2008 (right graph). Even though there was an increase in nitrate concentrations between 2008 and the period 2012-2014, there is a noticeable decrease afterwards. The decrease in nitrate concentrations is particularly noticeable for monitoring points with high concentrations (0.9 quantile), where concentrations decreased significantly since 2012 (left graph). There was also visible improvement in other monitoring points with high concentrations (0.6 to 0.8) when comparing values before and after year 2019. Monitoring points in lower quantiles (0.3 to 0.1) show rather stable concentration levels.

The graphs display the groundwater nitrate concentration for all monitoring points for the entire country. The left plots show the time series of the quantiles, while the right graphs represent the annual box plots of the concentration. The black dots represent the mean concentration for a specific date. Red lines represent the quartiles.

Figure 13 Distribution of Annual Nitrate Concentrations in mg/L for monitoring points in groundwater in Romania from 2008 to 2023, Divided into 10 Quantiles

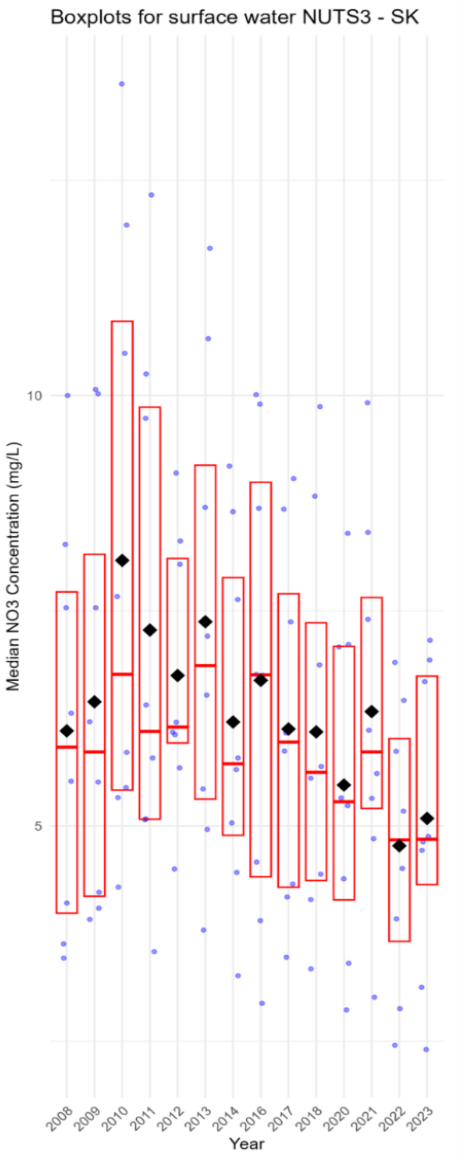


7. Development of the nitrate concentrations in Slovakia between 2008 and 2023

There has been generally decreasing average and median nitrates concentrations at NUTS3 regional level for surface waters in last decade. Gradual decrease is particularly prominent in NUTS3 regions with highest levels of nitrate concentrations with decrease by almost 10 mg/l between 2010 and 2023. Also, the NUTS3 regions with lowest levels of nitrate concentrations show decrease in nitrate concentrations.

The graph displays the surface water nitrate concentration at NUTS3 level for the entire country on an annual basis. Each blue dot is the average concentration of a NUTS3 for a specific date. The black dots represent the average concentration for the whole country. Red lines represent the 25% quantiles.

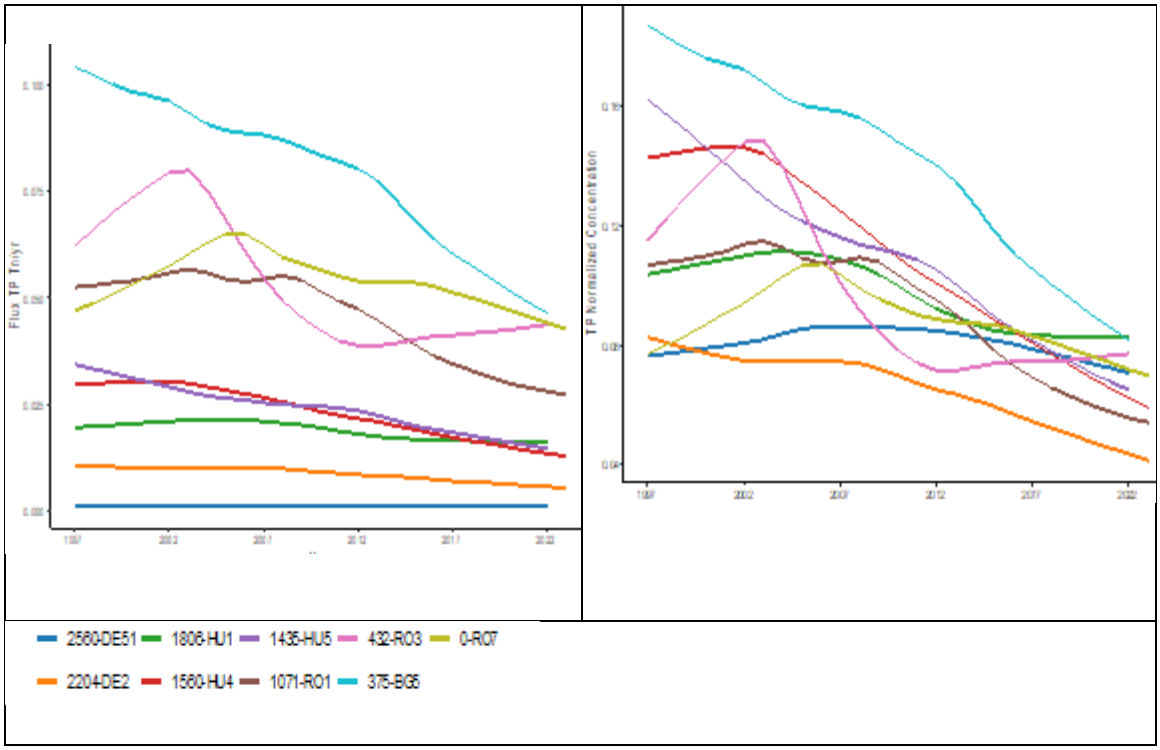
Figure 14 Distribution of annual Nitrate concentration levels (mg/L) in surface water in NUTS3-regions in Slovakia from 2008-2023



8. Trends in nitrogen and phosphorus dynamics along the Danube River between 1996 and 2021

JRC study demonstrates substantial improvements in nutrient-related water quality of the Danube River Basin in the last 25-year (1996-2021)[12]. The most notable findings include dramatic reductions in flow-normalized ammonium loads (approaching 90% in the lower reaches) and significant decreases in phosphorus loads (around 50% at many stations). The study concluded that successes are strongly linked to the effective implementation of point source control measures across the basin, primarily driven by the EU Urban Waste Water Treatment Directive, and national efforts targeting wastewater treatment upgrades and phosphate detergent restrictions. While nitrate loads have also decreased (approximately 20-40% flux reduction at the mouth depending on the specific location), the rate of reduction has been slower, underscoring the persistent challenge posed by diffuse pollution, mainly originating from agricultural sources and influenced by catchment legacy effects.

Figure 16 Temporal evolution of flow-normalized Total Phosphorus fluxes (left) and concentrations (right) for various stations along the Danube River from 1997 to 2023.



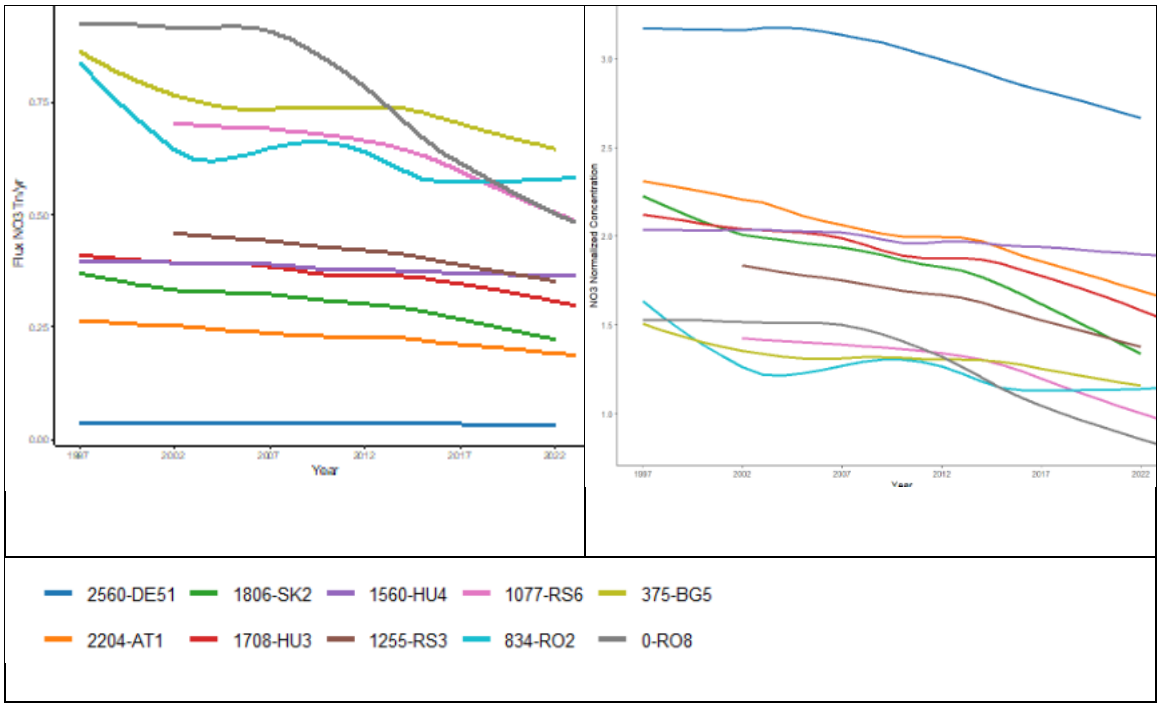
Nitrate reductions, while significant, are less pronounced, reflecting its more diverse sources, including substantial diffuse contributions from agriculture. The application of WRTDS flow-normalization was instrumental in decoupling the influences of

[12] Udias A., Bouraoui F., Vigiak O., Moschini F., Grizzetti B., "Long-term assessment of nutrient dynamics in the Danube River (1996-2021) using flow-normalized indicators: Decoupling hydrological variability from management impacts" (under review).

hydrological variability—including strong seasonal fluctuations and an observed long-term decrease in streamflow, particularly significant in the upper reaches—from changes driven by management actions and other pressures effectively. The WRTDS-derived flow-normalized (FN) trends for NO3-N along the Danube (**Error! Reference source not found.**), which removed the confounding impact of discharge variability, demonstrate a clear trend of reduced concentrations and fluxes across the entire Danube basin over the 1996-2021 period. FN flux reductions ranged from approximately 13% in the upper reaches to over 20% near the river's mouth. In absolute terms, this corresponds to a decrease in the nitrate flux entering the Black Sea, from around 820 tonnes per year in 1996 to approximately 650 tonnes per year in 2021.

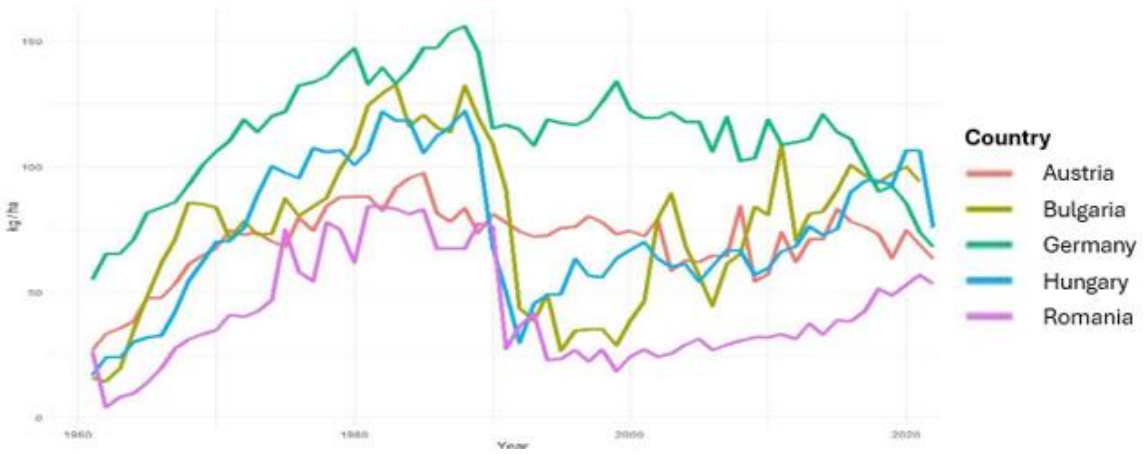
Germany exhibits the highest nitrogen inputs to agricultural land among the countries studied (Figure 18), which aligns with the elevated nitrate concentrations observed in upstream monitoring stations like 2560-DE51 (Figure 17). In the upper Danube Basin declines in nitrate concentrations were modest (approximately 15%).

Figure 17 Temporal evolution of flow-normalized NO3-N fluxes (left) and concentrations (right) for selected representative stations of the Danube River from 1996 to 2021.



Nitrogen applied to agricultural land, especially during periods of high surplus before the 1990s, accumulated in soil organic matter, in the unsaturated zone, and groundwater systems (Van Meter et al., 2016; Wang et al., 2025). The release of this legacy pool of nitrogen into rivers is a slow process, with time lags that can span years to decades (Meals et al., 2010; Vero et al., 2018). Consequently, the decreasing nitrate trends observed in the Danube from 1996 to 2021 likely reflect, in part, the delayed impact of substantial reductions in nitrogen inputs that occurred in the early 1990s (Figure 18), with legacy nitrogen gradually being flushed out.

Figure 18 Evolution of nitrogen application (kg/Ha UUA) from 1960 to 2022 in five Danube countries (data source: FAO)



The EU Nitrates Directive, aimed at improving nitrogen use efficiency and reducing N surpluses from agriculture, has been in effect throughout much of our study period. While fertilizer application rates might have stabilized, the Directive encourages better management practices (e.g., optimized fertilization timing and rates, cover crops) that can reduce the fraction of applied nitrogen lost to the environment (Grizzetti et al., 2021; Bouraoui & Grizzetti, 2014). These ongoing improvements in agricultural management likely contributed to the gradual reduction in the N surplus entering the groundwater systems, and to the observed downward trend in riverine nitrate concentrations. Therefore, the overall enhancement in the Danube's nitrate status likely reflects a multifaceted response: a primary influence of the lagged impact of past large-scale reductions in N inputs from the early 1990s, compounded by the continuous, albeit perhaps more gradual, effects of improved agricultural practices and nutrient management strategies implemented under EU and national policies over the last two to three decades.

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PART 7/11

COMMISSION STAFF WORKING DOCUMENT

EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XV. COHERENCE WITH THE WATER FRAMEWORK DIRECTIVE AND WITH THE NATIONAL EMISSION REDUCTION COMMITMENTS DIRECTIVE

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2. Coherence with National Emission Reduction Commitments Directive (NECD)

1. COHERENCE WITH WATER FRAMEWORK DIRECTIVE

1.1 Links between the Water Framework Directive and Nitrates Directive

The Water Framework Directive (WFD) and the Nitrates Directive (ND) are intricately linked and work together to achieve water quality objectives in the EU. The integration and synergy between these directives highlight their mutual dependability in achieving both overarching and specific water quality targets within the EU.

Here are some key points regarding their interlinkages:

- Complementary role: The WFD provides an overarching framework for water protection. It sets comprehensive environmental water quality objectives, including on chemicals and biology and deadlines for achieving these objectives that the Nitrates Directive supports through its specific focus on reducing nutrient pollution from agriculture.
- Conditional achievement of objectives: The achievement of the environmental objectives of the WFD is conditional on the full implementation of other EU directives, including the Nitrates Directive, as confirmed by the 2019 fitness check of the WFD. The WFD does not replace the Nitrates Directive. The latter is crucial for achieving good chemical status in groundwater bodies where nitrates concentrations are one of the key parameters. It is also relevant for achieving good ecological status of surface waters as **eutrophication**[1] remains one of the most significant water quality problems and obstacles in reaching good status in surface waters. The ND defines eutrophication and includes the requirement for Member States of reviewing every four years whether natural freshwater lakes, other freshwater bodies, estuaries, coastal waters and marine waters are found to be eutrophic or in the near future may become eutrophic if no measures are taken.
- Integration of the ND into the WFD Framework: There are several references in the WFD to the ND and nitrate pollution, interlinked concepts and methodologies. The most relevant interlinkage is within the Programme of Measures. The WFD requires Member

[1] *'Eutrophication' means the enrichment of water by nitrogen compounds, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned* (Art. 2, Nitrates Directive).

States to develop and implement River Basin Management Plans (RBMPs) that include measures to tackle pollution from agricultural sources. The measures implemented under the Nitrates Directive serve as **basic measure** within the WFD's **Programmes of Measures**, reflecting the ND's fundamental role in reaching the WFD's objectives of good chemical status of groundwater and good ecological status of surface waters, by contributing to reducing diffuse nutrient pollution from agriculture. Also, both directives have specific requirements for monitoring water quality. The results from the monitoring under the ND can be used to assess pressures and impacts in the context of the WFD and the other way around. (See table 1 Below) Nevertheless, 25 years on, the integration of the ND and the WFD, especially in the preparation and design of the national measures in the NAP remains generally incomplete and uneven among Member States, although there has been a significant acceleration in the 3rd RBPM report. With the approaching 2027 deadline under the WFD, the interlinkages between the two directives become more prominent.

- Flexibility: The broad flexibility of national implementation under both the ND and the WFD creates important differences of approaches between Member States. As an illustration, reporting under the ND and the WFD shows that many Member States do not have a complete view on the nutrient load reductions required in the different catchments, watercourses and estuaries to reach good ecological status, nor on how much the measures under the ND would contribute to these load reductions. As a result, the measures under the ND may not be sufficiently targeted or in line with the nutrient load reductions required to ensure that the good status of waterbodies are achieved by 2027 and is not hampered by nutrient pollution from agriculture in areas draining into them.
- Supplementary directives: The Groundwater Directive (GWD) complements the WFD by defining specific groundwater quality standards that depend on the measures of the ND to reduce nitrates pollution in groundwater. Other water related directives also have close tights and interactions with the ND as reflected in table 2.

The following **Table 1** summarises the intersections between the Water Framework and the Nitrates Directives. It looks at parallelism and complementarities. The left column cites specific articles and annexes of the WFD, and the right one shows how the WFD specific elements contribute to the ND and its effectiveness.

Table 1 Intersections between the WFD and the ND.

Water Framework Directive and Groundwater Directive	Nitrates Directive
Art. 1. Purpose of the WFD: Sets the ultimate goal of water protection and sustainable approach to water management.	The article reinforces the implementation of the Nitrates Directive by promoting the long-term protection of water resources.
Art.2. Definitions: Provides the definitions of the key terms used in the Directive.	Several terms are common and key to both directives: types of water bodies, pollution/pollutant... Many WFD definitions provide clarifications to terms used in the ND.
Art. 4. Objectives: Sets out the environmental objectives for Member States, requiring them	The WFD sets overarching objectives covering all water bodies, i.e. to achieve good status of all water bodies by

to prevent the deterioration of water bodies and ensure they achieve 'good status'.	2027. These objectives enhance the implementation of the ND by ensuring that agricultural nitrate pollution is considered within the broader environmental objectives for water. It enhances policy coherence.
Art. 6. Register of protected areas (also in Annex IV): Sets the obligation for MS to make a register of protected areas. **The register should include, among other, Nitrates Directive nutrient-sensitive areas.**	This triggers knowledge improvement between the link of protected areas and water bodies. It helps improving coordination among competent authorities and aligning the objectives of the Nitrates Action Programme (NAP) with other environmental goals from other EU directives, such as those related to biodiversity, ecosystem health and drinking water.
Art. 8. Monitoring: requires Member States to establish monitoring programs for surface water, groundwater, and protected areas.	The monitoring required under the ND informs and complements the one under the WFD. This improves overall data collection and analysis. The broader information gathered under the WFD helps identifying and differentiating pollution sources essential for a proper ND implementation (see full analysis of monitoring requirements and synergies on tables 2 and 3).
Art. 10. Combined approach for point and diffuse sources: establishes that MS require a combined approach to control pollution impacting water bodies.	This article connects achieving the objective of good status with the control of diffuse sources under the ND aligning knowledge on different pressures.
Art. 11. Programme of measures: mandates the establishment of 'programmes of measures' for each river basin to achieve good water status. Art. 11(3) refers specifically to 'basic measures'. **This article also addresses transboundary aspects as Member States may adopt coordinated measures and plans applicable to international river basin districts.**	The Nitrates Directive serves as basic measure (minimum requirements to be complied with), i.e. measures to prevent diffuse pollution of nutrients. This requires that MS take into account WFD objectives when designing their NAP. This promotes the interconnection of measures leading to more effective planning, targeted actions and optimisation of resources The ND includes provisions for the Commission to support Member States in specific transboundary pollution cases (art 3 (3). Transboundary pollution aspects should also be covered by the river basin management approach under the WFD supported by the common standards and intercalibration developed to define good ecological status. This allows to address transboundary cases in a coordinated and integrated way.
Art. 13. River basin management plans (RBMPs): mandates the development of plans that outline actions, known as a 'programme of measures', needed to achieve good status for all water bodies.	Specific measures under the ND are essential to address diffuse pollution of nutrients and achieve good status of water bodies. This also provides the opportunity for the ND to access a broader picture and identify technical measures, many of which could complement good agricultural practices. RBMPs and NAPs work jointly

	towards the common goal of water protection, and the NAP is part of the programme of measures to achieve good status.
Art 14. Public information and consultation. **Addresses early and broad public participation in planning. It is dedicated to public information and consultation related to the RBMPs and their updates.**	This has ensured public participation and stakeholder involvement and led to greater awareness and cooperation among farmers, policymakers, and the public regarding nitrate pollution and the overall link with water policy. These exchanges have had a positive impact on the understanding of ND goals and their implementation.
Art. 15. Reporting: requires MS to submit information every 6 years on the implementation of the measures and progress to improve and protect water quality.	The monitoring and reporting required under the ND complements the one under the WFD (see below full analysis of monitoring requirements and synergies on tables 2 and 3).
Annex II. provides specific criteria to characterise water body types and their status and identify pressures.	This annex provides detailed descriptions of water body types useful when monitoring and assessing nitrates pollution and reporting results.
Annex IV. Protected areas: refers to the types of protected areas MS need to include in the register required under Article 6.	Among other, this annex refers to nutrient-sensitive areas, including areas designated as vulnerable zones under the ND (NVZ). It promotes policy coherence and links the ND to protected areas and water protection.
Annex V. Describes quality elements for the classification of ecological status in surface waters and for quantitative status for ground waters. It specifies how surveillance and operational monitoring should be addressed.	Under the WFD, Nitrate is a core parameter to monitor in surveillance monitoring in groundwater. This is essential to validate risk assessments and track trends in water bodies. The ND specifies a maximum concentration of 50 milligrams per Liter (mg/L) of nitrates in groundwater and surface waters. Waters exceeding this concentration are regarded as polluted or at risk of pollution
Anne VI. Refers to the list of measures to be included within the Programme of Measures.	(ix) Measures required under the ND. (See benefits listed under Art. 11).
Annex VIII. Provides an indicative list of main pollutants. **MS must identify pressures impacting water bodies, coming e.g. from substances which contribute to eutrophication (in particular, nitrates and phosphates).**	This allows gathering relevant information for the ND implementation and eutrophication assessment (e.g. the role of phosphates, nutrient limitation levels, synergistic effects of N and P)

GWD Art. 3. Sets the criteria required for MS to assess groundwater chemical status. **GWD Art. 4. Sets the procedure required for MS to assess groundwater chemical status.** **GWD Art. 5. Describes the need for MS to identify upward trends of pollutants and define points to reverse these.**	The measures under the ND are essential to reduce nitrates pollution from agriculture. These are needed to meet WFD's environmental objectives for groundwater quality. The GWD complements the WFD by laying down criteria and procedures for assessing groundwater chemical status and trends, including the EU groundwater quality standard for nitrate. The WFD/GWD provide key information for understanding nutrients and other pollutants interaction, and design measures that address the root causes of eutrophication.
GWD Annex I. provides EU-wide groundwater quality standards for nitrates and pesticides (individual and total). **It establishes 50 mg/l as the EU groundwater quality standard for assessing groundwater chemical status.**	Reinforces the implementation of the Nitrates Directive by using the same maximum concentration at EU level. The ND uses the 50 mg/l nitrate value as a criterion for identifying waters affected by pollution or at risk.

1.2 How the WFD has impacted the implementation and results of the ND

The WFD and the ND are two directives that aim to improve water quality, but they target issues from slightly different angles. The impact of the WFD on the Nitrates Directive's implementation and results can be understood through several dimensions:

- **Integrated Approach**: The WFD promotes an integrated approach to water management across entire river basins, which has enhanced the implementation of the Nitrates Directive by ensuring that agricultural nutrient pollution is considered within the broader context of water management. This holistic approach encourages coordination among different policy measures and stakeholders, and should lead to more effective planning and targeted actions.
- **Monitoring and Assessment**: The WFD has introduced comprehensive monitoring and assessment requirements, which have improved the data collection and analysis related to water quality, including nitrate levels and eutrophication. This enhanced understanding has helped in identifying pollution sources more accurately and in evaluating the effectiveness of measures taken under the Nitrates Directive.
- **Synergies with Other Environmental Objectives**: By encouraging the integration of various environmental policies, the WFD has helped align the objectives of the ND with other environmental goals, such as those related to biodiversity and ecosystem health. This alignment has led to more cohesive strategies that address multiple environmental challenges simultaneously, improving overall water quality.
- **Increased Stakeholder Involvement**: The WFD emphasises public participation and stakeholder involvement, which has led to greater awareness and cooperation among farmers, policymakers, and the public regarding nitrate pollution. This increased

engagement is essential for the successful implementation of measures required by the ND.

- **Enhanced Legal and Institutional Framework**: The WFD has reinforced the legal and institutional framework for water protection in the EU, providing additional support for the implementation of the ND. This has included more stringent reporting and compliance mechanisms, which have encouraged Member States to effectively implement action programs to control nitrate pollution.
- **Focus on Achieving Good Status and its deadline**: The WFD's goal of achieving good status for all waters has provided a clear target that complements the ND's aim of reducing and preventing water pollution from nitrates of agricultural origin. The WFD's aim was to achieve this status by 2015. Extensions were allowed to **2027** under certain conditions, as detailed in WFD article 4(4), including technical feasibility, disproportionate costs, or natural conditions that require more time for recovery. Thus, 2027 is the final deadline for Member States to put in place the measures necessary to ensure that all EU water bodies will achieve good status[2]. Under the ND, there are no specific deadlines as in the WFD. Instead, the ND focuses on recurring cycles of designation and action (NVZs, NAPs). This shared end goal of protecting waters in both directives has fostered greater alignment and prioritization of measures aimed to reduce nitrate levels.

Overall, the WFD has had a significant positive influence on the implementation and results of the ND by promoting an integrated approach to water management, improving monitoring and data analysis, fostering stakeholder collaboration, and strengthening the legal framework for addressing water pollution in the EU.

The existing legal framework is coherent and complementary, and the WFD and 'daughter directives' do not substitute the more focused approach of ND on the nutrients pollution originating from agricultural pressures.

1.3 Coherence of Monitoring and reporting

The following **Table 2**and **Table 3** offer an overview on the main overlaps regarding monitoring and reporting between water related directives (not only WFD) and the ND. The information is presented per water type. The table shows important overlaps among directives. For example, both directives require monitoring of water bodies, focusing on establishing baseline conditions, validating risk assessments, and assessing long-term trends. Nitrates is a core parameter to monitor under both directives. Under the WFD and MSFD, eutrophication caused by nutrients, including nitrates, is monitored to assess ecological status. This aligns with ND's focus on identifying waters affected by nitrates from agricultural sources.

However, there are also important differences on focus, frequency and specific methodologies. The ND targets nitrate pollution from agricultural sources, while the WFD has a broader scope (all types of pressures). The WFD guidance documents provide detailed methodologies to monitor eutrophication, which are lacking in the ND.

[2] The deadline can still be extended where natural conditions do not allow timely improvement in the status of a water body (WFD Art. 4(4)(c). Also, not reaching the objective by 2027 can be justified under the provisions of WFD article 4(5), given that all feasible and not disproportionately costly measures have been implemented

Overall, EU water policies provide important flexibility on methodologies, thresholds and number of monitoring sites, which allow local adaptation. This flexibility has led to large variations on how MS have approached monitoring and data reporting. These variations may hamper for instance comparability efforts, but should not hinder the proper implementation of the directives and achievement of water protection objectives.

Table 2 Overview of main overlaps in the ND's and the water acquis' approach to monitoring and reporting

Monitoring of nitrates concentrations in groundwaters	
Other water acquis	**ND**
• **WFD/GWD: Nitrates one of the core parameters** to be monitored in selected groundwater bodies under surveillance monitoring. Moreover, nitrates are listed as pollutant in WFD Annex VIII, No. 11, which means they are a parameter for the determination of groundwater chemical status (WFD Annex V, No. 2.3.1). • Surveillance monitoring sites for groundwaters are generally set up across a broad range of locations. The requirement states that sufficient monitoring sites shall be selected for bodies identified as being at risk and bodies which cross a Member State boundary. • Under the WFD, the operational monitoring of groundwaters shall be undertaken in the periods between surveillance monitoring programmes in order to establish the chemical status of all groundwater bodies or groups of bodies determined as being at risk, and to establish the presence of any long-term anthropogenically induced upward trend in the concentration of any pollutant. It thus aims to supplement and validate the impact assessment procedure carried out in accordance with Article 5 and Annex II, and to provide information for use in the **assessment of long-term trends** both as a result of changes in natural conditions and through anthropogenic activity. • **DWD:** Monitoring is laid out in Article 13 and in Annex II. The DWD monitoring is directed at the entire water supply chain, including the abstraction area – which can include groundwater and surface water. The obligations in Article 4 include concentration requirements for nitrates, determined in Annex I (Art. 4 (1)). Moreover, MS shall ensure that measures taken in the DWD do not have the effect of allowing any deterioration of the present quality of water intended for human consumption or any increase in the pollution of waters. Hence, this includes eutrophication processes and nitrate concentration.	• The ND's monitoring has the purpose of allowing Member States to correctly identify **waters affected by nitrate pollution**, **waters which could be affected if no action is taken** and, where relevant, **to correctly designate and revise the designation of Nitrate Vulnerable Zones**. • Article 6 requires that groundwaters be sampled for their nitrate concentrations, over a period of one year, at **sampling stations representative of the groundwater aquifers of Member States**, at regular intervals. This one-year monitoring programme should be repeated at least every four years. For those sampling stations for which the nitrate concentration in all previous samples has been below 25 mg/l and no new factor has appeared that is likely to increase the nitrate concentration, the programme need be repeated only every eight years. • **Trends are to be calculated** based on the averages of the annual means for the entire reporting period. In addition to the comparison with the previous reporting period, reports may include comparisons with earlier reporting periods to assess longer-term trends. The Article 10 reports should provide the percentage of stations with strong decrease, weak decrease, stable, weak increase or strong increase in nitrate concentrations.
Monitoring of nitrates concentrations in inland surface waters	
Water acquis	**ND**
• **WFD:** The surveillance monitoring of surface waters aims to provide an **overall picture of water status**, to **establish long-term trends**, and to **validate risk assessments**. It is typically used to assess the impacts of human activity and natural conditions on water status over time, and to gather data that helps in the design of future monitoring programs. Surveillance monitoring sites are generally set up across a broad range of locations to establish baseline conditions. • The objective of the surveillance monitoring of surface waters is to provide information for (1) supplementing and validating the impact assessment procedure detailed in Annex II, (2) the efficient and effective design of future monitoring programmes, (3) the assessment of long-term changes in natural conditions, and (4) the assessment of long-term changes resulting from widespread anthropogenic activity. • Nutrients are to be measured as part of the assessment of ecological status (based on biological quality elements plus physico-chemical supporting elements, with nutrients as part of the latter), Nitrates are not always monitored for this purpose, nor	• The ND monitoring of surface waters takes place at sampling stations (1) used or intended for use in the abstraction of drinking water and/or (2) other sampling stations representative of surface waters. The ND's monitoring has the purpose of allowing Member States to correctly identify **waters affected by nitrate pollution due to agricultural sources, waters which could be affected if no action is taken and where relevant to correctly designate and revise the designation of Nitrate Vulnerable Zones**. The correct identification of these waters requires a monitoring network that is generally representative of the waters in the MS. The link to agricultural sources can in practice mean that monitoring networks are more dense in agricultural areas. • The monitoring requirements for surface waters are that Member States shall monitor the nitrates concentrations at the surface water sampling stations (used or intended for use in the abstraction of drinking water and/or other sampling stations representative of surface waters) at least monthly and more frequently during flood periods, over a period of one year. • **Trends are to be calculated** based on the averages of the annual

are they monitored as part of chemical status assessments (which is on the basis of priority substances). Member States decide which nutrient parameters to measure (which can include Total P, soluble reactive P, Total N, ammonia, nitrates, and nitrites). According to European Commission, JRC (2024), under the WFD most but not all Member States measure nitrates for rivers, approximately half measure nitrates for lakes. Total Nitrogen (TN) is measured by almost all countries. • **DWD:** Monitoring is laid out in Article 13 and in Annex II. The DWD monitoring is directed at the entire water supply chain, including the abstraction area – which can include groundwater and surface water. The obligations in Article 4 include concentration requirements for nitrates, determined in Annex I (Art. 4 (1)). Moreover, MS shall ensure that measures taken in the DWD do not have the effect of allowing any deterioration of the present quality of water intended for human consumption or any increase in the pollution of waters. Hence, this includes eutrophication processes and nitrate concentration.	means for the entire reporting period (winter means for surface waters when relevant). In addition to the comparison with the previous reporting period, reports may include comparisons with earlier reporting periods to assess longer-term trends. The Article 10 reports should provide the percentage of stations with strong decrease, weak decrease, stable, weak increase or strong increase in nitrate concentrations.
Monitoring of eutrophication in inland surface waters	
Water acquis	**ND**
• **WFD:** The surveillance monitoring of surface waters aims to provide an **overall picture of water status**, to **establish long-term trends**, and to **validate risk assessments**. It is typically used to assess the impacts of human activity and natural conditions on water status over time, and to gather data that helps in the design of future monitoring programs. Surveillance monitoring sites are generally set up across a broad range of locations to establish baseline conditions. • The objective of the surveillance monitoring of surface waters is to provide information for (1) supplementing and validating the impact assessment procedure detailed in Annex II, (2) the efficient and effective design of future monitoring programmes, (3) the assessment of long-term changes in natural conditions, and (4) the assessment of long-term changes resulting from widespread anthropogenic activity. • The WFD's evaluation assessment of ecological status includes an assessment of eutrophication. WFD Eutrophication Guidance states that being worse than good ecological status for algal and plant quality elements due to nutrient enrichment implies a eutrophication issue.. The Member States BQE methods have been developed and intercalibrated to address eutrophication pressure. For each of the 440 BQE methods currently in use, pressure(s) addressed have been defined and included in the intercalibration reports, 370 methods address eutrophication pressure, many of them are used specifically for eutrophication (for details see Poikane et al., 2020; Nikolaidis et al., 2024). Member States monitor a series of biological and physico-chemical parameters which are related to eutrophication pressure (and to other pressures). • It is possible to use WFD data to determine eutrophication status of water bodies, following the WFD Guidance on eutrophication[3] and the information on assessment methods provided by Member States. The majority of MS have established links between the WFD BQE methods and eutrophication (nutrients) (information in the intercalibration reports). To streamline ND and WFD assessments, it would be necessary to hold a coordination exercise to discuss and agree on the approaches used for eutrophication assessment.	• The ND's monitoring has the purpose of allowing Member States to correctly identify waters affected by nitrate pollution **due to agricultural sources**, waters which could be affected if no action is taken and to correctly designate and revise the designation of Nitrate Vulnerable Zones. The correct identification of these waters requires a monitoring network that is generally representative of the waters in the MS. The link to agricultural sources can in practice mean that monitoring networks are more dense in agricultural areas. Monitoring requirements for inland surface waters - Eutrophication: Member States shall review the eutrophic state of their fresh surface waters, estuarial and coastal waters every four years. No detail is provided regarding the methodology to be used However ND Guidelines and WFD Eutrophication guidance both recommend the use of a specific methodology (eutrophic = less than good status according to algal and plant elements), supported by nutrient conditions.
Monitoring of eutrophication in transitional, coastal and marine waters	

[3] Guidance Document No. 23: Guidance Document on Eutrophication Assessment in the Context of European Water Policies. Common Implementation Strategy for the Water Framework Directive. Technical report 2009-030.

Water acquis	ND
• **WFD:** See above, monitoring of eutrophication in inland waters. • **MSFD:** Under the MSFD, monitoring programmes are intended to provide the data needed to assess whether in the relevant coastal or other marine waters a good environmental status (GES) has been achieved or maintained or not, the distance from and progress towards a GES and to assess progress towards achieving environmental targets that the MS have defined individually (see Art. 9 and 10 MSFD). • Monitoring programmes serve: o For the ongoing assessment of the environmental status of marine waters, on the basis of the 'indicative list of ecosystem elements, anthropogenic pressures and human activities relevant to the marine waters' in Annex III; ♣ Relevant biotic and abiotic elements ♣ Dominant pressures and activities (MSFD Annex III) in order to quantify pressures associated with activities and assess effectiveness of measures in relation to the targets set; ♣ Monitoring should provide the data in support of the relevant criteria and indicators of the COM Decision 2010 (now 2017) o To identify suitable indicators for the environmental targets. o To assess the effectiveness of measures. o Monitor/assess activities regarding restoration of good environmental status. o Monitor/assess chemical contaminants in species for human consumption from commercial fishing areas o monitor/assess activities regarding corrective measures as well as side effects' • There are overlaps with the ND's monitoring of eutrophic status in surface water (ecosystem impacts): o Overlap for coastal water since under the MSFD and the Commission Decision 2017/848, human induced eutrophication is one of the 11 descriptors of the GES-assessment. The Decision states that eutrophication assessment in coastal waters should use the threshold values set in accordance with the WFD, and in marine waters values consistent with those for coastal waters under the WFD. o Overlap for marine waters since ND Annex I refers to analysis of "marine waters" when assessing "pollution" of waters that are within the scope of the ND (Coastal waters, estuaries).	• The ND's monitoring has the purpose of allowing Member States to correctly identify waters affected by nitrate pollution due to agricultural sources, waters which could be affected if no action is taken and to correctly designate and revise the designation of Nitrate Vulnerable Zones. The correct identification of these waters requires a monitoring network that is generally representative of the waters in the MS. The link to agricultural sources can in practice mean that monitoring networks are more dense in agricultural areas. Monitoring requirements for surface, estuarial and coastal waters - Eutrophication: Member States shall review the eutrophic state of their fresh surface waters, estuarial and coastal waters every four years. No detail is provided regarding the methodology to be used. However, ND Guidelines and WFD Eutrophication guidance both recommend the use of a specific methodology (eutrophic = less than good status according to algal and plant elements), supported by nutrient conditions.

Source: Ecorys. Complementary study to provide specific elements for the evaluation of the Nitrates Directive (Council Directive 91/676/EEC), February 2025.

Table 3 Overview of relevant differences in the ND's and the WFD/GWD's approach to monitoring and reporting

WFD/GWD approach	ND approach
General differences (applicable to all types of water bodies)	
• **Monitoring:** The WFD's monitoring aims to establish a coherent and comprehensive overview of water status within each river basin district. The WFD is thus tasked with monitoring impacts **due to a variety of pressures** affecting a water body's quality (e.g. urban areas, point sources, background concentrations). This can have implications for the geographic location and the types of water	• **Monitoring:** The ND's monitoring has the purpose of allowing Member States to correctly identify waters affected by nitrate pollution **due to agricultural sources**, waters which could be affected if no action is taken and to correctly designate and revise the designation of Nitrate Vulnerable Zones. The correct identification of these waters requires a monitoring network that is generally

bodies chosen for monitoring points (e.g. monitoring sites shall be representative of the quality of the relevant water body/bodies in operational monitoring).	representative of the waters in the MS. The link to agricultural sources can in practice mean that monitoring networks are more dense in agricultural areas.
• **Monitoring (applied to groundwater):** Surveillance monitoring should be carried out at water bodies identified as being at risk following the characterisation exercise undertaken in accordance with Annex II. Operational monitoring, on the other hand, shall be undertaken in the periods between surveillance monitoring programmes in order to establish the chemical status of all groundwater bodies or groups of bodies determined as being at risk.	• **Monitoring:** The ND only defines one type of monitoring.
• **Reporting:** The monitoring under the WFD refers to the water status **at the water body level**. The monitoring data of several monitoring sites within one water body (whose boundaries are defined by the Member State) are **aggregated to a single assessment** for the water body.	• **Reporting:** The monitoring outcomes under the ND are reported **per monitoring station** (e.g. as yearly/winter averages).
• **Reporting:** The WFD's reporting cycle is a six-year one.	• **Reporting:** The ND's Article 10 reports have to be submitted by MS every four years.
Differences in groundwater monitoring and reporting	
• **Reporting:** Per groundwater body the **outcome of chemical status assessment** is reported (good chemical status / not of good chemical status), as well as results of trend and trend reversal assessments. Additional information related to nitrates varies in its degree of detail, but as a minimum, water bodies that fail to meet good status due to nitrates concentrations will be reported as such.	• **Reporting:** Per monitoring station the monitoring outcomes are reported as **concentration values in mg/l of nitrates** (typically in yearly averages). Values for concentration trends (over consecutive monitoring periods) and maxima are reported.
• **Reporting:** Under the GWD, **trends** and **trend reversal** are to be established using recognised statistical trend assessment techniques. The use of statistical methods allows for evaluations of the level of confidence associated with a trend or trend reversal.	• **Reporting:** Under the ND, **trends** are calculated by comparing the average of annual means over the four-year reporting period with the same average of one (or more) preceding reporting period(s).
• **Reporting:** The GWD (as the ND) defines the quality standard for nitrates at 50 mg/l. The GWD defines starting points for trend reversal by default at 75% for its quality standards/threshold values. This **threshold for trend reversal** (trigger for action) is thus defined at **37.5 mg/l** for nitrates. Methodology for trend assessment is elaborate and robust.	• **Reporting:** The ND (as the GWD) defines the quality standard for nitrates at 50 mg/l. Waters at risk of short-term overstepping of the 50 mg/l standard are those between **40 mg/l** and 49.99 mg/l (i.e. waters which could be polluted if action is not taken, trigger for action). It should be noted that this threshold is not defined in the legal text but part of the non-binding "Guidelines for reporting under Article 10".
Differences in surface water monitoring and reporting	
• **Reporting:** Per surface water body the **outcome of the overall ecological status assessment** is reported as one of five classes (high/good/moderate/poor/bad), based on the monitoring of biological quality elements and supporting physico-chemical quality elements, following the one-out-all-out principles. Nitrates are measured as part of physico-chemical quality elements 'nutrient conditions', and reported as either high, good, or less than good.	• **Reporting:** Per monitoring station the monitoring outcomes are reported as **concentration values in mg/l of nitrates** (typically in yearly averages). Values for concentration trends (over consecutive monitoring periods) and maxima are reported.
Differences in eutrophication assessment	
• **Reporting:** Strictly speaking there is no eutrophication assessment under the WFD, but the WFD's biological boundary good/moderate status is linked to the ND's non-eutrophic status as explained in CIS Guidance No. 23. Under the WFD, for a surface water body to achieve the policy objective of Good Ecological Status (GES), the assessment is based on biological parameters and supporting physico-chemical quality elements, following the one-out-all-out principle. Nutrients are part of supporting physico-chemical elements . Member States have to establish nutrient boundary thresholds, typically chosen to correlate with the biological boundary between good/moderate ecological status.	• **Reporting:** The eutrophication assessments under the ND are based on a combination of physico-chemical and biological criteria (with a handful of MS only using physico-chemical and one MS using only biological criteria). In the majority of Member States these thresholds are defined in terms of *inter alia* nitrates (NO_3^-) or nitrates as nitrogen ($N\text{-}NO_3^-$). Surface water bodies in these MS thus often have to meet nitrate threshold values under the ND, in addition to the ND's 50 mg/l nitrates concentration threshold.

Source: Adapted from Ecorys. Complementary study to provide specific elements for the evaluation of the Nitrates Directive (Council Directive 91/676/EEC), February 2025.

Differences and approaches to address challenges

Nitrates concentration

For groundwater chemical status under the WFD/GWD, nitrate concentrations are assessed against the EU groundwater quality standard of 50 mg/l established in the GWD. The assessment is carried out at groundwater-body level and is supported by groundwater monitoring designed to provide a coherent and comprehensive overview of chemical status and to detect long-term anthropogenically induced upward trends. Exceedances at individual monitoring points do not automatically determine the final status classification of a groundwater body, but Member States must explain how such exceedances have been considered in the final assessment.

Under the Nitrates Directive, groundwater nitrate monitoring serves to identify waters affected by pollution or at risk of pollution from agricultural sources, support the designation or revision of Nitrate Vulnerable Zones, and assess the effectiveness of Nitrates Action Programmes. Therefore, while the same monitoring data may often be used under both frameworks, the assessment scale and conclusions can differ.

The ND requires regular and consistent monitoring of nitrate concentrations in both surface and groundwater in all waters, and annual reviews. Monitoring is often more focused and frequent in agriculture areas or within Nitrate Vulnerable Zones (NVZs) to assess compliance with established limit values and effectiveness of action programs. Furthermore, the ND includes requirements related to the concentration of nitrates in groundwater and surface waters, which are linked to the 50 mg/L maximum admissible concentration for nitrates in drinking water (human health protection goal). Information reported by Member States includes concentration classes and calculations of trends (based on a comparison between monitoring periods). This leads to more differentiated results than those reported under the WFD and provides the possibility of showing more subtle changes (e.g. when improvements happen at a slow pace).

Efforts are on-going to increase exchanges among EU technical groups on reporting data, methodologies and results. This enhanced understanding should help in identifying nitrates trends more accurately and in evaluating the effectiveness of measures taken under both Directive.

Specifically for groundwater, the monitoring of nitrate concentrations required by the ND can be very relevant for groundwater quality assessment. Most Member States use partially overlapping data and data processing methods under the ND and WFD/GWD, although the situation varies among MS. Consultations of Member States experts in the ND and Ground Water working groups in 2025, showed a very diverse approach among Member States and challenges in streamlining approaches, nevertheless Member States acknowledged potential for better alignment. The consultations highlighted that:

- The overlap between monitoring stations (WFD/GWD and ND) varies across MS. The design and use of monitoring networks also varies (e.g. WFD/GWD often track multiple pressures), which questions the potential comparability of results between MS. Nevertheless, Member States see the potential to align monitoring networks: either as having the ND network as a sub-network of the WFD/GWD network focused on agriculture or even using the same monitoring networks.

- Most Member States see potential for harmonisation of data collection and processing between directives. Data are in most Member States fully or partially collected by the same teams or authorities under both WFD/GWD and ND.
- Regarding assessment, MS see room for harmonisation specially in case of using the same threshold value for identification waters at risk of being polluted, using the same aggregation periods or the same trend assessment.
- Most MS see potential in aligning the monitoring and reporting cycle to match exact same years of GWD/WFD cycle. However, under the GWD/WFD Member States have a margin of freedom for the assessment periods which results in differences in data used for an assessment. This would complicate the aligning the cycles at EU level.
- MS also expressed concerns regarding the complexity of aligning assessments and reporting or combining data and resources. There are differences in objectives, monitoring strategies and national approaches, which make it difficult to harmonise status/trend assessments, evaluation units, and reporting requirements. Bringing together monitoring efforts and merging ND and WFD/GWD assessments could be demanding and might make it more burdensome.

Ecological status and eutrophication

The WFD's evaluation assessment of ecological status also involves assessment of eutrophication. The WFD Eutrophication Guidance states that being worse than good ecological status for algal and plant quality elements due to nutrient enrichment implies a eutrophication issue. The Member States use BQE intercalibrated methods to address eutrophication pressure. Thus, Member States monitor a series of biological and physico-chemical parameters which are related to eutrophication pressure (and to other pressures). The nutrient concentrations of nitrogen and/or phosphorus and their thresholds for supporting good ecological status is part of the analysis. The WFD does not specify which nutrients should be used. Member States establish nutrient boundary thresholds, typically chosen to correlate with the biological boundary between good/moderate ecological status. Thresholds are established at the national level by each Member State (and present wide variations). MS might report results based on concentrations of N and P both dissolved and total fractions. Boundaries of Biological Quality Elements (BQEs) are compared and harmonised through an intercalibration process but there are no European wide nutrient targets per water body types.

The ND does not provide detail on how the eutrophication assessment should be performed, allowing Member States to establish their own eutrophication criteria and thresholds[4]. The nitrates threshold for surface water set in the Nitrates Directive to meet drinking water standards (50 mg nitrate/L) is inappropriate to assess eutrophication, as the more ecologically relevant criteria for nutrients concentrations, necessary for achieving good ecological status for the WFD, would be much lower. However, the WFD CIS guidance on eutrophication

[4] Nikolaidis, N., Poikane, S., Bouraoui, F., Salas Herrero, M.F., Free, G., Varkitzi, I. and Van De Bund, W., Comparison and harmonization of eutrophication assessment criteria under the WFD and the Nitrate Directives, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/23475, JRC137238.

assessment provides recommendations for a methodology[5], and the ND Guidelines recommend assessing eutrophication in line with this Guidance document[6].

The 2019 WFD fitness check noted: *The main challenge regarding the interaction between the WFD and the Nitrates Directive lies in implementing the legislation rather than in the legislative framework itself. While Member States can in theory adopt compulsory measures outside the NVZs and deadlines in order to meet the WFD objective, in practice this is not often done. Furthermore, there is also some inconsistency between the designation of NVZs (and sensitive areas under the UWWTD) and the assessment of ecological status. This is because not all Member States link the assessment of 'eutrophication' required by the Nitrates Directive with WFD ecological status* and related quality elements. *To improve coherence and consistency, a CIS guidance document was published in 2009 on the assessment of eutrophication. Nonetheless, reporting under the Nitrates Directive in 2016 showed that the methodologies used to assess eutrophication still varied widely among Member States and often were not well linked to the WFD quality. Efforts are continuing to improve coherence and synergies at Member State and EU levels*[7].

Additional efforts have been invested and are on-going for comparing and harmonising eutrophication assessment criteria under the WFD and ND (JRC, 2024 report[8]). While the report recommends that Member States use the WFD ecological status assessment for determining eutrophication under the Nitrates Directive, inconsistent criteria and thresholds between the WFD and ND in the classification of water bodies regarding eutrophication persist. It is also the case that countries with higher percentages of agriculture tend to use higher values for nutrient thresholds, providing less adequacy with biological quality elements[9].

Discussions are on-going on how to better harmonise eutrophication relevant definitions, criteria (parameters, metrics and thresholds) and the possibilities to report data in a disaggregated way. This would streamline approaches and provide better water quality information, which in turn would contribute to address current and future water protection and management challenges. Also, a specific task for the 2025-2027 work programme on harmonisation of eutrophication criteria under WFD and Nitrates Directive has been setup in the Working Group ECOSTAT. ECOSTAT is working under the WFD Common Implementation Strategy on the harmonization of the assessment of ecological status across Europe.

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5 The CIS guidance states that "eutrophic status" under the ND corresponds to "Worse than Good ecological status for the algal and plant quality elements" (supported by nutrient conditions) under the WFD (Tables 4 -7): European Commission: Directorate-General for Environment, Guidance document on eutrophication assessment in the context of European water policies. Guidance document No 23, Publications Office, 2009, https://data.europa.eu/doi/10.2779/49795

6 'Guidelines for reporting under Article 10 of the Nitrates Directive', v.3.0, 2024

7 European Commission, Commission Staff working document fitness check of the Water Framework Directive, Groundwater Directive, Environmental Quality Standards Directive and Floods Directive, SWD (2019) 439 final.

8 European Commission, Joint Research Centre, Nikolaidis, N., Poikane, S., Bouraoui, F., Salas Herrero, M.F., Free, G., Varkitzi, I. and Van De Bund, W., Comparison and harmonization of eutrophication assessment criteria under the WFD and the Nitrate Directives, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/23475, JRC137238.

9 Nikolaidis *et al*. Comparison of eutrophication assessment for the Nitrates and Water Framework Directives: Impacts and opportunities for streamlined approaches, Ecological Indicators, v 177, 2025.

Strengthening coordination mechanisms between the directives can mitigate overlap issues. Regular discussions and agreements on methodologies should promote coherence in monitoring practices.

Streamlining of reporting

Reporting cycles under WFD and ND are set to converge end of 2027, aligning strategic water quality goals. From that moment, there is scope to coordinate reporting processes better and improve communication of the results to the public. However, there are many practical challenges that will need to be examined with the Member States in view to maximise the benefits in improved coherence and burden reduction:

- There are limits on how far reporting can be streamlined, given the differences in reporting cycles and reporting periods used for data among the MS under the WFD.
- Less frequent reporting under the ND could lead to reduced information benefits and could jeopardise the Directive's correct application and enforcement.
- Better streamlining in monitoring and assessments is necessary but requires addressing related technical challenges and a certain level of harmonisation
- If the underlying monitoring and assessments are not sufficiently streamlined for nitrate concentrations in groundwater and eutrophication in surface waters, the coordination of reporting processes may have limited added value and low simplification potential, and might even increase the burden on Member State authorities having to two sets of reporting at the same time.

As a response to these existing challenges, and the objective to streamline processes and foster simplification, cooperation with the Member States has been reinforced in the working groups under the ND and the WFD/GWD and WFD/ECOSTAT. The aim is to investigate these issues and assess the best way forward which would combine simplification in monitoring and reporting and increased coherence in the national implementations.

In addition, the Commission published an amendment of the WFD/GWD/EQSD in 2026 [10]It includes changes on the data reporting and its frequency, and simplifications (integration of data flows and increased digitalisation). The amendment aims to streamline monitoring and reporting obligations, and includes interim reporting for biological quality and chemical quality data (which will be reported respectively every three and two years). These changes could in turn increase the knowledge of nutrients pollution, existing risks and pressures, facilitate the exchanges between both directives and ultimately the implementation of the ND.

Concluding remark

The WFD and the ND are interdependent, intricately linked and complement each other to achieve water protection objectives. The legal framework is coherent, provides compatible objectives and should allow Member States to achieve objectives in a coordinated way. The integration of the ND as a basic measure in the WFD makes that achievement of the WFD objectives critically dependent on the effective implementation of the ND. Nevertheless, 25 years on, the integration of the ND and the WFD, especially in the preparation and design of the national measures in the NAP remains generally incomplete and uneven among Member

[10] Directive - EU - 2026/805 - EN - EUR-Lex

States, although there has been a significant acceleration in the 3rd RBPM report and in the approaching 2027 deadline. The flexibility provided to MS allows adapting the directives implementation to local conditions, although this has also translated into large discrepancies in monitoring networks, reporting data and status assessment. There is room for improvement in the coordination, information exchange and streamlining of efforts among competent authorities dealing with the implementation of both directives.

2. COHERENCE WITH NECD

The evaluation of the NECD published in December 2025 analysed the coherence with the ND, based on an analysis of the NAP measures in all Member States. The evaluation concluded that Nitrates Directive and the NECD are mostly coherent. Only a few marginal measures from either the Nitrates Directive or the NECD have been identified as having unintended negative effects on the other.

Table 4 Links with NECD (From the Evaluation of the NECD)

Nitrates Directive	*Links between the policies* The Nitrates Directive requires Member States to designate Nitrate Vulnerable Zones, to establish Codes of Good Agricultural Practice to be followed on a voluntary basis, and to establish Nitrate Action Programmes (NAPs), to be followed within Nitrate Vulnerable Zones. As explained in the AAQD Fitness Check, "Although it does not apply specifically to air emissions, the Nitrates Directive has an indirect impact on air quality. It aims to protect water quality across Europe by preventing nitrates from agricultural sources to pollute both ground and surface waters and by promoting the use of good farming practices. Since manure and fertilisers are also sources of air emissions (in particular nitrogen oxides (NO_x) and ammonia (NH_3); both are precursors of particulate matter), preventing water pollution with nitrates from agriculture can have an impact on air emissions." A technical report analysing NAPs and their interactions with policies and measures in NAPCPs submitted by Member States, was published in 2020[11]. At the time of the drafting of this technical report (2019), 20 Member States had submitted their first NAPCP. The support study added further elements for a detailed analysis of coherence between NECD and Nitrates Directive[12]. Looking at impacts of measures included in NAPs on pollutants covered by the NECD, some NAP measures were identified as representing a *potential* conflict (notably measures increasing manure storage periods), which *could* result in increases of NH_3 emissions. However, exact impacts on NH_3 are highly dependent on the manure collection and storage systems in which those measures are implemented. Regarding other NAP measures, they were either synergetic with or neutral towards the NECD. Regarding NECD measures that potentially impact on Nitrates Directive objectives, these were all found to be supporting those objectives or to have limited or no impact. The support study provides a detailed

[11] Tzilivakis, J., Green, A., Warner, D.J and Lewis, K.A. (2020), Identification of approaches and measures in action programmes under Directive 91/676/EEC. Report prepared for Directorate-General Environment, European Commission.

[12] See support study for the NECD evaluation section 3.4.2.

	mapping of measures across the two Directives and all Member States in Tables 3-14 to 3-17. *Coherence between the policies* The Nitrates Directive and the NECD are mostly coherent. Only a few marginal measures from either the Nitrates Directive or the NECD have been identified as having unintended negative effects on the other. *Change in coherence over time* No changes observed over the NECD evaluation period.

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COMMISSION STAFF WORKING DOCUMENT

EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XVI. INTERLINKS BETWEEN THE COMMON AGRICULTURAL POLICY AND THE NITRATES DIRECTIVE

This Annex analyses

(1) The links between the CAP Regulation and the Nitrates Directive,

(2) How the CAP reforms have influenced the implementation of the Nitrates Directive

(3) Coherence of monitoring and reporting and controls

1. LINKS BETWEEN THE CAP REGULATION AND THE NITRATES DIRECTIVE

The Common Agricultural Policy (CAP Regulation) and the Nitrates Directive (ND) are intricately linked and work together for the sustainability of agriculture in the EU. The integration and synergy between these instruments highlight their mutual dependability in implementing good agriculture practices for sustainable farming and environmental protection throughout the EU.

Here are some key points regarding their interlinkages (see also detailed table below):

- Contribution to the achievement of CAP's and Nitrates Directive's objectives: The ND and the CAP support each other in the achievement of their respective objectives.
    - On the one hand, the ND ensures that all farmers apply the same type of environmental protection rules as regards nutrient pollution, thus providing a common baseline and facilitating a level playing field. Also, through the promotion of good agriculture practices for *all* farms in the EU, with mandatory requirements for farms in NVZ (that is about 75% of farms in the EU) and voluntary requirements for farms outside the NVZ, the ND contributes to the general and specific objectives of the CAP of supporting and strengthening environmental protection in relation to the prevention and reduction of nutrient pollution from agricultural souces, in improving sustainable development and efficient management of natural resources.
    - Conversely, the CAP Strategic Plans should contribute to, and be consistent with, the objectives of the Nitrates Directives, which is mentioned in Annex XIII of the CAP Regulation.
    - The indicators on achieving the objectives of the CAP specifically refer to the protection of water quality and improvement of nutrient management, and some are indicators directly linked to the implementation of the ND.
- Integration of the core of the Nitrates Directive in the CAP:
    - Articles 4 and 5 of the Nitrates Directives (including the Member States' Nitrates Action Plans), are part of Statutory Mandatory Requirement (SMR) 2. This legally integrates the Nitrates Directive as an element of the CAP Regulation. This implies, notably, that the obligations laid down on farmers by the NAPs are part of those that they must comply with in order to receive direct payments. This strengthens the implementation of the ND.
    - Additionally, as per the CAP Regulation, ND measures are a baseline for all payments under the CAP. This further strengthens the role of the ND as a

common baseline for all farms throughout the EU, preventing distortion between farmers in the EU.

- Finally, the CAP further supports the implementation of the ND through the possibility of financing investments for 2 years after a requirement has become mandatory for the farmer. (e.g. manure storage).

- Complementarity:
  - There is a strong complementarity between the ND measures and the CAP interventions. The CAP GAECs (4, 5, 6 and 7) complement the good agriculture practices under the ND by extending the scope and coverage of mandatory requirements of the Nitrates Directive (e.g. buffer strips - when farmers outside NVZ and beneficiaries of the CAP also apply mandatory buffer strips). Some GAECs and NAP provisions may regulate the same issue (e.g. width of buffer strips); however, these mostly help to strengthen the implementation overall and are not generally seen as an overlap.
  - Voluntary measures, eco-schemes and AEC commitments, build upon the ND baseline and provide incentives for farmers to go further in reducing nutrient losses, thereby strengthening the implementation of the ND and further contributing to its objectives.
  - The CAP farm advisory services (FAS), specifically required for nutrient management and including the development of electronic tools, complement the training and information requirements of the ND. The broader scope, the financing possibility and the quality requirements for the FAS strengthen the ND requirements and support their implementation.
  - Overall, there are no major overlaps of the measures or duplication of efforts. The exchanges of best practices for the implementation of the CAP further complement and reenforce the implementation of measures to reduce nutrient losses[1]. Overall, the CAP relies on the implementation of the Nitrates Directive and does not make it redundant.
- Synergies at national level: There are important synergies for administrative and on-site controls of farms. All Member States reported that they heavily rely on the controls under the CAP (checking SMR compliance) for checking general compliance under the ND, which not only helps to reduce burdens for farmers and the administration, but also allows more targeted controls by the environmental authorities. The CAP regulation also explicitly mentions the possibility of synergies between controls on eco-schemes and controls on the SMR.

Detailed analysis:

Regulation (EU) 2021/2115 (CAP-SPR) establishes rules on support for the CAP strategic plans to be drawn up by Member States and financed by the European Agricultural Guarantee Fund (EAGF) and the European Agricultural Fund for Rural Development (EAFRD).

The objectives of the regulation of relevance for this analysis is that the two funds shall "further improve the sustainable development of farming, food and rural areas" and shall contribute "to support and strengthen environmental protection, including biodiversity,

[1] https://eu-cap-network.ec.europa.eu/index_en

and climate action and to contribute to achieving the environmental and climate-related objectives of the Union" [Article 5(b)].

The Regulation lays down rules on [Article 1]:

a) the objectives to be pursued through Pillar 1 (EAGF) and Pillar 2 (EAFRD) funds under the CAP as well as the related indicators;

b) types of intervention and common requirements for Member States to pursue those objectives, as well as the related financial arrangements;

c) the CAP Strategic Plans to be drawn up by Member States;

d) the coordination and governance arrangements as well as monitoring, reporting and evaluation

There are many interlinkages between the Nitrates Directive and the 2023-2027 CAP Regulation[2]. The most meaningful interactions are (1) the objectives (2) the conditionality, (3) subsidies for investments (manure storage), (4) ecoschemes and agri-environmental and climate commitments and (6) farm advisory services. The table below details these links.

Table 1 Interlinkages between the Nitrates Directive and the 2023-2027 CAP Regulation

CAP Regulation	Link with Nitrates Directive
objectives	
Article 5 - General objectives In accordance with the objectives of the CAP set out in Article 39 TFEU, with the objective to maintain the functioning of the internal market and a level playing field between farmers in the Union and with the principle of subsidiarity, support from the EAGF and the EAFRD shall aim to further improve the sustainable development of farming, food and rural areas and shall contribute to achieving the following general objectives in the spheres, which will contribute to the implementation of the 2030 Agenda for Sustainable Development: (a) to foster a smart, competitive, resilient and diversified agricultural sector ensuring long-term food security; (b) to support and strengthen environmental protection, including biodiversity, and climate action and to contribute to achieving the environmental and climate-related objectives of the Union;	By requiring mandatory or voluntary implementation of good agriculture practices to protect water for all farms in the EU, the Nitrates Directive contributes to the general objectives of the CAP, namely, maintain a level playing field between farmers in the Union, further improve the sustainable development of farming and contribute to to the implementation of the economic, environmental and social objectives for the 2030 Agenda for Sustainable Development,.
Article 6 - Specific objectives 1. The achievement of the general objectives shall be pursued through the following specific objectives: (d) to contribute to climate change mitigation and adaptation, including by reducing greenhouse gas emissions and enhancing carbon sequestration, as well as to promote sustainable energy; (e) to foster sustainable development and efficient management of natural resources such as water, soil and air, including by reducing chemical dependency;	The Nitrates Directive contributes to the specific objectives of the CAP, in particular article 6.1(e), and also to 6.1 (d) by limiting the use of fertilisers (chemical and manure responsible for GHG). In addition, by setting a manure spreading limit for NVZs, the directive promotes manure distribution to non-NVZs towards more efficient resource distribution and contributing to enhancing carbon sequestration in soils.

[2] REGULATION (EU) 2021/2115

Article 7 - Indicators 1. Achievement of the objectives referred to in Articles 5 and Article 6(1) and (2) shall be assessed on the basis of common indicators related to output, result, impact and context as set out in Annex I **Impact indicators**: **I.15 Improving water quality**: Gross nutrient balance on agricultural land **I.16 Reducing nutrient leakage:** Nitrates in ground water – percentage of ground water stations with nitrates concentration over 50 mg/l under Directive 91/676/EEC **I.11 Enhancing carbon sequestration**: Soil organic carbon in agricultural land **Context indicators** – **water C. 39 Water quality** Gross nutrient balance – nitrogen Gross nutrient balance – phosphorus Nitrates in ground water **Result indicators:** **R.19PR Improving and protecting soils**: Share of utilised agricultural area (UAA) under supported commitments beneficial for soil management to improve soil quality and biota (such as reducing tillage, soil cover with crops, crop rotation included with leguminous crops) **R.20PR Improving air quality:** Share of utilised agricultural area (UAA) under supported commitments to reduce ammonia emission **R.21PR Protecting water quality:** Share of utilised agricultural area (UAA) under supported commitments for the quality of water bodies **R.22PR Sustainable nutrient management:** Share of utilised agricultural area (UAA) under supported commitments related to improved nutrient management	The impact and context indicators to assess the achievement of CAP objectives I.15, I.16 and C.39 are directly related to the implementation of the Nitrates Directive, and are indicators used in the reporting under the Nitrates Directive. Results indicators build on the measures of the Nitrates Directive, and complement measures in and outside NVZ.
Conditionality	
Article 12 - Principle and scope 1. Member States shall include in their CAP Strategic Plans a system of conditionality under which farmers and other beneficiaries are subject to an administrative penalty if they do not comply with the statutory management requirements under Union law and the GAEC standards established in the CAP Strategic Plans, as listed in Annex III	Strengthens implementation of environmental legislation as SMR
Annex III – Statutory management requirement SMR 2: Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (OJ L 375, 31.12.1991, p. 1): Articles 4 and 5 SMR 1: Directive 2000/60/EC of 23 October 2000 of the European Parliament and of the Council establishing a framework for Community action in the field of water policy - Article 11(3), point (e), and point (h), as regards mandatory requirements to control diffuse sources of pollution by phosphates	Articles 4 and 5 of the Nitrates Directive are SMR for all CAP beneficiaries. These articles refer to the establishment of nitrates action programmes in NVZ, voluntary code of good agriculture practice outside NVZ as well as training for all farmers, based on the measures set out in Annexes II and III of the ND. The SMR requirement strengthens the implementation of the Nitrates Directive. SMR 1 on the WFD referring to mandatory requirements to control diffuse sources of pollution by phosphates is also relevant for the implementation of the Nitrates Directive, when

	phosphates from agriculture are a source of eutrophication. [see Annex XY on the implementation of Annex II and III measures in Member States – measures on P].
Article 13 - obligations of Member States relating to GAEC 1. Member States shall ensure that all agricultural areas, including land which is no longer used for production purposes, are maintained in good agricultural and environmental condition. Member States shall set, at national or regional level, minimum standards for farmers and other beneficiaries for each GAEC standard listed in Annex III in line with the main objective of those standards as referred to in that Annex. In setting their standards, Member States shall take into account, where relevant, the specific characteristics of the areas concerned including soil and climatic condition, existing farming systems, farming practices, farm size and farm structures, land use, and the specificities of outermost regions. 2. In respect of the main objectives laid down in Annex III, Member States may set standards additional to those laid down in that Annex concerning those main objectives. Such additional standards shall be non-discriminatory and proportionate and shall correspond to the needs identified. […]'.	The GAECs have nearly all potential positive effects on reducing nutrient pollution in water. Many GAECs have some similarity to obligations under the ND (Annex II). Overall the GAECs will complement the ND, by allowing to set the obligations on more farmers (eg outside NVZ) or in more Member States. Depending on the national or regional implementation there may be some overlap or differences in rules where the GAEC is more prescriptive than the ND, eg on buffer strips.
GAEC 4 - Establishment of buffer strips along water courses	GAEC 4 complements requirement for buffer strips under the Nitrates Directive in Annex II. In NVZ, GAEC 4 requirement between the CAP and the ND is overlapping. Outside NVZ, GAEC 4 increases mandatory requirement for buffer strips, further reducing distortion. Minimum harmonisation of GAEC 4 has further strengthened the baseline in Member States where the buffer strips under the Nitrates Directive were below 3m.
GAEC 5 Tillage management, reducing the risk of soil degradation and erosion, including consideration of the slope gradient Minimum land management reflecting site specific conditions to limit erosion	GAEC 5 complements the ND requirement in Annex II A regarding the land application of fertilizer to steeply sloping ground, although GAEC 5 has a wider scope. As erosion is an important cause of nutrient losses and eutrophication of surface water, the systemic approach to erosion of GAEC 5 strengthens the implementation of the Nitrates Directive.
GAEC 6 Minimum soil cover to avoid bare soil in periods that are most sensitive	GAEC 6 complements the ND requirement in Annex II B- the maintenance of a minimum quantity of vegetation cover during (rainy) periods that will take up the nitrogen from the soil that could otherwise cause nitrate pollution of water. As Member States are not obliged to include this requirement in their nitrates action programme, GAEC 6 ensures that there are mandatory rules on soil cover in all Member States and outside NVZ.
GAEC 7 Crop rotation in arable land, except for crops growing under water[3]	GAEC 7 complements the ND requirement in Annex II B - land use management, including the

[3] There is an exemption for organic farmers and farms in conversion

	use of crop rotation systems. As Member States are not obliged to include this requirement in their nitrates action programme, GAEC 7 ensures that there are mandatory rules on crop rotation in all Member States and outside NVZ.
Farm Advisory Services	
Article 15 - Farm advisory services 1. Member States shall include in their CAP Strategic Plans a system providing services for advising farmers and other beneficiaries of CAP support on land management and farm management ('farm advisory services'). Member States may build upon existing systems. 3. Member States shall ensure that the advice given is impartial and that advisors are suitably qualified, appropriately trained and have no conflict of interest. 4. The farm advisory services shall be adapted to the various types of production and farms and shall cover at least the following: (a) all requirements, conditions and management commitments applying to farmers and other beneficiaries set in the CAP Strategic Plan, including requirements and standards under conditionality (g) sustainable management of nutrients, including at the latest as from 2024 the use of a Farm Sustainability Tool for Nutrients, which is any digital application that provides at least: (i) a balance of the main nutrients at field scale; (ii) the legal requirements on nutrients; (iii) soil data, based on available information and analyses; (iv) data from the integrated administration and control system (IACS) relevant for nutrient management	The CAP requires farm advisory services for all SMR Article 4(a), but also for nutrient management specifically 4(g) with the development of electronic tools. The CAP also sets requirements for quality and independence, and the possibility to build upon existing systems. The FAS complement the ND requirements of Article 4 to set up where necessary a programme, including the provision of training and information for farmers, promoting the application of the code(s) of good agricultural practice. The broader scope and the quality requirements for the FAS strengthen the ND requirements and support their implementation.
Financial support schemes	
Article 31 – Eco-schemes Member States establish voluntary schemes ('eco-schemes') in their CAP Strategic Plans to support farmers who make commitments to observe agricultural practices beneficial for the environment. The schemes should help to meet the environmental objectives of the CAP and cover among others measures for **(**c) protection or improvement of water quality and reduction of pressure on water resources; (d) prevention of soil degradation, soil restoration, improvement of soil fertility and of nutrient management and soil biota; Member States shall only provide payments covering commitments which: (a) go beyond the relevant statutory management requirements and GAEC standards (b) go beyond the relevant minimum requirements for the use of fertiliser as established by national and Union law; Without prejudice to Article 87(1) of Regulation (EU) 2021/2116, active farmers or groups of active farmers participating in eco-schemes established in accordance with the first subparagraph shall be	The eco-schemes build on the ND requirements. They are designed to benefit farmers that go beyond the ND measures. Payments can only be done for measures that go beyond the baseline established by the ND. Eco-schemes contribute to the achievement of the ND objectives, and provide an incentive to go beyond which should help to increase the impacts. The article also explicitly mentions the possibility of synergies between controls on eco-schemes and controls on the SMR.

deemed to comply with the relevant requirements and standards referred to in Annex III, provided that they fulfil the commitments under the eco-scheme concerned. Member States that establish eco-schemes may ensure that their management and control systems do not duplicate checks where the same requirements and standards apply both under those eco-schemes and the obligations set in Annex III.	
Article 70 - Environmental, climate-related and other management commitments Member States shall include agri-environment-climate commitments for farmers or other beneficiaries who undertake, on a voluntary basis, management commitments which are considered to be beneficial to achieving one or more of the specific objectives set out in Article 6(1) and (2), and go beyond the relevant statutory management requirements and GAEC standards and beyond the relevant minimum requirements for the use of fertiliser established by national and Union law. The commitments are different from eco-schemes.	The AEC commitments build on the ND requirements. They are designed to benefit farmers that go beyond the ND measures. Payments can only be done for measures that go beyond the baseline established by the ND. They contribute to the achievement of the ND objectives, and provide an incentive to go beyond which should help to increase the impacts.
Article 73 - Investments 1. Member States may grant support for investments in tangible and intangible assets that **c**ontribute to achieving one or more of the specific objectives set out in Article 6(1) and (2). 5. Where Union law results in the imposition of new requirements on farmers, support may be granted for investments to comply with those requirements for a maximum of 24 months from the date on which they become mandatory for the holding.	Under Article 73, as an exception to the SMR rules, Member States may support investments resulting from the obligations under the Nitrates Directive, eg manure storage. As manure storage is an important investment for farms in NVZ resulting from the ND requirements, the possibility of investment support for a limited duration has been an important factor for compliance and cost reduction.
CAP Strategic Plans	
Articles 104 and 105 on CAP Strategic plans Promote an increased ambition with regard to environmental and climate-related objectives in the CAP Strategic plans in particular through the elements of the intervention strategy	The CAP Strategic Plans should aim at strengthening the achievement of environmental objectives and contribute to achieving the objectives of the Nitrates Directive.
Article 109 – Intervention strategy The intervention strategy shall demonstrate the consistency of the strategy and the complementarity of interventions across the specific objectives set out in Article 6(1) and (2) by providing: (a) an overview of the environmental and climate architecture of the CAP Strategic Plan which describes the following: (v) how the environmental and climate architecture of the CAP Strategic Plan is meant to contribute to the achievement of, and be consistent with, the long-term national targets set out in or deriving from the legislative acts listed in Annex XIII	
Annex XIII - Union legislative acts concerning the environment and climate to whose objectives member states' cap strategic plans should contribute to, and be consistent with, pursuant to articles 108, 109 and 115: Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources;	

2. THE INFLUENCE OF CAP REFORMS ON THE IMPLEMENTATION OF THE NITRATES DIRECTIVE

Overall, the CAP has a strong influence on the implementation of the Nitrates Directive and on the achievement of its objectives. Furthermore, the CAP, as an MFF funding instrument, is subject to changes with each new funding cycle (7 years), including as regards the level of environmental requirements. Major reforms of the Common Agricultural Policy (CAP) since the adoption of the Nitrates Directive have had repercussions on the implementation and effectiveness of the Directive, and more generally on the contribution of the CAP to water quality objectives. Through the different reforms of the CAP the interconnections and synergies between the two legal instruments have continuously grown:

- **In 1984, the Milk Quota had been introduced:** To prevent excessive drops in farmers' income and to address the issue of overproduction, in 1984 the EU introduced a **quota system** for products such as milk to limit overproduction and manage supplies. Each producer would receive a quota representing the amount of food they could produce. A levy would be due from those who exceeded the quota. Until its abolition in 2015, the milk quota has contributed to cap the intensity and concentration of dairy farming. This has contributed to cap the manure production from the dairy sector, thereby contributing to limit nitrogen and phosphorus emissions from the dairy sector.
- **The Nitrates Directive was adopted in 1991.**
- **1992 MacSharry Reform** led to a major change in the common agricultural policy. The system of income support via guaranteed prices was replaced by a system of direct payments. The policy shifted from a market support system to direct income support for farmers, and included new agri-environmental schemes to protect the environment and incentives to improve food quality. Direct payments to farmers were introduced for the first time, based on the area of land cultivated or number of livestock maintained. With reduced support on production, and direct support to the farmer’s income, the 1992 reform has gradually reduced the incentive for increased production and thereby opened the way for a more balanced use of fertilisers promoted by the Nitrates Directive as it aligned with the economic interests of the farmers. With direct support on the number of livestock maintained, there was however little incentive to reduce manure production which but continued to increase in most of EU15 Member States after 1992 (and overall remained rather constant in EU 27). [See Annex XII on the implementation of Annex II & III measures in Member States]
- **2003 Fischler Reform**. The introduction of the Single Farm Payment the 2003 CAP reform brought a new direct payment scheme decoupled from production. Another innovation concerned cross-compliance. For the first time, direct payments were linked to compliance with obligations from other areas. This concerned environmental protection, food safety, animal welfare as well as human, animal and plant health. Compliance with the Nitrates Directive was one of obligations and it led to improvements in the implementation and compliance at farm level.

  Cross compliance was indeed introduced as part of the 2003 reform of the Common Agricultural Policy (CAP) as a compulsory measure. As from the 1st January 2005,

following Regulation 1782/2003, farmers benefiting from direct payments under the first pillar of the CAP may be subject to reduction or withdrawal of those payments in the case of non-compliance with certain standards in the areas of the environment, public, animal and plant health and animal welfare. This approach was extended from the 1st January 2007 to beneficiaries receiving aid with regard to eight measures under 'Axis 2' of the second pillar of the CAP. In order to avoid any possible reduction in the total level of support received under these aid schemes, farmers had to comply with 19 Statutory Management Requirements (SMRs referred to in Annex III of Regulation 1782/2003) and a number of minimum requirements for ensuring the 'good agricultural and environmental condition' (GAEC) of agricultural land, to be defined by the Member States on the basis of the framework given under Annex IV of Regulation 1782/2003. Nitrates Directive article 4 and article 5 are one of the SMR since 2003.

A Study in 2007[4], and ECA report in 2014[5], both concluded that cross compliance has had a positive effect in ensuring compliance with the Nitrates Directive. It appears that many and severe issues of compliance with the Nitrates Directive at farm level were brought to light (inadequate storage facilities or insufficient storage capacity for manure, incomplete or erroneous fertiliser records, absence of a nitrogen analysis, nitrate output higher than 170 kg/ha, storage of manure on land during a prohibited period, etc.), and thereby farmers and Member states have had to remedy these issues. ECA Special Report found that the introduction of cross compliance has increased farmers' awareness and triggered changes in farming practices in relation to water, especially as regards nitrates and pesticides. It also highlighted that phosphorus use in agriculture was not sufficiently covered by cross-compliance, only indirectly through the Nitrates Directive measures. Cross-compliance with the WFD on phosphorus measures was subsequently introduced in the CAP regulation from 2014. On the other hand, the studies found that the positive impact on supporting the policy objectives was also dependent on the policy ambition set for the CAP Regulation and on the ambition and level of compliance with the ND.

- **2013 CAP reform** led to the introduction of the "greening payment'. 30 percent of the direct payments in the first pillar of the CAP were granted exclusively to reward farmers for respecting three obligatory agricultural practices, namely maintenance of permanent grassland, ecological focus areas and crop diversification. In the second pillar of the CAP, rural development, included as priorities restoring, preserving and enhancing ecosystems related to agriculture and forestry. This reform strengthened the focus on environmental objectives of the subsidies, both in the first and second pillar.

  An evaluation study in 2019 examined the impact of the CAP Regulation (EU) No 1306/2013, measures and instruments on water[6]. The CAP framework was assessed as effective for maintaining minimum practices beneficial for water quality, especially through the cross-compliance, which includes the implementation of the Nitrates Directive. The study found that cross-compliance ensures the implementation of mandatory minimum practices for beneficiaries of direct payments, but that it has

[4] Alliance Environnement: Evaluation of the application of cross compliance as foreseen under Regulation 1782/2003 - Part I: Descriptive Report - 26/07/2007

[5] European Court of Auditors, Special Report, Integration of EU water policy objectives with the CAP: a partial success, 2014. ISBN 978-92-872-0028-0

[6] Evaluation of the Impact of the CAP on Water, EEIG Alliance Environnement, November – 2019

overall no effect on the livestock density and on preventing the associated agricultural pressures on water quality and quantity.

The study further concluded that the CAP also contributed to raising awareness on water issues and putting the topic of water higher on the agenda, and that CAP incentives increasingly contributed to reduce nutrient losses and thus complemented the implementation of the water quality objectives of the Nitrates Directive beyond the mandatory requirements, as these help. It was found that voluntary measures such as Organic Farming, and to a lesser extent Investments, encourage the implementation of agricultural practices that help improve further the chemical status of waterbodies, beyond the minimum practices, depending on the uptake by farmers in each Member State. The study found that soil and climatic conditions also highly influence the effectiveness of the instruments and measures, whereas economic factors play a significant role in inducing farmers to implement specific agricultural practices or produce specific crops.

- **In 2015 the Milk Quota were abolished.** This reform took away the capping of milk production and has let to important increases in livestock concentrations and milk production, and subsequent manure production in certain Member States. The Nitrates Directive allows to accommodate this situation by means of derogations to the 170 kg/ha ceiling in manure application when this does not compromise water quality. (See Annex XII – manure production graphs in Member States with nitrates derogations). A report from the European Court of Auditors in 2023[7] concluded that "As regards the application of the Nitrates Directive provisions relating to manure, we found that policy decisions such as the abolition of milk quotas led to an increase in the herd size in farms benefiting from a derogation from the nitrogen limits, which were constraining the application of manure. As a result, the derogation limited the achievement of the Directive's objective." [see also Annex XII on the implementation of Annex II & III measures in Member States].

- **2023 CAP Reform**. The reform introduced a new delivery model where MS develop CAP strategic plans covering both interventions from the 1st and 2nd pillar. It maintained the cross-compliance requirements now called conditionality. Reducing nutrient losses from agriculture, water protection and soil protection are important priorities, with increased attention to advisory services or digital support services (FaST Platform | Digital services for EU Agriculture). The 2023-2027 CAP reenforced the environmental objectives and the environmental ambition of the CAP Strategic plans. The table in the previous section detailed the legal and policy interlinks between the current CAP and the implementation of the Nitrates Directive.

  In practice, the reduction of nutrient pollution was seen as an important challenge in many Member States and the CAP Strategic Plans included many measures on reducing nutrient pollution going beyond and complementing the mandatory measures in the Nitrates Directive as SMR, as confirmed by the following two studies.

  A 2023 Study on the CAP SP (CSP) as adopted by Member States[8], analysed the overall potential contribution of CSPs towards improvement of water quality and status. The study found that "the CSPs will likely contribute to improve water quality and – albeit to a lesser extent - overall status (including water balance) across the EU.

[7] European Court of Auditors, Special report 19/2023, EU efforts for sustainable soil management.

[8] *Mapping and analysis of CAP strategic plans – Assessment of joint efforts for 2023-2027*, Publications Office of the European Union, 2023, **https://data.europa.eu/doi/10.2762/71556**

The improvement of water quality and status is seen as a priority in the CSPs. To contribute to the improvement of water quality and status, the CSPs present several valuable instruments and changes compared to the previous programming period. Conditionality now includes stricter requirements with regards to buffer strips, additional requirements with regards to soil management, which can be indirectly beneficial for water, and the new GAEC on the protection of wetlands and peatlands. Furthermore, SMR1 relates to requirements from the Water Framework Directive (controls on diffuse sources of phosphates and controls on abstraction and impoundment). Voluntary schemes through Eco-schemes and ENVCLIM offer support to a large panel of farm practices beneficial for water management, from measures to improve nutrient, pesticide and irrigation water use in agriculture, to agronomic measures on soils and the maintenance and restoration of landscape features. Several CSPs also support area-based support and support to non-productive investments for the restoration of wetlands and peatlands." Ch. 8.4.2.3 of the same study provides an overview of the practices in the CAP SPs for improved nutrient management. Depending on the national or regional implementations, which vary a lot across the EU, there may be some overlap or differences in rules where the GAEC is more prescriptive or different than the ND, eg on buffer strips or cover crops. This can create potential difficulties in some MS or regions but some Member States have solved this by modifying either the ND or the CAP measures to ensure coherence.

The June 2025 publication: "The 28 CAP strategic plans underway- Summary of implementation in 2023-2024 – facts and figures[9]" found that: *Surface and groundwater water protection is addressed by improving the efficiency or limiting the use of fertilisers and pesticides. Overall, 16% of agricultural area is covered by practices for protecting water quality. Significant efforts have been made towards more sustainable use of pesticides, with relevant practices covering already 29% of total EU agricultural area. Commitments on sustainable nutrient management have been carried out on 14% of EU agricultural area, in line with planned milestones in most Member States. This result indicator encompasses a wide range of actions such as ban of mineral fertiliser (mainly grassland, catch crops, crops for biodiversity), adaptation of the timing/quantities of nitrogen fertilisers applied (mainly arable crops), organic fertilisation (manure, compost) to replace mineral fertilisers and contribute to nutrient recovery as well as improvement of soil organic matter, diversified crop rotations with adding leguminous, and management practices to reduce nutrient losses and improve the soil' natural fertility limiting fertiliser applications.*

3. COHERENCE OF MONITORING, REPORTING AND CONTROLS BETWEEN THE CAP REGULATION AND THE NITRATES DIRECTIVE

This subsection analyses more in detail the coherence of monitoring and controls based on the support study[10] analysing the coherence of the ND's monitoring and reporting (M&R) framework with that of other EU legislation, including the CAP. The main aspect is the monitoring and reporting on ND directive compliance.

[9] 30 June 2025; https://agriculture.ec.europa.eu/document/download/693bd246-94a9-4d34-b82a-fb14546adccb_en?filename=csp-implementation-executive-summary_en%282%29.pdf

[10] Complementary Study to Provide Specific Elements for the Evaluation of the Nitrates Directive (Council Directive 91/676/EEC).

Monitoring

Of direct relevance to the Nitrates Directives are the controls that beneficiaries of CAP payments are subject to, which are known as conditionality checks. Beneficiaries are given an administrative penalty if they do not comply with the statutory management requirements (SMRs) under Union law and with the good agricultural and environmental conditions (GAEC) standards established by the MS in their CAP strategic plans.

The CAP Horizontal Regulation (Regulation (EU) 2021/2116) sets out the rules for the financing of CAP expenditure and for the relevant management and control systems. A control system for conditionality is defined in Art. 83 (Title IV Control Systems and Penalties, Chapter IV Control system and administrative penalties in relation to conditionality).

Regarding type of controls, the regulation states in Art. 83 that '[...] 6. [...] Member States: (a) shall include on-the-spot checks to verify the compliance of beneficiaries with the obligations laid down in Title III, Chapter I, Section 2, of Regulation (EU) 2021/2115; (b) may decide, depending on the requirements, standards, legal acts or areas of conditionality in question, to use the checks, including administrative checks, carried out under the control systems applicable to the respective requirement, standard, legal act or area of conditionality, provided the effectiveness of these checks is at least equal to the on-the-spot checks referred to in point (a); (c) may, where appropriate, make use of remote sensing or the area monitoring system or other relevant technologies assisting them to carry out the on-the-spot checks referred to in point (a);

Regarding control requirements, Art. 83 states that Member States '[…] (d) shall establish the control sample for the on-the-spot checks referred to in point (a) to be carried out each year on the basis of a risk analysis that: (i) takes into account, and applies weighting factors to, farm structure, the inherent risk of non-compliance and, where applicable, participation of beneficiaries in the farm advisory services as referred to in Article 15 of Regulation (EU) 2021/2115, (ii) includes a random component, and (iii) provides the control sample to cover at least 1 % of the beneficiaries listed in paragraph 1 of this Article;'.

Regarding frequency, Art. 83 of the regulation states that the control sample for monitoring is to be defined and monitoring to be carried out each year, on the basis of a risk analysis.

We are not aware of guidelines beyond requirements in Art. 83 of the CAP Horizontal Regulation (Regulation (EU) 2021/2116).

Reporting

The CAP Horizontal Regulation (Regulation (EU) 2021/2116) sets out the rules for the Annual financial report, Title V Common Provisions, Chapter III Reporting, Art. 97 Annual financial report: 'By 30 September of each year following the budgetary year, the Commission shall submit to the European Parliament and to the Council a financial report on the administration of the EAGF and EAFRD during the previous budgetary year.'

This reporting requirement does not really reflect the situation of compliance with the conditionality, as presented in a 2016 report by the European Court of Auditors ('Making cross-compliance more effective and achieving simplification remains challenging'). However, figures for checks and breaches are included in some Nitrate Reports (Article 10 Reports) by Member States for the Commission.

Summary of overlaps

Even if there are multiple thematic linkages between the CAP and the ND's objectives, the main overlaps regarding monitoring and reporting of compliance with the ND are the compliance checks of SMR 2 (ND provisions) and GAEC 4 (buffer strips).

However, in many MS the CAP checks of ND provisions **are** the one and only system for monitoring compliance with the ND implementation. In these MS there are no two systems overlapping, but only one system monitoring ND compliance. (Interactions with stakeholders show that some MS perform additional checks.)

LIST OF TABLES

Table 1 Interlinkages between the Nitrates Directive and the 2023-2027 CAP Regulation 401

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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XVII. THE LIVESTOCK MANURE APPLICATION LIMIT IN NITRATE VULNERABLE ZONES UNDER THE NITRATES DIRECTIVE

Contents

1. Origin of the manure application limit
2. Necessity of a limit for manure application
3. Is the limit of 170 kg N/ha per year appropriate?
4. A common limit throughout the EU

This Annex to the evaluation of the Nitrates Directive examines the effectiveness and relevance of the livestock manure application limit. In particular, responding to questions and feedback from stakeholders, it examines (1) the origin of the limit, (2) the necessity of setting an application limit, (3) whether the limit of 170 kg N/ha is appropriate and (4) the relevance of a common limit.

The Nitrates Directive sets a specific limit linked to manure application in NVZ

The Nitrates Directive establishes measures to safeguard water quality across Europe by reducing and preventing nitrate pollution from agricultural sources, especially targeting the management of both chemical fertilisers and livestock manure. In particular, the directive sets a limit for the application of livestock manure equivalent to **170 kg of nitrogen per hectare per year at farm level in areas designated as nitrate vulnerable zones (NVZs)**. This limit addresses specific risks associated with livestock manure, due to its organic nature and the need for the farm to dispose of it all year round regardless of crop needs, and indirectly due to the associated ammonia emissions and phosphorus compounds. The limit applies to all forms of manure, including processed manure. The limit is implemented by Member States as part of their nitrates action programmes, in NVZ or for the whole territory when the Member State has an action programme applying to the whole territory.

The directive allows Member States to set different amounts above 170 kg N/ha, provided these amounts are justified based on objective criteria and do not prejudice the achievement of the directive's objectives. Such decisions are approved by the Commission via a comitology procedure, requiring the endorsement of a qualified majority among the Member States (Annex III of the Nitrates Directive).

1. Origin of the manure application limit

The Commission's legislative proposal for the Nitrates Directive in 1989 originally referred to a requirement for Member States to ensure that the amount of livestock manure applied to the soil would not exceed the one produced by two dairy cows or by the equivalent number of other animal types[1]. This was calculated to avoid negative impacts of leaching and run-off. It also reflected the importance attributed to addressing the risks of excessive concentrations of livestock[2]. When the directive was being

[1] OJ No C 54, 3.3.1989, p. 4

[2] The problems connected with the disposal of animal waste have received much attention in recent years, especially in regions with intensive animal agricultural husbandry per hectare. Whereas the production of animal manure land increased strongly, the need for it decreased because of the introduction of cheap inorganic fertilizers which are easier to handle and have a more reliable effect on

negotiated in the Council, the limit was modified to an amount of nitrogen from manure of 170 kg N/ha per year estimated as equivalent to the manure produced by 2 livestock units (LSU) per hectare[3]. The limit was not arbitrary as it reflected field experience, the typical manure N excretion per livestock unit (roughly 80-90 kg N/year) and average crop uptake and soil nitrogen retention capacity for grassland and the main arable crops (30-155 kg N/ha/year)[4]. It was further justified as a safety threshold to avoid that groundwaters would reach 50 mg of nitrates per litre[5]. At that time, it was clear that the limit was sufficiently high for the large majority of the livestock sector in the EU but sufficiently constraining to avoid major water pollution situations. Member State experts further explained that the limit expressed in amounts of nitrogen rather than LSU has ensured that the limit was clearly defined throughout the EU and linked to the objective to limit nitrogen pollution from manure.

It is important to note that the limit was set to minimise risk of water pollution originating from manure, as the negative impact of excessive or inappropriate manure application was clearly recognised[6],[7]. It is not, however, an agro-environmental fertilisation limit, as it applies in addition to the requirement of balanced fertilisation. The Directive requires that Member States and farmers implement 'balanced fertilization' under action programmes in NVZ. This approach involves limiting the application of (nitrogen) fertilisers by applying the optimal amount and type of nutrients to crops based on their specific needs, nitrogen available in the soil, soil characteristics, and environmental conditions, to ensure crop yield and minimize excess nitrogen[8]. The agro-environmental fertilisation limits determined through balanced fertilisation thus vary in function of the crop, the soil, the climate etc. and there is not one common limit. The

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crop growth. As a consequence, many farmers dispose of animal manure as cheaply as possible, whilst avoiding damage to grassland and crops and paying little attention to effective use of the plants nutrients contained in the manure. Present practices of manure handling and application often lead to environmental problems. The rise in awareness of these problems renewed interest in possibilities to improve the utilization of nutrients from animal manure in crop production. [Animal Manure on Grassland and Fodder Crops. Fertilizer or Waste?: Proceedings of an International Symposium of the European Grassland Federation, Wageningen, The Netherlands, 31 August–3 September 1987]

3 As a transitional measure, during the first action programmes, the general limit was set to 210 kg N/ha for all Member States.

4 FAO Statistics - Fertilizer use by crop- Fifth edition-2002. The document lists the average nitrogen fertiliser rates per crop for the years 1999-2000 in the Member States. In the EU at that time in terms of total N demand the most important crops were wheat, grassland and barley. The inputs from the Member States show that fertilisation rates vary between 30 kg N/ha to 155 kg N/ha. Only in the Netherlands the fertilisation rates were higher with 190 kg N/ha for wheat and 240 kg N/ha for grassland. https://openknowledge.fao.org/server/api/core/bitstreams/75cffe68-8760-46d4-8059-a4abe0f017db/content.

5 On the basis of examples of leaching potential on certain soils.

6 The use of excessive amounts of animal manure raises concern about the accumulation and emission of nutrients to the environment through leaching or volatilization.[Schröder and Dilz, 1987, Cattle slurry and farmyard manure as fertilizers for forage maize, in Animal Manure on Grassland and Fodder Crops.Fertilizer or Waste? https://link.springer.com/book/10.1007/978-94-009-3659-1]

7 Undoubtedly, over-application of manure resulting from a too high regional animal density is unacceptable from many points of view including emissions and so is the injudicious handling of even moderate application rates [J. Schröder, 2005, Revisiting the agronomic benefits of manure: a correct assessment and exploitation of its fertilizer value spares the environment, https://doi.org/10.1016/j.biortech.2004.05.015]

8 Balanced fertilisation specifically applies to nitrogen fertilisers, but given the role of phosphorus in eutrophication, it may also be necessary for Member States to enforce balanced fertilisation for phosphorus. See also Annex XII that presents the implementation of phosphorus measures in the Member States.

requirement of balanced fertilisation applies to all crops independently of the type of fertilisers, including manure, which will always be limited to 170 kg N/ha per year. Balanced fertilisation is the main instrument of the directive by which Member States and farmers can adapt fertilisation to the local soil and climatic conditions and the crop needs, thereby limiting the risk of nutrient emissions to water.

In practice, farmers will when available employ a combination of different types of (chemical and manure) fertilisers with complementary attributes and risk profiles, with a total maximum determined by the limits set at national level for balanced fertilisation. While organic fertilisers such as manure have certain risks linked to the slow mineralisation of nitrogen into the soil and the high ratio of phosphorus, for example, chemical nitrate containing fertilisers have other risks due to the high solubility of nitrates, which make them prone to leaching if not immediately taken up by crops. By combining the two types of fertiliser, while respecting overall limits in line with crop needs, such risks can be better managed, resulting in lower losses[9].

2. Necessity of a limit for manure application

Thirty-five years after the adoption of the Nitrates Directive, scientific studies and experience confirm that limiting the amount of manure applied on agricultural land is necessary and justified to control nitrogen and phosphorus emissions from manure and processed manure, including with regard to other EU environmental goals. The manure application limit plays a key role in limiting various forms of polluting nitrogen and phosphorus emissions to the environment by:

- **Limiting nitrogen surplus in the soil and the risk of nitrate leaching and run-off to water**. The disposal of manure on land increases the potential for nitrate leaching and runoff, as manure has a higher leaching and run-off risk than chemical fertilisers, thereby raising the risk of ground and surface water pollution. Among other factors, this is due to a more unpredictable release of nitrogen to the soil[10], a high risk of ammonia emissions[11], and as a result, lower overall nutrient use efficiency[12]. The unpredictable release of nutrients from manure also means that farmers may tend to apply a pessimistic estimate to the fertiliser value of manure when planning their fertiliser use. The fact that livestock manure is continuously available and needs to be disposed of regardless of crop needs further increases the risks. (See also Annex XI on the environmental effect of measures). Without a limit on manure fertilisers and only relying on balanced fertilisation, it would have been very difficult to ensure that intensive livestock production would not pose a risk to water bodies. Without a clear and legally defined limit, total amounts of nitrogen applied to land would certainly be higher, as the calculation of optimal fertilisation rates on farms typically only takes into account the share of nitrogen in manure that is expected to be available for the crops during the current growing season. In most cases, the major part of the nitrogen

[9] de Boer et al (2024) “Lower nitrate leaching from dairy cattle slurry compared to synthetic fertilizer calcium ammonium nitrate applied to grassland” https://doi.org/10.1016/j.envpol.2023.123088

[10] A large share of the nitrogen in manure comes in organic form and is released slowly over several years.

[11] Ammonia emissions to the air later result in the deposition of nitrogen from the air, which can provide a significant additional contribution to the nitrogen balance in agricultural soils. In natural areas, lakes and coastal seas this can result in the eutrophication of natural ecosystems.

[12] Nutrient use efficiency refers to the share of nutrient contained in a fertiliser that is taken up in the crop.

contained in manure will not be considered when planning the fertilisation rates, as it will be considered unavailable[13] for crops, but which risk leach into waters. The manure application limit therefore has the potential to limit excessive nitrogen input and to be one of the determinant factors in the reduction of the N-surplus on agricultural soils. Excess nitrate concentrations in ground waters and eutrophication of surface waters due to nitrates from agriculture are key factors for not reaching good chemical and ecological status in water bodies.

- **Limiting phosphorus surplus in the soil and the risk of phosphorus emissions to water**: manure adds phosphorus to the soil - often in a higher ratio than nitrogen with regard to the crop needs and increases the potential of phosphorus runoff to aquatic environments leading to eutrophication. By limiting nitrogen application from manure, the directive indirectly controls phosphorus emissions. Without a limit, higher amounts of manure application will result in higher risks of over-fertilisation with phosphorus, leading to further phosphorus saturation of soils and higher risks of eutrophication. Eutrophication due to phosphorus from agriculture (from direct run-offs or erosion of saturated soils) is one of the key obstacles to reaching good ecological status in surface waters.
- **Limiting ammonia air emissions from manure production and application**: as manure application is generally responsible for about half of ammonia emissions associated with manure, the manure application limit directly limits ammonia emissions. The limit also contributes to limiting ammonia emissions from manure production and management in stables and storages, especially where the overall livestock density and manure production in a region remains within the boundaries of the amounts that can be applied on land in the same region. Ammonia emissions harm human health, but will also contribute to eutrophication of water, soils and nature. Atmospheric deposition of Ammonia is recognised as an important source of eutrophication of fresh and coastal waters in the EU.
- **Limiting organic matter run-off in water**: The presence of organic matter in drinking water can facilitate the growth of harmful microorganisms, posing risks to human health. The manure livestock limit set by the directive indirectly helps to minimize such risks. By regulating the application and management of manure, the directive contributes to reducing the runoff and seepage of organic material into water bodies.

Therefore, the limit of manure application not only limits nitrates emissions to water but also critically contributes to addressing other pathways and forms of emissions from manure (ammonia and phosphorus), which are key additional factors for eutrophication of surface waters. The multi-purpose role of the limit is intrinsically linked to the policy objective of limiting negative environmental effects of intensive livestock production and also explains why the limit equally applies to processed manure as it generally shares many of the same emission risks to air, water and soil as raw manure. Taking away the limit for the application of processed manure, which has been suggested by some stakeholders, would in effect bypass the limit as a whole and annul its intended effects in addressing the environmental risks of nitrogen pollution from the excessive

[13] In principle, the contribution from manure application in previous years should be considered in the calculations, but this contribution is reduced by losses to air and water and is difficult to assess.

concentrations of livestock, thereby undermining the objectives of the Nitrates Directive. The scientific publications brought together in the European Nitrogen Assessment of 2011[14] have indeed highlighted the cascading effect of nitrogen pollution, as reactive nitrogen released in the environment will transform from one pollutant into another, causing multiple environmental impacts.

The manure application limit not only contributes to the objectives of the Nitrates Directive, but by promoting sustainable agriculture and livestock production, also plays a key role in the achievement of the objectives of other EU legislations and international commitments. By limiting the risks of leaching of nitrates, the run-off of nitrates and phosphorus, the emissions of ammonia and ensuing depositions of nitrogen on waters and limiting run-off of organic matter, the manure application limit contributes to achieve the objectives of the DWD, the WFD, the MSFD, the NECD and the Air quality Directive, among others. Measures to limit ammonia and nitrates emissions from manure under the NECD and IED complement the manure application limit of the Nitrates Directive, but do not replace it. The manure limit is also instrumental in protecting aquatic and terrestrial biodiversity. It also supports key objectives of the CAP[15].

3. Is the limit of 170 kg N/ha per year appropriate?

While there is sufficient consensus that a limit on manure application is necessary to limit environmental impacts of manure and desirable to promote sustainable agricultural models, the ideal value for such a limit is more disputed. As mentioned above, the manure limit 170 kg N/ha is not an agronomic limit for specific crops, but a common precautionary threshold balancing the needs of agriculture and livestock production with environmental and public health concerns. Nevertheless, it reflects livestock excretion rates crop uptake and soil retention capacity for grassland and arable crops, as explained.

Thirty-five years after the adoption of the Directive, the 170 kg N/ha limit for manure application is recognised as generally appropriate for good agricultural practices and supporting sustainable agriculture. The fertilization limit encourages farmers to adopt practices that optimise nutrient use, improve efficiency, and enhance soil health, ultimately making agriculture more sustainable and reducing the need for chemical fertilisers. The limit also incentivises farmers to adopt organic farming methods thereby emphasising natural nutrient cycles and reducing reliance on synthetic fertilisers. This not only aligns with organic agricultural principles but also enhances soil biodiversity and health, contributing to a more resilient and sustainable farming ecosystem. The 170 kg N/ha limit has become the legal fertilisation norm for organic agriculture in the EU.

From an environmental point of view, the relevance of the 170 kg N/ha limit is confirmed by studies indicating that application rates above this threshold significantly increase the risk of nitrates leaching for many crops and soil/climatic conditions[16]. Studies indicate that when looking only at limiting groundwater pollution, manure application rates below or around that limit would be sufficiently safe for high nitrogen demanding crops and

[14] Sutton et al, The European Nitrogen assessment, 2011, CUP.
[15] See also Coherence analysis.
[16] Recommendations for establishing Action Programmes under Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources.

many soil types but applications above this threshold significantly increase the risk of nitrate leaching[17].

On the other hand, a limit at 170 kg N/ha for manure application may not always be strict enough to address eutrophication in fresh, coastal and saline waters due to the nitrogen and phosphorous emissions. Maximum nitrogen concentration levels to avoid eutrophication and support good ecological status are much lower than the groundwater drinking water norm of 50 mg/l of nitrates. Therefore, it is essential that all pathways of nitrogen pollution responsible for surface water eutrophication (deposition, surface runoff and ground water connectivity) are sufficiently controlled. Groundwaters with high levels of nitrates concentrations even below 50 mg/l can cause eutrophication when resurfacing to surface water bodies. As mentioned earlier, ammonia emissions from manure can also be responsible for eutrophication through deposition on water bodies.

The phosphorus content in livestock manure varies depending on the animal type and housing systems, but in many cases the 170 kg limit for nitrogen tends to result in an amount of phosphorus that exceeds crop needs, especially in regions with high legacy phosphorus content in agricultural soils. The concentration of phosphorus relative to nitrogen in livestock manure increases further due to the ammonia losses from animal housing and manure storages, which can result in N:P ratios manure ex storage well below 4, or even below 2 depending on the manure type[18] (which means inputs of P varying between 45 kg and 85 kg per ha for 170 kg N). The higher the application rate for total nitrogen, the higher the overall soil phosphorus surplus becomes[19]. In the Baltic Sea region, which is particularly sensitive to P, HELCOM (Baltic Marine Environment Protection Commission) has recommended a maximum application rate of 25 kg P/ha/year for Baltic states as a goal in manure-based applications to agricultural land[20].

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[17] See for example modelling studies in the Netherlands prepared by Wageningen University in 2005 comparing the leaching of nitrates in well managed grassland and maize systems fertilised with manure and chemical fertilisers or a combination of both.[Schröder et al., 2005, Limits to the use of manure and mineral fertilizer in grass and silage maize production in The Netherlands, with special reference to the EU Nitrates Directive]. On the one hand the studies show that on sensitive soils and dry climate, manure inputs above 170 kg N/ha significantly increase the risk of leaching above 50 mg/l. On the other hand the study shows that higher manure inputs up to 300 kg for maize and up to 600 kg N/ha for intensive mowed grassland in dairy farms would lead to average leaching of 50 mg/l at rootzone level in non-sensitive soils. These studies however have important limitations as they focus on a goal of nitrates leaching from a field at 50 mg/l. This is not in compliance with the objectives of the Nitrates Directive in polluted areas, nor does it take into account the risks of eutrophication of surface water. It is also the case that the manure fertilisation rates put forward in the studies, as admitted by the authors, would need to be significantly lowered to take into account real-life management conditions and the over-fertilisation by phosphorus and further lowered when the fertilisation of grassland is partly done through the grazing of animals rather than manure applied from a 100% indoor system. When taking all those factors into account, the manure amounts that would lead to leaching about 50 mg/l would range between 130 kg N/ha – 165 kg N/ha for maize and 170 kg N/ha and 230 kg N/ha for grassland, in mixed farming system with 30% maize.

[18] The ratio is generally higher for cattle and lower for pig and poultry.

[19] "While striving to meet the 170 kgN/ha/year limit, farmers will be applying levels of 60–80 kgP/ha/year. With a crop offtake of 20–40 kgP/ha/year, this would leave a surplus of 20–60 kgP/ha/year." Rosemarin, A.; Ekane, N.; Andersson, K. Phosphorus Flows, Surpluses, and N/P Agronomic Balancing When Using Manure from Pig and Poultry Farms. Agronomy 2021, 11, 2228. https://doi.org/ 10.3390/agronomy11112228. P 21.

[20] https://helcom.fi/about-us/convention/annexes-to-the_convention-2/annex-iii/. Combined with the 170 kgN/ha limit, the result of this requirement would be close to the N:P ratio needs for grain crops.

Moreover, in Member states with intensive livestock production and high manure application for decades, agricultural soils are already overloaded with phosphorus. This would indicate the need to strive to better P balances, taking into account the phosphorus already available in the soil. The JRC study[21] similarly argues that soil health and addressing eutrophication would rather call for a lower P limit than the indirect P limit provided through the 170 kg N/ha.

Whereas local conditions will influence the environmental effects of the manure on air quality and nature conservation, it is argued that overall standard levels of manure production of 170 kg N/ha could lead locally to very high ammonia emissions and N-deposition on nature.[22] Setting higher manure application limits to 200-250 kg N/ha would lead to even higher ammonia emissions and high risk of N-deposition on nature exceeding critical loads[23].

In the situations where the manure limit of 170 kg N/ha is too high for reaching environmental goals, it is open for the Member States to set lower limits adapting to local circumstances. For example, following the HELCOM recommendation to address eutrophication in the Baltic Sea, Sweden and Estonia are limiting phosphorus input from manure below 25 kg P/ha.

On the other hand, there are studies and arguments in favour of a higher manure limit. In specific conditions, such as grasslands with long growing season and sufficient rainfall, more manure could be applied without significant increase of nitrates leaching to groundwater[24]. This is however not a reason to question the 170 kg N/ha limit but rather an argument for flexibility in the application of the limit to cater for special circumstances, which is provided for in Annex III of the Nitrates Directive in the form of derogations from the limit, approved through a special procedure. Such cases substantiated the derogations under the directive. However, the implementation experience shows that these need to be managed cautiously, as the pollution risks increase with time and spatial concentration, and in many cases these derogations had to be brought to an end.

In this respect, following negotiations in the Council on the legal text, a clause was indeed inserted to allow Member States to set a higher manure application limit, subject to approval by the Commission and the Member States via a comitology procedure, where justified based on objective criteria such as long growing seasons, crops with high nitrogen uptake, high net precipitation in the vulnerable zone, or soils with exceptionally

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21 JRC study

22 Position paper, UNECE TFRN. How to define extensive livestock systems in relation to emissions to the environment. 2023. Estimations of nitrogen deposition and critical loads to avoid eutrophication would correspond to emissions of about 10 kg NH3/ha/year emission (as being typical of a representative critical load), whereas 2 LSU/ha UAA (with excretion rates of 80 kg/N per LSU) would corresponds to NH3 emission of 49 kg NH3/ha/year That would lead to very high NH3 concentrations and therefore, N deposition rates locally, which when extended over wider areas is likely to be in excess of critical loads. (This calculation is based on the expectation that livestock are housed for at least part of the year, leading to associated emissions from housing, manure storage and manure spreading, in addition to direct emissions while grazing).

23 Idem. Note that the consequences of ammonia emissions depend also on the wider concentrations of livestock in the region and that/or the proximity of farms to sensitive nature sites.

24 For example, inputs from the Wageningen University argue that higher N application rates (above 170 kg N/ha) would still keep nitrates concentrations in rootzones below 50 mg/l. [ref Wageningen uni input to public consultation]

high denitrification capacity. It should also be demonstrated that derogations do not jeopardise the attainment of the objectives of the Nitrates Directive. The comitology procedure reflects the sensitivity of the derogation with the Member States due to the risk of distortion (level playing field). The first derogations were granted in 2004, and their number has increased and reached 6 Member States in 2013. The amounts of manure authorised under the derogations typically varied between 220 and 250 kg N/ha. After 2013, the number of derogations has been steadily reduced. The European Commission initiated infringement proceedings due to declining water quality and ineffective measures in Germany (2013), Italy (2018), and Belgium-Flanders (2023), leading to the cessation of derogations in these countries. Denmark chose not to renew its derogation in 2024 due to water quality concerns. The Netherlands was in 2022 granted a "phasing-out" derogation until the end of 2025, agreed upon due to water pollution challenges.

While derogations should in principle be designed in a way that avoids negative environmental effects, there is increasing concern that the higher livestock concentration and manure production allowed by derogations have contributed to negative effects on water, soil, air quality and protected habitats in the Member States concerned. Whereas experience and studies in the Member States concerned have confirmed that more manure on grasslands on non-sensitive soils would not generally lead to significant increase of nitrates leaching to groundwater, this view does not sufficiently take into account the effects on eutrophication nor the cumulative effect of many derogations in the same region, with the ensuing higher concentration of livestock and levels of ammonia. The environmental impacts of allowing manure limits above 170 kg N/ha on a large scale in certain Member States have come under increasing scrutiny, due to the possible effects on the objectives of the WFD and Habitats and Birds Directives. A 2023 report from the European Court of Auditors (ECA)[25] concluded that derogations provided an opportunity for farmers to increase herd sizes and limited the achievement of the Nitrates Directive's objectives and recommended that the Commission should limit the use of derogations and review conflicting objectives in other policy areas.

4. A common limit throughout the EU

Another question around the manure limit is whether it is appropriate to have one common limit defined at EU level, rather than allowing Member States to set limits adapted to the crops and local circumstances.

As explained earlier, the manure limit is separate from the balanced fertilisation requirement. Through the balanced fertilisation requirement, farmers in NVZ must adapt the amount of fertilisers to the need of the crop, the available nitrogen in the soil, the expected yields and the local soil and climate conditions. Therefore, it is not the purpose of the manure limit to be an agronomic limit. Rather it provides a common threshold as part of the minimum common basis for all farmers in the EU (in NVZ) to mitigate environmental and health risks related to intensive livestock production. It provides a common legally binding value promoting a level playing field among farmers across the EU. It has acted as common minimum standard to comply with at EU level, allowing Member States to decide whether to use lower levels or to apply for derogations when they wanted to apply higher ones.

[25] Special report: EU efforts for sustainable soil management – Unambitious standards and limited targeting 19/2023. European Court of Auditors.

The common limit and the derogation process also involving the Member States through the Nitrates Committee help to maintain a common baseline and avoid distortions of competition in the internal market, which is also an important objective of the common agricultural policy. The comitology procedure has the added benefit of improving transparency and peer review among the Member States, which can contribute to greater attention to mitigating environmental effects, better trust in the rules and hence compliance throughout the EU. The common limit is also essential as a basis for organic farming and allows organic farms, where only manure is allowed as a fertiliser, to compete with other farms. Without a common limit for the EU, there is an additional risk of undermining the competitive position of organic farming, while the EU is promoting its expansion as one of the paths to increase sustainability of EU agriculture. In short, to achieve its goals the directive provides a share of responsibility between the Commission and the Member States in regulating and controlling the excess of fertilisers. By setting a common EU limit for manure which entails the highest risks and giving to Member States the responsibility to set the overall fertilisation limits (and thus limits on chemical fertiliser use) the directive has defined this crucial balance of responsibility and flexibility associated with the manure and chemical fertilisers.

If the Directive had let Member States set their own manure application limits, the pollution risks from manure may have been higher, as the Commission would not have had the opportunity to monitor and assess the impacts of higher limits through the derogation process[26]. Without a common legally binding limit and the specific derogation process, distortion and competition between livestock sectors in different Member States would lead to a "race to the bottom". As an illustration for comparison, Annex XII describes the approaches taken by Member States in applying balanced fertilisation, where experience shows that Member States find it difficult to regulate the fertilisation in relation to environmental concerns, and that the actual rates applied most often are calculated to maximise yields rather than minimise emissions. In Member States or regions with very high manure production, there would be a real risk that the limits are set to accommodate excess manure production levels rather than environmental concerns[27]. The risk of excessive flexibility is even higher for the manure limit than for the broader fertilisation limits. The latter have an economic upper limit in the form of the optimal economic rate (for the farmer) of fertiliser application. The corresponding optimal economic rate limit for manure application would far exceed the environmentally sustainable level. This is confirmed by the cases in which derogation requests have been addressed to the Commission from the national level, which were not supported by the situation on the ground and the water quality data. Without a common limit, it would have been very difficult to compare compliance efforts among Member States and to determine the risk posed to water bodies.

It is important to point out that the manure limit includes a number of flexibilities, *apart from the derogations*. These include the fact that the limit is applied at farm level, not at field level, which allows for excess manure production at the farm, thereby promoting circulation of nutrients between farms and recycling of nutrients. Therefore, it is not

[26] Derogation decisions typically come with a requirement of annual reporting of application and effects of the derogations, in addition to the four-yearly general implementation reports.

[27] Some farmers' organisations in those Member States and regions are calling for letting Member States set the manure limit.

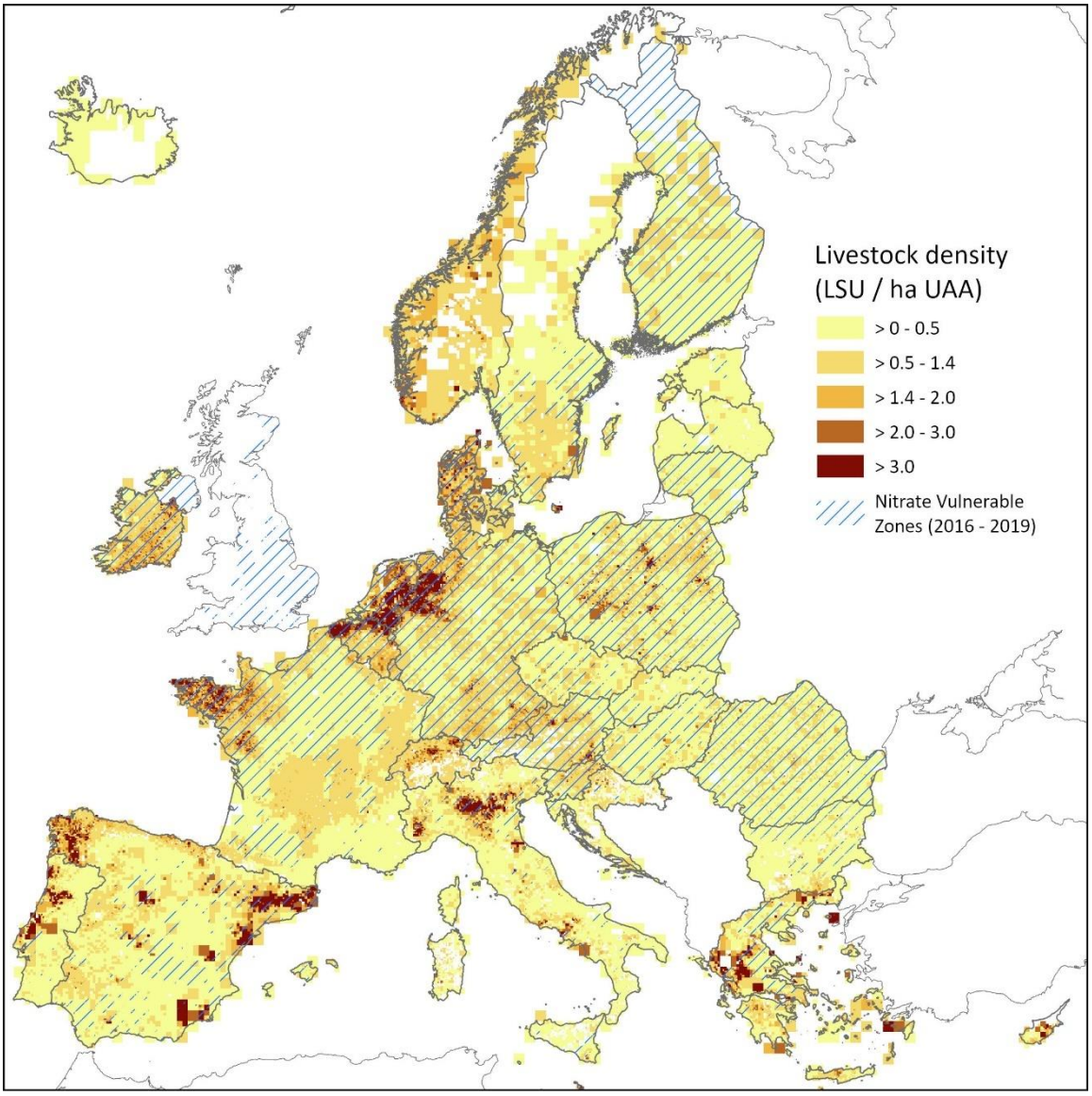
correct to state that the manure limit increases the use of chemical fertilisers (and associated GHG emissions)[28]. On the contrary the excess manure on one farm will be used on another farm (as raw or processed manure) and thus reduces the chemical fertiliser use by an equivalent amount on this other farm. So that there is no significant difference in GHG emissions as long as the manure or processed manure is reused on another farm[29]. This is rather an argument to accelerate the circulation of nutrients on the internal market as promoted under the Fertiliser Products Regulation. Annex XII further explains the inherent flexibilities of the manure application limit and how Member States have used these flexibilities. Annex XIX explains the role of the Nitrates Directive in promoting the recycling of nutrients, particularly from biogas digestates.

Overall, the large majority of Member State experts considered the limit effective, relevant and appropriate. However, some Member States continue to struggle with very high levels of manure production concentrated in a few regions, which makes it difficult to comply with the limit. This reflected - and still reflects - the agricultural sectors in the Member States where livestock density can in certain cases be much higher than the number of livestock units per hectare corresponding to the manure limit, even when looking at whole regions, let alone individual farms. Such high densities make it more challenging for livestock farms to comply with the limit on livestock manure application, as it may involve processing and exporting manure over larger distances and is an incentive for fraud. While this concerns only a small part of the entire territory of the EU, these regions account for a major share of total livestock production.

Figure 1 Livestock density (Livestock units / ha agricultural area) based on gridded Farm Structure Survey data for the year 2020 and Nitrate Vulnerable Zones.

[28] In consultations, farmers often point out that the manure limit is bad for climate goals because they have to use more chemical fertilisers.

[29] In cases where the reactive nitrogen is is transformed in atmospheric N2 to get rid of the excess manure, the manure would not replace chemical fertilisers. Such techniques are used in some regions with very high excess of manure.



Source: JRC analysis, 2025.

These very high-density areas also correspond to nutrient pollution hotspots, where the nutrient pollution in soil, air and water have negative impacts on human health and economic sectors, including tourism and fisheries, and make compliance with the Nitrates Directive and other EU environment legislation very challenging. One reason for this situation is that economic pressures for livestock concentration have largely prevailed over environmental considerations, and that it remained beneficial to increase livestock concentration in a few areas despite increasing costs for farms to dispose excess manure[30].

Therefore, the manure application limit, as a common minimum standard with inbuilt flexibilities, is not always sufficient on its own to reduce or maintain livestock concentrations below harmful levels, and it has thus not been sufficiently able to control the levels of nutrient pollution from manure in certain areas. It is for the Commission and the Member States in the comitology procedure to pay sufficient attention to these factors when granting derogations, but it remains the responsibility of the Member States to

[30] See also cost-benefit analysis.

enforce limits on livestock concentrations which are compatible with the environmental limits for specific areas and the requirements of EU law. In those areas, it may not be enough to limit the livestock manure application per farm but could be necessary to take into consideration the cumulative effects of the manure production by all farms in a region so as to ensure that there is coherence between the overall livestock density and the manure (including processed manure) that can be applied in the area without exacerbating the negative impacts on the environment.

A recent study[31] based on modelling concludes that reducing overall livestock density below two livestock units per hectare (i.e. 1.4 LSU/ha) could significantly reduce nitrates leaching and runoff. This is especially relevant in hotspot regions with the highest livestock densities, where reductions in the nitrogen surpluses and nitrogen leaching and run-off could reach 50%. Note that this does not mean that each farm would have to reduce its stocking rate to 1.4 LSU/ha, but that this level would be reached on average over a wider area, which could also be attained by promoting arable and mixed farming alongside farms specialised in livestock production. In its Vision for agriculture and food[32], the Commission highlighted that "special attention needs to be paid to improving nutrients management at farm level and increasing nutrients circularity. Priority should be given to addressing nutrient pollution hotspots and promoting integrated territorial approaches. A key aspect of this would be the management and control of nutrients from livestock farming to limit negative externalities, support extensification in regions with high livestock concentrations, and promote circularity which can help reduce the use of synthetic fertilisers".

5. Conclusions

Thirty-five years after the adoption of the Nitrates Directive, there is little doubt that limiting the amount of manure applied on agriculture land is necessary and justified to control nitrogen and phosphorus emissions from manure and processed manure, including with regard to other EU environmental goals. Setting a common limit for the application of nitrogen from manure has served as a pivotal benchmark in curbing different pathways of nutrient pollution from manure, contributing positively to limiting nitrates pollution and eutrophication. The multi-pathway role of the limit is intrinsically linked to the cascading effect of nitrogen pollution and the policy objective to limit negative environmental effects of intensive livestock production. This also explains why the limit equally applies to processed manure as it generally shares a number of similar risks of emissions to air, water and soil as raw manure. The manure application limit not only contributes to the objectives of the Nitrates Directive, but by promoting sustainable agriculture and livestock production, specifically plays a key role in the achievement of the objectives of other EU legislation and international commitments.

The manure limit of 170 kg N/ha was set not as an agronomic limit for specific crops, but as a common precautionary threshold balancing the needs of agriculture and livestock production with environmental and public health concerns. It applies in addition to the requirement of balanced fertilisation. It was seen as sufficiently high for the large majority of the livestock sector in the EU but sufficiently constraining to avoid major

[31] Assessing the effectiveness of the Nitrates Directive: implications for agriculture and for water, soil and air quality. JRC, 2025 (in review).

[32] COM/2025/75 final

water pollution situations. It provides a common legally binding value promoting a level playing field among farmers across the EU. The manure application limit is recognised as generally appropriate for good agricultural practices and has become the reference point for sustainable agricultural practices. By promoting the responsible (re)use of manure, limiting key pollutants and enhancing ecosystem protection, it has been integrated as the legal norm for fertilisation in the organic farming regulation. Without a common legally binding limit and the specific derogation process, distortion of competition between livestock sectors in different Member States would have a much higher risk of leading to a "race to the bottom".

On the other hand, environmental and human health protection as well as EU law requirements would often call for a precautionary approach. Applying up to 170 kg N/ha on agriculture land may not be appropriate in all situations as it may not sufficiently limit the soil, water and air pollution by nitrogen and phosphorus, nor the negative impacts on biodiversity. The necessity to address eutrophication and the experience gained from the cumulative and long-term environmental effects of high levels of manure application (including due to derogations) could rather point to a necessity of lowering the manure application limit in some polluted areas. A lower limit may also be warranted for certain types of crops or soil types. In the situations where the manure limit of 170 kg N/ha is too high for reaching environmental goals, it will be for the Member States to set lower limits adapting to local circumstances.

Member States can apply for derogations to apply manure above the 170 kg N/ha limit under specific conditions. The common limit and the derogation process through the comitology committee help to maintain a common baseline and avoid distortion of competition, which is also an important objective of the common agricultural policy. However, derogations to the manure limit have come under increased scrutiny as there is increasing concern that the higher livestock concentration and manure production allowed by derogations have contributed to negative effects on water, soil, air quality and protected habitats in the Member States concerned.

The manure limit still includes a number of flexibilities, apart from the derogation. These include the fact that the limit is at farm level and that the limit does allow for excess manure production at the farm, thereby promoting circulation of nutrients between farms and recycling of nutrients. By enforcing a maximum of 170 kg of nitrogen per hectare annually, Member States are incentivised to adopt improved nutrient management practices encouraging farmer accountability and promoting innovation in fertiliser use and livestock management, thereby advancing both ecological and economic objectives across the EU. The Directive allows for updates as new scientific data and agricultural practices emerge, helping ensure that the limit remains relevant and effective. The Commission has amended the directive to allow some forms of recycled nitrogen compounds from manure (RENURE) to be used above the limit.

While the large majority of Member State experts considered the limit effective, relevant and appropriate, the manure application limit, as a common minimum standard, is not always sufficient on its own to reduce or maintain livestock concentrations below harmful levels. As economic factors for livestock concentration have prevailed over environmental considerations, the limit on its own has not been sufficiently able to control the levels of nutrient pollution from manure in certain areas, making compliance with the Nitrates Directive and other EU environment legislation very challenging. In its

Vision for agriculture and food, the Commission highlighted that priority should be given to addressing nutrient pollution hotspots.

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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XVIII. IMPACT OF NITRATES DIRECTIVE ON COMPETITIVENESS OF EU AGRICULTURE

Contents

1. Introduction
2. Income-related indicators
3. Activity level indicators
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1. Introduction

This Annex presents an econometric analysis of the impact of the Nitrates Directive (ND) on the competitiveness of farms in the European Union[1]. Competitiveness is assessed through several indicators that capture farm performance. The analysis exploits the distinction between farms located in Nitrate Vulnerable Zones (NVZs), where the ND is binding, and those outside NVZs, where it is not. This setup enables an effective comparison between farms directly affected by the ND and those unaffected.

We will assess the impact of the ND on two groups of indicators:

- Income-related indicators (costs, margins, income and subsidies) provide insight into the effect of the ND on farmers' cost structure and income.
- Activity-level indicators (crop yields, livestock numbers) capture structural changes in agriculture potentially resulting from the ND.

The effect of the ND on these indicators is estimated econometrically, using EU-wide farm-level panel data covering the period from before the first adoption of the ND in the early 1990s up to 2023. A fixed-effects regression framework is used, exploiting both the time dimension (before vs. after implementation) and the cross-sectional variation (affected vs. unaffected farms) in a single analysis. The main explanatory variable in this approach is the percentage of agricultural land that is designated as NVZ in each region, over time (Copernicus, 2018; European Environmental Agency, 2024; Eurostat, 2021). This variable serves as a proxy for the extent to which the ND has been implemented in each region. By comparing farmers in regions with varying ND adoption rates over time, one can arrive at an estimate of the effect the ND has had with regard to the above indicators.

[1] The analysis was performed by a consultant from Ghent University as part of a service contract supporting the evaluation of the Nitrates Directive. The entire study including methodological annexes is published in ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

2. Income-related indicators

Methodology

Table 1 provides an overview of the income-related indicators that are considered, accompanied by their respective definition from FADN[2] (Committee for the Farm Sustainability Data Network (FSDN), 2025). To test for an association between these indicators and the ND, a fixed-effect regression framework was used, with the indicator as the dependent variable and the regional share of NVZ as the main predictor. To account for the differential impact of the ND in regions with high livestock density, the interaction between NVZ coverage and livestock density was incorporated into the model. Price indices were used as controls. Year-, region-, and farm-type fixed effects were used to control for unobserved heterogeneity across years, regions, and farm classes. Regional granularity is at the NUTS2 level, or in some cases, at the NUTS1 Level or country level, depending on FADN data availability. The analysis was performed separately for livestock and arable farmers in order to account for the differential effect of the ND on both activities.

Table 1 Income-related indicators that are considered in the analysis and their definition according to FADN (Committee for the Farm Sustainability Data Network (FSDN), 2025). FADN-code is given between brackets.

Indicator	Definition (FADN)
specific costs (€/LU or €/ha)	Crops: Total specific crop costs, i.e. seeds and plants (both purchased and home-grown), fertilisers, crop protection products and other specific costs related to crop production / Total utilised agricultural area of holding (SE284). Livestock: Total livestock costs, i.e. feed, veterinary costs and other livestock-specific costs / Number animals present on holding (annual average), converted into livestock units (SE309).
specific output (€/LU or €/ha)	Crops: Total crop output (SE135)/ Total utilised agricultural area of holding (SE025). Livestock: Total livestock output (SE206) / Number animals present on holding (annual average), converted into livestock units (SE080)
specific margin (€/LU or €/ha)	specific output (€/LU or €/ha) - specific costs (€/LU or €/ha)
farm net income (€/farm)	Farm Net Income (SE420): Total output (SE131)+ – Intermediate Consumption (SE275) + Balance Subsidies/Taxes (SE600)– Depreciation (SE360) – Total External Factors (SE365) + Balance Subsidies/Taxes on Investments(SE405)
farm subsidies (€/farm)	Total subsidies excl. on investments (SE605) + Subsidies on investments

[2] The Farm Accountancy Data Network (FADN) is a stratified sample survey of commercial farms across the EU, designed to represent the economic performance of the agricultural sector. It covers roughly 1.5–2 % of all EU farms, representing about 90 % of total agricultural output value and around 40 % of agricultural area. Sampling is stratified by region, farm type, and economic size to ensure representativeness of the main production systems (EC DG AGRI, 2020).

	(SE406)

Livestock production

The effect of the NVZ designation and its interaction with country-average livestock density (LD, LU/ha) on various income-related indicators for livestock production is presented in Table 2. The net effect of the ND is always a combination of the isolated effect of the NVZ in the left column, and the change of the isolated effect with increased regional livestock density[3]. The net effect is the effect of the NVZ, compared with regions outside of the NVZ both with any level of regional livestock density[4].

Table 2 The effect of the share of NVZ and its interaction with the average livestock density (LD) at the country level (LU/ha) for various income-related indicators for livestock production, expressed in %. 95%-confidence interval between brackets. The datasets consist of all livestock-producing farms for the product-level indicators, and farms of specific farm categories for farm-level indicators[5]. Statistical significance according to legend in the last row[6].

Income related indicator	NVZ effect (%)	NVZ_share effect × country-average LD (%/LU/ha)	Interpretation
Product-level indicators. Based on all FADN farms with livestock production.			
Specific livestock costs (€/LU)	**21.3 (***)** **(11 ; 31)**	**10.4 (*)** **(-1; 23)**	NVZ exposure is associated with higher costs and the effect is increased at high livestock density (10.4% increase per unit increase in the country average LD (LSU/ha).
Specific livestock output (€/LU)	**13.7 (***)** **(6 ; 22)**	1.8 (ns) (-6 ; 10)	NVZ exposure is associated with higher output, with no significant effect of regional livestock density.
Specific livestock margins (€/LU)	5.6 (ns) (–16 ; 27)	**-6.3 (***)** **(–9 ; –3)**	NVZ exposure has little effect on margins in low density regions but is associated with a statistically significant decrease of margins

[3] For example: for a Member State with an average livestock density of 1 LSU/ha, the combined effect of the NVZ on specific livestock costs is 21.3% (base effect NVZ) + 1*10.4% (LD effect) = 31.7%.

[4] The latter is valid, as the isolated effect of the regional livestock density is not significant for any of the indicators (ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

[5] Why not taking the same subset for both analyses? Taking only the mentioned farm types for the analysis of livestock margins decreases the number of observations and makes the statistical model less powerful. Taking all farms with any livestock in the analysis of farm income, would include farms for which income from other sources than livestock is more important than livestock, obscuring the effects of the NVZ on income of livestock farmers, via its effect on livestock production.

[6] As an example, the first row can be interpreted as follows: Livestock farming in a region that is 100% designated as NVZ, is associated with specific livestock production costs that are 21.3% higher than in a region that is fully outside of the NVZ (at 1% significance). This effect is increased by 10.4 percentage points for every unit increase in the average livestock density (LU/ha) where that region is located (at 10% significance). The percentages are to be interpreted as relative compared to farms outside of the NVZ at any level of regional livestock density, as the effect of regional density as such is statistically not significant.

			with increasing regional livestock density.
Farm-level indicators. Based on a subset of FADN farm categories, for which livestock contribute for an important part to farm income: "Other grazing livestock", "Granivores", "Mixed", "Milk"			
Farm Net Income (€/farm)	4.9 (ns) (–24 ; 34)	-1.2 (ns) (–28 ; 26)	NVZ exposure has no significant impact on overall farm net income; slight negative trend for high-density farms (but not significant).
Total subsidies[7] (€/farm)	19 (.) (-3.58 ;41.6)	10.2 (ns) (-7.01 ; 27.4)	No o**r very weak** evidence for a statistically significant effect of NVZ exposure on subsidies, independent of density.
(***) at 1% (**) at 5% (*) at 10% (.) at 15% (ns) not significant			

The results indicate that livestock farming in a region that is 100% designated as NVZ is associated with specific livestock production costs that are 21.3% higher than in regions fully outside the NVZ, at low levels of livestock density. At the same time, specific livestock output is 13.7% higher for this group. These effects largely offset each other, as no significant impact is observed on livestock margins. This suggests that, at low regional livestock density, the nitrate directive (ND) increases costs, but higher productivity correlated with the NVZ[8], results in no net effect on margins.

At elevated levels of livestock density, the interaction term shows that specific livestock costs associated with the ND increase by 10.4% per unit increase in livestock density at the country level (LU/ha), compared to farms in regions with any livestock density outside of the NVZ. The interaction term for the NVZ and livestock density for specific livestock output is not significant. This means productivity does not appear to rise proportionally in NVZ regions with higher livestock density, which is in contrast to the case of costs. Given that the additional cost increase is not offset by higher output in livestock-dense regions, a decreasing margin at increasing livestock density is expected. This is indeed the case, as data suggests a 6.3% decrease in livestock margin per unit increase in livestock density. This interaction term indicates that the effect of NVZ coverage on margins increases with higher livestock density. While the average NVZ

[7] Subsidy coefficients should be interpreted with caution. Statistically, once year and country fixed effects are controlled for, there is very limited within-country variation left for NVZ coverage to explain. This pattern reflects the structure of agricultural subsidies, which are primarily determined by national-level CAP implementation choices (country fixed effect) and policy reform cycles (year fixed effects) rather than by regional characteristics. In contrast to the production and cost indicators, where substantial regional heterogeneity allows for a clear identification of NVZ effects, subsidies exhibit almost no spatial variation that is independent of broader policy shifts.

[8] The correlation between NVZ designation and productivity increases does not imply causality. Indeed, while it might be true that NVZ exposure has lead to more efficient input use (causality), it might also be true that historically, regions with higher productivity have been more sensitive to water pollution leading it to be designated as NVZ (reverse causality). Although methodological methods have been taken to limit reverse causality, it cannot be ruled out entirely.

effect at low density levels is statistically indistinguishable from zero, the negative interaction suggests that NVZs are associated with lower margins in more intensive regions[9].

The observed increase of production costs due to the ND and the effect of regional livestock density thereon, are consistent with the estimates for implementation costs on farms set out in section 4 of the evaluation report (see also ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming)). The cost assessment also includes the breakdown of the ND adjustment costs revealing the cause of the increased production cost. This analysis revealed that costs are dominated by storage and buffer strip costs in areas with low livestock density and increase with increased regional livestock density due to the costs related to excess manure management (transport, processing and disposal) in the livestock sector. Indeed, when regional livestock density increases, the most cost-effective options for excess manure management would be exhausted first, and marginal production costs increase[10].

At the farm income level, no significant effects are observed for the ND nor for the interaction with livestock density. This suggests that NVZ exposure has had no significant impact on overall farm net income; neither at low or at elevated levels of livestock density. For lower-density regions, the lack of a net income effect is not surprising as the effect on livestock margins is not significant as well. However, the result at increasing livestock density is, as the observed effect on livestock margins is not translated into an effect on farm income.

Several factors might explain this. The first element is the fact that margins are observed at the product level and income is observed at the farm level. As a consequence, the margins in livestock products can be analysed in all farms in the FADN dataset that produce these products, while the analysis of the effect on income is only meaningful for farmers for which these products play an important role in farm income. These are the farmers classified as "Other grazing livestock", "Granivores", "Mixed" and "Milk" in FADN. So the analysis does not use identical subsets of farms. Secondly, the observed effects of livestock margin might be moderated at the level of income, as farm income is derived from more than livestock products alone. This is especially the case for ''Mixed" farming types, that have significant income from both livestock and crops. Finally, other factors such as subsidies are included in farm income, but not at the level of product margin. Although this effect might be limited, as no significant evidence of an effect of the NVZ on subsidies was observed.

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9 To estimate the net effect of the NVZ on the livestock margin, both the NVZ coefficient as well as the level of LD and the interaction term are required. E.g., at LD = 0.5, the effect is $0.056-0.063\times0.5=0.0245$.

10 When a farm produces more manure than can be applied at its lands during a full year (even after storage), it needs looking for alternatives to spreading on own land. This can be spreading on other farmer's lands, but also other management options such as manure separation, (biological) treatment or long-distance transport. Costs will dictate what options are applied. The least costly one (disposal on other lands) is applied first, but is exhausted when LD is high, as disposal on surrounding lands becomes limiting as well. Then, more expensive options come into play, such as treatment options and long-distance transport.

Crop production

The effect of NVZ designation on various income-related indicators for crop farmers and its interaction with country-average livestock density (LD, LU/ha) is presented in Table 3 below.

Table 3 The effect of the share of NVZ and its interaction with the average livestock density (LD) at the country level (LU/ha) for various income-related indicators for crop production, expressed in %. 95%-confidence interval between brackets. The datasets consist of all crop-producing farms for the product-level indicators, and farms of specific farm categories for farm-level indicators[11]. Statistical significance according to legend in the last row[12].

Income related indicator	NVZ effect (%)	NVZ_share effect × country-average LD (%/LU/ha)	Interpretation
Product-level indicators. Based on all FADN farms with crop production.			
Specific crop costs (€/ha)	1.5 (ns) (−8; 11)	2.1 (ns) (−5.1; 9.4)	No evidence for a statistically significant effect of NVZ exposure on specific crop costs, independent of density.
Specific crop output (€/ha)	1.5 (ns) (−14.8; 17.8)	21.2 (ns) (−0.190; 0.615)	No evidence for a statistically significant effect of NVZ exposure on specific crop output, independent of density.
Specific crop margins (€/ha)	9.8 (ns) (−8.4; 28)	2.1 (ns) (−7.3; 11.5)	No evidence for a statistically significant effect of NVZ exposure on specific crop output, independent of density.
Farm-level indicators. Based on a subset of FADN farm categories, for which crops contribute for an important part to farm income: "Fieldcrops", "Other permanent crops", "Horticulture", "Mixed".			
Farm Net Income	−22.5 (.) (−49; 4)	+20.9 (.) (-5; 47)	NVZ exposure is associated with lower farm income, but the effect reverses with increasing livestock density. At country averages higher than 1.07 LSU/ha[13], the

[11] Why not taking the same subset for both analyses? Taking only the mentioned farm types for the analysis of arable margins decreases the number of observations and makes the statistical model less powerful. Taking all farmers with any arable income in the analysis of farm income, would include farms for which income from other sources than crops is more important than crop production, obscuring the effects of the NVZ on income of arable farmers, via its effect on crop production.

[12] As an example, the first row can be interpreted as follows: Arable farming in a region that is 100% designated as NVZ, is associated with crop production costs that are 1.5% lower than in a region that is fully outside of the NVZ. This effect increases by 10.4 percentage points for every unit increase in the average livestock density (LU/ha) where that region is located. The percentages are to be interpreted as relative compared to farms outside of the NVZ at any level of regional livestock density, as the effect of regional density as such is statistically insignificant.

[13] Since the NVZ share and the regional livestock density work in opposite direction. The point where the effect switches direction happens at an LSU level of 1.07 LU/ha since, -0.225 + 1.07*0.209=0.

(€/farm)			correlation becomes positive.[14] Effects significant at 15% level.
Total subsidies (€/farm) [15]	+27.5 (.) (-2.91; 57.9)	+0.772 (ns) (-34.3 ; 35.8)	No o**r very weak** evidence for a statistically significant effect of NVZ exposure on subsidies, independent of density.
(***) at 1% (**) at 5% (*) at 10% (.) at 15% (ns) not significant			

The results indicate that there are no statistically significant effects of NVZ exposure on specific crop costs, output, or margins, independent of livestock density, at significance levels of 1%, 5% or 10%.

At 15% significance level, NVZ exposure is associated with a 22.5% decrease in farm net income at zero density levels. Interestingly, this effect reverses with increasing livestock density: the interaction term shows a positive effect of 20.9% per unit increase in LD, also significant at the 15% level. The net effect of both these effects will depend on the country-average livestock density[16]. Given that these findings are only significant at 15%, they are accompanied by large confidence intervals, suggesting substantial uncertainty in these estimates.

The counteracting effects on crop farm income suggest that in regions with high livestock density, NVZ designation may actually benefit crop farm incomes. This pattern can plausibly be explained by increased manure distribution from livestock farms to crop farms, reducing fertiliser costs for arable farmers in densely stocked regions. This observation is consistent with the estimates for implementation costs on farms set out in section 4 of the evaluation report (see also ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming)), where positive effects for crop production were found under the ND in livestock dense areas, both as a consequence of less mineral fertiliser spending, as well as the income

[14] Due to manure limits under the ND, some livestock farmers have manure surplus, which gives rise to manure transport. Arable farmers can accept manure from manure surplus farmers, resulting in a decrease in their fertilizer spending, explaining the positive effect of regional livestock density on arable farmer's income within the NVZ.

[15] Subsidy coefficients should be interpreted with caution. Statistically, once year and country fixed effects are controlled for, there is very limited within-country variation left for NVZ coverage to explain. This pattern reflects the structure of agricultural subsidies, which are primarily determined by national-level CAP implementation choices (country fixed effect) and policy reform cycles (year fixed effects) rather than by regional characteristics. In contrast to the production and cost indicators, where substantial regional heterogeneity allows for a clear identification of NVZ effects, subsidies exhibit almost no spatial variation that is independent of broader policy shifts.

[16] For a farms in a country with a livestock density of 0.5 LU/ha, the effect would be 22.5%-0.5*20.9=12%.

from manure disposal fees[17]. For total subsidies, no significant effects of NVZ exposure were observed, and this remained the case regardless of livestock density.

In summary, unlike in the livestock sector, NVZ exposure has limited direct impact on crop costs, output, or margins. The only notable effect appears in farm income in livestock-dense regions, likely reflecting the indirect benefit of manure redistribution under the ND.

3. Activity level indicators

Animal numbers

The regional animal number is used as an indicator of competitiveness, as it reflects the level of economic activity in the livestock sector within a given region. It can be hypothesised that if the ND has created a competitive (dis-)advantage for affected farmers over the past 30 years, this would be observable in a change in livestock activity. This does not mean that the ND has targeted or limited livestock numbers directly, but rather that the set of measures implemented in the region has increased costs to livestock owners, making the activity less competitive. Therefore, one would expect to see a divergence in livestock number trends between regions located within NVZs or outside, if there have been differing trends in competitiveness.

To estimate the relationship between NVZ policy intensity and livestock density, the model adopts a panel regression framework at the NUTS-2 regional level. The dependent variable is the relative change (compared to pre-ND levels) in the logarithm of livestock density, measured as the log-difference over multi-year intervals, in order to mitigate selection bias[18]. The analysis draws on data from Eurostat (Eurostat, 2023, 2024, 2025b, 2025a). The regression results are summarised in Table 4.

Table 4 Coefficients and p-values[19] of the effects of the ND (NVZ share) on livestock density of pigs and cattle. Effects significant at 5% confidence level are indicated in bold. Short term effects are observed within 2 years of the policy adoption; long term effects are observed later.

Variable	Estimate	Std Error	p-value
Cattle sector			

[17] In livestock dense regions under the ND, land disposal of manure is limited and arable farmers having excess land for disposal receive monetary compensation from farmers with manure excess for accepting the manure on their land.

[18] Selection bias arises from the possibility that NVZ designations are not randomly assigned and might tend to be introduced in regions already characterised by intensive agricultural activity and high livestock density. That could lead the reverse causality when interpreting the results. Selection bias might be true for some member states, although some member states adopt a full country approach in which the whole territory is designated as NVZ, regardless of farming intensity. This is the case for DE, DK, AT, NL amongst others. The econometric model minimizes this bias.

[19] The p-value represents the probability of obtaining a test statistic at least as extreme as the one observed, under the assumption that the null hypothesis is true. In simpler terms, it tells us how likely it is that our results could have happened just by random chance if there were actually no real effect. When the p-value is lower than e.g. 5%, this means that the likelihood of the effect being observed by chance (instead of there being an actual effect) is lower than 5%.

Δ NVZ share *(short-term effect)*	0.0037	0.0372	0.9218
NVZ share *(long-term effect)*	-0.0197	0.0337	0.5615
Pig sector			
Δ NVZ share *(short-term effect)*	-0.0250	0.0854	0.7745
NVZ share *(long-term effect)*	0.3199	0.2036	0.1421

For cattle, they indicate no statistically significant effect of NVZ policy on regional cattle density growth. Both the long-term share of NVZ area (NVZ_share, $\beta = -0.019$, $p = 0.56$) and its short-term change (ΔNVZ_share, $\beta = 0.003$, $p = 0.92$) are relatively small and not statistically significant. This suggests that, despite regulatory pressure in NVZs, there is no evidence that the cattle sector has responded systematically by reducing herd sizes. A similar conclusion arises for pig density: neither short- nor long-term NVZ exposure effects are statistically significant at the 5% level. Contrary to cattle, the NVZ coefficient for pigs is positive[20] and marginally significant at the 15% level (ΔNVZ_share, $\beta = 0.31$, $p = 0.14$), suggesting that pig herd sizes might have responded somewhat different to ND than cattle herd sizes, although at 15%, the evidence is very weak[21].

These results suggest that the ND has not influenced the competitiveness of the livestock sector to the extent that it has led to decreases in livestock numbers when comparing EU regions designated as NVZs with those that are not. These findings are consistent with the results observed at the level of farm income, where no evidence of a long-term effect of the ND on farm income was identified.

This does not imply that livestock numbers remained unchanged; rather, it indicates that any changes observed were not statistically different between regions within and outside of the NVZs. This pattern reflects the structure of past trends in animal numbers, which have been influenced by factors other than the ND, such as path dependency, consumer preferences, CAP support, prices, and macro drivers (EC, 2023; Neuenfeldt et al., 2019). In the statistical model, these effects are captured by year and country fixed effects. After correcting for those effects, there is very limited variation left for NVZ coverage to explain.

Crop Yield

Balanced fertilisation within the ND has decreased the amount of fertiliser farmers use. This policy might be associated with a change in crop yields. To estimate the relationship

[20] The positive correlation between NVZ and pig numbers might reflect developments in regions such as Catalonia and Aragon (Spain), where pig numbers have respectively doubled and nearly quintupled since the 1990s, despite long-standing NVZ designations (38% since 2007 in Catalonia; 15% since 2004 and 40% since 2020 in Aragon).

[21] Several factors may explain the differing responses of the cattle and pig sectors to NVZ exposure (1) Manure transport and manure treatment are generally cheaper for pigs due to higher nutrient concentration and easier collection and handling. (2) Pig farming systems, being largely indoor and intensive, can adapt more easily to environmental regulations than the land-based systems typical of cattle farming. (3) As a less land-dependent activity, pig farming is more suitable for spatial agglomeration and economies of scale, enabling continued growth even under stricter environmental constraints.

between NVZ policy intensity and crop yields, the model adopts a panel regression framework at the reference farm level.

The idea behind this statistical analysis is that if balanced fertilisation leads to suboptimal fertilisation, we would see significant differences in yield evolution between regions inside and outside the NVZ. If so, it would create a competitive disadvantage for farmers affected by the ND. The analysis was done for maize and wheat yields in the FADN data (European Commission, 2019). Table 5 shows the results of the regression analysis.

Table 5 Coefficients and P-values of the effects of the ND (NVZ share) on livestock density of pigs and cattle. Effects significant at 5% confidence level are indicated in bold. Short term effects are observed within 2 years of the policy adoption; long term effects are observed later.

Variable	Estimate	Std Error	P value
Wheat			
Δ NVZ share *(short-term effect)*	**-0.032**	0.007	0.004
NVZ share *(long-term effect)*	**0.073**	0.026	0.024
Maize			
Δ NVZ share *(short-term effect)*	-0.053	0.047	0.317
NVZ share *(long-term effect)*	**0.114**	0.029	0.011

The results indicate that in the short term, the impact of the ND is either not significant (maize) or slightly negative (-3.2%). The negative effect could be related to the short-term decrease in mineral fertiliser use, leading to decreased crop yields. However, for both maize and wheat, the long-term effects of the ND on crop yields are positive. This might indicate that farmers adapt to balanced fertilisation requirements and achieve yields that are higher than those of farmers without these requirements. A causal interpretation of this effect should be made with care, because of the risk of selection bias[22]. Additional analysis of crop yield data from Eurostat[23] confirms the absence of a long-term negative effect; however, it does not confirm a significant positive effect in the long term[24]. However, some explanations for the observed positive correlation could be

[22] The positive relationship between the ND and crop yields might also be related to selection bias in the model setup, referring to the likelihood of high intensity farms (or regions) being targeted by the ND. The model accounts for this effect in various ways, but some remaining impact of this effect should nevertheless not be ruled out.

[23] ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

[24] The fact that significant effects are not confirmed in both analyses originates from the use of different source data. Eurostat data provides more crop specific information, but it has less observations and

that: (1) NVZs have larger, more commercial farms, possible having stronger capacity to adopt high-efficiency machinery and optimise operations and benefiting from scale economies (Bokusheva R & Kimura S, 2016; OECD, 2023) and (2) NVZs often come with stricter nutrient management rules and monitoring. Farms operating under such regimes may adopt precision agriculture technologies (e.g., variable-rate fertilisation, yield mapping, NDVI monitoring) to comply and optimise productivity. Empirical studies find that such technologies improve yield and nutrient use efficiency (Basso et al., 2016; Silvestri et al., 2024; Videgain et al., 2024).

Given these findings, the general impact of balanced fertilisation on crop productivity appears to be limited, and even slightly positive. As a result, we find no evidence that the ND has had a significant impact on crop productivity. This finding aligns with the results at the level of farm income, where evidence of a long-term effect of the ND on farm income was not observed. Additionally, this result aligns with the technical literature on field trials, suggesting that fertilisation under balanced fertilisation standards tends to be at the agronomic optimum (Hofman et al., 2014).

4. Discussion of the results according to scientific literature

The previous sections have analysed the impact of the ND on livestock and crop production farmers, using statistical analysis based on FADN data. Income-related and activity-related indicators were analysed to account for both financial and structural impacts. The analysis compares farms within and outside the NVZ before and after implementation of the ND[25]. This way, farms impacted by the policy are statistically compared to their situation before implementation and the situation of comparable farms not impacted by the policy.

This analysis reveals that livestock production systems have been more significantly impacted by the ND than crop production systems.

For livestock farms, exposure to NVZ measures is associated with higher specific production costs (+21%) and higher specific outputs (+14%), both of which are significant at the 5% level. These effects offset each other at low livestock density levels, resulting in no significant change in livestock margins. However, at higher country-average livestock density, costs increase further—by about +10% per additional livestock unit per hectare (LU/ha)—while output does not increase proportionally. As a result, livestock margins decrease by approximately −6% per LU/ha, consistent with the notion that higher-density regions incur greater costs from ND compliance (e.g., manure management, storage, or transport). At the level of farm net income, no significant ND effect is observed.

By contrast, for crop farms, no statistically significant effects are found for the farmer in NVZ or its interaction with livestock density. Only a weak negative association

therefore less statistical power. On the other hand, FADN data contains more observations, but only reports on the yields of wheat and maize.

[25] Data ranged from early 90's to 2022, the starting point being dependent on data availability in country level.

(significant at the 15% level) is observed for farm net income (−22%), which becomes positive in regions with higher livestock density. This is consistent with a situation where, in areas where arable and livestock activities coexist in conditions of high livestock density, the ND has fostered manure redistribution from livestock to crop farms, thereby reducing fertiliser costs and improving crop farmers' net positions.

Overall, the results indicate that the ND has imposed higher compliance costs on livestock systems, especially in high-density regions. Conversely, crop systems have been mitigated through nutrient recycling and cross-sectoral adaptations.

The effects found at the farm income level are consistent with those identified at the activity level. Since income from livestock production has not exhibited a significant change, a corresponding effect on the number of animals is not expected. Indeed, the statistical analysis provides no evidence of significant changes in animal numbers in regions impacted by the ND, compared with others. This holds true for both cattle and pig production. However, this does not imply that animal numbers have remained stable over the past 30 years; rather, it indicates that historical trends in animal numbers have not differed significantly between regions within or outside the NVZ.

One of those trends has been a decrease in livestock density in the EU. This is shown in Figure 1 on Cattle and pig density in heads/ha per member state between early 90's and 2023 (Eurostat, 2025a). Most member states have seen stagnating or decreasing trends for both cattle and pig numbers over the last decades[26]. The total number of LU for EU-27 member states taken together fell from 121 million LSU in 2007 to 113 million in 2020. This trend has been observed in countries with varying degrees of exposure to the ND, and in some instances, started well before the inception of the ND[27]. Moreover, some regions have seen a notable increase in animal numbers (for instance, pigs in Catalonia and Aragon, Spain), despite being at least partially designated as NVZ. This suggests that other factors may play a more significant role in animal population trends than the ND (CAP, prices, macro drivers etc.). In the livestock sectors, Neuenfeldt et al. (2019)[28] shows that farm structural change is mostly determined by path dependency followed by – especially for livestock - natural conditions such as land type and topography and input and output prices (Neuenfeldt et al., 2019). Other sources cite prime drivers for shifts in animal numbers to be consumer demand (population and dietary preferences), commodity and meat prices and CAP support (EC, 2023).

Measures in the ND are typically more costly for farmers in livestock-dense regions[29]. As a result, it would be expected that the concentration of livestock production would decrease and become more evenly distributed across regions. However, Figure 1 shows

[26] With Spain (pigs) and Cyprus (cattle) as notable exceptions to this trend.

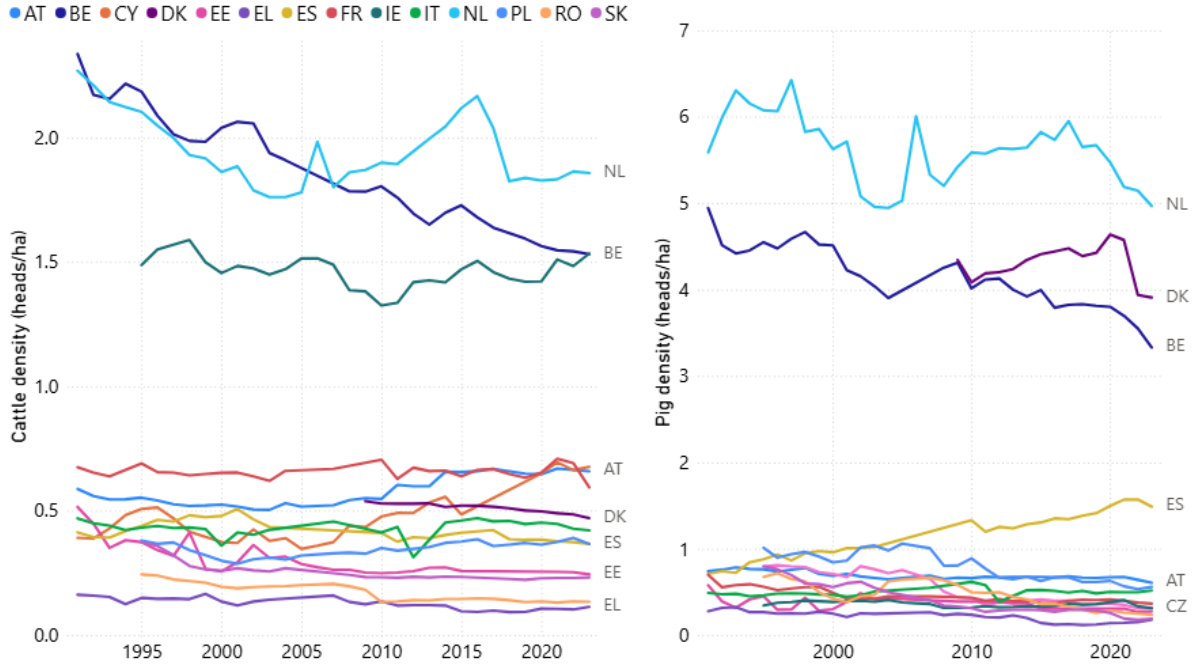
[27] For example, in Belgium, cattle number decrease ever since the late early 90's, while the ND livestock limit became binding around 2002.

[28] Sebastian Neuenfeldt, Alexander Gocht, Thomas Heckelei, Pavel Ciaian, Explaining farm structural change in the European agriculture: a novel analytical framework, *European Review of Agricultural Economics*, Volume 46, Issue 5, December 2019, Pages 713–768, https://doi.org/10.1093/erae/jby037

[29] For example: the manure application limit induces costs for farmers producing more manure than they can dispose. The higher the livestock density of the region where the farmer is located, the more costly will be the management of the excess manure, as disposal options become more scarce.

that there has been a concentration of livestock production in the most competitive areas and on increasingly larger farms, and that this concentration has persisted over the last 35 years. Production is indeed unevenly distributed across the European territory with areas characterised by a high livestock density stretching from northern Denmark to Belgian Flanders, through north-west Germany and the Netherlands, western France, northern Italy (Po Valley), north-eastern Spain (Catalonia) and, to a lesser extent, in Ireland, western Great Britain, southern Germany, central-eastern Poland, and along the northern, western and south-western edges of the Massif Central. High livestock density often results from the simultaneous presence of several animal species in the same area (as is the case, for example, in Brittany, the Netherlands, or Belgium), or from a significant concentration of grain-fed animals (e.g., Spain, Denmark). By relying on feed purchased from other regions or countries and being less directly dependent on land, these productions allow for higher levels of intensification than those of herbivore-based systems (European Commission, 2023).

Figure 1 Cattle and pig density in heads/ha per member state between early 90's and 2023 (European Commission, 2019).



Note that a decline in cattle and pig density (heads/ha) does not necessarily result in a decline in production. In general, productivity per head has increased, resulting in higher livestock production (mostly dairy) than in the 1990s. Moreover, our results show that livestock productivity (reflected by specific livestock output) has increased more in the NVZ than outside of the NVZ. This does not signify a causal relationship per se, but in an attempt to understand these effects, one could argue that the ND was an incentive to increase productivity per animal because this contributes to higher nitrogen use efficiency. Thus, even though the ND leads to measurable implementation costs, it could also have contributed to the long-run efficiency gains that increase (international) competitiveness. These dynamics can help understand the results that we observe, namely (1) the attributable direct costs of the Nitrates Directive), (2) seeing these costs increase being confirmed statistically while (3) at the same time observing significantly

higher productivity to (4) arrive at no significant long term impacts on income, gross margins or animal numbers. These results suggest that the ND has not influenced the competitiveness of the livestock sector to the extent that it has led to decreases in livestock numbers when comparing EU regions designated as NVZs with those that are not.

Regional trends confirm this finding. One such example is dairy production in Belgium. The cost of compliance with the Nitrates Directive is the highest in Flanders and much higher than in the Walloon region. Yet, 71% of the milk production of 2024 was delivered by Flemish farms, while in 2005 the Flemish production accounted for only 60% of the total Belgian production (Belgische Confederatie van de Zuivelindustrie, 2025; Van Der Straeten et al., 2012). The dairy production in Flanders increased by 71% for the period 2005 – 2024[30]. Only Ireland and Cyprus have achieved similar or higher dairy production increases during the same period, and both of these member states fall under the Nitrates Directive.

These results show that the ND has not had the effect of significantly curbing the phenomenon of territorial concentration of livestock activities, and that other factors have had more significant effects. In particular, improvements in animal performance, technological progress, the consolidation of strategies between upstream and downstream sectors, and the pursuit of economies of scale and agglomeration have been the main factors influencing developments in animal numbers. Also, the rationalisation of livestock management practice, such as the batch management of sows, together with the reorganisation of housing structures and the advancement of technologies (including the automation of tasks, milking robots, and automatic feeders), has led to significant gains in labour productivity. These gains are further amplified by farm consolidation, which facilitates economies of scale in the execution of specific operations (feeding, cleaning, milking, etc.). The expansion of livestock units is also driven by the increasing specialisation of farms, a trend attributable to the limited potential for economies of scope arising from the integration of diverse production activities within a single holding. Moreover, this process is reinforced by the development of corporate farming structures and the growing reliance on hired labour in the EU (Bokusheva R & Kimura S, 2016; OECD, 2023).

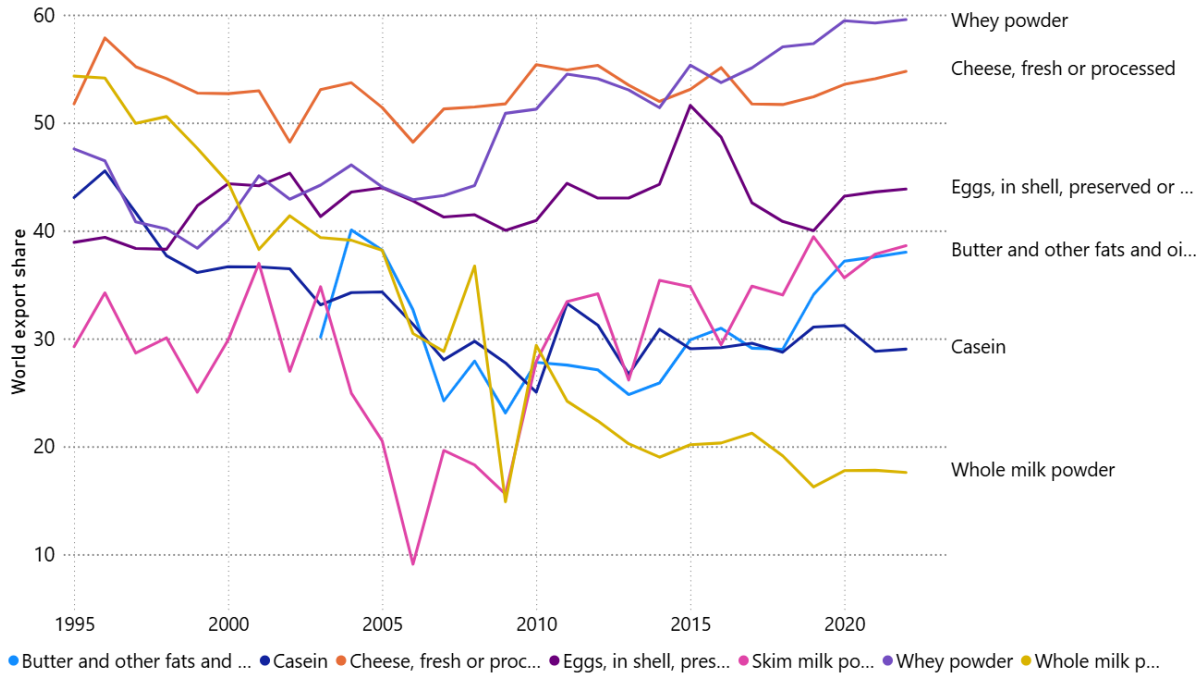
Finally, our results are also reflected in international competitiveness indicators. Taking dairy again as an example[31], Figure 2 shows the relative share of the EU-28 in the total global dairy product exports (OECD/FAO, 2021). It shows that the share in 2025 is comparable to the share in the 1990s for most of the products, with the exception of whole milk powder (decline) and whey powder (increase). Furthermore, it shows a clear dip in the mid-2000s for butter and skimmed milk powder. This dip can be explained by the fact that the dairy quota from the CAP kept the dairy industry from growing, and this

[30] Despite of the fact that the number of cows have actually decreased (as shown in Figure 1). This is because of productivity gains in milk production such as feed optimisation, milking robots, automatic feeding, etc.

[31] The dairy sector being an agricultural sector where international trade is relatively more important (OECD/FAO, 2021)

resulted in a loss of market share (Tacken et al., 2009). Additionally, this may have also slowed the pace of structural change, which could have reduced the speed of cost reductions. After the abolition of the dairy quota, the EU share for butter and skim milk powder returned to levels comparable to those of the 1990s. Overall, these statistics suggest that other forces are significantly more influential in shaping the industry's development than EU environmental legislation. Furthermore, the relative long-term stability of the export share of the EU livestock sector suggests that the impact of the Nitrates Directive on competitiveness has been limited.

Figure 2 Share of the EU-28 in the world market export of dairy products (OECD/FAO, 2021).



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EVALUATION

Evaluation of the Nitrates Directive (Council Directive 91/676/EEC)

{SWD(2026) 235 final}

ANNEX XIX. BIOGAS PRODUCTION AND THE USE OF DIGESTATES IN AGRICULTURE

This annex analyses the role of biogas production in the EU in relation to the Nitrates Directive rules on livestock manure and fertilisers. It is based on a study carried out in support of the evaluation[1].

Definition

Biogas production is the process of generating a renewable fuel, called biogas, by breaking down organic materials such as manure or crop residues by bacterial activity in the absence of oxygen. This happens inside a sealed system known as an anaerobic digester, where microorganisms naturally decompose the material and release a gas mixture mainly composed of methane (CH_4) and carbon dioxide (CO_2) along with smaller amounts of hydrogen sulfide (H_2S), water vapor, and other gases. This biogas can then be burned to produce heat and electricity in a combined heat and power (CHP) unit. Alternatively, it can be upgraded to biomethane to be injected into the gas grid or used directly as natural gas that is used for cooking, heating, or as a vehicle fuel. The remaining material after the digestion process, called **digestate**, is a nutrient-rich by-product that can often be used as fertilizer.

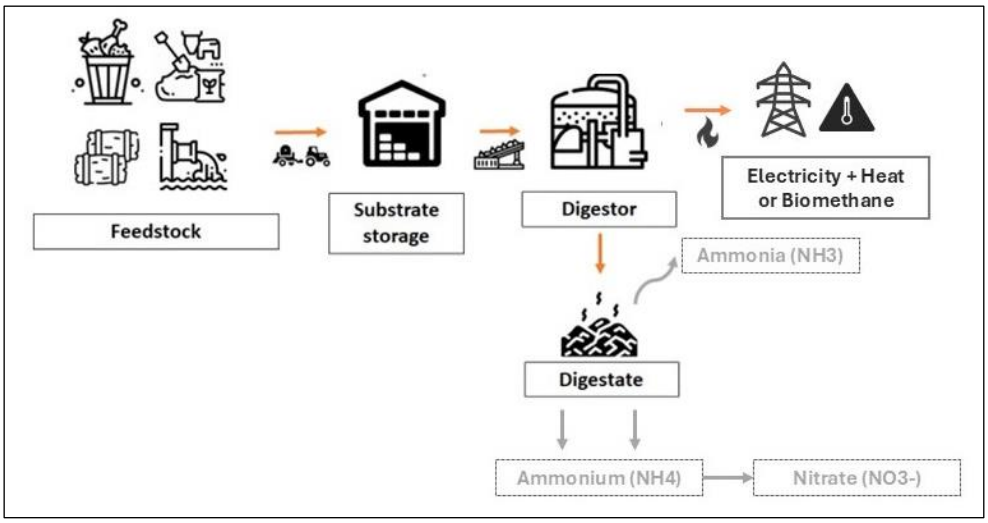
The consistency and nutrient composition of digestate depend on the type of feedstock, the input material used for the digestion process, as well as on process conditions. Nevertheless, digestate usually consists of organic matter, nitrogen, phosphorus, potassium, and other trace elements. It can be separated into a solid and a liquid phase, which and used for different purposes. During anaerobic digestion, much of the organic nitrogen in the feedstock is converted into ammonium (NH_4^+). Because the process occurs without oxygen, nitrate (NO_3^-) is not formed within the digester. However, when digestate is applied to soil as fertilizer, the ammonium can be oxidized to nitrate through microbial nitrification. Nitrate and ammonium are the main components of nitrogen fertilisers, both readily available to plants. Nitrate is also highly mobile in soils and can leach into groundwater. Ammonium can be lost to the atmosphere as ammonia gas if the digestate is not incorporated into the soil properly.

While anaerobic digestion converts a large part of the organic nitrogen from organic feedstocks into mineral nitrogen, the process is not complete, and some fraction remains in organic form. Therefore, digestates also remain rich in organic matter, retaining a certain amount of carbon. Depending on the feedstocks used, digestates can also contain various contaminants, which needs to be taken into account for their potential use as fertilisers. Both biogas and digestate can contribute to sustainable waste management and energy production, supporting circular economy principles by transforming waste into valuable resources. Digestate use is included in Fertilization Action Plan (2026) as a local source of nutrients and irrigation water. Within the Biomethane Industrial Partnership: the Commission, academia,

[1] ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

farmers and industry have jointly developed a practical review[2] on digestate valorisation and best practice use.

Figure 1 Simplified scheme of biogas production process. Source: Adapted from JRC-Report 2024[3]



Expansion of biogas production in the EU

The biogas sector has expanded significantly in Europe over the past years. Biogas production is based on a variety of inputs, including agricultural and other waste streams such as **livestock manure**. The utilisation and valorisation of the digestates can represent an important income stream for the developing biogas sector. **Figure 2** below shows the estimated production of biogas digestates in Member States (MS), distinguishing between the parts that originate from livestock manure and other agricultural residues (e.g. straw) and those that come from various co-feedstocks (the main one being energy crops) [2].

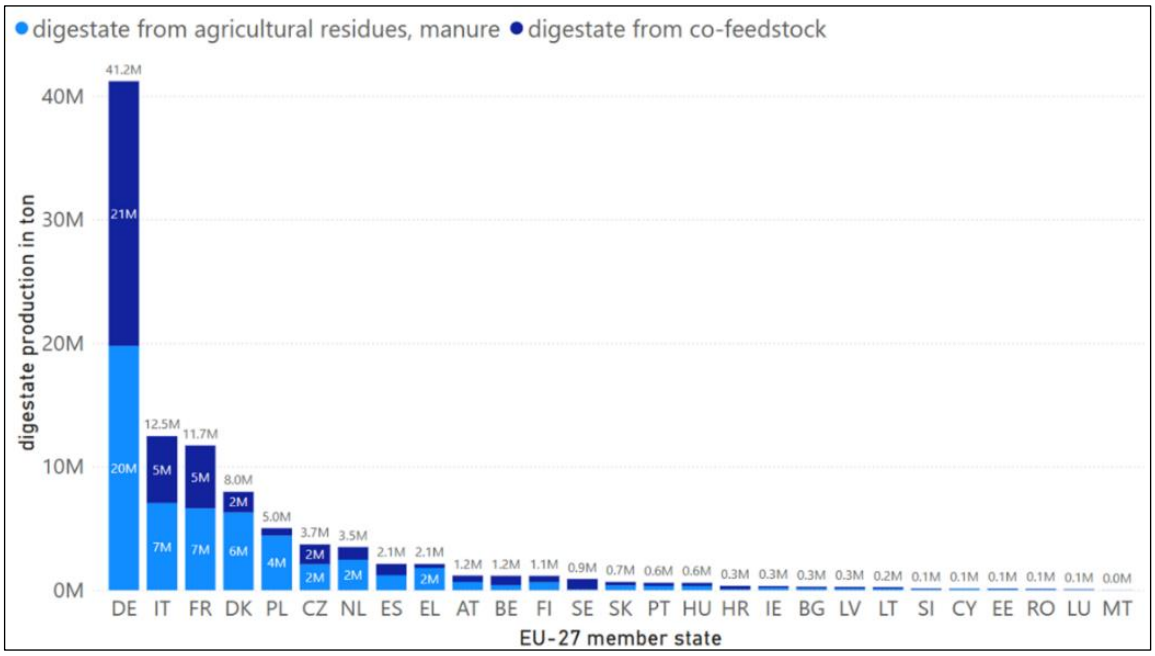
Currently, around 86% of digestate is disposed of on agricultural land, with 70% used without further treatment and 16% applied after first being upgraded. Upgrades involve processing methods that enhance transportability, storage, and fertiliser efficiency. Digestate is typically separated into liquid and solid fractions using screw presses or centrifuges. The remaining 14% is not applied to land and finds its use in horticulture, is biologically treated or landfilled [2]. Digestates can contain nutrients from agricultural origin (manure, residues), and nutrients from other feedstocks. While nutrients from agricultural origin are typically applied to land regardless of whether they are converted into digestate, other feedstocks (co-feed) are only used on agricultural land as fertiliser in digestate form. This effectively increases the total supply of organic nitrogen for agriculture, depending on the amount of co-

[2] Biomethane Industrial Partnership, The Task Force 2 co-chaired by DG GROW of the European Commission, EnviTec Biogas, and the European Waste Management Association (FEAD): Use and valorisation of digestates: a practical review, 2025.

[3] European Commission, Joint Research Centre (JRC), Buffi, M., Hurtig, O. and Scarlat, N., Methane emissions in the biogas and biomethane supply chains in the EU, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/7927411, JRC139485.

feedstock that is used in the anaerobic digestion process. It should be noted, that feedstocks based on crops (e.g. maize) also require fertiliser to be produced.

Figure 2 Yearly digestate production in tons by EU-27 Member State and by origin. Source: Ecorys, 2025[4].



Challenges to the use of digestates as fertiliser

As a fertiliser, digestate poses many of the same challenges as those associated with untreated manure, such as variability in nutrient concentrations, high bulk and water content, and inconsistency in nutrient release dynamics due to the slow mineralisation of organic nitrogen. Nevertheless, nutrients contained in digestate are generally more readily available for plant uptake than those in raw manure, improving overall nutrient use efficiency. During anaerobic digestion, between 20% and 95% of the organic matter in the feedstock is converted into biogas, while the remaining organic content contributes to the build-up of soil humus, supporting long-term soil fertility. However, the application of digestate carries both environmental benefits and risks.

Improper application may cause ammonia emissions and nitrate leaching particularly when applications are not synchronised with plant uptake. Furthermore, digestates can contain a variety of potentially harmful substances, depending on the feedstocks from which it is produced. Such substances may include heavy metals, antibiotic residues, organic micropollutants, and pathogens which can pose risks to both human health and ecosystems[5][6][7].

[4] Complementary study to provide specific elements for the evaluation of the ND (Council Directive 91/676/EEC), 2025.

[5] Czatzkowska, M.; Rolbiecki, D.; Korzeniewska, E.; Harnisz, M. Heavy Metal and Antimicrobial Residue Levels in Various Types of Digestate from Biogas Plants—A Review. Sustainability 2025, 17, 416.

[6] Wolak, I.; Bajkacz, S.; Harnisz, M.; Stando, K.; Męcik, M.; Korzeniewska, E. Digestate from Agricultural Biogas Plants as a Reservoir of Antimicrobials and Antibiotic Resistance Genes—Implications for the Environment. Int. J. Environ. Res. Public Health 2023, 20, 2672.

The risks depend in part on the feedstocks used. Heavy metals and antibiotic residues used for animal welfare and remaining in manure present either inhibitors or hazard to anaerobic digestion, reducing the crucial anaerobic bacteria needed to produce biogas. Therefore, a set of screening and pre-treatments are applied prior to feeding manure to the anaerobic digestor. Compared to the unprocessed manure, digestate has significantly lower weed seed germination rate, less pathogens and diluted heavy metal and antibiotic content. Sewage sludge digestate has to pass post-treatments to be applied on soil (BIP, 2025)[8]. Member States have developed their own national strategies and regulatory frameworks to address these risks since there is no harmonised regulation on digestate quality at EU-level. Some countries have introduced specific thresholds for contaminants in digestate used as fertiliser, while others have implemented certification schemes or restricted the use of certain feedstocks in anaerobic digestion processes (JRC, 2024; BIP, 2025). The considerable variability in feedstock types, processing methods, and application practices complicates the ability to draw generalised or quantitative conclusions regarding the overall effectiveness of digestates and their consequent risks in terms of nutrient losses.

To address environmental risks, the timing and rate at which digestate is applied need to be managed carefully to prevent losses of ammonia and nitrates. Application might need to be spread across different periods to prevent overloading the soil with nitrogen during any single application. Farmers may also adopt management practices such as incorporating digestate into the soil and using precision application techniques, to maximize nutrient uptake by crops and minimize potential losses to the environment. (See Annex XII on measures)

Legal compatibility with the Nitrates Directive

The Nitrates Directive treats digestate as any other fertiliser, which has to be considered when applying the balanced fertilisation principle [23]. The directive does not specifically limit the production or use of digestate, but it sets rules and conditions under which fertilisers, including digestates, can be used, with the aim to protect water quality. For instance, the codes of good agricultural practice that the directive requires, apply to the use of digestate. Farmers and operators using digestate must ensure that its application to land aligns with nutrient management practices, particularly concerning timing and quantity, to minimise leaching and runoff into water bodies. The ND sets restrictions on the amount of nitrogen that can be applied to land from organic and inorganic fertilizers, including digestate. This means that the nitrogen content of digestate will be a key factor in determining how much can be applied. Other measures under the ND also apply to digestates, where relevant, and Member

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7 See also Nkoa, R., 2014. Agricultural benefits and environmental risks of soil fertilization with anaerobic digestates: a review: R. Nkoa. Agronomy for Sustainable Development, 34(2), pp.473-492. Koszel, M. and Lorencowicz, E., 2015. Agricultural use of biogas digestate as a replacement fertilizers. Agriculture and Agricultural Science Procedia, 7, pp.119-124. Al Seadi, T. and Lukehurst, C., 2012. Quality management of digestate from biogas plants used as fertiliser. IEA bioenergy, 37, p.40.

8 Biomethane Industrial Partnership, The Task Force 2 co-chaired by DG GROW of the European Commission, EnviTec Biogas, and the European Waste Management Association (FEAD): Use and valorisation of digestates: a practical review, 2025.

States may include certain rules in the action programmes to address the specific characteristics of digestates.

The 170 kg of N/ha limit and its impact on the use of digestate

To the extent that the digestate is based on livestock manure, its use has to consider the livestock manure limit (see Annex XVII on the 170 kg/ha limit) in NVZs. Digestate derived from animal manure is regarded as manure under the Nitrates Directive and is therefore subject to the application limit of 170 kg N/ha in NVZs. The directive does not provide a specific approach to include digestate into that limit, leading to varied regulatory interpretations among Member States. Three main approaches exist:

- Integral Approach: All digestate is subject to the manure limit, regardless of feedstock (e.g. Germany).
- Manure Presence Approach: If manure is part of the feedstock, the entire digestate is counted under the manure limit. Digestate from non-manure sources is exempt (e.g. Denmark, the Netherlands, and Belgium-Flanders)
- Manure Proportion Approach: Only the manure-derived nutrient share counts towards the limit (e.g. France, Belgium-Wallonia, and Italy)

To comply with the limit, it is necessary to calculate the nitrogen content of the digestate and possibly to estimate the relative contribution of livestock manure, to ensure that its application does not exceed 170 kg of nitrogen per hectare per year (or whatever limit is set out in a derogation decision, where relevant). This requires testing and analysis of the digestate's nutrient profile (BIP, 2025)[9]. If the nitrogen content of digestate results in reaching the 170 kg/ha limit on a given farm, additional land may be required to spread the digestate without breaching regulatory limits. This can influence planning and logistics around digestate application. Nevertheless, it would be wrong to say that the livestock manure limit represents a constraint on the promotion of recycled organic fertilisers in agriculture. The directive is based on the very notion of better using the nutrient content of livestock manure while maintaining the close organic link between the livestock and the soil (land-based farming) in consideration of the limited carrying capacity of the soil. The limit on livestock manure therefore promotes natural circularity. By putting a constraint on manure application especially in high livestock density regions, the limit also promotes the redistribution of excess nutrients from such regions where nutrients are a pollutant to regions where nutrients are needed, through processing and transport. Moreover, the limit promotes the sharing of livestock manure between farms at the regional level and the processing of livestock manure in biogas plants. This can facilitate the redistribution of nutrients in the form of digestates within the region. Additional requirements on digestate production, type of fertiliser

[9] This may also be done by the provider of the digestate.

composition or rules for placing the product in the EU market are covered by the Fertilising Products Regulation[10].

The Nitrates Directive and technological developments

The directive allows the Commission to adapt non-essential elements of the directive's annexes to scientific and technical progress through a comitology procedure. An example of this is the recent RENURE amendment[11]. This amendment will allow Member States to authorise the application of certain types of materials derived from manure processing attaining qualities close to chemical fertilisers (see section 4.3 of the report). Such materials may be based on digestates subjected to further processing. In this way, the directive provides flexibility to reflect technical progress and encourages technological innovation and new processing methods. The amendment stopped short of allowing digestates as such above the limit, as the results of the analysis carried out by the JRC in 2020[12] did not provide a robust basis for considering digestates as sufficiently close to chemical fertilisers. Indeed, the RENURE amendment is based on the premise that RENURE materials are fundamentally different from livestock manure and present agronomic and environmental qualities and risks more similar to chemical fertilisers. The amendment therefore lists specific types of processing that are required for materials to be considered as RENURE. Further processes may be considered in the future, based on robust scientific evidence, and added to the annex through another comitology procedure.

Concluding remarks

Biogas production and the application of digestates in agriculture hold significant promise for advancing sustainability and circular economy principles. As biogas facilities continue to expand, the integration of digestates into agricultural systems can help close nutrient cycles, reducing reliance on synthetic fertilizers and minimise waste. However, this approach requires careful management to balance the environmental benefits with potential risks, such as ammonia emissions, nutrient leaching and contamination from harmful substances originating from diverse feedstocks. The Nitrates Directive can affect the use of digestates in agriculture by imposing constraints aimed to protect water quality. One of the limitations established by the directive is the 170 kg N/ha per year limit on nitrogen from livestock manure in NVZ. This restriction directly influences the amount of digestate derived from livestock manure that can be applied to agricultural lands, ensuring that nitrogen levels do not contribute to water pollution. The RENURE amendment will provide flexibility for some materials, subject to further processing, and can be further expanded in the future based on scientific evidence. All in all, the directive does not hinder the adoption of digestate as a fertiliser under environmentally safe conditions. The directive promotes judicious nutrient

[10] Regulation (EU) 2019/1009

[11] Comitology register

[12] Huygens, D., Orveillon, G., Lugato, E., Tavazzi, S., Comero, S., Jones, A., Gawlik, B. and Saveyn, H., Technical proposals for the safe use of processed manure above the threshold established for Nitrate Vulnerable Zones by the Nitrates Directive (91/676/EEC), EUR 30363 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21539-4, doi:10.2760/373351, JRC121636.

management planning, requiring farmers to calibrate the nitrogen content of digestate applied to soils. While the ND provides a general framework for nutrient management, it also offers large flexibility to Member States. Different national strategies, ranging from strict integral approaches to more flexible manure proportion methods (see above), mean that farmers and land managers must be acutely aware of regional mandates when using digestate. Increased cooperation among stakeholders—farmers, industry experts, policymakers, and researchers—can facilitate the development of best practices, ensuring that digestates contribute positively to both environmental goals and economic viability. These collaborative efforts can facilitate the redistribution and effective use of nutrients, aligning with regional agricultural requirements and promoting resilience of the farming sector.

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