Miljøeffekten af den danske undtagelse fra nitratdirektivet til brug for afrapportering til EU-Kommissionen i 2022

Fagligt notat fra DCE – Nationalt Center for Miljø og Energi

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Indhold

1 Baggrund

Miljøstyrelsen (MST) har d. 12. september 2022 fremsendt en bestilling til DCE – Nationalt Center for Energi og Miljø – ved Aarhus Universitet omhandlende punkter til brug for afrapportering til EU-kommissionen af miljøeffekten af den danske undtagelse fra nitratdirektivet (Se bilag) i henhold til kommissionens gennemførelsesafgørelse (EU) 2020/1074.

Dette notat indeholder DCE's besvarelse af bestillingen i form af et kapitelbidrag til MST's udgivelse "Derogation Report 2022". Kapitlet præsenterer en analyse af udviklingen inden for landbrugspraksis på nationalt niveau i perioden 2005-2021. Analysen er baseret på nationale registerdatasæt fra Ministeriet for Fødevarer, Landbrug og Fiskeri. I notatet præsenteres også en modelleret nitratudvaskning, som er baseret på nationale data for afgrødefordeling og kvælstofbalancer fra det generelle landbrugsregister og indberetninger til gødningsregnskaber. Nitratudvaskning er opgjort for forskellige bedriftstyper og geografiske områder samt for forskellige niveauer af forbrug af husdyrgødning. Endelig præsenteres målinger af vandkvalitet fra overvågningsprogrammet "Landovervågningsoplande" for perioden 1990/91-2020/21. Besvarelsen er udført på engelsk.

2 Introduction

Since the late 1980s, Denmark has done a comprehensive and efficient effort to improve the environmental state of groundwater and surface water by lowering nitrate concentrations, especially through reductions of nitrate leaching from agricultural sources. The first Action Plan on the Aquatic Environment was adopted in 1987 and has since then been followed by subsequent action programmes to ensure efforts are made to reduce the loss of nitrogen and phosphorus to the aquatic environment.

In 1998, the Action Plan on the Aquatic Environment (APAE) II was accepted by the EU Commission as the Danish Nitrate Action Plan implementing the Nitrates Directive (1998-2003). In 2003, a final evaluation of Action Plan II was performed. The results showed a 48% reduction of the nitrate leaching from the agricultural sector, thus fulfilling the reduction target set in 1987.

In the subsequent action plans, the Green Growth Agreement from 2009, the first and the second River Basin Management Plan from 2014 and 2016 as well as the Food and Agricultural Agreement in December 2015, further mitigation measures were adopted to fulfil reduction targets for the N load to marine areas and the targets of the Water Framework Directive.

In 2015, Denmark implemented the EU Greening component under CAP direct payments (REG EU 1307/2013), implying that at least 5% of the arable land of farms shall be appointed as ecological focus areas with a greening element such as set-aside, catch crops etc.

From autumn 2012, it was decided to establish 50,000 ha of obligatory buffer zone placed approximately 10 m from the edge of open streams and lakes larger than 100 m2. In 2014, the buffer zone area was adjusted from 50,000 to 25,000. From the beginning of 2016, the additional buffer zones are no longer mandatory and restricted to the former requirements of 2 m buffer zones along target streams and lakes larger than 100 m2, amounting to approximately 6,000 ha.

The Political Agreement on Food and Agricultural Package from December 2015 includes a diverse selection of measures aimed to change the environmental regulation of the agricultural sector. The first part of this political agreement was implemented from 2016.

In 2016, farmers were allowed to use more fertiliser. According to the APAE II agreement, farmers were restricted in the application of fertiliser at a level that was lower than the economic optimum. This measure in APAE II was set to reduce the fertiliser application of nitrogen to 10% below this optimum. This rule was regulated so that the total national nitrogen quota was set to a fixed level but with the possibility of an adjustment relative to changes in crop cover. This adjustment made sense as crops having a high application standard also have a higher nitrogen uptake. If crops such as grass increase in cover, then the fertiliser application and N quota will increase as well. However, due to the suspension of set-aside in 2008, higher yields and increases in the prices of cereals and proteins, the gap between the economic optimum and the national N quota increased, especially after 2008, amounting to 18% in 2015.

According to the Political Agreement on Food and Agricultural Package implemented in 2016, extra N fertiliser application, amounting to 2/3 of the gap between the economic optimum and the reduced N quota, was allowed. From 2017, farmers were allowed to apply nitrogen up to the economic optimum. Additional cover of catch crops and the greening element, for instance more catch crops and set-aside, were, among other measures, introduced to counteract the potential increase in leaching due to the extra application of N fertiliser from 2016 and onwards.

Additionally, targeted catch crops of 145,000 ha were implemented in 2017 to counteract the potential increase in leaching due to the extra application of N fertiliser in 2017. In 2018 and 2019, the need for targeted catch crops was approximately 114,000 and 139,000 ha, respectively. For 2020 and 2021, this area was increased to approximately 373.000 ha. The targeted catch crops scheme was introduced to ensure that the status of coastal waters and groundwater does not deteriorate. Therefore, targeted catch crops are established in catchments where reduction of the nitrogen load is needed. Applicants for targeted catch crops could be all farmers who either own or lease fields for cultivation in such catchments.

The second River Basin Management Plans (RBMPII) was adopted in June 2016. It proposes schemes for implementation of mitigation measures, such as re-establishment of riparian areas, construction of wetlands, set-aside of organic soils, afforestation and adjustment of greening elements. The national reduction target for the annual marine N load in 2021 is estimated to 13,100 t N. However, the RBMPII only includes mitigation measures to obtain an annual reduction of the marine N load of 6,900 t N in the period 2015-2021 (SVANA 2016). The decision on which measures to initiate to reach a further reduction in the annual nitrogen load of 6,200 t N has been postponed to after 2021.

The N load to marine waters has been reduced incrementally along with the successful implementation of measures to reduce loadings from point sources and agriculture. Approximately half of the Danish land area is located within catchments equipped with stream water gauging stations where the N load to marine areas is regularly measured (Kronvang et al., 2008). The nitrogen load for ungauged catchments has been modelled using an empirical model (Windolf et al., 2011), and the combination of measurements and modelling shows that the total annual load to marine waters varied between 55,000 and 59,000 t N, yielding an average of 57,000 t N for the five years (2010-2014) used as status level in the RBMPII (SVANA (2016), Wiberg-Larsen (2015)). However, the calculation of this total nitrogen load to coastal areas has been updated and now includes a higher proportion of gauged catchments as well as an improved and more detailed calculation of discharge in ungauged catchments (Thodsen et al., 2021). For the period 2016-2020, the updated calculation yields an annual flow-normalised nitrogen load ranging between 51,000 and 66,000 t N with the highest value in 2019 following a year with drought-related low crop harvest. For 2020, the normalised total nitrogen load was 51,000 t N, which is the lowest value in the monitoring period (1990-2021). For 2021, the normalised total nitrogen load was 55,000 t N (Thodsen, 2023).

The regulation and effects described in this chapter cover the period 2005-2021. Additional agricultural regulation, such as requirement to increase the utilisation efficiency of nitrogen in manure (2020/21), a reduced fertiliser application norm on soil with a high content of organic matter (2020/21) were implemented in 2020. A ban on application of solid manures in autumn and ban on application of fertilizer on §3 extensive and permanent grasslands are fully implemented in 2021/22.

The remaining part of this chapter is divided into three parts:

First, the general development in agricultural practices at national level is presented for the period 2005-2021. This analysis is based on national register datasets from the Ministry of Food, Agriculture and Fisheries, i.e. the single-payment register and the farmers' mandatory fertiliser accounts.

Second, modelled nitrate leaching, including crop distribution and nitrogen balances, is presented for various farm types (including those benefitting from an authorisation of derogation) and geographical areas. The impact of derogation farms is analysed based on a dataset derived by linking data from the single payment register, including data on the crops on each field comprised by the farms, and the fertiliser accounts. Both datasets cover agriculture in the year 2021. Modelling of nitrate leaching at national level is carried out by means of the empirical model N-LES (version 4) (Kristensen et al., 2008).

Third, measurements of water quality from the National Monitoring Programme are presented for the period 1990/91-2020/21, with particular reference to the Agricultural Catchment Monitoring Programme (Blicher-Mathiesen et al., 2023). This section includes:

- Modelling of nitrate leaching in the agricultural monitoring catchments as referred to in Article 10(3).

- Measurements of nitrate and phosphorus in water leaving the root zone, including fields receiving more than 170 kg N ha^{-1} in organic manure as referred to in Article 10(2).

- Nitrogen in surface water, draining from agricultural catchments as referred to in Article 10(2).

Modelling of nitrate leaching for the agricultural monitoring catchments in this section is carried out by means of a new version of the empirical model N-LES (version 5) (Børgesen et al., 2020, 2022). This model is partly based on data from the Agricultural Catchment Monitoring Programme. The model requires input data for agricultural practises (N fertilisation, cropping system), soil data and water percolation from the root zone. Percolation is calculated using the Daisy model (Abrahamsen & Hansen, 2000) and a standardised climate dataset from a 10 km grid net (Danish Meteorological Institute), representing weather measurements from the period 1990-2010. The climate dataset contains dynamic correction factors for rainfall (Refsgaard et al., 2011). Thus, modelled nitrate leaching represents the leaching in a standardised climate (water percolation). In contrast, all measurements from the Agricultural Catchment Monitoring represent nitrate leaching under the actual climatic conditions.

So far, model-based calculations of phosphorus losses from farms benefitting from an authorisation of derogation are not available but measured phosphorus concentrations in root zone water on fields with average application of less and more than 170 kg N ha^{-1} in organic manure are presented.

3 Development in agricultural practices at the national level from 2005 to 2021

Crop distribution

The development in crop distribution for 2005-2021 was analysed on the basis of the single payment registration. Figure 1 presents the results for cash crops, fodder crops and non-cultivated areas. The year 2005 was the first year with single-payment, and it was anticipated that the reporting of areas for this first year would be overestimated. Hereafter, the total reported agricultural area, including set-aside, decreased from approximately 2,757,000 ha in 2006 to 2,596,000 ha in 2021.

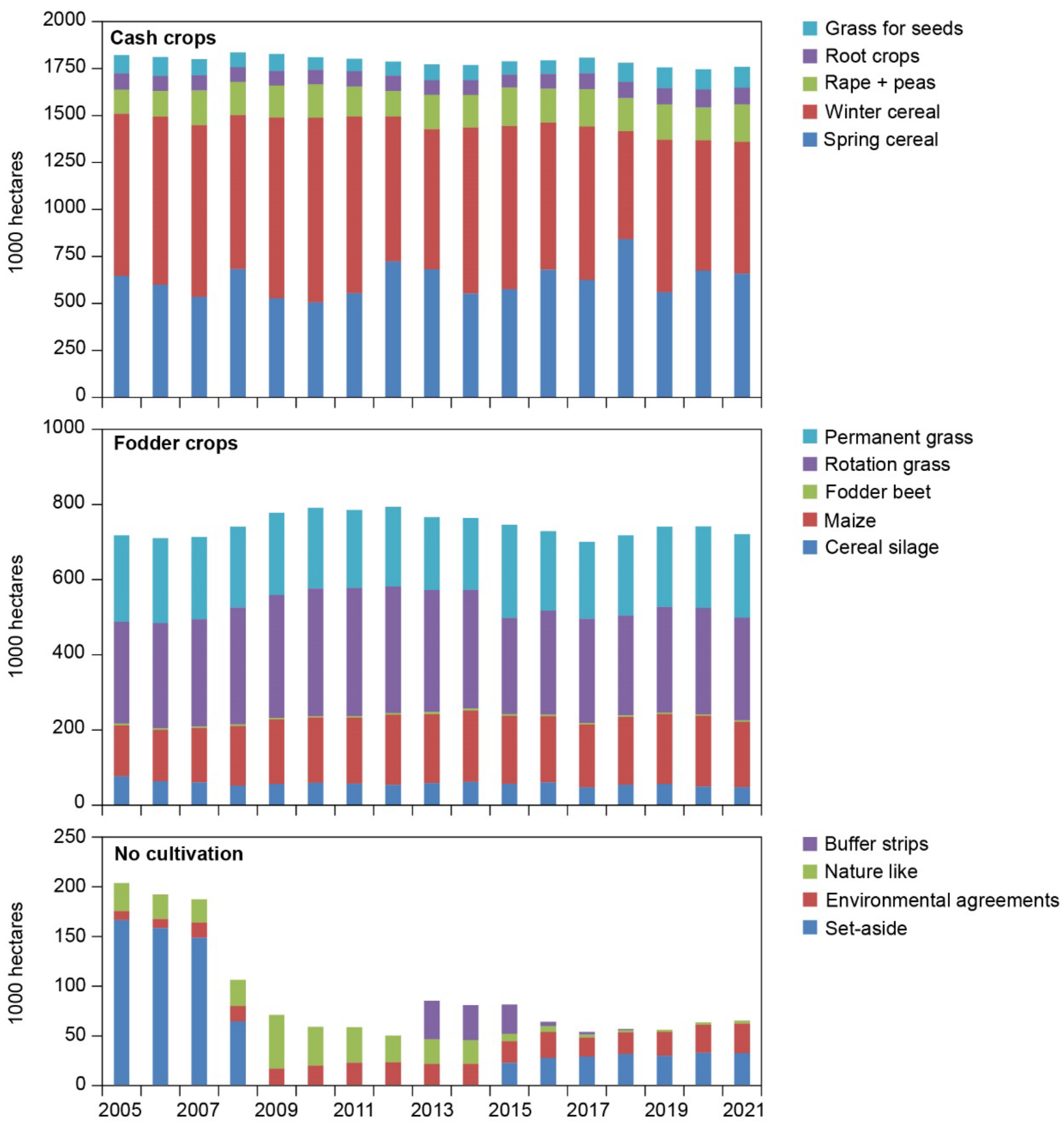

Figure 1 Development in crop distribution at the national level from 2005 to 2021, data from the single payment register.

The decrease in agricultural area of about 10,000 ha per year is due to road construction, afforestation, urbanisation etc. During the years 2006-07, set-aside comprised about 160,000 ha. As from 2008, the set-aside obligation was suspended, and in 2008 and 2009 most set-aside areas were converted to cash crops, fodder crops and nature-like areas. Set-aside covered between 23,000 and 33,000 ha in the period 2015-2021 as set-aside is an element in the Danish implementation of the EU Greening. The area with cash crops and fodder crops has decreased slightly since 2012.

Catch crops

In Action Plan III, the requirement for growing catch crops was carried over from the former Action Plan, stipulating that farmers in 2005-2009 should grow catch crops on at least 6% of the potential catch crop area if they applied less than 80 kg organic manure N ha^{-1} and on 10% of the area if they applied more than 80 kg organic manure N ha^{-1}. The potential catch crop area was defined according to crop type, including cereals, oilseed rape, maize, turnip rape, soy, faba bean, sunflower, oil flax and other rotation crops without substantial nitrogen uptake in the autumn. In 2008, the requirement for growing catch crops was raised to counterbalance the effects of the set-aside suspension. From autumn 2009, an additional catch crop area, equivalent to an extra 4% of the potential catch crop area, was implemented, yielding a total requirement for the growing of catch crops of 10% or 14%, respectively. A further adjustment of catch crop area was made to 10.7 and 14.7% from 2020.

During this period (2005-2010), farmers growing winter crops (wheat, rye, winter barley, oilseed rape), preventing fulfilment of catch crop requirements, were granted a reduction of the required catch crop area. From 2011, this possibility ceased.

At the same time, voluntary alternatives to catch crops were introduced such as:

- Reduction of the farm nitrogen fertilizer quota
- Growing of special crops between harvest and sowing of winter crops
- Growing catch crops on other farms
- Establishment of perennial energy crops
- Separation and treatment of animal manure (biogas and burning of the solid fraction of manure)
- From 2015, substitution of one ha of catch crop by four ha of set-aside near open streams and lakes larger than 100 m2 and located next to agricultural areas in rotation
- From 2014, substitution of one ha of catch crop by four ha of winter cereals, if sown earlier than September 7. From 2020, the area to substitute one ha of catch crop was decreased to two ha of winter cereals sown earlier than September 7
- From 2016, substitution of one ha of catch crop by one ha of set-aside

- From 2022, substitution of one ha of catch crop by eleven ha of precision agriculture

- From 2022, substitution of one ha of catch crop by one ha of catch crop with N-fixing species and a deduction of 50 kg N ha^{-1} from the N-quota due to expected effect of nitrogen taken up by the catch crop in the following crop

The possibility to grow catch crops on other farms to fulfil the catch crop requirement ceased in 2021.

Data from the fertiliser accounts show that establishment of catch crops increased from about 118,600-138,000 ha in 2005/06-2007/08 to about 480.900 ha of catch crops in 2021/22 (Table 1). The introduction and use of catch crop alternatives were equivalent to the effect of 13,900-95,000 ha catch crops in the period 2011/12-2021/22.

Table 1 Area with catch crops and catch crop alternatives (1,000 ha of catch crop equivalents) reported by the farmers in the annual fertiliser account in the period 2005/06-2021/22.

	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
Catch crops	138.0	118.6	127.2	196.6	183.0	211.0	211.0	224.0	295.7	321.1	390.0	353.1	415.2	366.5	355.6	505.1	480.9
Catch crop alternatives	0	0	0	0	0	0	28.6	44.0	13.9	43.3	37.6	36.1	28.5	42.8	16.2	95.0	32.7

In 2017, a new regulation of animal husbandry was implemented. With this regulation, additional catch crops, called "livestock catch crops", were to be established in certain areas on certain farms using organic fertilisers, including livestock manure. The regulation applies only to farms cropping more than 10 ha and with the use of organic fertiliser of > 30 kg N ha^{-1}. In addition, the cropped area must be located in catchments with an increasing use of manure or other organic fertilisers, and the area must drain into nitrate sensitive types of nature habitats of the Natura 2000 area. Alternatively, to specific areas selected on a voluntary basis, which drain into near coastal waters with a need for N load reduction according to the River Basin Management Plans. The additional catch crops in certain areas on certain farms using manure or other organic fertilisers can replace all or a part of the need for 80% fodder crops on derogation farms and catch crops grown to fulfil the EU greening requirements.

Consumption of nitrogen fertiliser and nitrogen in manure

Data on the annual use of inorganic fertilisers and the use of nitrogen in animal manure are obtained from the fertiliser accounts (Table 2). The application of animal manure N varied between 216.000 and 227.000 t N from 2005 to 2021. The use of inorganic fertilisers amounted to about 181,000-202,000 t N year^{-1} in 2005-2007 and increased to 205,000 and 209,300 t N year^{-1} in 2008 and 2009, probably due to the cultivation of previous set-aside areas. This was expected to be a temporary effect as the procedure for setting the crop nitrogen standards implies that an increase in agricultural area with fertiliser requirements must be followed by an equivalent reduction in nitrogen standards. Administratively, however, this reduction is based on statistical data on the cultivated area, resulting in a delay of two years. Thus, in 2010-2014, the use of inorganic fertilisers decreased again, reaching the same level as in 2005-2007. The use of inorganic fertiliser increased from 210,000 t N in 2015 to 242,000, 237,000 and 224,000 t N in 2016, 2017 and 2018, respectively, after the implementation of the Food and Agricultural Package, according to which farmers were allowed to use more fertiliser after 2015. The lower use of inorganic fertiliser in 2018 compared to the two former years is caused by an increase in organic farming, farms that do not use inorganic fertiliser, as well as a decrease in the cultivated area. A change in the crop distribution with higher cover of spring cereals at the expense of winter cereals also contribute to a lower use of inorganic fertiliser of approximately 20,000 t N in 2018 as winter cereals have a higher N uptake, higher harvest yield and therefore a higher economic optimal standard N-quota than spring cereals. The use of inorganic fertilisers amounted to 223,000 t N in 2019, which is almost the same level as in 2018. For the growing season 2019, farmers were recommended to apply app. 4 kg N ha^{-1} less as a significant amount of nitrogen still remained in the soil in spring due to a very dry autumn and winter. A wet autumn in 2019 made the establishment of winter cereals difficult. This resulted in a decrease in the 2020 winter cereal area compared to 2019.

Table 2 Development in the use of inorganic nitrogen fertiliser and of nitrogen in animal manure as reported by the farmers in the annual fertiliser accounts for the period 2005-2021 (1,000 t N yr^{-1}).

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fertilizer	191	181	202	205	209	198	203	198	199	203	210	242	237	224	223	230	200
Animal manure	227	218	236	230	226	224	223	220	215	212	216	219	218	224	219	216	216

However, the use of N in inorganic fertiliser increased to 230,000 t N, partly due to a recommended higher application rate to compensate for a low soil N content prior to the growing season of 2020 in some parts of the country. In 2021, the use of inorganic N has decreased to 200,000 t N, partly due to the requirement to increase the utilisation efficiency of nitrogen in manure.

4 Modelled nitrate leaching for farm types and geographical areas and the impact of derogation farms at the national level – 2021 data

Modelled nitrate leaching demonstrates the effect of crop distribution, nitrogen input, soil type and water percolation through the soil. This section includes a presentation of all of these parameters. Regarding crop distribution and nitrogen input, the analyses are based on the national datasets from the single payment register and the fertiliser accounts. However, before the data can be used for this purpose, a detailed compilation of the two datasets must be made (Børgesen et al., 2009). The single payment register contains information on crops at field-block level, and the fertiliser accounts contain information on the use of nitrogen (inorganic fertiliser and organic manure) at farm level. The two datasets are linked by means of the common farm identity number or a common farm address, and the reported amounts of fertiliser and manure from the individual accounts are distributed on the fields of each farm according to the crop nitrogen standards. Hereby, we obtain a dataset with coherent data on crops and nitrogen application at field level. We have no information on grass-ley from either dataset. Therefore, we estimate this parameter based on the area with rotation grass, assuming a conversion rate of three years. If there is not sufficient space in the crop rotation, the area with grass-ley is reduced accordingly. Data on catch crops are derived from the fertiliser accounts.

The field-blocks are geographically mapped, implying that each field can be linked to soil maps and to the meteorological grid. Having established the soil type for each field-block, the standard harvest yield may be estimated. Furthermore, nitrogen fixation is included using standard values for each crop. This final dataset now contains all information necessary for geographically distributed computation of crop coverage and field nitrogen balances and for modelling nitrate leaching.

Farm type

The data are divided into three main groups of farm type – arable farms, pig farms and cattle farms. A pig farm is defined as a farm where more than 2/3 of the used organic N including manure originate from pigs, and a cattle farm is defined as a farm where at least 2/3 of the used organic N including manure originate from cattle. An arable farm is a farm with a production of organic fertiliser including manure of less than 20 kg N ha^{-1}. The farm may import animal manure, which will appear in the fertiliser account and is therefore included in this analysis. Other farm types are not included in this analysis. The area occupied by organic farms constitutes about 313,000 ha in 2021 (Landbrugsstyrelsen, 2022).

Figure 2 shows that arable farms and pig farms grew cereals, particularly winter wheat, on most of the agricultural area (58 and 74%) in 2021. Other major cash crops were oilseed rape, peas, root crops (potatoes and sugar beet) and grass for seeds (20-23%). Cereal silage, grass and maize constituted a lesser part of the area (5-16%). Catch crops were grown on 17-22% and newly established grass-ley on 3-4% of the agricultural area on arable and pig farms as an autumn-winter plant cover.

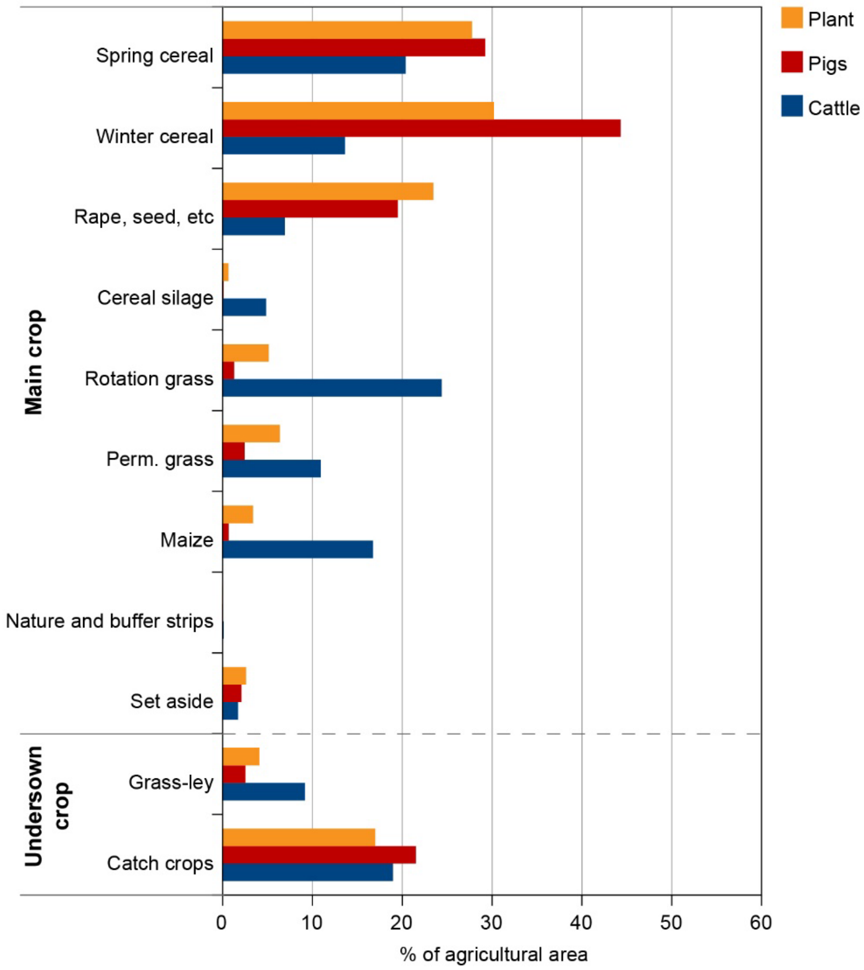

Figure 2 Crop distribution for three main farm types in 2021. Combined dataset from the single payment register and the fertiliser status accounts.

Cattle farms have a different crop rotation. Cereals and other cash crops were grown on 34% of the area, whereas cereal silage, grass and maize were grown on 57% of the area. In addition, grass-ley was found on 9% and catch crops on 19 % of the area.

On arable farms, an average amount of about 51 kg N ha^{-1} from animal manure was applied. For pig and cattle farms, the amounts were, respectively, 102 kg N ha^{-1} and 129 kg N ha^{-1} (Table 3).

The use of inorganic fertilisers decreased with increasing application of animal manure. Total inputs of nitrogen from inorganic fertiliser, manure, other organic sources, N fixation and atmospheric deposition amounted to 177, 198 and 246 kg N ha^{-1} for arable farms, pig farms and cattle farms, respectively. N balances, calculated as the difference between the total input of nitrogen and removal by harvested crops, were 65, 84 and 95 kg N ha^{-1} for arable farms, pig farms and cattle farms, respectively. As expected, modelled nitrate leaching was lower from arable farms (on average 51 kg N ha^{-1}) than from animal husbandry farms (59 kg N ha^{-1} from pig farms and 65 kg N ha^{-1} from cattle farms).

N leaching was, on average, 6 kg N ha^{-1} higher for cattle farms compared to pig farms.

Table 3 N inputs, N balances, nitrate leaching and nitrate concentration at the bottom of the root zone for three main farm types in 2021 based on model calculations. Combined dataset. Organic farms were not included in the analysis.

	N balance									Root zone water		
	Inorganic fertiliser	**Animal manure**	**Other org.**	**N fix.**	**N depos.**	**Seeds**	**Total input**	**Harvest**	**N balance**	**Percol.**	**Nitrate leaching**	**NO_3^- conc.**
	(kg N ha^{-1} a^{-1})									(mm a^{-1})	(kg N ha^{-1})	(mg l^{-1})
Arable	98	51	4.9	8,0	13	2.0	177	112	65	339	51	67
Pigs	73	102	1.6	4,8	14	2.2	198	114	84	373	59	70
Cattle	78	129	1.5	22,0	14	1.6	246	151	95	409	65	70

On arable farms, the modelled nitrate leaching amounted to 78% of the N balance, which is a high value relative to the 70% calculated for pig farms and the 68% for cattle farms. An explanation may be that leaching on these soils with low input of organic manure is affected by mineralisation of the soil organic pool, i.e. depletion of the total soil N content. However, the high leaching fraction may also be caused by the uncertainties associated with the two separate calculations of the N leaching and N balance.

Water percolation through the soil is considerably higher on cattle farms than on arable and pig farms. However, this is not due to the differences in farm type but the fact that the cattle farms are located mainly in the western part of the country with more sandy soil and higher rainfall and a consequently higher percolation. The higher percolation may contribute to an increased nitrate leaching and a dilution of the nitrate concentration in the soil water. Thus, the modelled average nitrate concentrations in soil water were 67 and 70 mg NO_3 l^{-1} on arable and pig farms, respectively, and 70 mg NO_3 l^{-1} on cattle farms for the year 2021.

Geographical areas

Farm types are not evenly distributed throughout the country because of variations in farming conditions. For the following analysis, Denmark has therefore been divided into five farming regions (Figure 3).

Table 4 shows that Zealand is dominated by arable farming, whereas arable farming and pig production dominate Eastern (E) Jutland and Funen. Finally, North (N), North-West (NW) and West (W) Jutland have the highest density of cattle farming. Thus, arable and pig farms are located mainly in the eastern part of Denmark on loamy soils and with low rainfall, whereas cattle farms are located mainly in the northern and western parts of Denmark on sandy soils and with higher rainfall, the rainfall increasing from north to south.

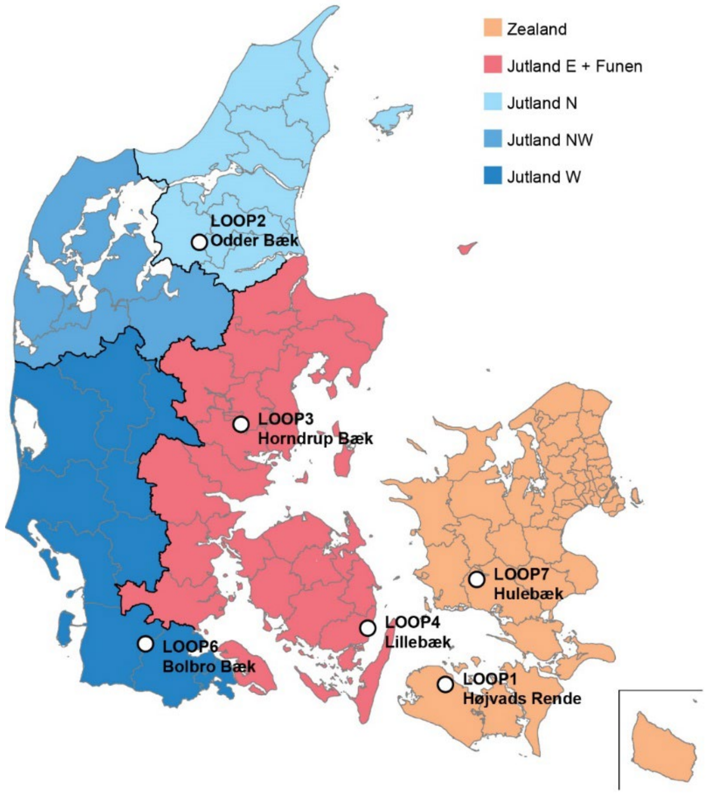

Figure 3 Farming regions in Denmark used in the analysis and the location of the six monitored agricultural catchments.

Table 4 Distribution of farm types and soil types in Denmark divided into five main geographical areas – 2021.

	Arable	Pig	Cattle	Other	Sand	Loam	Organic soils
	% of agricultural area				% of agricultural area		
Zealand	68	12	13	7	4	93	3
Jutland E+ Funen	47	23	23	7	26	71	4
Jutland N	41	15	34	9	79	10	11
Jutland NW	33	21	38	7	61	33	6
Jutland W	38	13	42	8	75	19	6

The crop distribution within the five farming regions of Denmark follows the same pattern as for farm types, i.e. mainly cereals and other cash crops on the islands and in Eastern Jutland and cereals and fodder crops in West and North Jutland (Figure 4).

The input of nitrogen with animal manure, the total nitrogen input and the field nitrogen balances are lowest on Zealand, higher in E Jutland and on Funen and highest in W, NW and N Jutland (Table 5). In the latter three areas, the average nitrogen input varied between 200 and 220 kg N ha^{-1}. The average modelled nitrate leaching generally increased from east to west due to increases in nitrogen input and percolation. Within the three western and northern parts of Jutland, the nitrate leaching increased from northern to southern Jutland, mainly due to increased water percolation through the root zone. Higher water percolation led to dilution of the nitrate concentrations of the soil water, resulting in an average nitrate concentration in soil water of 79, 69, 71, 65 and 60 mg NO_3 l^{-1} on Zealand, Funen + E and N Jutland, and NW and W Jutland, respectively.

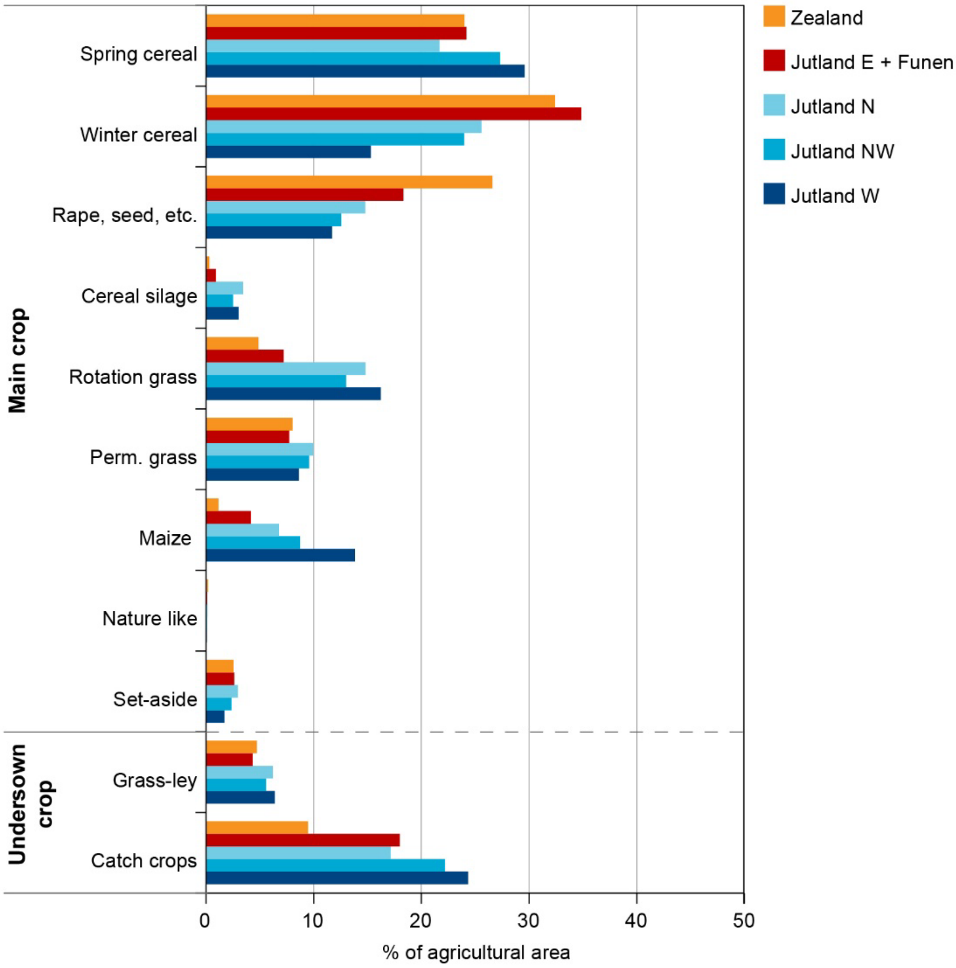

Figure 4 Crop distribution for five farming regions in Denmark in 2021. Combined dataset from the single payment register and the fertiliser accounts.

Derogation farms

Derogation farms are mainly located in N, NW and W Jutland where cattle farming is dominant. The effect of the derogation was evaluated for these three geographical areas. The cattle farms were grouped into four livestock density groups depending on the application of organic N including manure: 0-100, 100-140, 140-170 kg N ha^{-1} and derogation farms with the use of organic N including manure of 170-230 kg N ha^{-1}.

The crop distributions for the three geographical areas were found to be almost identical, with some differences in crop cover between spring and winter cereals as well as larger proportions of maize and catch crops in W Jutland (Figure 5.). There is a clear trend indicating a decrease in areas with cereals and an increase in the areas with catch crops with increasing livestock density. In addition, the area with fodder crops increases with increasing livestock density. The area with roughage amounted to 57, 63 and 76% for the three groups, 0-100, 100-140, 140-170 use of organic N including manure ha^{-1}, respectively, whereas derogation farms grew roughage on an average of 86% of the area.

Table 5 N inputs and N balances, nitrate leaching and nitrate concentration at the bottom of the root zone (1 m) calculated for five geographical areas in Denmark in 2021. Combined dataset from the single payment register and the fertiliser accounts. Organic farms were not included in the analysis.

	N balance									Root zone water		
	Inorganic fertiliser	Animal manure	Other org. N	N-fix.	N-depos.	Seeds	Total input	Harvest	N balance	Percol.	Nitrate leaching	NO_3^- conc
	kg N ha^{-1} a^{-1}									mm a^{-1}	kg N ha^{-1}	mg l^{-1}
Zealand	114	35	3.7	8.8	11	1.8	174	117	57	199	36	79
Jutl. E +Funen	89	72	3.1	9.2	13	1.9	188	118	70	328	51	69
Jutland N	71	97	2.5	14.9	14	1.7	200	120	80	364	59	71
Jutland NW	67	111	0.9	13.1	14	1.8	208	123	85	446	66	65
Jutland W	72	112	4.7	13.7	16	2.0	220	131	85	540	66	60

The effect of derogation on nitrate leaching was evaluated separately for the three geographical areas. The nitrogen input as well as the field nitrogen balances increased with increasing livestock density (Table 6). Modelled nitrate leaching is generally a combined effect of two opposing mechanisms – an increase in leaching due to increased nitrogen input and a decrease in leaching due to an increased area with roughage and catch crops. Table 6 shows that the modelled nitrate leaching generally increased with increasing livestock density and hence with increasing nitrogen input. Thus, differences occurred in the modelled annual nitrogen leaching of 0, 7 and 5 kg N ha^{-1}, respectively, between derogation farms and farms using 140-170 kg N ha^{-1} of N in manure and other organic fertilisers in the three Jutland regions N, NW and W, respectively. Modelled nitrate concentrations in the soil water leaving the root zone were 2, 6, and 3 mg NO_3 l^{-1} higher for derogation farms than for cattle farms using 140-170 kg N ha^{-1} of N in manure and other organic fertilisers in Jutland N, NW and W, respectively.

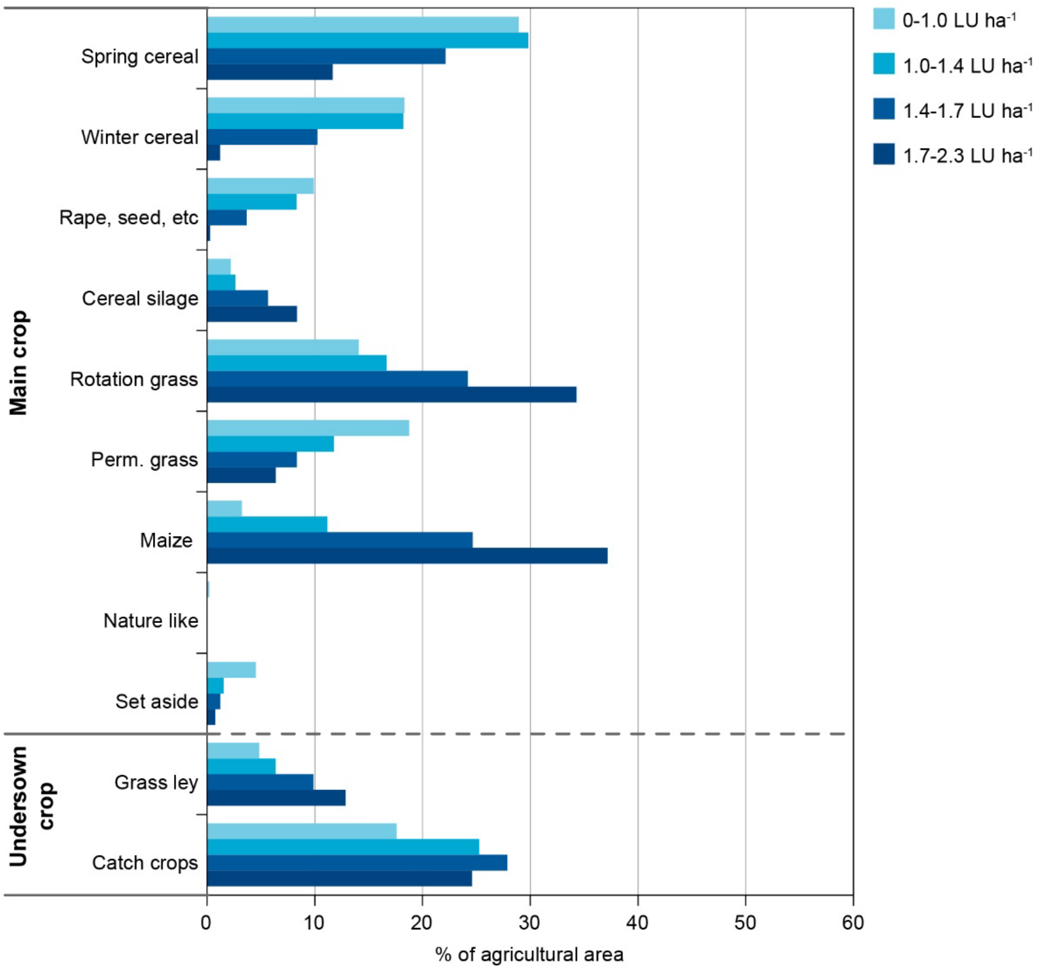

Figure 5 Average crop distribution for four groups of livestock density in N, NW and W Jutland in 2021. Combined dataset from the single payment register and the fertiliser accounts. Organic farms were not included in the analysis.

The use of legumes (clover, alfalfa, peas) in grass and cereal silage is shown in Table 7. The general trend is that derogation farms grow less legumes than non-derogation farms (Table 7). Thus, clover or alfalfa (max. 50% share) in rotation grass was used on 65% of the rotation grass area for derogation farms and on 77-79% for non-derogation farms. For permanent grass including legumes, the equivalent values were 20% for derogation farms and 25-40% for non-derogation farms. Cereal silage with peas amounted to 15% of the silage area for derogation farms and 15-20% for non-derogation farms.

Table 6 N inputs, N balances and nitrate leaching and nitrate concentration at the bottom of the root zone calculated for four groups of livestock densities at cattle farms and for three geographical areas in Jutland, Denmark, 2021. Combined dataset from the single payment register and the fertiliser accounts. Organic farms were not included in the analysis.

Region	Annual use of organic N	**N balance**									**Root zone water**		
		Inorganic fertiliser	Animal manure	Other org.N	N fix.	N de-pos.	Seeds	Total input	Harvest	Balance	Percol.	Nitrate leaching	NO_3^- conc
	kg N ha^{-1}	kg N ha^{-1} a^{-1}									mm a^{-1}	kg N ha^{-1}	mg l^{-1}
Jutland N	0-100	85	51	1.6	16	14	1.2	167	105	63	355	52	64
	100-140	77	117	1.1	22	14	1.5	233	135	98	361	59	72
	140-170	68	157	0.1	30	14	1.4	271	161	109	359	67	83
	170-230	63	199	0.1	37	14	1.3	314	188	126	349	67	85
Jutland NW	0-100	84	61	3.8	17	14	1.5	180	113	68	430	52	54
	100-140	72	120	0.0	18	14	1.5	226	130	95	458	70	68
	140-170	63	153	0.0	27	14	1.5	259	155	104	436	70	71
	170-230	57	196	0.2	34	14	1.5	303	184	119	445	77	77
Jutland W	0-100	79	55	5.3	17	16	1.6	173	115	59	520	56	48
	100-140	78	119	1.7	18	16	1.7	235	139	96	546	75	61
	140-170	72	158	0.8	25	16	1.7	273	166	107	544	84	68
	170-230	69	201	0.2	26	16	1.5	314	192	123	550	89	71

Table 7 Use of legumes in grass and cereal silage at cattle farms for derogation and non-derogation farms 2021. Organic farms were not included in the analysis.

	Use of organic N, including manure (kg N ha^{-1} a^{-1})			
	0-100	**100-140**	**140-170**	**170-230**
	share of agricultural area (%)			
Rotation grass	10.7	15.1	22.5	33.5
	share of rotation grass (%)			
No clover/alfalfa	23	21	23	35
< 50% clover/alfalfa	77	79	77	65
> 50% clover/alfalfa	1	1	0	0
	share of agricultural area (%)			
Permanent grass	15.7	10.8	7.3	6.0
	share of permanent grass (%)			
No clover/alfalfa	60	72	75	80
< 50% clover/alfalfa	40	27	25	50
> 50% clover/alfalfa	0	0	0	0
	share of agricultural area (%)			
Cereal silage	1.4	2.2	4.5	7.9
	share of cereal silage (%)			
No legumes	90	78	82	85
< 50% legumes	9	20	15	15
100% legumes	1	2	3	0

5 Development in modelled nitrate leaching in the Agricultural Catchment Monitoring Programme 1990-2020

This section deals with the general development in nitrate leaching from 1990/91 to 2020/2021 for measured nitrated concentrations in soil and ground water and to 2020/21 for the modelled nitrate leaching for tree loamy and two sandy agricultural-dominated catchments. Information on agricultural practises is derived from the Agricultural Catchment Monitoring Programme. This programme includes six small agricultural catchments situated in various parts of the country in order to cover the variation in soil type and rainfall and hence in agricultural practises (Figure 3). The farmers are interviewed every year about livestock, crops and fertilisation and cultivation practises.

Modelled nitrate leaching presented for these five catchments was in the former derogation reports modelled using the NLES3 and NLES4-models. The model was updated and recalibrated to a new NLES5-model using a larger dataset in 2020 (Børgesen et al., 2020, 2022).

Nitrate leaching for the agricultural catchments in the present report is modelled with the NLES5 model. The modelling results are therefore not directly comparable to the results in the former reports.

The modelling has been conducted for all fields in the catchments based on the information from farmers on agricultural practises and standard percolation values that are calculated on the basis of the climate for 1990-2010.

In 2021, 120 farmers participated in the investigation. 88 farms agreed to give information about part of their farming area. Of all the investigated farms, 19 were cattle farms. Three of the cattle farms were registered as derogation farms. These derogation farms covered 8% of the total area in the Agricultural Monitoring Catchments in 2021.

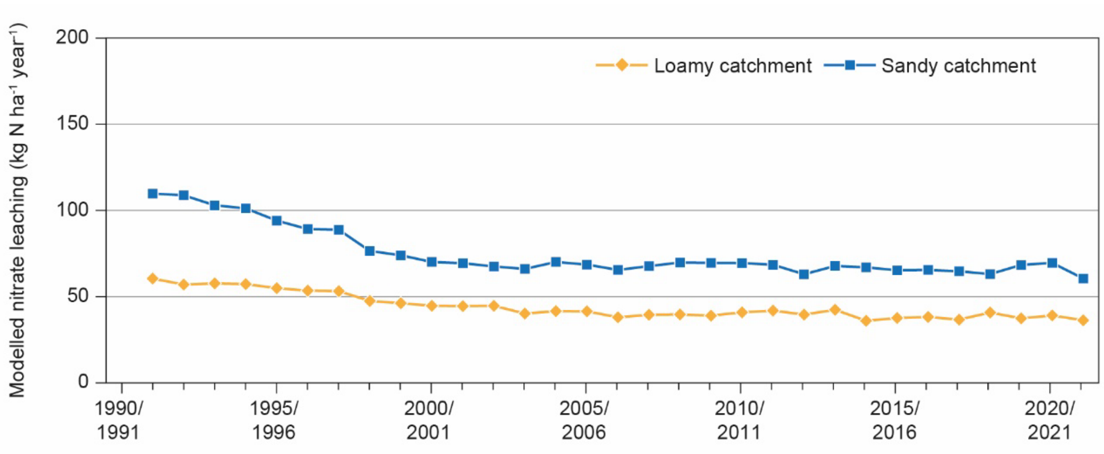

Figure 6 Simulation of the nitrate leaching using the NLES5 model in a standard climate for the fields of tree loamy and two sandy catchments within the Agricultural Catchment Monitoring Programme 1990/91-2021/22.

The modelled nitrate leaching from the agricultural area in the catchments was calculated for the period 1990 to 2021 (representing the hydrological years 1990/91 to 2021/22). The modelled leaching is shown in Figure 6 as an average for sandy and loamy catchments, respectively.

With the present model calculation with NLES5, a decrease in the modelled nitrate leaching of 42 % has been achieved for the entire period 1991/92 to 2021/22, with each LOOP catchment weighing 1/5. In this way, the average corresponds to clay soil in Denmark covering 60% and sandy soil 40%. For the period 1991/92 to 2003/04, the decrease in modelled nitrate leaching amounts to 37%. With model calculation of nitrate leaching with NLES3 and NLES4, the corresponding decrease was approx. 43% (Blicher-Mathiesen et al., 2021). The model calculation in LOOP only has data from 1991, while it is expected that nitrate leaching was also reduced before this time. At the final evaluation of Water Environment Plan II in 2003, it was calculated that nitrogen leaching at national level had been reduced by 48% from 1985 to 2003 (Grant & Waagepetersen, 2003). Here there was a reduction in leaching from 1985 to 1989 estimated to 12 percentage points.

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 just below 40 kg N ha^{-1} in the period 2015-2021. For the sandy catchments, the modelled annual nitrate leaching was relatively stable around 67-68 kg N ha^{-1} during the period 2003-2021.

The purpose of the root zone modelling is to show the effects of measures introduced to mitigate nutrient losses from agriculture. The modelling is therefore 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.

6 Measurements of nitrate in water leaving the root zone

In five of the six Agricultural Monitoring Catchments, soil water samples are collected regularly at 30 sites. One of the sites is covered by forest and is therefore not included in the data on nitrate concentrations measured in agricultural areas. Measurements were ceased on a sandy site in 2011 as the farmers did not want to participate in the monitoring. Two sites on a loamy catchment are located very close to the edge of the field, and tractor transport in and out of the fields results in high damage to crops, possible uneven fertiliser application and very high values of measured nitrate leaching in some of the monitored years. Out of the remaining 27 sites on agricultural areas, 14 are located on loamy soils and 13 on sandy soils, and the data on these are considered valid for use in the trend analysis of the loamy and sandy catchments. The samples represent the root zone water (approx. 1 m depth – 30 samples per year) and the upper oxic groundwater (1.5-5 m depth – 6 samples per year). To obtain an annual representative value for the nitrate leaching, the measured nitrate concentration is multiplied by the percolation in the sampling period. Samples are taken weekly in periods with percolation (autumn, winter and spring) and monthly in summertime when percolation is scarce or zero. Percolation values are modelled as measurements of soil water content and flow in soil, covering soil variability at field level, are difficult to perform (Blicher-Mathiesen et al., 2014). The annual flow-weighted nitrate concentration is calculated by dividing the annual percolation by the annual nitrate leaching.

Since the publication of the annual derogation report for 2018, inconsistencies in the precipitation time series have been detected (Svendsen & Jung-Madsen (Ed.) (2020); Andersen (Ed.) (2021)). These inconsistencies affect the reported flow-weighted concentrations as the precipitation time series are used for the calculation of percolation. Specifically, it was found that the relation between precipitation and stream runoff in the monitoring catchments was inconsistent before and after 2010, respectively. The precipitation is measured at several rain gauge stations and distributed to cover 10x10 km2 grids by the Danish Meteorological Institute (DMI). The type of rain gauge station was changed from 2011, and also the number of stations decreased significantly. This explains some of the inconsistency related to measured discharge. DMI has delivered new precipitation data for the period after 2010, but all inconsistency in the data has not yet been resolved. In order to address the possible bias or inconsistency in the precipitation time series, we included an uncertainty in the precipitation data, which is reflected in the calculated percolation and flow-weighted nitrate concentration. This uncertainty was derived from an analysis of radar-detected precipitation in five subplots within ten precipitation grids of 10x10 km2. The standard error bars on the flow-weighted nitrate concentration in Figure 7 and Figure 11 represent this uncertainty from variation in precipitation on field level but tabulated as an average uncertainty from ten precipitation grids (Blicher-Mathiesen et al., 2023).

The flow-weighted nitrate concentrations are shown as annual average values for loamy and sandy soils, respectively, for the period 1990/91 to 2020/21 (Figure 7).

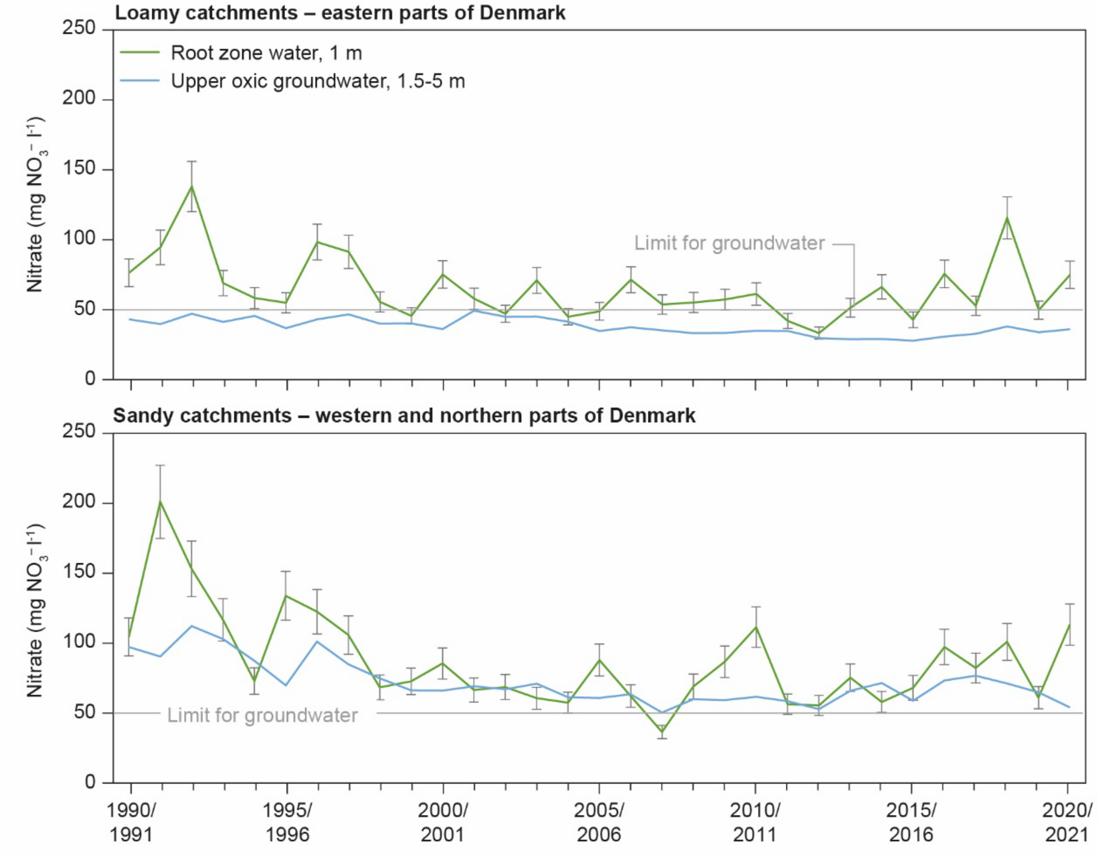

Figure 7 Annual flow-weighted nitrate concentrations measured in root zone water (1 m below ground level) and annual average nitrate concentrations measured in upper oxic groundwater (1.5-5 m below ground level), the Agricultural Catchment Monitoring Programme 1990/91 to 2020/21. Error bars indicate variation in percolation as precipitation variated on local scale within a DMI 10 x 10 km^2 precipitation grid.

Generally, measured data on nitrate leaching from the root zone at only 27 sites cannot be used directly for estimating the effect of a single variable as the input of fertiliser or manure because of the high variability in actual fertiliser and manure practice and climate between the monitoring fields and the measured years. Instead, the measured nitrate leaching data, together with other leaching data, were used for the development of the nitrate leaching model, N-LES5, which was subsequently used for calculating the leaching from all the fields in the catchments accounting for agricultural practises.

General trend for nitrate concentrations in water leaving the root zone

There is strong inter-annual variation in the measured nitrate concentrations due to differences in rainfall and temperature. Therefore, a long time series and a large number of measuring points are needed to detect any statistically significant trend. Such data series are available from the Danish Monitoring Programme. A statistical trend analysis – a Mann-Kendall test, incorporating annual variations in the mean annual flow-weighted nitrate concentrations for water leaving the root zone – showed that concentrations decreased significantly by 1.2 and 2.6 mg NO_3 l^{-1} a^{-1} for the measured sites on loamy and sandy soils, respectively, and for the whole 26-year monitoring period from 1990/91 to 2015/16.

In loamy catchments, the measured nitrate concentrations in root zone water decreased from 61-155 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 37-66 mg NO_3 l^{-1} in the 5-year period 2011/12-2015/16. In the latest 5-year period

2016/17-2020/21 the concentrations have varied from 50 to 116 mg NO3 l^{-1}. The high nitrate concentrations are seen in years with low percolation– as observed on loamy soils in 2004/05, 2010/11, in 2016/17, in 2018/19 and in 2020/21. In sandy catchments, the nitrate concentration decreased from 73-192 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 54-73 mg NO_3 l^{-1} in the 5-year period 2011/12-2015/16. In the latest 5-year period 2016/17-2020/21 the concentrations have varied from 61 to 113 mg NO_3 l^{-1} (Figure 7). High nitrate concentrations were measured after 2018, a year with drought and low yield as well as low percolation. In contrast, low nitrate concentrations were measured in 2019/20 due very high percolation diluting the nitrate in the root zone.

After 2003/04 (Action Plan III + Green Growth), no statistically significant change in measured nitrate concentrations in soil water leaving the root zone has been recorded. However, before 2011/12, high concentrations were temporarily observed for sandy soils. This is most likely due to growth of crops with high leaching potential on these fields, such as turnover of grassland followed by cereals with no catch crops the following years, growing of maize and winter oilseed rape etc.

It should be noted that the measurements of nitrate leaching originate from a small number of sampling stations (27 stations). Furthermore, the measurements are affected by high crop yields, in particular in 2009, and effects of crop rotation, especially of grass in rotation. These conditions induce higher inter-annual variations than seen in the average modelled nitrate leaching, which covers a larger area including approx. 124 farms.

In the upper groundwater (1.5-5.0 m below ground level), nitrate concentrations were lower than in the root zone water especially on loamy catchments, indicating nitrate reduction in the aquifer between the bottom of the root zone and the uppermost groundwater (Figure 7).

In loamy catchments, the measured annual mean of nitrate concentrations in the upper oxic groundwater decreased from 40-47 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 31-38 mg NO_3 l^{-1} in the 5-year period 2016/17-202020/21. In sandy catchments, the nitrate concentration decreased from 87-112 mg NO_3 l-1 in the 5-year period 1990/91-1994/95 to 54-77 mg NO_3 l^{-1} in the 5-year period 2016/17-2020/21.

Nitrate concentrations in water leaving the root zone from cattle farms with average manure N applications below and above 170 kg N ha^{-1} during the 10-year period 2011-2020.

Five of the monitoring sites received an average between 130 and 170 kg organic manure N ha^{-1} in the period 2011/12 -2020/21, and six sites received an average of more than 170 kg organic manure N ha^{-1} In the same period. Measurements of nitrate in water leaving the root zone are shown annually for each site for the period 2000/01 to 2020/21 (Figure 8A and B).

At two of the sites, station "st 604" and "st 202", the manure input changed from a high annual input (>170 kg N ha^{-1}) in the period 2000-2010 to a lower input (<170 kg N ha^{-1}) in the following years (Figure 8.A). In the period with an annual average manure application of more than 170 kg N ha^{-1}, nitrate concentrations were very high at "st 604" compared to the following period.

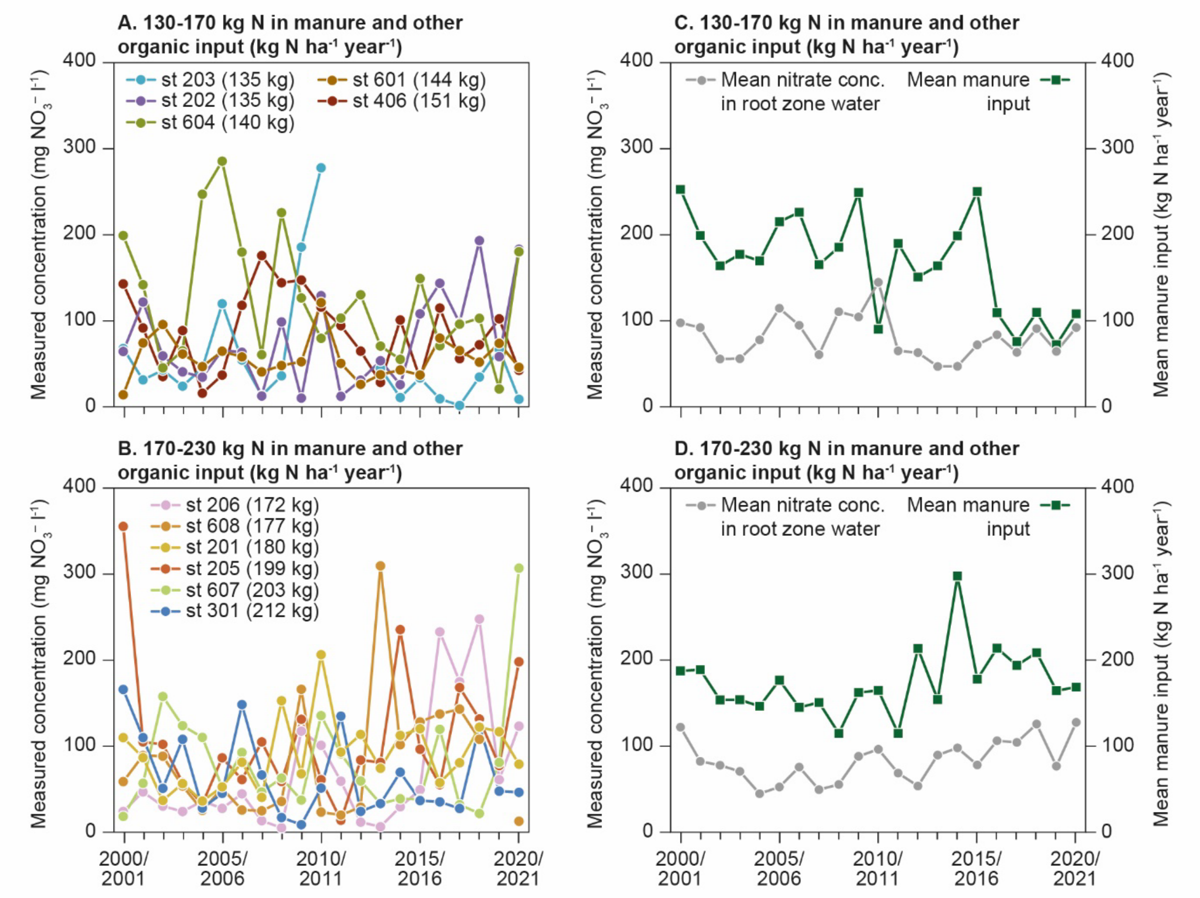

Figure 8 Measured flow-weighted nitrate concentrations in root zone water (1 m depth) with average application during the last ten years of 130-170 N ha^{-1} (A) and more than 170 kg N ha^{-1} in manure and other organic fertilisers (B) at the sites (average application of organic manure N is shown in brackets). Annual averages for the measured stations, average application of 130-170 kg ha^{-1} (C) and more than 170 kg N ha^{-1} in manure and other organic fertilisers (D). All data from the period 2000/01 to 2020/21 are shown.

At "st 202" the nitrate concentrations varied at a lower level than "st 604" in the period where the annual average manure application was more than 170 kg N ha^{-1}, (2000/01 to 2010/11) and showed increased concentrations in the period where the annual average manure application was less than 170 kg N ha^{-1} (2011/12 to 2020/21).

At two other sites, station "st 201" and "st 206", the manure input changed from a low annual input (<170 kg N ha^{-1}) in the period 2000-2010 to a higher input (>170 kg N ha^{-1}) in the following years (Figure 8.B). In the period with an annual average manure application of less than 170 kg N ha^{-1}, nitrate concentrations were very low at "st 206" compared to the following period. At "st 201" the nitrate concentrations did not show a general increase in the period where the annual average manure application was more than 170 kg N ha^{-1}, (2000/01-2010/11).

The average flow-weighted nitrate concentrations in root zone water for the six specific sites with an average manure application within 170-230 kg N ha^{-1} during the last 10-year period (2011/12-2020/21) varied between 54 and 128 mg NO_3 l^{-1} for the recent ten hydrological years (2011/12-2020/21) (Figure 8D).

The average flow-weighted nitrate concentrations in root zone water at five specific sites with an average manure application within 130-170 kg N ha^{-1}

varied between 47 and 92 mg NO_3 l^{-1} for the recent ten hydrological years (2011/12-2020/21) (Figure 8C). Thus, there was no clear difference in flow-weighted nitrate concentration between monitored fields with application of 130-170 kg N ha^{-1} and 170-230 kg N ha^{-1} in manures.

Annual variations in measured concentrations at the individual monitoring stations were expected, partly due to crop rotation and variations in yield and meteorological conditions. Both the sites that annually received an average of 130-170 kg N in manure ha^{-1} in the period 2011/12-2020/21 and the sites that received an average >170 kg N in manure ha^{-1} in the period had high average nitrate concentrations (>100 mg/l) in some of the years (Figure 8).

High nitrate concentrations are most likely a result of crop rotation, especially turnover of clover grass in rotation, followed by cereals without catch crops or high N input to maize, and they cannot be linked to the level of manure input alone.

Phosphorus concentrations in the water leaving the root zone are shown in Figure 9. Generally, the concentrations varied between 0.005 and 0.050 mg PO_4-P l^{-1}, irrespective of the use of organic manure. However, in two fields receiving an average of above 170 kg organic N ha^{-1} ("st 607" and "st 608") in the entire period from 2000/02-2020/21, P concentrations were much more variable in the first part of the period (until 2011/12) with P concentrations exceeding 0,05 mg PO_4-P l^{-1} in three hydrological years. The soil texture in these fields is coarse sand, and they are located in an area with high rainfall. Since 2011/12, the max. annual P concentrations at all monitored stations have been below 0.020 PO_4-P l^{-1}.

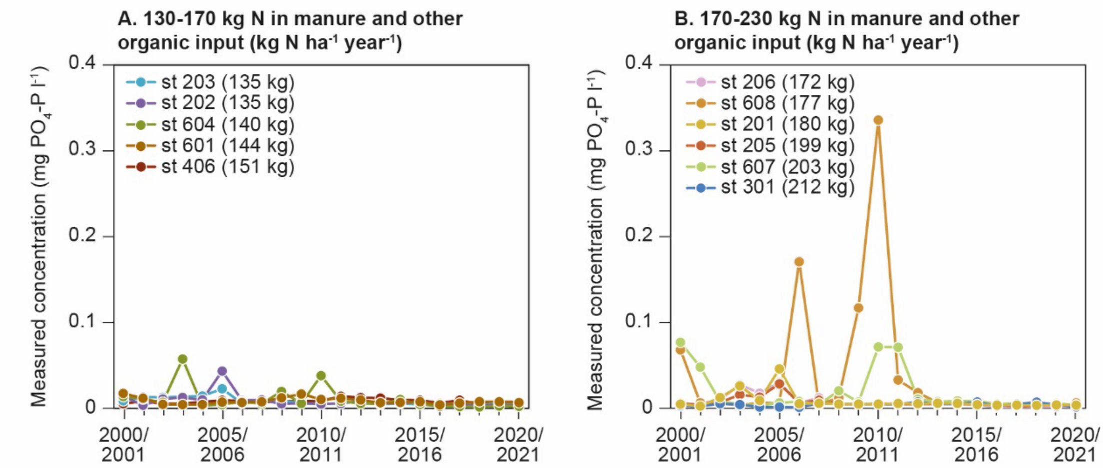

Figure 9 Measured phosphorus concentrations as dissolved orthophosphate (PO_4-P) at soil water stations (1 m depth) with average application of 130-170 (A) and more than 170 kg organic manure N ha^{-1} (B) at the sites in the recent 10 years (average application of organic manure N is shown in brackets). All data for the period 2000/01 to 2020/21 are shown.

7 The nitrogen flow to surface water in agricultural catchments

This chapter gives an overview of the nitrogen pathways in the hydrological cycle and describes the trends for nitrate in water for the period 1990 to 2021. Continued monitoring within the framework of the Agricultural Catchment Programme and the Stream Programme will provide indicators for the future development.

When percolating water leaves the root zone, it can conceptually be partitioned into a component that discharges directly to surface water and a component that discharges to groundwater from where it will eventually – often some years later – discharge into the streams. In Denmark, the pathways for water and nutrients in agricultural catchments are analysed in the Agricultural Catchment Monitoring Programme. Nitrate concentrations are measured in soil water, water from tile drains, upper groundwater and surface water from three loamy catchments and two sandy catchments.

The monitoring programme does not allow a specific evaluation of the effect of derogation farms on the nitrate transport in the streams since measurements at the catchment outlet integrate the effects of all activities in the catchment. However, the monitoring programme will provide an overview of the general trend for surface water, including the effect of any derogation farms in the catchment.

The hydrological pathways

An analysis of the water flow in the streams of the five agricultural catchments has shown that water flow can be conceptually divided into three components – rapid, intermediate and slow response to precipitation (Table 8) (Blicher-Mathiesen et al., 2021). These components may be regarded as flow from the upper soil layers (including tile drainage), from the upper oxic groundwater and from deep reduced groundwater.

Table 8 Partitioning of water flow in streams into three components – rapid, intermediate and slow responding water. The analysis included three loamy catchments and two sandy catchments (1989/90-2002/03).

	Flow response		
	Rapid	**Intermediate**	**Slow**
Loamy catchments	41%	16%	43%
Sandy catchments	20%	23%	57%

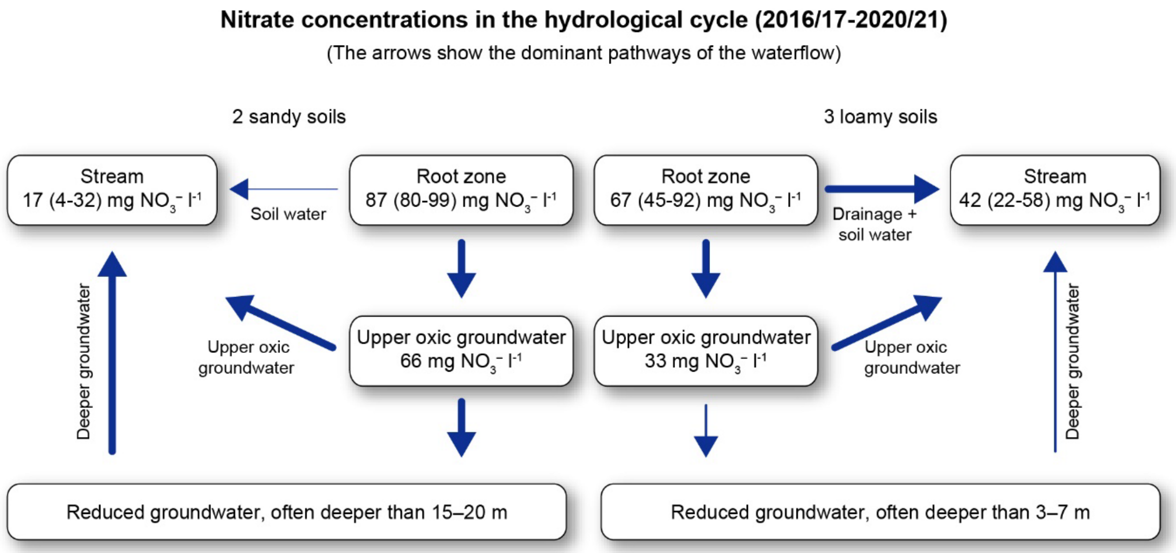

Figure 10 Measured means of nitrate concentrations in the hydrological cycle in three loamy catchments and two sandy catchments included in the Agricultural Catchment Monitoring Programme. Values instreams and root zone are shown as means, and data on min and max for the individual catchments are given in brackets. The values are calculated as an annual mean for the period 2015/16 to 2020/21.

In loamy catchments, the flow path is characterised by relatively rapidly responding water (from upper soil layers), whereas there is a larger proportion of slowly responding water (from deeper groundwater) in sandy catchments (Figure 10) (Blicher-Mathiesen et al., 2023).

Figure 11 illustrates measurements of nitrate concentrations (mg NO_3 l^{-1}) in soil root zone water, upper oxic groundwater (1.5-5 m below ground level) and in streams. When water percolates from the root zone to the upper groundwater, denitrification processes may take place depending on the redox conditions and reduction potentials. Thus, nitrate concentrations in the upper groundwater are lower than in the root zone water especially in the loamy catchments. When the water passes through the deeper aquifers, it can also be denitrified in anoxic nitrate reducing zones.

As streams in sandy catchments are dominated by deeper groundwater flow, the groundwater discharging to the streams has often been exposed to reduction processes. Thus, nitrate concentrations in the stream water are relatively low. In loamy catchments, the discharging water has mainly passed through the upper soil layers and through the drainage system where there is less nitrate reduction. Hence, nitrate concentrations in the streams on loamy soils are higher than in sandy catchments.

In this context, it should be noted that cattle farms, i.e. the derogations farms, are mainly located in the western and northern parts of Jutland that are characterised by sandy soils and deep groundwater flow, leading to relatively high nitrate removal and lower nitrogen concentrations in the streams but high nitrate concentrations in the upper oxic groundwater.

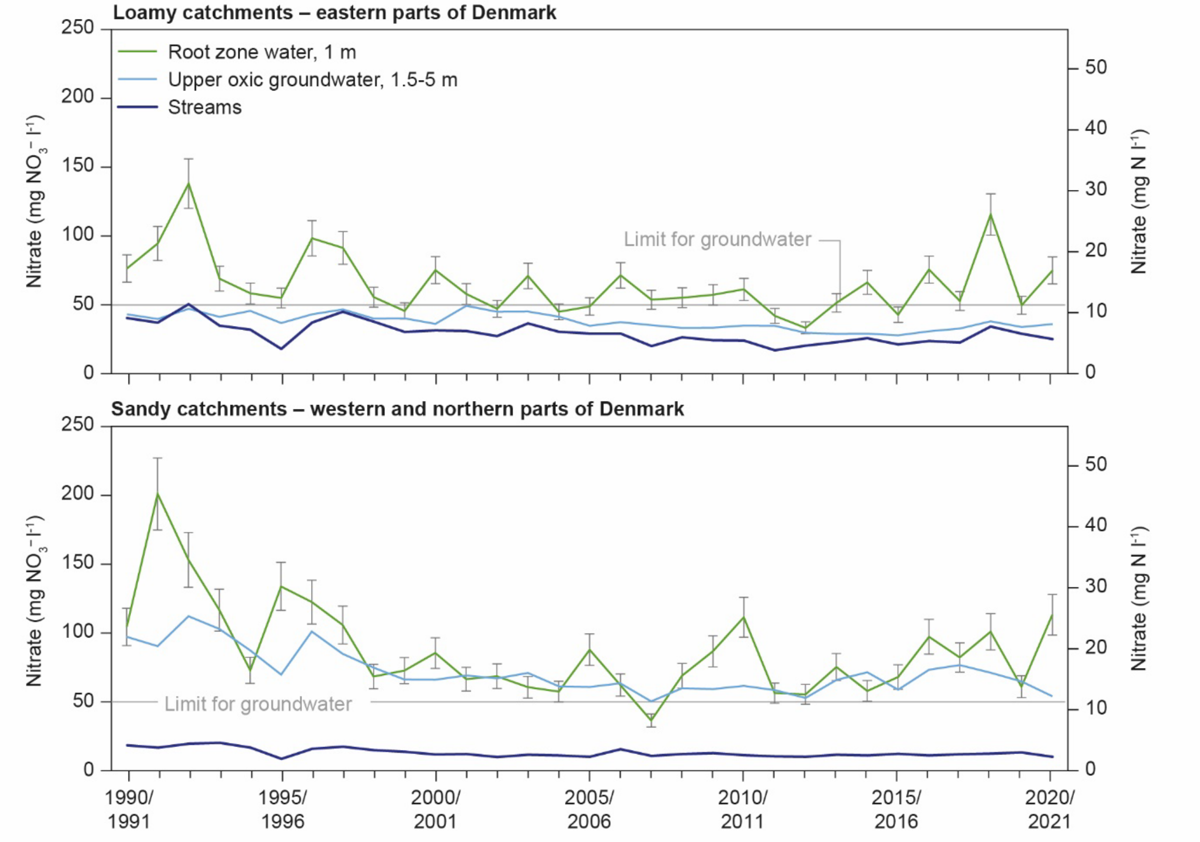

Figure 11 Nitrate concentrations measured in root zone water, upper groundwater and in streams for three loamy catchments and two sandy catchments according to the Agricultural Catchment Monitoring Programme, 1990/91-2020/21.

Trends in nitrate concentrations in the hydrological cycle

The development in nitrate concentrations in root zone water, upper oxic groundwater and stream water is shown in Figure 11. Statistical analyses incorporating the annual variations showed that the nitrate concentration in water leaving the root zone decreased significantly by 1.2 and 2.6 mg NO_3 l^{-1} a^{-1} at the measured sites on loamy and sandy soils, respectively, for the 26-year monitoring period from 1990/91 to 2015/16. However, as mentioned before, the root zone concentrations have varied from 50 to 115 mg NO_3 l- in the latest 5-year period 2016/17-2020/21 on loamy soils and between 61 to 113 mg NO_3 l^{-1} in the corresponding five years, on sandy soils. In the Stream Monitoring Programme, the development is analysed for a larger number of streams. This programme reported that during the period 1989-2021, in 45 agriculturally dominated catchments representing both loamy and sandy soils, there was an average reduction of 48% (±5%) of the total nitrogen transport (Thodsen et al., 2023).

8 Conclusions

In 1998 the Action Plan for the Aquatic Environment (APAE) II was accepted by the EU Commission as the Danish Nitrate Action Plan implementing the Nitrate Directive (1998-2003). In 2003, a final evaluation of Action Plan II was performed, showing a reduction of 48% of the nitrate leaching from the agricultural sector, fulfilling the reduction target set in 1987.

Further mitigation measures were implemented in the following Action Plans. The APAE III from 2008 were implemented to reduce N leaching from the root zone and the Green Growth Agreement from 2009. Hence, the first and second River Basin Management Plan from 2014 and 2016, respectively as well as the Food and Agricultural Agreement in December 2015 suggests mitigation measures and reductions target for N load to marine areas in order to fulfil the targets in the Water Framework Directive.

Modelling of the nitrate concentrations in the soil water leaving the root zone at national level showed an average concentration of 71-85 mg NO_3 l^{-1} for cattle holdings using 170-230 kg organic manure N in 2021 and the concentrations were 2-6 mg NO_3 l^{-1} higher for derogation farms than for cattle farms using 140-170 kg N ha^{-1} of N in manure and other organic fertilisers.

Measured average flow-weighted nitrate concentration in root zone water at six specific sites with an average manure application within 170-230 kg N ha^{-1} during the last 10 years varied between 77 and 128 mg NO_3 l^{-1} for the recent five hydrological years (2016/17-2020/21). Thus, there was no clear difference in flow-weighted nitrate concentration between monitored fields with application of 130-170 kg N ha^{-1} and 170-230 kg N ha^{-1} in manures. Phosphorus concentrations in the water leaving the root zone varied in general between 0.005 and 0.050 mg PO_4-P l^{-1}, irrespective of the amount of applied organic manure.

The general conclusions to be drawn on trend in measured nitrate concentrations in root zone water and upper oxic ground from the Agricultural Catchment Monitoring Programme are that:

- Nitrate concentrations in root zone soil water (1.0 m below soil surface) have decreased steadily from 1990/91 to 2015/16. On loamy catchments the measured nitrate concentration decreased from 61-155 mg NO_3 l^{-1} in the five-year period 1990/91 to 1994/95 to 37-66 mg NO_3 l^{-1} in the five-year period 2011/12 to 2015/16. On sandy catchments the nitrate concentration was 73-207 mg NO_3 l^{-1} in the five-year period 1990/91 to 1994/95 and decreased to 54-73 mg NO_3 l^{-1} in the five-year period 2011/12 to -2015/16. High annual variation was measured after 2015/16 until 2020/21, 50-115 mg NO_3 l^{-1} on loamy soils and 61-113 mg NO_3 l^{-1} on sandy soils with the highest concentrations in years with low precipitation and subsequent percolation and lowest concentrations in years with high precipitation and subsequent percolation as seen in 2019/20.

- Average annual nitrate concentrations in the upper oxic groundwater (1.5-5.0 m below soil surface) are well below the limit of 50 mg NO_3 l^{-1} for loamy catchments since 1990/91 and at 54-77 mg NO_3 l^{-1} for sandy catchments in the 5-year period 2016/17 to 2020/21.

9 References

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10 Bilag

Bestilling fra miljøstyrelsen.

Miljøministeriet
Miljøstyrelsen

Hav- og Vandmiljø
J.nr. 2022-63190
Ref. MAILO
Den 12. september 2022

Miljøeffekten af den danske undtagelse fra nitratdirektivet til brug for afrapportering til EU-Kommissionen i 2022

Der bedes om et dokument (omfang cirka 20 sider), der består af afrapporteringen for de nedenfor nævnte punkter, svarende til en opdatering af kapitel 4 og kapitel 8 afsnit 2 fra den seneste rapport (Derogation Report 2021).

1. Resultaterne af overvågningen af grundvandet og overfladevandet hvad angår nitrat- og fosfor-koncentrationen, herunder oplysning om tendensen i vandkvaliteten. jf. artikel 10, stk. 2

2. Resultaterne af overvågningen af arealerne hvad angår målt nitrat- og fosfor i rodzone-vandet, for marker på kvægbrug opdelt i forhold til tilførsel af henholdsvis 130-170 kg N ha^{-1} og 170-230 kg N ha^{-1} som organisk gødning, jf. artikel 10, stk. 2.

3. Resultaterne af undersøgelserne af den lokale arealanvendelse, sædskifter og jordbrugspraksis, jf. artikel 10, stk. 3

4. Resultaterne af modelberegningerne af omfanget af nitrat-udvaskning fra kvægbrug, der er omfattet af en tilladelse, jf. artikel 10, stk. 3

5. Tabeller over den procentvise andel af landbrugsarealer omfattet af en undtagelse, som er udlagt med kløver eller lucerne i græsmarker og med byg/ærter udlagt med græs, jf. artikel 10, stk. 4

6. Et dokument (omfang cirka 1 side) med det tilsvarende bidrag til rapportens konklusioner, svarende til kapitel 8 afsnit 2 i den seneste rapport.

Geodataene i rapporten skal i de relevante tilfælde være i overensstemmelse med direktiv 2007/2/EF. Danmark benytter ved indsamlingen af det nødvendige datamateriale, hvor det er relevant, de oplysninger, der tilvejebringes i det integrerede forvaltnings- og kontrolsystem, der er oprettet i overensstemmelse med artikel 67, stk. 1, i forordning (EU) nr. 1306/2013.
Til opdateringen anvendes de nyeste tilgængelige oplysninger fra registre (frem til planåret 2020/2021) og overvågningsdata (frem til og med 2021).

DCE kan offentliggøre sit bidrag i eget format efter aflevering til Miljøministeriet. DCE modtager den endelige rapport i kopi, når Miljøministeriet har oversendt denne til Kommissionen.

Leveringsfrist: På grund af forsinkelsen af data for landovervågningen, sættes fristen for levering til marts 2023