NW European Policy-Science Working Group on Reducing Nutrient Emissions

Mitigation options: Evaluating the impact of implementing nutrient management strategies on reducing nutrient emissions from agriculture in NW Europe

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In the northwestern part of Europe, many surface waters suffer from eutrophication through diffuse losses of nutrients from agriculture to surface water and relatively high nitrate concentrations in groundwater in nitrate vulnerable zones. A lot of research and policy has been devised to decrease these losses. The northwestern European countries (Denmark, NW Germany, Belgium (Flanders), United Kingdom, Ireland and the Netherlands) are working together in an active policy-science working group to improve water quality by evaluating the impact of implemented nutrient management strategies. More insight into the effectiveness and cost-effectiveness of different mitigation options under specific circumstances is needed. Therefore, each country has prepared factsheets with specific information for the top six mitigation options. Based on this information, general factsheets were made to compare the effects and cost-effectiveness of mitigation options between the NW European countries. The results are presented in this report.

Keywords: mitigation options, NW Europe, Nitrate Directive, Water Framework Directive, cost-effectiveness, Policy-Science Working Group, eutrophication, agriculture, diffuse losses

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Summary

Background
In the northwest part of Europe, many surface waters suffer from eutrophication through diffuse losses of nutrients from agriculture to surface water and relatively high nitrate concentrations in groundwater in nitrate vulnerable zones. Also, many research and policy actions have been undertaken in each of those countries to decrease these losses.

The northwestern European countries (Denmark, northwest Germany, Belgium (Flanders), United Kingdom, Ireland and the Netherlands) are working together in an active policy-science working group with two goals: 1) to reduce nutrient emissions from agricultural land to surface water and groundwater, 2) to improve water quality by evaluating the impact of implemented nutrient management strategies. As a result, the aim of this policy-science working group is to try to improve groundwater and surface water quality more efficiently and effectively, by (a) exchanging information and experiences between the group of policymakers and scientific researchers, (b) combining the knowledge and insights obtained by research conducted in the different countries and (c) if necessary, setting up new initiatives to collect important missing data for policy decision making.

Objectives
One main objective is understanding the cause of nutrient problems within catchments and developing integrated solutions for these catchments. The diffuse pollution of groundwater and surface water in rural areas is complex because of the heterogeneity within catchments/regions. Different types of agricultural systems often exist and different soil types and groundwater systems determine the amount of nutrients lost via different pathways to groundwater and surface waters.

Mitigation options
To develop integrated solution for catchments, there is a need for more insight into the effectiveness and cost-effectiveness of different mitigation options under specific circumstances. Therefore an overview of mitigation options for reducing nitrogen and phosphorus leaching to groundwater and surface water was made and discussed with the participating countries. Seven mitigation options were selected and factsheets with specific information were prepared by the individual countries (Table S.1).

In this report, the UK refers to England and Wales. Northern Ireland will be presented separately and Scotland was not taken into account.

Table S.1
Overview of the mitigation options for which factsheets have been prepared.

Mitigation options	Netherlands	Flanders	Denmark	UK[1]	NIE
Catch crops	X	X	X	X	
Application time	X			X	X
Buffer strips	X		X	X	
Controlled drainage	X				
Soil tillage	X		X		
Wetland restoration	x				
Constructed wetland			X		X

1. UK = England + Wales

The factsheets were discussed during a meeting with the Policy-Science working group and the following conclusions were drawn:

- The information that has been collected about similar systems is very valuable;
- There are varying definitions of measures, effects and goals for the mitigation options;
- The effect of the measures on the targets seems not to be known;
- ***Additional efforts are necessary to make the mitigation options comparable.***

As a result of these conclusions, efforts have been made to make the mitigations options more comparable by making general factsheets based on the individual country factsheets.

Results
Table S.2 presents the median reduction of the N- and P-leaching to groundwater and surface water. A distinction was made between the reduction of the N-load from the root zone, the reduction of the N-load to groundwater and the reduction of the N-load to surface water. Table S.3 shows the costs and cost-effectiveness of the mitigation options.

Table S.2
Overview of the effectiveness (median values in kg N ha^{-1} and kg P ha^{-1}) of mitigation options for reducing N- and P-leaching: 1) from the root zone, 2) to groundwater and 3) to surface water.

Mitigation options	Netherlands	Denmark	UK[1]	NIE
Nitrogen				
Root zone	***kg N ha^{-1}***			
Catch crops	33	26		
Application time	24			
Soil tillage		15		
Groundwater	***kg N ha^{-1}***			
Catch crops	41			
Buffer strips	5.4	50		
Surface water			***kg N ha^{-1}***	
Catch crops			13	
Application time			2.1	
Buffer strips	0.73		27	
Soil tillage		6.7		
Wetlands	0.20			23
Phosphorous				
Surface water			***kg P ha^{-1}***	
Catch crops			0.16	
Application time			0.03	2.2
Buffer strips	0.013	3.1	0.010	

1. UK = England + Wales

Table S.3

Overview of the cost (€/year) and cost-effectiveness (€ kg^{-1} N, € kg^{-1} P) of mitigation options for reducing N and P-leaching to groundwater and surface water.

Mitigation option	Costs €/year				Cost-effectiveness € kg^{-1} N-reduction				Cost-effectiveness € kg^{-1} P-reduction			
	NL	DK	UK[1]	NIE	NL	DK	UK[1]	NIE	NL	DK	UK[1]	NIE
Catch crops	85-88	56	676	-	3.1-5.0	4.0	56	-	-	-	4228	-
Application time	-	-	195	7599	-		167	-	-	-	8739	86
Buffer strips	0 - 135[2]		58-12741	-	0-9	3.3	3-554		22	15	588-3117647	-
Wetlands	42000[3]		-	4000	-	-	-	-	-	-	171	16

1. UK = England + Wales

2. € ha^{-1} year

3. € km^{-1} wet buffer

The above results show that the effectiveness of the measures within and between the different countries varies widely. The information available in the factsheets was not sufficient to explain and understand the observed differences. A more thorough comparison of the underlying data is necessary to fully understand the observed effects of the various measures under different site conditions. Based on such a comparison, transfer functions might be developed to translate the effects of certain measures to a situation with other site conditions. If such information were available for northwestern Europe, a better selection of suitable measures would be possible and the reduction of nutrient loads to groundwater and surface waters would become more cost effective.

Conclusions

- Catch crops, application time and soil tillage seem to be very effective (mean values of 15 to 33 kg ha^{-1}) in reducing the N-loads from the root zone, but the variation is rather high. For instance, a negative effect of the measure application time was calculated in the Netherlands.

- Catch crops can also be used to reduce N-loads to groundwater (41 kg ha^{-1}N). In Denmark, buffer strips are effective as well (reduction of 50 kg ha^{-1} N). It should be noted that their effectiveness is rather low in the Netherlands (5.4 kg ha^{-1} N).

- Catch crops (13 kg ha^{-1} N) and buffer strips (27 kg ha^{-1} N) are effective measures for reducing N-loads to surface water in the UK (England and Wales). In Northern Ireland, constructed wetlands are effective (23.3 kg ha^{-1} N). In the Netherlands, the effectiveness of buffer strips (0.7 kg ha^{-1} N) and wetland restoration (0.2 kg ha^{-1} N) were rather low.

- Buffer strips (Denmark) and application time (Northern Ireland) seem to be effective measures for reducing P-loads to surface water. However, the effectiveness of buffer strips is very low in the Netherlands and the UK.

- There are large variations cost and cost-effectiveness among the mitigations options. In addition, the costs for a number of measures are not known.

- The amount of data for some measures is very low, so the reliability of the results for some mitigation options is very low. To increase the reliability, more data are needed.

- Assumptions were made so that the effectiveness of some mitigation options could be compared. For example, the reduction of NO_3-concentration in upper groundwater in the Netherlands was converted into N-loads using a precipitation surplus of 300 mm/year.

1 Introduction

Denmark, the northwestern part of Germany, Belgium (Flanders), the United Kingdom, Ireland, the northwestern part of France and the Netherlands have rather similar agriculture, landscapes and catchments. Many surface waters in these countries suffer from eutrophication through diffuse losses of nutrients from agriculture to surface water and relatively high nitrate concentrations in groundwater in nitrate vulnerable zones. Many research and policy actions have been undertaken to decrease these losses in all these countries.

The northwestern European countries are collaborating in an active policy-science working group to improve water quality. They are doing this by evaluating the impact of implemented nutrient management strategies on reducing nutrient emissions from agricultural land to surface water and groundwater. The aim of this group is to improve groundwater and surface water quality more efficiently and effectively by (a) exchanging information and experiences between the group of policymakers and scientific researchers, (b) combining the knowledge and insights of research obtained in the different countries and (c) if necessary, setting up new initiatives to collect important missing data for policy decision making.

1.1 Objectives

The working group meets twice a year to discuss the progress made and the results of research activities that have been defined within the group. Their main objectives are:

1. To transfer information between policy makers about approaches and the basis of regulations in the various countries;
2. To understand the causes of the nutrient problems within catchments and develop integrated solutions for these catchments;
3. To monitor and predict the effectiveness of nutrient management strategies;
4. To develop a communication strategy for cost-effective solutions.

Simply 1) Transferring information between policy makers about approaches and the basis of regulations in the various countries

The main points of interests are:

a. How are the application standards calculated and what is the basis for the excretion standards (which data/research is available and can be shared)?
b. How are the surface water targets set in different catchments?
c. How are regional and national balances (nutrient surpluses) calculated and controlled?
d. How can the transport of manure be monitored?
e. Which modelling tools are used to support policy makers in making decisions?
f. How should nutrient management in horticulture (related to organic matter content) be dealt with?
g. How can we come to a common strategy for Brussels?
h. How do we involve farmers in implementing mitigation options?
i. Who pays the bills?

The main strategy is for policy makers to share and discuss this kind of information.

Simply 2) Understanding the problem and developing integrated solutions (mitigation options)
The diffuse pollution of groundwater and surface water in rural areas is complex because of the heterogeneity within catchments/regions. Often, there are different types of agricultural systems. Different soil types and groundwater systems also determine the nutrient losses via different pathways to groundwater and surface waters.

The northwestern European countries use different methodologies to define critical source areas for nutrient losses (N and P) to groundwater and surface water and critical farms/farm systems. Comparing these different strategies highlights the similar and different vulnerable areas, which provides information about the certainty of selected critical source areas.

Furthermore, a comparison includes background information about the rules that have been used to identify the vulnerability of certain areas and farm systems and which characteristics determine high nutrient losses. Such information helps to clarify the validity of the approaches and enables the development of a more common strategy based on the discussions and conclusions made by the policy-science group.

One step is to define a short list of mitigation options (e.g. based on the COST action 869). Their cost-effectiveness can then be determined and they can be ranked for different conditions based on the materials available in each country. The COST-database can then be updated. Finally, an economic cost-benefit analysis of different approaches (implementations) can be made for different catchments with high nutrient diffuse pollution.

Simply 3) Monitoring and predicting effectiveness
Catchment measurement programmes are necessary to quantify the contribution of different point and non-point sources to the nutrient pollution of surface water. However, it is rather difficult, and sometimes impossible, to separate all causes/events of diffuse nutrient losses to surface water by different pathways (e.g. overland flow, interflow, subsurface leaching, upward seepage). Therefore, models are needed for the final interpretation for the whole catchment. In the last decade, more attention has also been paid to the influence of specific conditions within the catchment (e.g. downtrodden parts of parcels, cow tracks, septic tanks, farmyard runoff). These conditions should be included in the catchment analyses to improve the quantification of sources (source apportionment method). The main points of interest defined by the policy-scientific working group are:

i. Which models and tools are available to quantify the sources and pathways of nutrients on a catchment scale?
ii. Which models and tools are available to quantify the effectiveness of mitigation options on water quality?
iii. How should the effectiveness of implemented mitigation options (on a catchment scale) be measured?
iv. Ranking measures from the point of view of farmers (acceptable) and control by other parties;
v. Developing metrics (ranking) for the environmental performance of farming.

Simply 4) Developing a communication strategy
First, the policy-science working group is an internal informational network platform between the countries. This exchange programme uses meetings and workshops to fulfil the defined (and updated) action plan. The outcome of the action plan should lead to recommendation schemes and can be used to change and update the countries' regulations. Furthermore, more specific attention will be paid to determining how to involve stakeholders.

This report describes the activities related to mitigation options (2nd objective) in more detail.

2 Mitigation options

After the first meeting in Amsterdam (March 2012), the participating countries were asked to give an overview of mitigation options for reducing nitrogen and phosphorus leaching to groundwater and surface water. Table 1 gives an overview of the most important mitigation options and how they are implemented in regulations (degree of implementation):

- Basic implemented: BI
- Basic planned: BP
- Supplementary implemented: SI
- Supplementary planned: SP
- Optional planned: OP
- Optional: O

Table 1
Overview of the most important mitigation options within the different countries/regions and the degree of implementation.

Mitigation options	NL[1]	DK[1]	FL[1]	SL[1]	UK[1]	NIE[1]	IE[1]
NO_3							
Catch crops	BI	BI				BI[2]	
Application time	BI	BI	BI	BI	O[3]	BI	BI
Reducing application standards	BI	BI	BI	BI	O[3]	BI	BI
Increase efficiency BMP	?				O[3]	SI	
Nitrogen							
Catch crops		SI				BI[2]	
Buffer strips	BI[4]	BI	BI[4]	BI	O	OP[5]	
Wetland restoration		BI[4]			O		
Constructed wetland		O			O	OP[6]	
Controlled drainage	O	O			O		
Soil tillage	O	BI		O	O	BI[2]	
Phosphorous							
Cover crops					O		
Catch crops		SI					
Buffer strips	BI[4]	BI	BI[4]	BI	O	OP[5]	
Wetland restoration		BI[4]			O		
Constructed wetland	O				O	OP[5]	
Lowering P-surplus	BI (SP)	BI	BI		O	OP[6]	
Controlled drainage	O	O			O		
Fe filters	O						
Soil tillage	O	BI		O	O	BI[2]	

1. NL = the Netherlands, DK = Denmark, FL = Flanders, SL = Schleswig-Holstein (Germany), UK = England / Wales, NIE = Northern Ireland, IE = Ireland.
2. Farmers must choose one of three options following harvest: 1) the stubble of the harvested crop remains on the land; 2) the land is sown with a crop that takes up nitrogen; or 3) the land is left with a rough surface, ploughed or disced, to encourage infiltration.
3. Unless in Nitrate Action Zone, where these measures are Basic Implemented.
4. Limited.
5. Plans to be implemented through voluntary agri-environmental scheme.
6. Focus will be on CW used for treatment of dirty water from farmyards.

The selected mitigation options were discussed during the second meeting in Denmark (January 2013). The outcome of the discussion was a need for more insight about:

- Influence of agricultural practice on water quality: contribution of sources and pathways;
- Cost-effectiveness of mitigation options under specific circumstances;
- Resource efficiency and impact on the water quality;
- Improvement of indicators for water quality;
- Knowledge of how to restore ecological systems (what to do when 'all' possible measures don't work?);
- Communication strategies for successful involvement of stakeholders and implementation of management strategies;
- Sustainable Intensification: Achieving Agronomic and Water Quality Targets.

One recommendation is to obtain more insight into the effectiveness and cost-effectiveness of different mitigation options under specific circumstances. For the top six, mitigation options factsheets were prepared with specific information. This included:

- *Description*: the exact definition of the mitigation option;
- *Rationale, mechanism of action*: the mechanisms/processes that induce the reduction in losses;
- *Time frame*: the time frame in which reductions in N- or P-leaching will occur;
- *Applicability*: the (specific) circumstances (e.g. areas, period, crops) where the mitigation option is/can be implemented;
- *Effectiveness and cost-effectiveness*: overview of the effectiveness and costs of the mitigation option in the countries under specific circumstances and type of study and references for:
  - Groundwater
  - Surface water
- *Environmental side effects*: the change in nitrogen and phosphorus losses due to this measure in/to the soil-air-water compartments;
- *Feasibility*: the feasibility of the mitigation options in practice;
- *Mode of implementation*: the impact of implementation of mitigation options on the administrative/regulatory/communication platform.

An overview of the factsheets is given in Table 2.

Table 2
Overview of the mitigation options for which factsheets have been prepared.

Mitigation options	Netherlands	Flanders	Denmark	UK[1]	NIE
Catch crops	X	X	X	X	
Application time	X			X	X
Buffer strips	X		X	X	
Controlled drainage	X				
Soil tillage	X		X		
Wetland restoration	X				
Constructed wetland			X		X

1. England and Wales.

The first results were presented in the third meeting in Amsterdam (November 2013). The first results were:

- The information collected in similar systems is very valuable;
- There are differing definitions of measures, effects and goals for the mitigation options;
- The effects of the measures on the target realisations seems not to be known;
- ***Additional efforts are necessary to make the mitigation options comparable.***

In 2014, efforts were made to make the mitigations options more comparable. This involved creating general factsheets based on the individual country factsheets. The general factsheets are presented in Chapter 3. The original country-level factsheets are presented in Appendices A through F. The first results were presented during the meeting in Belfast (October 2014).

3 General Factsheets

3.1 Catch crops

Description
Catch crops are sown following the harvest of the main crop or undersown in the main crop to prevent bare soils, to reduce the leaching of nitrate and/or to improve soil fertility. In temperate humid climates, catch crops have proven to be a useful tool for abating soil erosion, nutrient leaching and soil organic carbon losses.

Rationale, mechanism of action
Nitrogen (N) fertiliser is not entirely recovered by crops as a result of intrinsic plant characteristics or the incomplete rooting of the soil profile. After harvest, the mineral N that is not taken up by the crop remains in the soil. The soil mineral N (SMN) pool can further increase in late summer and autumn due to the mineralisation of crop residues and soil organic matter. This nitrogen can be lost to the environment. Catch crops can partly intercept this N in autumn and fix it temporarily until the catch crop is destroyed by frost, herbicide or incorporation. Once destroyed, the plant organic matter decomposes and nutrients in it can become available to a next crop ('mineralisation'). Consequently, the N rate applied to these subsequent crops can be reduced by 15-60 kg N per ha, depending on the catch crop species, the rate of development (N uptake) and the time of destruction.

This catch crop can also be used as a 'cover' to protects the soil's surface, leaving it less exposed and vulnerable to surface runoff and therefore less vulnerable to erosion. Reducing erosion reduces the mobilisation of P attached to sediment particles.

The effectiveness of the catch crop depends on the sowing date and crop development, the time of destruction and the extent to which the next crop is able to utilise the N released by the catch crop. The earlier the catch crop is sown at the end of summer or beginning of autumn, the better the crop can develop before winter time and the more N will be fixed. The timing of planting crops and incorporation has to fit in with appropriate weather, farm management and rotations. If destruction of the catch crop occurs too early, the release of N will not coincide with the N demand of the next crop and N will still be lost during the winter. Generally, the most effective is a winter-hardy catch crop that is incorporated in March.

Time frame
The emission to soil and surface waters is reduced in autumn and winter and can be effective within the first leaching season.

Applicability

General
Catch crops can be cultivated in any cropping system as long as there is enough time for ample development and uptake of nutrients. In the moderate marine climate of northwestern Europe, catch crops can best be cultivated after cereals or other early harvested crops (e.g. some vegetables), as it is generally advised to sow catch crops before 1 September to obtain sufficient N uptake to reduce N losses during winter (Herelixha *et al.*, 2002).

Weather conditions during and shortly after sowing the catch crop are crucial to obtaining high catch crop N yields. Late summer drought can cause delayed germination, resulting in effects similar to those for catch crops sown late.

In drier climates, soil moisture depletion by catch crops can negatively influence the next main crop. Undersowing the catch crop in the main crop can also create problems with soil moisture availability for both the main crop and the catch crop. Furthermore, establishing the catch crop under the main crop is not always successful.

The Netherlands
Farmers are legally obliged to grow a catch crop after cultivating maize on sandy soils and loess soils. It has been estimated that green manures are grown on about 15% of the remaining arable land to add organic matter to the soil in favour of soil fertility. This type of *green manure* is mostly grown after cereals and fertilised, unlike catch crops. To a certain extent, catch crops can also be grown after crops other than maize that leave behind substantial amounts of SMN.

UK (England and Wales)
This is applicable to arable land in areas with significant amounts of spring crops with sandy soils. It is more problematic and less effective in areas with medium/heavy soils.

Flanders
The environmental policy allows farmers to apply animal manure (slurry) at a rate of 60 kg total N ha^{-1} after harvest of winter cereals, when they sow a catch crop before 1 September (on light textures) or before 15 October (on heavy textures).

Effectiveness
The reduction of the N-load/nitrate concentration was calculated for four different parts in the water and nutrient cycle:
1. reduction of N-leaching from the root zone (N-loads);
2. reduction of nitrate concentrations in the upper groundwater (NO_3-concentration);
3. reduction of N-leaching to surface water on a farm scale (N-loads);
4. reduction of N-load to surface water on a catchment scale (N-loads).

To compare the effectiveness of catch crops under different field conditions between the countries, these differences should be taken into account (Figure 1). The possible reductions were converted to the same units and some assumptions were made to compare reductions in different parts of the water and nutrient cycle.

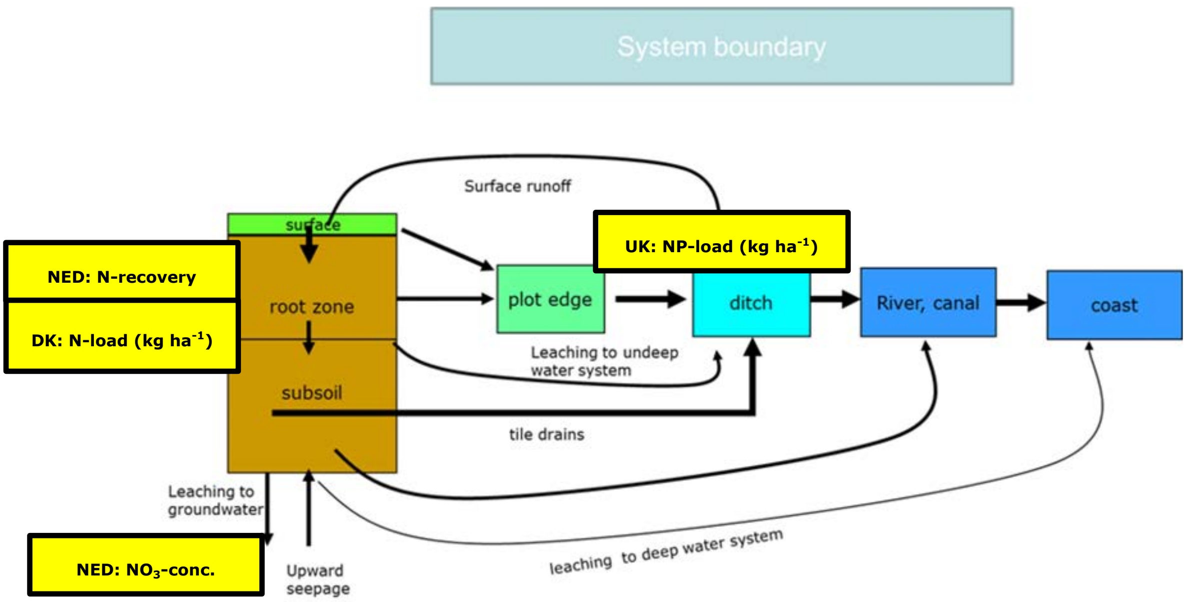

Figure 1 *System boundary condition: part of the water and nutrient cycle for which the effectiveness of catch crops are calculated in the different countries.*

Nitrogen
To compare the effectiveness of catch crops in the Netherlands, the reduction of NO_3-concentrations in the upper groundwater was converted into N-loads using a precipitation surplus of 300 mm/year. The results are presented in Figure 2 and Table 3.

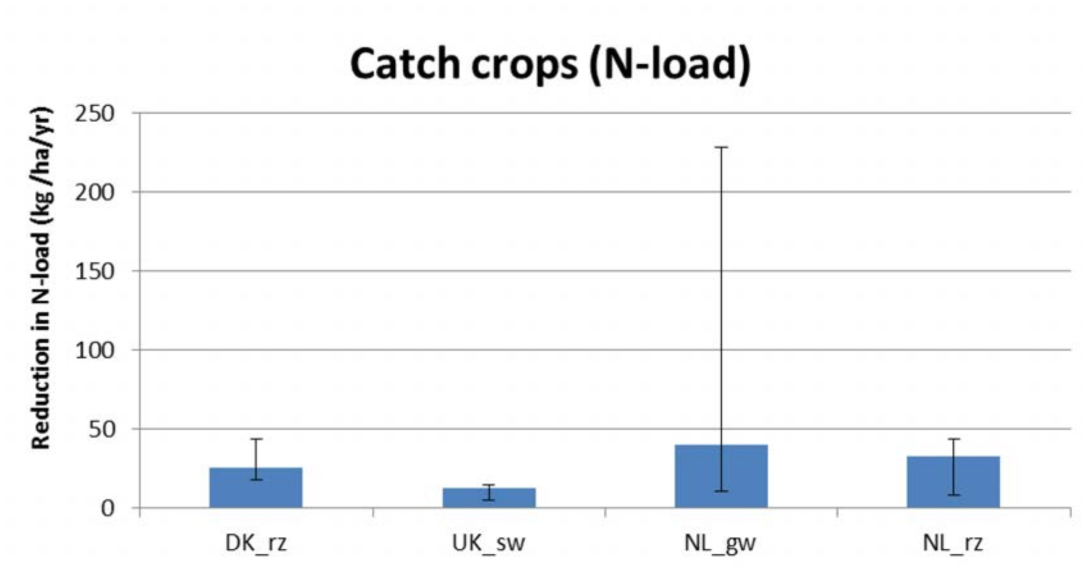

Figure 2 *The effectiveness of catch crops for reducing the N-load from the root zone (rz), to groundwater (gw) and to surface water (sw).*

Table 3
Reduction of N-loads from the root zone (kg ha^{-1}) to groundwater (kg ha^{-1}) and surface water (kg ha^{-1}) using catch crops.

N-loads	Denmark	Netherlands	Netherlands	UK[1]
	Root zone (kg ha^{-1})		Groundwater (kg N ha^{-1})	Surface water (kg ha^{-1})
	n = 5	n = 4	n = 18	n = 8
Average	30	29	73	11
Min	16	6	6	4
Max	46	44	346	15
Median	26	33	41	13
5% percentile	18	9	11	5
95% percentile	44	44	228	15

1. England and Wales.

The reduction of the N-loads to groundwater from the root zone by using catch crops in the Netherlands and Denmark are quite similar. The median reduction is 26 kg ha^{-1} for Denmark and 33 kg ha^{-1} for the Netherlands. The reduction of the N-load to groundwater is 41 kg N ha^{-1}. The reduction of the N-load to surface water in the UK is 13 kg ha^{-1}.

Phosphorus
The effectiveness of catch crops on the P-losses to surface was only calculated for the UK (median value of 0.16 kg ha^{-1}), so no comparison can be made (Table 4).

Table 4
Reduction of P-loads to surface water (kg ha^{-1}) in the UK using catch crops.

P-load	UK[1] Surface water (kg ha^{-1})
Average	0.13
Min	0.02
Max	0.18
Median	0.16
5% percentile	0.04
95% percentile	0.17

1. England and Wales.

Costs
The calculated costs for growing catch crops vary per crop species and consist of:
- seed costs;
- fuel for soil preparation and sowing;
- cultivation (€70–120 per ha in the Netherlands);
- labour costs (2–3 hours per ha in the Netherlands);
- additional treatment to destroy and incorporate the catch crop before ploughing (optional).

Potential benefits of catch crops are:
- saving nitrogen fertiliser in the next crop;
- possible yield increase in the next crop.

Table 5 presents the costs of using catch crops in the different countries. The costs of catch crops are more or less comparable in Denmark and the Netherlands; in the UK, the costs are much higher.

Table 5
Costs (€/year) of using catch crops to reduce N- and P-loads from the root zone, to groundwater and surface water.

N-loads	Denmark	Netherlands	Netherlands	UK[1]
	Root zone		Groundwater	Surface water
	n = 3	n = 4	n = 10	n = 8
Average	52	90	157	1338
Min	44	75	75	118
Max	56	115	770	3882
Median	56	85	88	676
5% percentile	45	75	75	118
95% percentile	56	112	475	3882

1. England and Wales.

Cost-effectiveness
When the effectiveness and the costs are known, the cost-effectiveness (€ kg^{-1} N- or P-reduction) can be calculated for the different countries (Figure 3 and Table 6). The figures only show the median values. The cost-effectiveness of reducing N-loads is less favourable (high costs, low reduction) for surface water than for groundwater, or for reducing nitrate concentrations in groundwater.

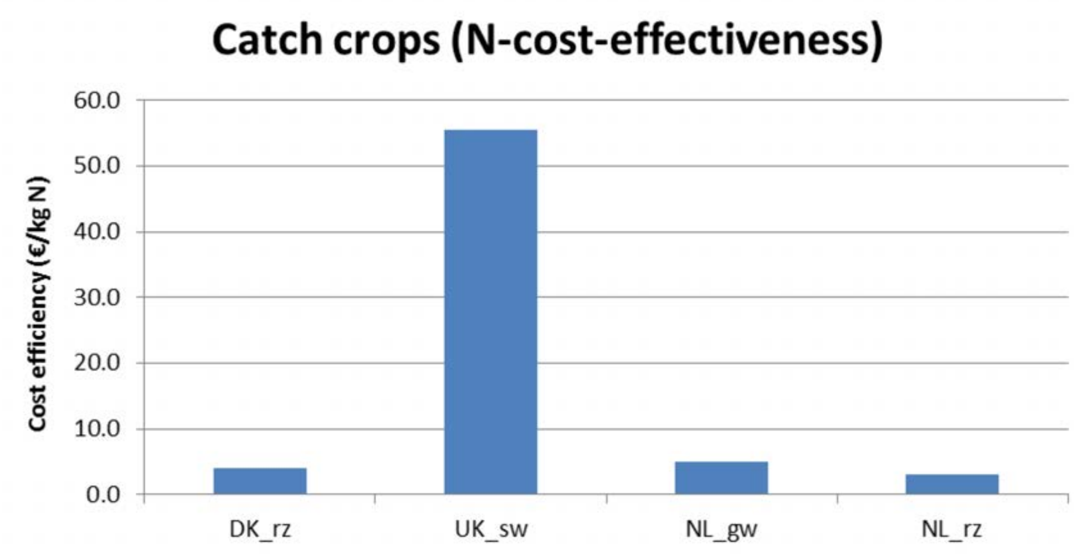

Figure 3 *Cost-effectiveness of catch crops for reducing N-loads from the root zone (rz), to groundwater (gw) and to surface water (sw).*

Table 6
Cost-effectiveness (€ kg^{-1} N- or P-reduction) of using catch crops.

	Denmark	Netherlands	Netherlands	UK[1]	
	Nitrogen				Phosphorous
	Root zone		Groundwater	Surface water	
	n = 3	n = 4	n = 10	n = 8	n = 8
Average	3.2	6.6	11	101	35472
Min	1.5	1.8	1.4	16	1176
Max	4.0	19	33	288	242647
Median	4.0	3.1	5.0	56	4228
5% percentile	1.8	1.9	1.4	20	1279
95% percentile	4.0	17	29	278	165270

1. England and Wales.

The cost-effectiveness of catch crops in the UK is much lower than in the Netherlands and Denmark. The lower cost-effectiveness is mainly the result of high costs.

Environmental side effects / pollution swapping
The following side effects are mentioned:

- When catch crops are left unincorporated on top of the soil, mineralised N may be partly lost to the air as ammonia (NH3) instead of being leached as nitrate.
- Small increases in CO2 emissions are expected during the establishment of a catch crop due to additional fuel use (sowing, harvesting the catch crop). This effect may be counteracted by a lower decline/increase in soil organic matter.
- Catch crops may affect N2 and/or N2O emissions. Both positive and negative effects have been recorded.
- Catch crops might stimulate weed and nematode suppression and therefore reduce the number of pesticide and herbicide applications. However, the Netherlands reported an increase in nematode presence.

Feasibility

The Netherlands
Apart from their compulsory use after maize is grown on sandy and loess soils, catch crops are not cultivated on a large scale. Crop rotation is often too intensive, leaving few opportunities for a successful catch crop; many main crops are not harvested before late autumn. However, to be effective, the catch crop should be sown before the end of September and preferably even before the beginning of September. Therefore the main crop must be harvested relatively early. It is estimated that a successful catch crop can be grown on no more than about 45% of the cultivated area of ware potatoes on sandy soils in the southeast of the Netherlands.

Catch crops are also host plants for parasitic nematodes and increase the infection degree of soil-borne nematodes that infect other crops as well. This is specifically a problem on sandy soils, resulting in the limited adoption of green manures by farmers (depending on the nematodes infection of the soil).

Denmark
The use of catch crops is a well-known measure and has been used for many years. Presently, an area corresponding to approximately 230,000 ha is annually covered with catch crops (mandatory). In the River Basin Management Plans (RBMPs), another 140,000 ha catch crops is foreseen, but has not yet been implemented.

UK (England and Wales)
Catch crops lead to potential increases or no effects if the development of a crop and hence its nutrient uptake does not coincide with leaching losses. Structural damage to the soil caused by establishing a crop in wet conditions can lead to further issues related to poor development and increased erosion risk.

Flanders
Only bad weather conditions can hinder the sowing of a catch crop. Dry spells after sowing can retard the development of the catch crop.

Mode of implementation

The Netherlands
Catch crops are not widely used on arable land (apart from their use after the cultivation of maize). A much larger implementation of catch crops would require an earlier harvest of the main crop, and the availability of species that are more tolerant to producing at relatively low temperatures and do not host plant parasitic nematodes. Improvement may be possible by introducing new plant species and/or plant breeding. Furthermore, an earlier harvest of the main crop should be pursued, without loss of yield, by growing earlier maturing varieties or (although less promising) by different cultivation techniques.

Denmark
Use of catch crops is mandatory (a certain percentage of the arable land should be covered; the percentage depends on the AU/ha) and is not targeted according to the need of the receiving water (a national regulation). Catch crops are also used in the individual environmental permits to ‘compensate’ for a high AU/ha level. Future use of catch crops (in RBMPs) will be targeted towards catchments of coastal areas with a documented need for a reduced load of N.

UK (England and Wales)
This is a voluntary measure, available under a stewardship scheme.

Flanders
As in some other countries or regions, farmers are given a subsidy to cover the costs of the seed and soil cultivation. To obtain the subsidy in Flanders, the catch crop must be sown before 15 October; although that it is too late to get the most beneficial effects of the catch crop.

3.2 Application time

Description

The application of N and P by fertilisers, manure or grazing is withheld in periods with excessive risk of losses to the environment. The following methods are used:

The Netherlands

- Mineral fertiliser nitrogen (N) and manures rich in mineral N ('slurries and liquid fractions') can only be applied when the risk of nitrate leaching is small, to avoid excessive losses of N to the environment.
- Mineral N fertiliser dressings can be split instead of applied once, to reduce the risk of N losses and to adjust rates to crop demand and the variable supply of N from the soil.

UK (England and Wales)

Four methods fall under the category of application time, within Newell Price *et al.* (2011):

- Reducing the length of the grazing day/season (Method 35);
- Avoiding spreading slurry of poultry manure (Method 69);
- Avoiding spreading farmyard manure (Method 72);
- Manufacturing fertiliser (Method 26) at high-risk times.

Northern Ireland

The closed period for organic and inorganic fertiliser spreading relates to the restrictions on the time of year farmers are allowed to spread fertiliser on their land. The current closed periods are described below. In addition, strict regulations apply to the application of organic and inorganic fertiliser outside the current closed period.

Rationale, mechanism of action

The application of organic and inorganic fertilisers to agricultural land poses a significant risk to water quality if it is spread when there is limited uptake of nutrient by plants and/or there is a high risk of runoff coinciding with applications. The closed periods for manure or fertiliser application largely coincide with periods when crop uptake is limited during late autumn and winter months.

Splitting mineral (N) fertiliser dressings reduces the risk of N losses due to leaching and denitrification in rainy periods during the growing season, especially in shallow rooting crops in soils that are susceptible to leaching (i.e. coarsely textured soils with little organic matter and/or a limited rooting depth). Splitting also allows N rates to be adjusted to soil and weather conditions (e.g. N mineralisation that tends to vary across fields and years). The required N rates can be based on the observed SMN content during the growing season or on the crop's N status as reflected in, for example, the nitrate content of the petioles. Such improvements in the synchronisation of N supply and demand can prevent an overdose of N. This results into a smaller N surplus and less residual SMN in autumn, which lead to a smaller loss to the environment. Reducing the time animals spend grazing reduces the amount of urine deposited in the field as 'hot-spots', which reduces the amount of nitrate leaching and N_2O emissions to the air.

Time frame

The Netherlands

- Manure is applied in spring and summer: the emission to groundwater and surface waters is reduced in autumn and winter.
- Splitting the N rate: the emission is reduced during the growing season if a precipitation surplus is expected to occur in rainy periods (e.g. in field production of vegetables in autumn).
- Improving the synchronisation of N supply and demand: reducing the emission in autumn and winter.

UK (England and Wales)

Time frame in which reductions to N- and P-leaching occur should be immediate.

Northern Ireland
15 September through 31 January

Applicability

The Netherlands
The application time of manures and mineral fertiliser N is legally controlled: it is forbidden to apply slurry on arable land between 1 August and 1 February and on grassland between 1 September and 15 February. An exception is made for application on arable land in August if a catch crop is sown before 1 September. Solid manures, such as farmyard manure, can be applied over the whole year on arable land with clay and peat soils, but even solid manures cannot be applied on sandy soils and loess soils between 1 September and 1 February. Mineral fertiliser N can generally not be applied between 15 September and 1 February. Some exceptions are made for crops grown in autumn.

Splitting the N rate is common practice in several crops, especially in grasslands, many vegetable crops and strawberries. Besides improving the efficiency of N use, splitting is meant to control crop development. Generally, the benefit of splitting the N supply to reduce N losses is highest in shallow rooting crops that are grown at the end of summer and in autumn when the risk of a precipitation surplus increases.

N splitting systems consisting of conditional, indicator-based post-emergence N applications are available for maize, potatoes, several vegetables crops, strawberries and flower bulbs. Some other systems are also available for potatoes next to SMN-based systems. These alternatives are based on monitoring petiole nitrate content and/or plant biomass. A new system developed for potatoes and leeks is based on monitoring the crop with a radiation reflection sensor. The crops' N requirements can thus be derived from their canopy reflection. Crop sensing may also be suitable and further developed for other crops.

UK (England and Wales)
Livestock farms where animals graze outside in spring and autumn. All farms that produce or use farmyard manure (FYM), poultry slurry or fertiliser and have drained and/or sloping land.

Northern Ireland
- The land application of chemical fertiliser to grassland is not permitted between 15 September and 31 January of the following year.
- The land application of chemical fertiliser to any land is not permitted between 15 September and 31 January of the following year for crops other than grass unless there is a demonstrable crop requirement between those dates.
- The land application of organic manure, excluding farmyard manure and dirty water, to any land is not permitted between 15 October and 31 January of the following year.
- The land application of farmyard manure to any land is not permitted between 31 October and 31 January of the following year.

Effectiveness
The reduction of the N-load/nitrate concentration was calculated for five locations in the water and nutrient cycle (Figure 4):
- reduction of the total N-rate, relative N fertiliser value (RNFV), apparent N-recovery (ANR);
- reduction of the total N-surplus of the soil system;
- reduction of residual mineral N in the root zone;
- reduction of P-leaching (kg ha^{-1} P) from surface runoff;
- reduction of N- and P-leaching to surface water on a farm scale.

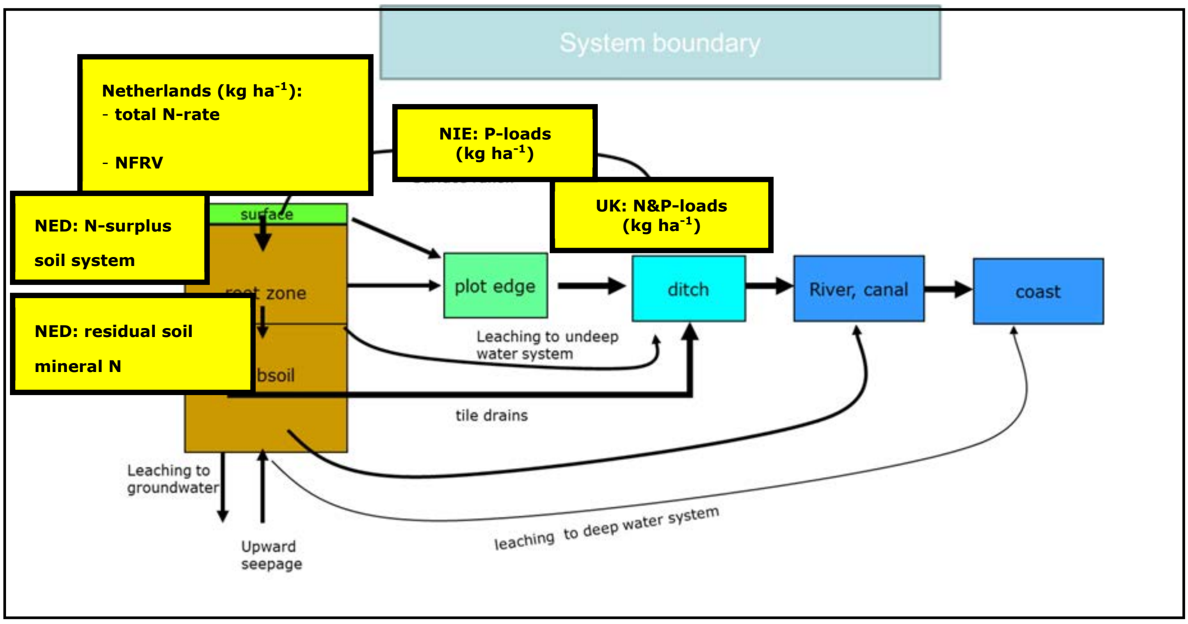

Figure 4 *System boundary condition: the part of the water and nutrient cycle for which the effectiveness of application times are calculated in the different countries.*

The reduction of nitrogen loads from the root zone (Netherlands) and to surface water (England and Wales) are presented in Figure 5 and Table 7.

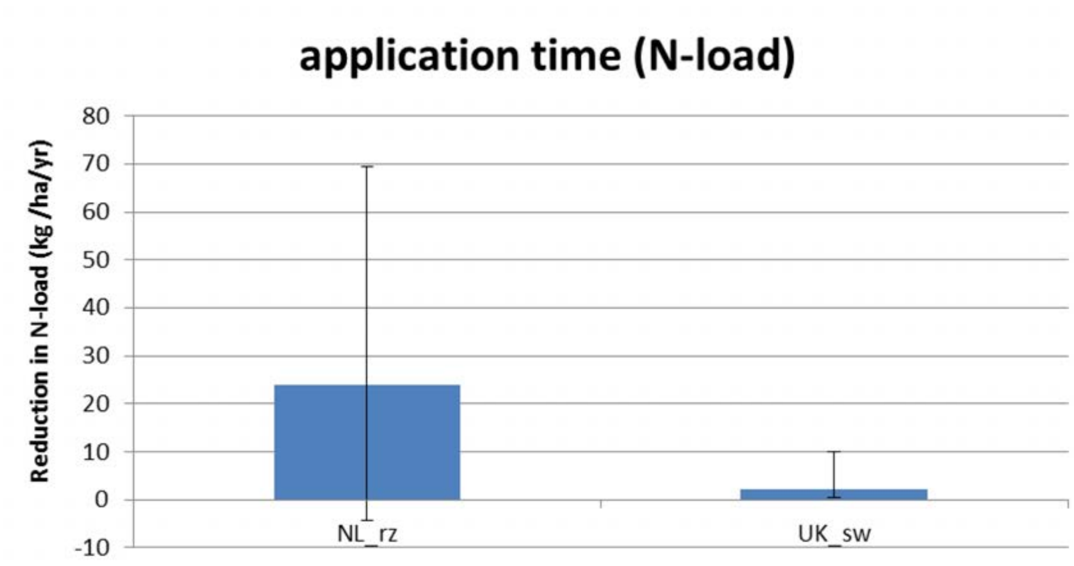

Figure 5 *Effectiveness of application time to reduce the N-load from the root zone (rz) and to surface water (sw).*

The effectiveness of the mitigation option application times between the Netherlands and UK were calculated for different locations in the soil-water-system (NL: root zone, UK: surface water). The effectiveness of the mitigation options in the Netherlands is higher than the effectiveness in the UK (median reduction of 24 kg ha^{-1} versus 2.1 kg ha^{-1}).

Table 7

Reduction of N-loads (kg ha^{-1}) from the root zone and to surface water.

N-loads	Netherlands (n = 23)		UK[1] (n = 32)	
	Root zone		Surface water	
	kg ha^{-1}	%	kg ha^{-1}	%
Average	27	38	3.2	11
Min	-35	-35	0.4	5
Max	85	92	10	20
Median	24	33	2.1	5
5% percentile	-4	9	0.6	5
95% percentile	69	86	10	20

1. England and Wales.

The effectiveness of application time to reduce P-loads to surface water is presented in Figure 6 and Table 8.

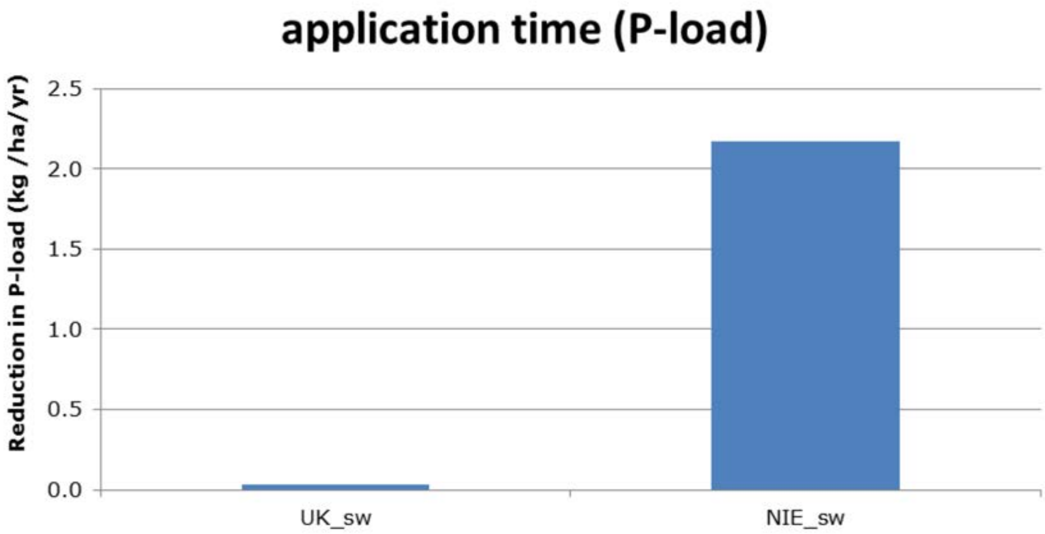

Figure 6 *Effectiveness of application time to reduce the P-load to surface water.*

The effectiveness of application time to reduce P-loads to surface water is much higher in Northern Ireland (2.17 kg ha^{-1} P versus 0.03 kg ha^{-1}) than in the UK. However, the figures are more comparable when the effectiveness is presented as a relative reduction. In addition, only one result is available for Northern Ireland.

Table 8

Reduction of P-loads (kg ha^{-1}) to surface water.

P-loads	Northern Ireland (n = 1)		UK[1] (n = 32)	
	Surface water			
	kg ha^{-1}	%	kg ha^{-1}	%
Average	2.17	24	0.07	16
Min	2.17	24	0.00	5
Max	2.17	24	0.45	50
Median	2.17	24	0.03	10
5% percentile	2.17	24	0.00	5
95% percentile	2.17	24	0.40	50

1. England and Wales.

Costs and cost-effectiveness

The Netherlands
Applying manure at another time will not necessarily affect the application costs. However, on heavier soil types, postponing manure applications to spring may require adjusted equipment with a much lower wheel pressure, thus increasing the costs. Moreover, when manures are applied in late summer instead of autumn to facilitate effective sequestration of manure-N by a vigorous green manure crop, this may require concessions to the length of the growing season of the preceding main crop and hence its yield potential. Cattle or pig farmers may need some extra storage capacity since the manure must be stored longer.

Splitting the N rates requires tractors to drive over the fields more often and hence use more fuel. Variable N rate systems also involve costs for required labour, sampling and analyses. The costs of sampling and analysis vary and depend, among others, on the type of variable N rate system and the number of samplings during the growing period. The costs amount to about €35 per ha on average.

In some cases, the application of a variable split N rate system caused some yield reduction, but in other cases, it increased yield. Therefore the effect on yield can be omitted from the cost calculation.

For potatoes, the average savings of N fertiliser amounts to about 30-35 kg N per ha, implying a reduction in fertiliser costs of about €35 per ha. So, on average, the costs of sampling and analysis are equivalent to the reduction in fertiliser costs.

UK (England, Wales) and Northern Ireland
The costs and cost-effectiveness of the measure application time for the UK and Northern Ireland are presented in Table 9.

Table 9
The costs (€/year) and cost-effectiveness (€ kg^{-1} N or P) of the measure application time to reduce N- and P-loads to surface water.

	England and Wales			NIE	
	Costs	Cost-effectiveness		Costs	Cost-effectiveness
	€	€ kg^{-1} N	€ kg^{-1} P	€	€ kg^{-1} P
Average	909	422	111950	7599	86
Min	35	115	383	7599	86
Max	6187	2946	825000	7599	86
Median	195	167	8739	7599	86
5% percentile	120	25	614	7599	86
95% percentile	5053	1903	516011	7599	86

Environmental side effects / pollution swapping
Limiting the period of application has the following results:
- Damage to the soil structure, which may result into a lower utilisation of N, more residual SMN in autumn and hence a higher loss of N to the environment;
- An increase in NH3 & CH4 emissions due to storage of slurry;
- A reduction in grazing length would lead to 20% increases in NH3 emissions and increases in methane emissions;
- Application of FYM to dry soils in summer months would be expected to marginally increase ammonia emissions;
- Splitting applications would increase CO_2 emissions due to more tractor usage and fuel consumption.

Feasibility

The Netherlands
Application of manures after wintertime is technically possible and is common practice in arable farming on sandy soils and in grassland farming on any soil type. On tilled clay soils, however, the application of manure with heavy machinery is restricted to avoid damaging the soil structure. Therefore, alternative application methods using lighter equipment are being developed.

Splitting the N rate is feasible or even recommended for grassland, a number of arable crops and many vegetable crops. It is not useful for all crops and a few crops can even respond negatively to splitting. Knowledge of the crop's N uptake pattern and its N requirements in different growth stages is an important condition for splitting. Incorrect splitting (by uninformed decisions) can cause severe N deficiency in an early growth stage of the crop.

Variable N rate systems to adjust the N rate to growth conditions can be used for potatoes and several vegetables crops. The reliability of the systems largely depends on the measurement error.

UK (England and Wales)
Reducing grazing days/seasons increases labour and the associated costs of forage production and manure management. Sufficient slurry or FYM storage facilities are necessary to allow for a greater choice of timing applications to land. Farmers need to delay the first spring application of fertiliser until the soils are drier, which could impact their yield.

Northern Ireland
This is a straightforward mitigation measure to implement once farmers have the capital funds required to increase slurry storage capacity. However, problems can occur if bad weather persists outside of the closed period, limiting the opportunities farmers have to empty their tanks before the start of the next closed period.

Mode of implementation

The Netherlands
Manures are only applied during the legally allowed periods. On sandy soils, manures are mostly applied in spring. On clay soils, they are mostly applied in August, after the harvest of cereals, followed by a green manure crop.

Splitting a fixed N rate is quite common in a number of arable crops and in many vegetable crops. Combinations of splitting while using variable N rates, however, are not yet widely implemented because of the extra labour needed and costs of sampling and analysis.

Moreover, not all farmers have sufficient confidence in these conditional N application systems. Nevertheless, farmers' interest in variable split N rate systems is increasing due to the reduction of permitted N application standards evolving from the EU Nitrates Directive action programme. Variable N rate systems based on canopy reflectance are receiving a lot of attention at the moment, but they need to be further implemented in practice.

UK (England and Wales)
This is a voluntary measure communicated by stakeholder engagement activities with CSFO/NE.

Northern Ireland
Under the Nitrates Action programme (Northern Ireland) 2010 regulations, strict adherence to the close period for slurry spreading is mandatory on all farms. To implement this measure, where necessary, farmers have been given significant capital grants to fund the building of slurry storage tanks.

3.3 Buffer strips

Description

A buffer strip is an unfertilised grass strip along the land contour, in valley bottoms or on upper slopes, that interrupts runoff or prevents leaching. Buffer strips can be permanent or temporary, natural or manmade, and can be any shape. A distinction can also be made between wet and dry buffer strips. Wet buffer strips are also known as constructed wetlands (see 3.6) and buffer strips adjacent to water courses are called riparian buffer strips.

Rationale, mechanism of action

Buffer strips may directly affect the loss of pesticides and nutrients and may affect losses due to runoff, erosion and leaching. A reduction in N losses is thought to mainly be due to less available N in the soil profile as the buffer strip receives no fertiliser, leading to lower leaching losses from the buffer zone. A reduction in direct fertilisation of the waterway by forcing the farmer or animals to keep a greater distance to water courses also contributes to a reduction in N- (and P-) losses to surface water. The mechanism for P is diverse: a reduction of surface runoff from the fields 'upstream' of the buffer strip reduces leaching (especially in situations with shallow groundwater) and stabilises the river banks (reducing erosion).

Time frame

Immediate effects are expected for direct losses like runoff and erosion. For leaching, the effects on N are expected within 1-4 years. For P, effects are delayed and an increase in effects may appear for a period of 25 years or more.

Applicability

Buffer strips of 10 m along watercourses are mandatory in Denmark and in England in Nitrate Vulnerable Zones (NVZ) areas where organic manure is used. Buffer strips are not mandatory in the Netherlands. In principle, buffer strips are applicable to all farming systems. The costs of fencing the buffer strip on farms with livestock are costly and make farmers reluctant to use buffer strips. On the other hand, it may be easier to implement buffer strips in grassland areas, because farmers have all the equipment for cutting and clearing the grass and the animals can use it. Farmers of arable land in the Netherlands tend to be reluctant to use buffer strips because of weeds.

Effectiveness

To compare the effectiveness of buffer strips between the countries and under different field conditions, it is necessary to consider the location in the water and nutrient cycle where the effectiveness of these measures are calculated (Figure 7).

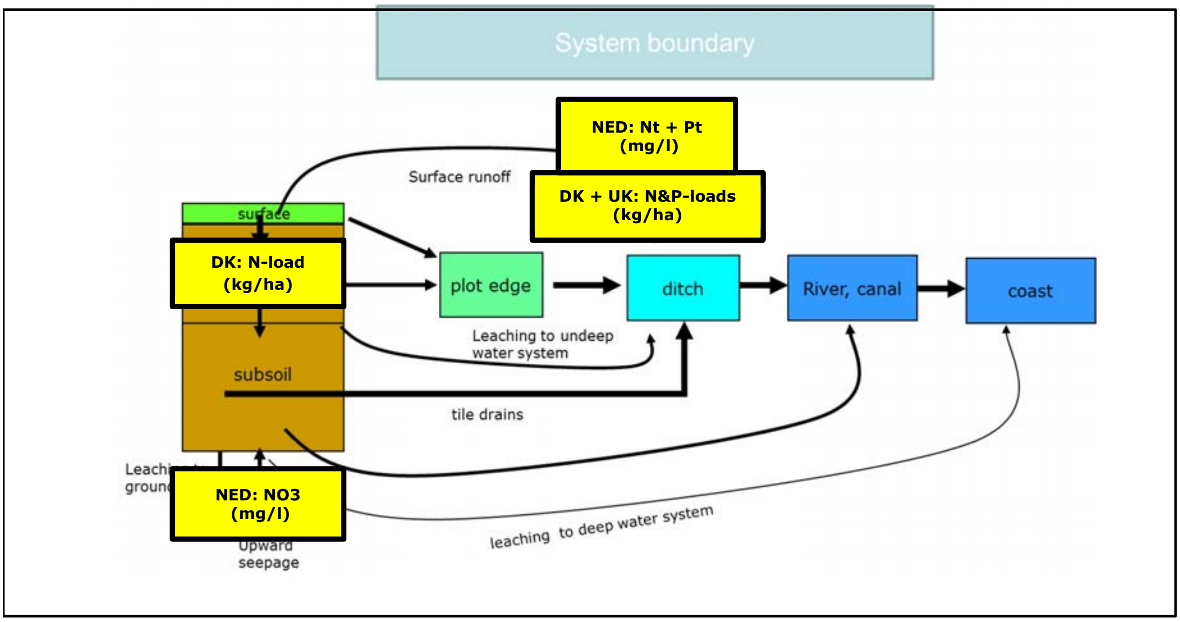

Figure 7 *System boundary condition: part of the water and nutrient cycle for which the effectiveness of buffer strips are calculated in the different countries.*

The reduction of the N load/nitrate concentration was calculated for different locations in the water and nutrient cycle:

- Reduction of total N load from the root zone to groundwater;
- Reduction of nitrate concentrations in the upper groundwater;
- Reduction of total N and P loads to surface water;
- Reduction of total N and P concentrations in surface water.

Nitrogen

The reduction of nitrogen loads to groundwater and surface water are presented in Figure 8 and Table 10.

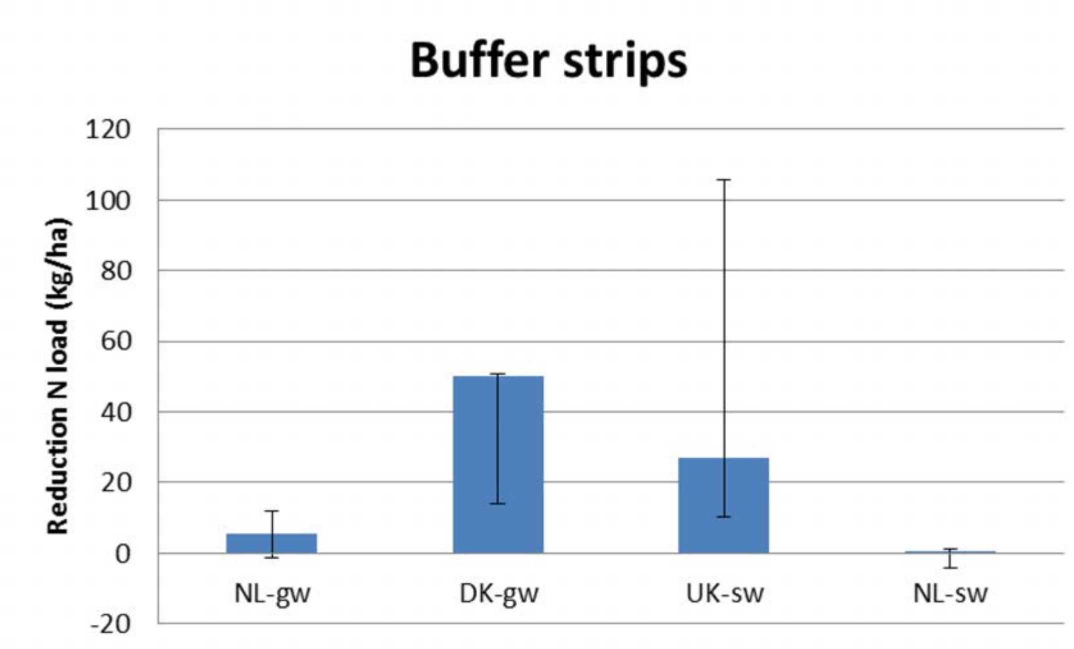

Figure 8 *Effectiveness of buffer strips for reducing N-load to groundwater and surface water.*

Table 10

Reduction of N-loads (kg ha^{-1}) to groundwater and surface water.

N-loads	Netherlands (n = 5)	Denmark (n = 3)	UK[1] (n = 14)	Netherlands (n = 5)
	Groundwater		Surface water	
Average	5.25	50	39	-0.71
Min	-2.14	10	4.5	-4.6
Max	12.8	51	135	1.27
Median	5.35	50	27	0.73
5% percentile	-1.45	14	10	-4.06
95% percentile	12.0	51	106	1.22

1. England and Wales.

The effectiveness of buffer strips in reducing N-loads to groundwater in the Netherlands is much lower than was measured in Denmark (median value of 5.35 kg ha^{-1} N versus 50 kg ha^{-1} N). The reduction of N-loads to surface water in the Netherlands is much lower than was calculated in England and Wales (0.73 kg ha^{-1} versus 27 kg ha^{-1}).

Phosphorus

The effectiveness of buffer strips in reducing P-loads to surface water is presented in Table 11.

Table 11

Reduction of P-loads (kg ha^{-1}) to surface water.

P-load	UK[1] (n = 14)	NL (n = 5)	DK (n = 2)
Average	0.043	-0.017	3.1
Min	0.002	-0.56	1.4
Max	0.2	0.40	4.8
Median	0.010	0.013	3.1
5% percentile	0.002	-0.45	1.6
95% percentile	0.2	0.33	4.6

1. England and Wales.

The effectiveness (in kg ha^{-1}) of buffer strips in reducing P-loads to surface water in England and Wales and the Netherlands are quite similar. In Denmark, they are much more effective.

Costs and cost-effectiveness

The estimated costs in England and Wales are much higher than in the Netherlands (Table 12).

Table 12

Overview of the costs of buffer strips to reduce N- and P-loads to groundwater and surface water.

Field conditions		UK[1]	Netherlands
Land use	*Soil type*	*€/year*	*€ ha^{-1}year*
Buffer strips			
Arable	All	941-4118	
	Sand		22-41
	Clay		135
Dairy	All	58-176	
	Sand (intensive)		12
	Clay (intermediate)		0
	Peat (extensive)		0
Others	All	588-1411	
Riparian buffer strips			
Arable		2823-12471	
Dairy		764-4000	
Others		2705-5294	

1. England and Wales.

Based on the estimated costs, the cost-effectiveness of buffer strips can be calculated (Table 13). Due to the high costs, the cost-effectiveness for England and Wales is less favourable than for the Netherlands.

Table 13

Overview of the cost-effectiveness of buffer strips for reducing N- and P-loads to surface water.

Field conditions		Nitrogen (€ kg^{-1} N)			Phosphorous (€ kg^{-1} P)		
Land use	*Soil type*	*UK*[1]	*NL*	*DK*	*UK*[1]	*NL*	*DK*
Buffer strips							
Arable	All	52-102			1471-1029412		
	Sand		3-6			22	
	Clay						
Dairy	All	3-87		3.3	1471-1029412		
	Sand (intensive)		3-9				15
	Clay (intermediate)						
	Peat (extensive)		0				
Others	All	11-37			588-588235		
Riparian buffer strips							
Arable		78-554			4412-3117647		
Dairy		34-296			1912-100000		
Others		39-183			2206-1647059		

1. England and Wales.

Environmental side effects / pollution swapping

- Sequestration of organic matter;
- Improved habitat, stronger biodiversity on land and in water;
- Declines in faecal indicator organisms;
- Increases in greenhouse gas emissions due to decay of biomass.

Feasibility

-

Mode of implementation

UK (England and Wales)
A 10 m buffer strip is required along surface waters within NVZ areas where organic manures are used. Otherwise, buffer strips are a voluntary measure, available under a stewardship scheme.

Denmark
An up to 10 m buffer strip is mandatory along all water courses. It has been estimated that about 50,000 ha of arable land has been taken out of intense production and transferred to extensive grass land.

The Netherlands
Legislation requires farmers to maintain buffer strips without cultivation (no tillage, arable crop, fertiliser, pesticide) with a width ranging from 0.25 m (grassland) and 0.5 m (cereals) to 1.0 m (root crops) and a maximum of 5 m wide (for some fruit trees). These widths are intended to minimise pesticide drift associated with spraying direction and groups of crops.

Unlike the abovementioned narrow strips, wider dry buffer strips have not been widely implemented. There are several regional projects in which buffer strips are being or have been implemented, or from regional authorities (province, water board).They are sometimes also supported by the EU (e.g. Actief Randenbeheer Noord Brabant, Hoekse Waard, Hunze en Aas). The width of the wider buffer strips is generally between 2 and 6 m.

3.4 Controlled drainage

Description
Controlled drainage systems actively vary drainage levels in order to regulate the amount of water to be drained from the fields and the resulting groundwater levels in the fields. The amount of drainage depends on the actual situation, the short-term (precipitation) and long-term (drought) weather expectations and the required agricultural management. Drainage levels are regulated by raising or lowering water levels in the ditches or the tile drainage systems themselves.

Rationale, mechanism of action
Changes in drainage level influence the pathways and residence times of the soil water and transported solutes and particles. These changes affect drainage fluxes and nutrient loads. The effects on the nutrient loads are determined by the changes in drainage fluxes, as well as by changes in residence time and moisture content in the unsaturated zone. Thereby, changes in physical, chemical and biological retention, and in transformation and decay processes modify the nutrient concentrations. For example, the decomposition of organic matter (N and P) leads to nitrification and denitrification (N) and sorption/desorption (P). In general, drainage levels should be lowered to reduce phosphorous emission, but should be raised to some extent to reduce the emissions of nitrogen and nitrate.

Time frame
Reductions (and increases!) in N- and P-leaching due to changes in drainage levels occur almost instantaneously. The effects depend on both the situation and the amount of change.

Applicability
Drainage is used almost everywhere in the Netherlands where it can be effective: in wet and moderately dry soils. Controlled drainage can be used to adapt to climate change in situations with temporary drought periods and can be used to control nutrient emissions in all situations with excess water during prolonged periods. Controlled drainage is applicable to all land uses and all soils with (structural) excess water.

Effectiveness
Controlled drainage influences the availability and quality of water. The effects on water quality depend on the management:
- Nitrate emissions: lowering the drainage level increases nitrate emissions to groundwater; raising the drainage level decreases them.
- P-emission: lowering the drainage level significantly reduces P-emission (less shallow drainage with relatively high phosphorous concentrations); raising the drainage level increases the P-emission (more shallow drainage with relatively high phosphorous concentrations), especially in wet soils.
- N-emission to surface water: lowering or raising the drainage level does not usually result in changes (the increase in nitrate concentration compensates for the decrease in shallow drainage), but locations with an increase or a decrease have to be expected as well.

The effectiveness of the mitigation option depends on the current situation (whether or not it has been drained) and the depth at which the drainpipes are installed.

Tables 14, 15 and 16 present the effectiveness of controlled drainage for different circumstances:
- Table 14: already drained areas ➔ drainpipes at the standard depth;
- Table 15: already drained areas ➔ drainpipes at a greater depth;
- Table 16: not yet drained areas ➔ drainpipes at a greater depth.

A) Already drained areas, drainpipes at the standard depth

Table 14
Controlled drainage at the standard depth in already drained areas — its effects on different soils and hydrologic conditions related to nitrate emissions to groundwater, and N-emission and P-emission to surface water. A + means a positive effect (i.e. a decrease in emissions).

Soil type	Sand			Clay			Peat
	Wet	Moderately dry	Dry	Wet	Moderately dry	Dry	Wet
NO_3	N/A	+	N/A	N/A	+	N/A	N/A
N	N/A	+	N/A	N/A	+	N/A	N/A
P	N/A	0	N/A	N/A	0	N/A	N/A

- The field is already drained, so wet and dry are irrelevant.
- It is assumed that the P-emissions largely occur through the subsoil.
- Because the field is drained, minor effects on the P-emissions are expected.

B) Already drained areas, drainpipes at a greater depth

Table 15
Controlled drainage at a greater depth in already drained areas — its effects on different soils and hydrologic conditions related to nitrate emissions to groundwater, and N-emission and P-emission to surface water. A + means a positive effect (i.e. a decrease in emissions).

Soil type	Sand			Clay			Peat
	Wet	Moderately dry	Dry	Wet	Moderately dry	Dry	Wet
NO_3	N/A	+	N/A	N/A	+	N/A	N/A
N	N/A	+	N/A	N/A	+	N/A	N/A
P	N/A	+	N/A	N/A	+	N/A	N/A

- The field is already drained, so wet and dry are irrelevant.
- It is assumed that the P-emissions largely occur through the subsoil.
- Because the field is drained, minor effects on the P-emissions are expected.

C) Not yet drained areas, drainpipes at a greater depth

Table 16
Controlled drainage at a greater depth in not yet drained areas — its effects on different soils and hydrologic conditions related to nitrate emissions to groundwater, and N-emission and P-emission to surface water. A + means a positive effect (i.e. a decrease in emissions).

Soil type	Sand			Clay			Peat
	Wet	Moderately dry	Dry	Wet	Moderately dry	Dry	Wet
NO_3	--	--	N/A	--	--	N/A	N/A
N	0	0	N/A	0	0	N/A	N/A
P	++	++	N/A	++	++	N/A	N/A

- Construction of controlled drainage is not applicable to dry soils.
- Significantly higher nitrate concentrations and loads to the groundwater are expected (due to the lowered groundwater levels).
- Lowering the drainage level significantly decreases the P-emission.
- The increase in nitrate concentration compensates for the decrease in shallow drainage, so nitrogen emissions are not expected to change.
- Because tile drainage is implemented almost everywhere it is useful in the Netherlands, the implementation of controlled drainage in not yet drained soils is of very minor importance.

The effects of controlled drainage on nutrient emissions are theoretically known but still need to be quantified. It appears to be very difficult to extrapolate the results of sparse field experiments to other situations. Effects at regional and national scales are equal to the totalled or averaged local effects.

Because controlled drainage is not effective and/or applicable everywhere, the maximum effect on regional and national scales will be smaller than the maximum local effect. Controlled drainage is a potentially suitable measure, but in practice it may fail.

Costs
The total costs are approximately €3000 per year.

Cost-effectiveness
No information is given.

Environmental side effects / pollution swapping
No information is given.

Feasibility
No information is given.

Mode of implementation
The effectiveness of the measure at regional and national scales is determined by the degree of implementation. This depends on the implementation process (e.g. voluntary vs. compulsory, stakeholder engagements, knowledge transfer, local vs. national, instruments and facilities).

In the Netherlands, controlled drainage is a very promising measure; several field experiments have begun to quantify its effects and optimise its management. Voluntary implementation by farmers is also encouraged. Not all northwestern European countries have identified controlled drainage as a possible part of their policy.

3.5 Tillage

Description

Tillage is the mechanical modification of soil structure. The results of tillage depend on the characteristics of the soil that is being tilled (e.g. texture, structure, moisture, friability, plasticity). Conventional, inversion tillage by mouldboard or disc ploughs (which flips over a layer of soil, burying surface residues) may lead to soil degradation. Negative effects of tillage are:

- Risk of crusts on the soil's surface and compaction of soil below the depth of tillage (i.e. the formation of a tillage pan);
- Deteriorating soil structure (resulting in decreased infiltration and storage of precipitation and irrigation water);
- Accelerated decomposition of soil organic matter (negative from a long-term perspective);
- Tillage in autumn may increase mineralisation of organic nitrogen and increase the risk of nitrate leaching during the following winter. This risk can be reduced by postponing the ploughing to spring before sowing the next crop;
- Increased susceptibility to runoff and erosion (from water and wind).

On the other hand, soil cultivation and management may reduce the risk of extremes in water logging and drought, may reduce runoff, may improve the efficient use of soil nutrients and may increase crop production and thereby reduce the nutrient emissions to the water system.

Rationale, mechanism of action

Reduced soil tillage by minimal or no cultivation maintains organic matter and preserves good soil structure (minimal cultivation also breaks up surface crusts). Tillage is often assumed to be particularly effective when the soil surface is mulched with crop residues. Transpiration is also reduced by mulching, leading to an increase in the moisture content of the upper soil layer. Soil organic matter breakdown products glue soil particles together into stable soil aggregates. These aggregates make the soil porous and resistant to compaction and erosion. The resulting soil conditions improve infiltration and increase moisture levels in the soil (i.e. increase the retention of water) as well as increase the soil's biological activity and diversity and promote the efficient use of nutrients. Thereby tillage reduces runoff, erosion and the resulting loss of nutrients (especially P). Increased infiltration prevents nitrogen loss through microbial denitrification in wet soil conditions, but also can increase leaching of mobile nutrients in the soil, especially nitrate. The increased moisture levels increase crop growth, drought tolerance and nitrate uptake (and reduce the leaching of nitrate). In the Netherlands, however, the soils' organic matter contents are already very good, so the additional organic matter is expected to have a minimal effect.

Time frame

It takes some years to attain the improved soil structure and increased crop yields that result from the conversion from ploughing (conventional tillage) to minimal or no cultivation systems. In the short-term, this conversion also decreases surface runoff and total N (and especially total P) concentrations in surface runoff. Again, this effect increases over some years. In the long-term, however, the total P concentrations in the runoff may rise due to an increasing amount of phosphate near the soil surface.

Reductions in nitrate leaching occur almost immediately through reduced mineralisation of soil organic matter in the autumn, although there are likely to be small increases in drainage volumes. This effect increases to a small extent over some years as long as the soil structure improves and the amount of organic matter increases in the soil.

Applicability

The Netherlands

Reduced soil tillage is not targeted to specific areas or sub-basins, but has to be adapted into the individual farmer's farm management (and requires careful control of compaction and weeds). Reduced soil tillage is the practice in (permanent) grassland and orchards, and major changes can be achieved in crop rotation systems (arable crops, horticulture and rotating maize/grassland).

Denmark
Grassland: A better use of N is released from the ploughed grass. Grass cannot be ploughed between 1 July and 1 February.
Other: Tillage in the autumn before a spring crop is not allowed before 1 November in clay soils and 1 February in sandy soils. The Danish water plans estimate that this measure can be applied to an area of 110,000 ha.

Effectiveness

The Netherlands
The effect of reduced tillage depends on the technique used (Table 17), the crop species, the soil type and the hydrologic conditions. The best results seem to be obtained on the heaviest clay soils (which are the most difficult soils to prepare with conventional soil tillage methods).

Table 17
Overview of the effectiveness of various alternate forms of tillage.

Nr.	Effectiveness	Applicability	Regulation	Reference
1	++	0	0	Geel *et al.*, 2009 Vermeulen and Wel, 2008
2	+	0	+	Vermeulen and Mosquear, 2009 Soane *et al.*, 2011 Vermeulen *et al.*, 2010
3	+	0	0	Weide *et al.*, 2008
4	+	0	0	Postma *et al.*, 2010 Haan *et al.*, 2010
5	+	0	0	Iepema *et al.*, 2008 Dam, 2007

1. Soil tillage during good conditions and with low ground pressure (to prevent compaction).
2. Fixed bridle paths.
3. Non-inversion tillage.
4. Conservation tillage systems returning crop residues.
5. Using crop residues or compost.

Denmark
Results in Denmark show that the effect of soil tillage on the leaching of nitrate seems to increase with more intensive cultivation, particularly when carried out in autumn (Table 18). Reducing soil tillage (especially in autumn) has a positive effect on preventing nitrate leaching. Reduced soil tillage also reduces the runoff of phosphorous. This effect is dependent on the reduction in runoff/erosion and the concentrations of dissolved phosphorous (strongly determined by the phosphate content of the soil at/near the soil surface).

Table 18
Overview of effectiveness of soil tillage to reduce N-loads from the root zone and to surface water.

Field conditions	DK	
Land use	Reduction of N-load (kg N ha^{-1})	
	Root zone	*Surface water*
Rotational grass (rotated every 3 years)	15.3 / 36.0	-
Crops grown in spring	10.0[1]	6.7

1. Field measures.

Effectiveness of phosphorus
The effect on phosphorus loss in Denmark is limited and estimated to equal 1 tonne P per year. In the Netherlands, data are scarce but indicate losses of 1.5–3 kg ha^{-1} per year due to runoff caused by poor soil structure. These losses might be avoided by improving soil structure (e.g. by adapting tillage techniques).

Costs
No information is given.

Cost-effectiveness
No information is given.

Environmental side effects / pollution swapping
No environmental side effects were mentioned.

Feasibility
Some exceptions are necessary (e.g. in organic farming where autumn tillage is required for weed control).

Mode of implementation
The measure is implemented through a statutory order (i.e. a mandatory measure).

3.6 Wetland restoration / constructed wetland

Description

Constructed (farm) wetland
This is defined as 'one or more shallow, free surface flow constructed cells containing emergent vegetation, which is designed to receive and treat lightly contaminated surface water runoff from farm steadings, in such a manner that any discharge from the wetland will not pollute the water environment'.

Wetland restoration
This is defined as the development or restoration of wet buffer strips along upstream rivers and streams, or isolated wet areas in an agricultural landscape.

Rationale, mechanism of action
Runoff water from agricultural areas that contains nutrients will pass the wetlands before entering the discharge system (ditches, streams, rivers). Wetland restoration and constructed wetlands are designed to optimise the natural processes of denitrification and/or sedimentation of phosphorus.
A short summary of the processes are described in Table 19.

Table 19
Rationale, mechanism of action

Water treatment process	Factors that optimise that process
Settling of suspended particulate matter by gravity	Low flow velocity, low wind speed, low disturbance, long residence time
Physical infiltration of suspended solids by wetland; Biomass action as a hydrological baffle to incoming flows	High vegetation density, low flow velocity
Uptake and breakdown of nutrients by plants and micro-organisms	Longer residence time, contact with high densities of micro-organisms and plants, readily available organic matter
Accumulation and increase of organic matter, which is important for nutrient cycling	Low flow velocity, availability of adsorption sites
Aerobic and anaerobic microbial mediated processes (e.g. nitrification an denitrification), which are important for the cycling of nitrogen and reduction of sulphur	Presence of oxidising and reducing conditions, high densities of a variety of micro-organisms, around neutral pH, high temperature
Chemical precipitation of phosphorous in and sorption on/by soils	Many available sorption sites, pH, redox potential
Predation and natural die-off of pathogens	High diversity and density of natural predators (e.g. protozoan), exposure to sunlight

Time frame
After construction or restoration of the wetlands or wet buffer strips, nutrient retention can start immediately. The time frame varies with the hydrological conditions (residence time, flow velocity); for example, in Northern Ireland, the residence time was approximately 70-100 days. During the first growing season, enhanced denitrification and vegetation uptake come in effect.

Applicability
In principle, all runoff and drainage water containing nitrogen and phosphorus can be treated in wetlands. For example:
- Livestock handling areas where livestock are held occasionally for less than 24 hours,
- Roof drainage from pig and poultry housing,
- Concrete areas that are lightly contaminated as a result of vehicle and occasional livestock movements,
- Machinery washings (unless contaminated with pesticides or veterinary medicines),

- Winter run–off from silage pits (but not silage effluent) between 1 November in one year and 30 April in the next,
- Baled silage storage areas on steading.

To be cost effective, the constructed wetland should receive drainage water from a considerable area (e.g. 100 ha drained field to 1 ha constructed wetland). Maintenance of the wetland, removal of the sediments and harvest of the plant products are needed to maintain high nutrient retention.

Effectiveness
The effectiveness of constructed wetland/wetland restoration is presented in Table 20.

Table 20
Effectiveness of constructed wetland / wetland restoration to reduce N- and P-loads to surface water.

Country	N-load (kg N ha^{-1})			P-load (kg P ha^{-1})		
	Before	After	Reduction (%)	Before	After	Reduction (%)
Denmark			20-50			
Northern Ireland	24.2[1]	0.89[1]	96	270.1	21.7	92
Netherlands			7.5-50			0-100

1. NH_3-N.

Costs
For example, a wet buffer costs €4000 per year in Northern Ireland and €42000 km^{-1} in the Netherlands. Because different starting points are used, these costs cannot be compared with each other.

Cost-effectiveness
Cost-effectiveness is only available for Northern Ireland: € 171 kg^{-1} N and €16 kg^{-1} P.

Environmental side effects / pollution swapping
\+ Correctly established, the constructed wetland can have positive effects on biodiversity, with habitats for flora and fauna.
\+ When harvested, aquatic vegetation on the wetland can be used for multiple purposes. If the biomass is not harvested, the storage of nutrients is mostly temporary and nutrients will be released again after the growing season.
\- N_2O, CH_4 and CO_2 emissions may be increased by the establishment of the wetlands.

Feasibility
\+ Easy to construct, low cost, applicable to all agricultural areas near waterways;
\- Area of land required.

Feasibility might increase when designed for multiple purposes (e.g. hydraulic retention, nature development, energy crops).

Mode of implementation

Denmark
The mitigation option is presently being tested under Danish climate conditions.

Northern Ireland
Uptake of constructed wetlands to treat dirty water is a voluntary measure and to date there has been limited uptake.

The Netherlands
The effectiveness of the measure will be impacted by the administrative / regulatory / communication platform used to implement it (e.g. voluntary vs. compulsory, stakeholder engagements, knowledge transfer, local vs. national).

4 Synthesis and evaluation

Chapter 3 presented the effectiveness of the mitigation options between the countries. This chapter presents a comparison between mitigation options. To compare the effectiveness of mitigation options, we made a distinction between the reduction of the N-load from the root zone, the reduction of the N-concentration in groundwater and the reduction of the N- and P-loads to surface water.

Root zone
The effectiveness of catch crops, application time and soil tillage in reducing N-loads from the root zone are shown in Figure 9. The highest median effectiveness was calculated for catch crops (33 kg ha^{-1} N). However, when the variation was taken into account, the highest effects were caused by the mitigation option application time.

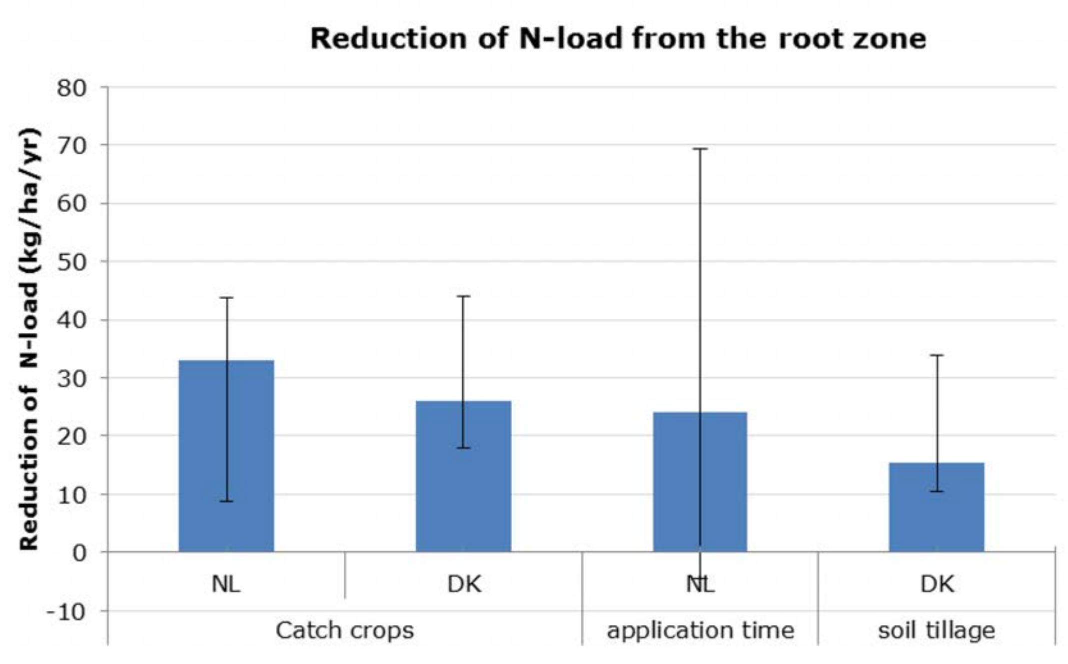

Figure 9 *Effectiveness of different mitigation options for reducing N-loads from the root zone.*

Groundwater

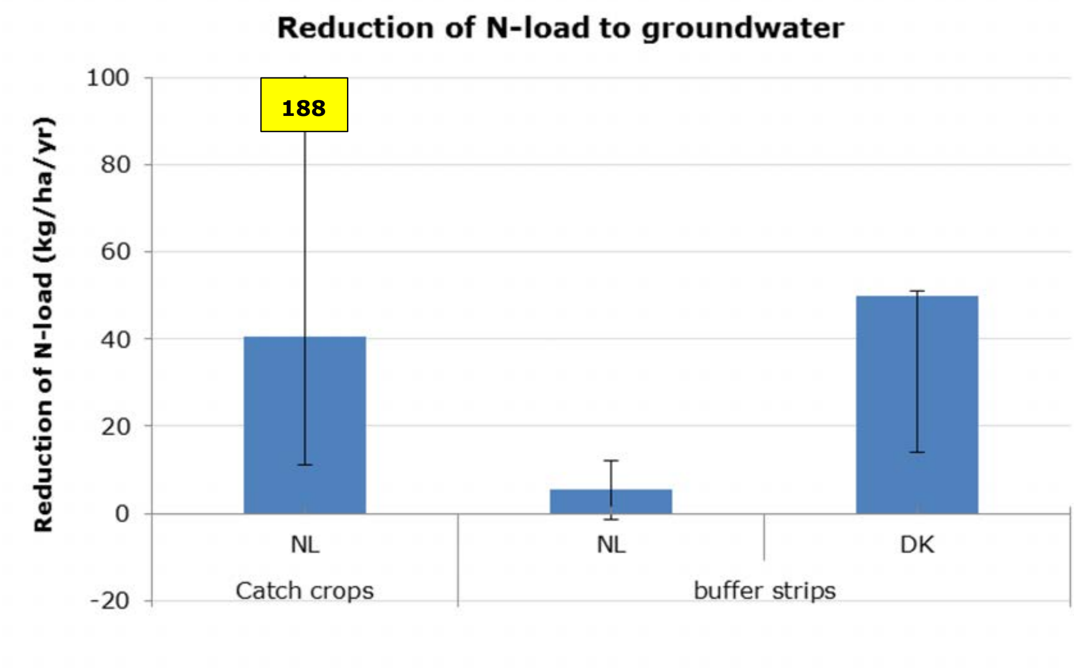

Figure 10 *Effectiveness of different mitigation options for reducing N-loads to groundwater.*

In Denmark, buffer strips seem to be an effective measure for reducing N-loads to groundwater (median effectiveness of 50.0 kg ha^{-1} N). Catch crops were also effective in reducing N loads from the root zone (Figure 9). This would be the second best option in Denmark if we assume that the effect on total losses to groundwater is comparable to the loss from the root zone.

However, in the Netherlands, buffer strips are relatively ineffective (5.4 kg ha^{-1}). Catch crops seems to be much more effective than buffer strips here.

Surface water

The effectiveness of different mitigation options for reducing N- and P-loads to surface water is presented in Figures 11 and 12.

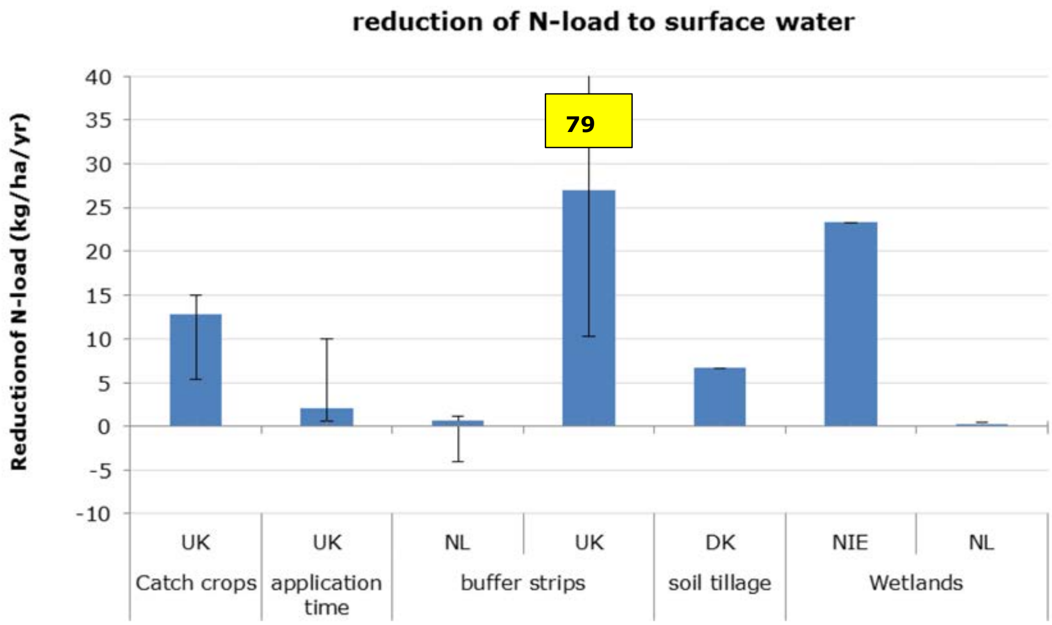

Figure 11 *Effectiveness of different mitigation options for reducing N-loads to surface water.*

Buffer strips seems to be an effective measure for reducing N-loads to surface water in England and Wales. Constructed wetlands are effective in Northern Ireland. Catch crops (England and Wales) and soil tillage (Denmark) are also effective for reducing N-loads to surface water.

Application time (Northern Ireland) and buffer strips (Denmark) are effective for reducing the P-loads to surface water. However the effectiveness of this mitigation option is very low in England and Wales and in the Netherlands.

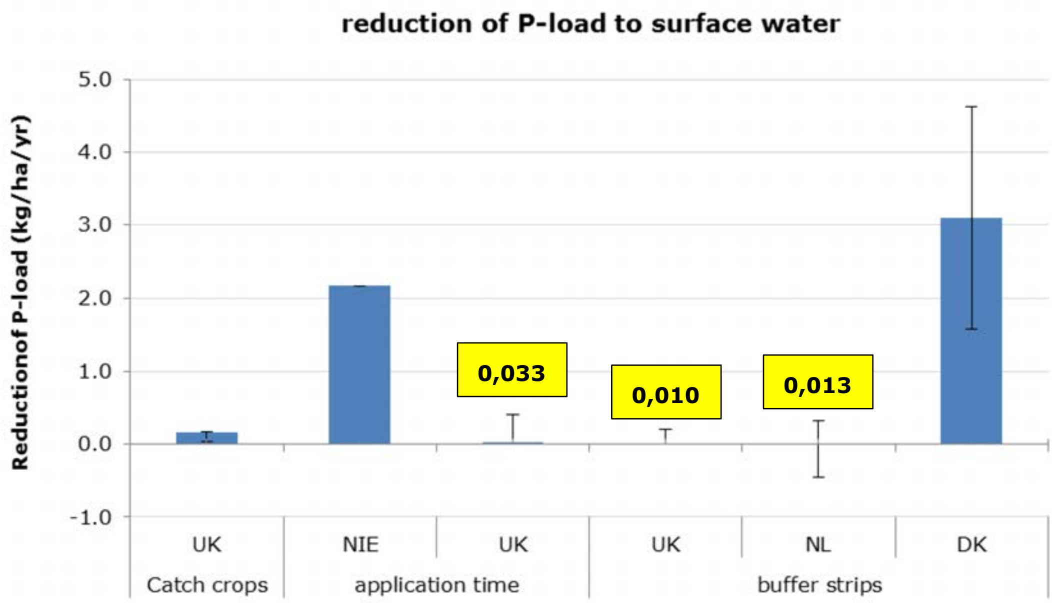

Figure 12 *Effectiveness of different mitigation options for reducing P-loads to surface water.*

Effectiveness (overall)

Tables 21 (nitrogen) and 22 (phosphorous) give an overview of the median reduction of N- and P-leaching to groundwater and surface water for the different mitigation options and the different countries. Table 23 shows the costs and cost-effectiveness.

Table 21

Overview of the effectiveness (kg N ha^{-1}) of mitigation options for reducing N-leaching from the root zone, N-concentration in groundwater and N-leaching to surface water.

Mitigation options	Netherlands	Denmark	UK[1]	NIE
Nitrogen				
Root zone	***kg N ha^{-1}***			
Catch crops	33	26		
Application time	24			
Soil tillage		15		
Groundwater	***kg N ha^{-1}***			
Catch crops	41			
Buffer strips	5.4	50		
Surface water			***kg N ha^{-1}***	
Catch crops			13	
Application time			2.1	
Buffer strips	0.73		27	
Soil tillage		6.7		
Wetlands	0.20			23

1. UK = England + Wales.

Table 22

Overview of the effectiveness (kg P ha^{-1}) of mitigation options for reducing P-leaching to surface water.

Mitigation options	Netherlands	Denmark	UK[1]	NIE
Phosphorous				
Surface water			***kg P ha^{-1}***	
Catch crops			0.16	
Application time			0.03	2.2
Buffer strips	0.013	3.1	0.010	

1. UK = England + Wales.

Table 23

Overview of the cost (€/year) and cost-effectiveness (€ kg^{-1} N, € kg^{-1} P) of mitigation options for reducing N- and P-leaching to groundwater and surface water.

Mitigation option	Costs €/year				Cost-effectiveness € kg^{-1} N reduction				Cost-effectiveness € kg^{-1} P reduction			
	NL	DK	UK[1]	NIE	NL	DK	UK[1]	NIE	NL	DK	UK[1]	NIE
Catch crops	85–88	56	676	-	3.1–5.0	4.0	56	-	-	-	4228	-
Application time	-	-	195	7599	-		167	-	-	-	8739	86
Buffer strips	0–135[2]		58–12741	-	0–9	3.3	3–554		22	15	588–3117647	-
Wetlands	42000[3]		-	4000	-	-	-	-	-	-	171	16

1. UK = England + Wales.

2. €/ha^{-1} year.

3. €/km^{-1} wet buffer.

The above results show a wide variability in the effectiveness and costs (cost-effectiveness) of the various measures within and between the different countries. Based on the information available in the factsheets, it is not yet possible to explain and understand the observed differences. A more thorough comparison of the underlying data would be necessary to fully understand the observed effects of the various measures under different site conditions. Based on such a comparison, transfer functions might be developed to translate the effects of certain measures to situations with other site conditions. If such information were available for northwestern Europe, a better selection of suitable measures would be possible and the reduction of nutrient loads to groundwater and surface waters would become more cost effective.

5 Conclusions

The collected information that was used to compare the effectiveness of mitigation options under different circumstances and in similar systems in northwestern Europe was very valuable. Additional efforts were made to make the mitigation options more comparable.

- Catch crops' application time and soil tillage seem to be very effective (mean value of 15 to 33 kg ha^{-1}) for reducing the N-loads from the root zone, but the variation is rather high. In the Netherlands, for example, negative effects of the measure application time have even been calculated.

- Catch crops can also be used to reduce N-loads to groundwater (41 kg ha^{-1}N). In Denmark, buffer strips are effective as well (reduction of 50 kg ha^{-1} N). However, their effectiveness is rather low in the Netherlands (5.4 kg ha^{-1} N).

- In the UK (England and Wales), catch crops (13 kg ha^{-1} N) and buffer strips (27 kg ha^{-1} N) are effective measures for reducing N-loads to surface water. In Northern Ireland, constructed wetlands are effective (23.3 kg ha^{-1} N). In the Netherlands, the effectiveness of buffer strips (0.7 kg ha^{-1} N) and wetland restoration (0.2 kg ha^{-1} N) were rather low.

- Buffer strips (Denmark) and application time (Northern Ireland) seem to be effective measures for reducing P-loads to surface water. However, the effectiveness of buffer strips is very low in the Netherlands and the UK.

- There are wide variations in the costs and cost-effectiveness of the mitigation options. In addition, the costs are unknown for a number of measures.

- The amount of available data for some measures is very low, and the reliability of the results of some mitigation options is very low. To increase the reliability of the results, more data are needed.

- To compare the effectiveness of some mitigation options, assumptions had to be made. For example, the reduction of NO_3-concentration in the upper groundwater in the Netherlands was converted into N-loads using a precipitation surplus of 300 mm/year.

6 Appendices

A: Catch crops

Denmark

Description
-

Rationale, mechanism of action
Catch crops are grown in the time between two main crops (i.e. typically sown after harvest in August and then ploughed before the new main crop is established in the spring). The mechanism of catch crops is to bind the nitrate so it will not leak out of the root zone.

To obtain the maximum effect, the NO_3 bound in the catch crops (i.e. the nitrate available for the next main crop) should be included in the fertiliser account.

Time frame
The effect on the N-leaching will occur from year 1.

Applicability
-

Effectiveness and cost-effectiveness

Effectiveness in the root zone

Table A.1
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N-losses from the root zone.

ID	Soil type	Land use	System boundary condition	NO_3 (mg/l) or N-load (kg N ha^{-1})	Reduction kg N ha^{-1}	Comments	Type of study
1	Not specified	Arable land	Root zone	N-load	26	Used in Danish RBMP's	Ref. 1
2	Sandy soil	Arable land	Root zone	N-load	34-46 [1)]		Ref. 4
3	Clay	Arable land	Root zone	N-load	16-26 [1)]		Ref. 4

1. The interval covers differences in manure application (lower figure <0.8 animal unit ha-1 (AU); higher figure >0.8 AU ha-1).

The effect of catch crops is based on field studies.
The N caught by the crops must be included in the next year's application account (i.e. the following year's fertilising effect of the catch crops is 17-25 kg N ha^{-1}, depending on the livestock intensity (AU)).

Effectiveness in surface water
The effectiveness in surface water (final recipient = coastal waters) is modelled using the root zone effect and the N-reduction from the root zone to the final recipient. The reduction percentage varies, so the modelling is performed on a catchment scale (e.g. a root zone effect of 30 kg N ha^{-1} and a reduction of 2/3 = a marine effect of 10 kg N ha^{-1}).

Table A.2
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the P loads to surface water.

ID	Soil type	Land use	Reduction	Author(s) references
1	All	Arable land	No effect foreseen	Ref. 5

Costs

Table A.3
Cost-effectiveness of mitigation options for different areas and specific circumstances.

ID	Total costs (€ ha^{-1} per year)	Cost-effectiveness		Author(s) references
	€ ha^{-1} per year	*€ kg^{-1} N-reduction[1]*	*€ kg^{-1} P-reduction*	
1	44	1.5	Not relevant	Ref. 6
2	56	4		Ref. 1

1. Using an average of 30 kg N ha^{-1}.

Environmental side effects / pollution swapping
No side effects related to phosphorus, nature or climate are foreseen.

Feasibility
Catch crops are a well-known measure that have been used in Denmark for many years. Presently, an area of approximately 230,000 ha is covered with catch crops every year (mandatory). In the RBMPs, another 140,000 ha of catch crops is foreseen, but not yet implemented.

Mode of implementation
The current use of catch crops is mandatory (a certain percentage of the arable land should be covered, depending on the AU ha^{-1}) and is not targeted according to the needs of the receiving water (a national regulation). Catch crops are also used in individual environmental permits to 'compensate' for a high AU ha^{-1} level.

Future use of catch crops (in RBMPs) will be targeted towards catchments of coastal areas with a documented need for a reduced N-load.

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Contact person(s)

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- Finn Pilgaard Vinther, DCA (finn.vinther@agrsci.dk) – effects of catch crops

England and Wales

Description
A catch or a cover crop is established post-harvest or under sown with spring crops to prevent bare soil (i.e. *cover* crop) or utilise any remaining nutrients in the soil (i.e. *catch* crop) to reduce the potential of leaching losses.

Rationale, mechanism of action
In order to reduce the amount of N available to leaching, catch/cover crops are planted to use any remaining N available in the soil profile. The catch crop is usually destroyed by frost or incorporated back into the soil, where the organic matter then breaks down, releasing the captured N to the next crop. This crop can also be used as a 'cover' to protects the surface of the soil, leaving it less exposed and vulnerable to surface runoff and therefore less vulnerable to erosion. Reducing soil erosion reduces the mobilisation of any P attached to sediment particles.

To perform well as a catch and cover crop, the timing for planting and incorporation has to fit in with appropriate weather, farm management and rotations.

Time frame
It can be effective within the first leaching season, if the crop is established well.

Applicability
Applicable to arable land in areas with significant amounts of spring crops with sandy soils. More problematic and less effective in areas with medium/heavy soils.

Effectiveness and cost-effectiveness

Effectiveness for surface water

Table A.4
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N-loads to surface water.

ID	Land use	System boundary conditions	N-load to surface water			Type of study	Author(s) reference
			Before (kg ha^{-1})	After (kg ha^{-1})	Reduction (%)		
1	Dairy	DC/C1 farm scale	15-50	6-35	30-60	Modelling	Newell-Price *et al.*, 2011
2	Grazing (low)		7-25	2.8-17.5	30-60	Modelling	Newell-Price *et al.*, 2011
3	Mixed		20-50	8-35	30-60	Modelling	Newell-Price *et al.*, 2011
4	Comb/roots		25-45	10-31.5	30-60	Modelling	Newell-Price *et al.*, 2011

Table A.5
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N-loads to surface water.

ID	Land use	System boundary conditions	N-load to surface water			Type of study	Author(s) reference
			Before (kg ha^{-1})	After (kg ha^{-1})	Reduction (%)		
1	Dairy	DC/C1 farm scale	0.2-0.8	0.04-0.64	20-80	Modelling	Newell-Price *et al.*, 2011
2	Grazing (low)		0.1-0.5	0.02-0.4	20-80	Modelling	Newell-Price *et al.*, 2011
3	Mixed		0.2-0.8	0.04-0.64	20-80	Modelling	Newell-Price *et al.*, 2011
4	Comb/roots		0.02-0.9	0.004-0.72	20-80	Modelling	Newell-Price *et al.*, 2011

Costs

Table A.6
Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Land use	Costs	Cost-effectiveness		Author(s) reference
		€ per year	*€ kg^{-1} N-reduction*	*€ kg^{-1} P-reduction*	
1	Dairy	470.59	31-52	2941	Newell–Price *et al.,* 2011
2	Grazing (low)	117.65	16-28	1176-1471	Newell–Price *et al.,* 2011
3	Mixed	882.35	59-74	5515	Newell–Price *et al.,* 2011
4	Comb/Roots	3882.35	288-259	21569-242647	Newell–Price *et al.,* 2011

Environmental side effects / pollution swapping
Small increases in CO_2 emissions are expected during establishment of a crop.

Feasibility
Catch crops lead to potential increases or no effects if the development of a crop and hence its nutrient uptake does not coincide with leaching losses. Structural damage to the soil caused by establishing a crop in wet conditions can lead to further issues related to poor development and increased erosion risk.

Mode of implementation
This is a voluntary measure, available under a stewardship scheme.

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Contact person(s)
- Martin Silgram & Roland Harrison (sheet prepared by Jennine Jonczyk)

The Netherlands

Description

Crops grown after the harvest of a main crop for the purpose of improving soil fertility are called green manures. If left unfertilised and intended to reduce the leaching of nitrate, these green manures are often called catch crops. Farmers in the Netherlands are legally obliged to grow such a catch crop after cultivating maize on sandy and loess soils. In other cases, green manures are mainly grown to add organic matter to the soil to increase soil fertility. This type of green manure is mostly grown after cereals and is fertilised (unlike catch crops).

Rationale, mechanism of action

Nitrogen fertiliser is not entirely recovered by crops as a result of intrinsic plant characteristics or the incomplete rooting of the soil profile. After harvest, the N that is not taken up by the crop remains in the soil. In addition, the soil mineral N supply can further increase in late summer and autumn due to the mineralisation of crop residues and soil organic matter. This nitrogen can be lost to the environment. Catch crops can partly intercept this N before winter and temporarily fix the N until the catch crop is destroyed by frost, herbicide or incorporation. Once destroyed, the plant organic matter decomposes and nutrients in it become available to a next crop ('mineralisation'). Consequently, the N rate applied to these subsequent crops can be reduced by 15-60 kg N per ha, depending on the catch crop species, the rate of development (N uptake) and the time of destruction.

The effectiveness of the catch crop depends on the sowing date and crop development, the time of destruction and the extent to which the next crop is able to utilise the N released by the catch crop. The earlier the catch crop is sown at the end of summer or beginning of autumn, the better the crop can develop before winter time and the more N will be fixed. If the catch crop is destroyed too early, the release of N will not coincide with the N demand of the next crop and N will be lost during winter. Generally, the most effective is a winter-hardy catch crop that is incorporated in March.

Several plant species are suited and used as a green manure / catch crop: *Cruciferae, Gramineae* and others, depending on the sowing time, crop rotation and soil-borne nematodes.

Time frame

The emission to soil and surface waters is reduced in autumn and winter.

Applicability

Catch crops are grown after the cultivation of maize. It is estimated that green manures are grown on about 15% of other arable land, mostly after cereals. To a certain extent, catch crops can also be grown after crops other than maize that leave behind substantial amounts of SMN.

Effectiveness and cost-effectiveness

Effectiveness for groundwater or surface water

Table A.7

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the N-losses from the root zone or NO_3-concentration in groundwater.

ID	Soil type	Hydrological (field) conditions	Land use	System boundary condition	NO_2 (mg/l) or N-load (kg N ha^{-1})	Without catch crop	With catch crop	Reduction (%)	Number of years	Type of study
1	Sandy soil	Groundwater level 0.5 m (winter) to 1.6 m (summer) below surface level	Continuous silage maize production	Subsoil at 1 m depth (by cups)	NO_3	70-145[1]	35-70[1]	50%	6	Field measures
2	Sandy soil	Dry sand soil	Arable land	Upper groundwater	NO_3	93	33	65%	3	Field measures
3	Sandy soil	Dry sand soil	Arable land	Upper groundwater	NO_3	141	59	60%	3	Field measures
4a	Sandy soil	Dry sand soil	Arable land	Root zone 0-90 cm	Residual soil mineral N 8 November	120	76[4]	37%	1	Field measures
4b	Sandy soil	Dry sand soil	Arable land	Root zone 0-90 cm	Residual soil mineral N 8 November	122	116[5]	5%	1	Field measures
5a	Sandy soil	Dry sand soil	Arable land	Root zone 0-90 cm	Residual soil mineral N 30 November	35	11	69%	1	Field measures
5b	Sandy soil	Dry sand soil	Arable land	Soil	Calculated N surplus[7]	1	-41		1	Field measures
6	Sandy soil	Groundwater level 0.6 m (winter) to 1.5 m (summer) below surface level	Arable land	Upper groundwater	NO_3	77	36	55%	2	Field measures
7a	Sandy soil	Average of wet and dry sand soils	Arable land	Upper groundwater	NO_3	94	90[8]	4%		Modelling study
7b	Sandy soil	Dry sand soil	Maize production	Upper groundwater	NO_3	82	58 (1/9)[9] 59 (10/9) 61 (20/9) 66 (30/9) 72 (10/10) 77 (20/10)	29% 28% 25% 19% 12% 6%		Modelling study

ID	Soil type	Hydrological (field) conditions	Land use	System boundary condition	NO_2 (mg/l) or N-load (kg N ha^{-1})	Without catch crop	With catch crop	Reduction (%)	Number of years	Type of study
7c	Sandy soil	Wet sand soil	Maize production	Upper groundwater	NO_3	39	28 (1/9)[9]	28%		Modelling study
							28 (10/9)	28%		
							30 (20/9)	25%		
							32 (30/9)	19%		
							35 (10/10)	12%		
							37 (20/10)	6%		

1 At fertiliser rates of 115 and 185 kg N per ha.

2 After cultivation of early potatoes, harvested in July or August.

3 In a rotation of peas followed up by beans within the same year, beans were replaced by a catch crop.

4 Sown on 12 September.

5 Sown on 1 October.

6 Sown on 13 September.

7 N fertiliser rate of the following crop maize minus (measured) N removal at harvest.

8 After potatoes were harvested in September.

9 Reduction of NO3 depending on the harvest date (between parentheses) of the maize.

Costs

The calculated costs of growing catch crops consist of seed costs and fuel expenses for soil preparation and sowing. These costs vary per crop species. The calculation presumes that catch crops are not fertilised, so no fertilisation costs are calculated. The cultivation of catch crops costs about €70-120 per ha and demands 2-3 hours of labour per ha. Sometimes, an additional treatment is necessary to destroy and incorporate the catch crop before ploughing. These costs are not taken into account in Table 2. Potential benefits of catch crops are:

- Saving of nitrogen fertiliser in the next crop (taken into account in the cost calculation);
- A possible yield increase of the next crop (not taken into account).

Table A.8

Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Total costs	Cost-effectiveness	Author(s) reference
	€ per year	*€ kg^{-1} N-reduction*	
1	75	1.35 / mg NO_3/l	KWIN-AGV 2012
2	80	1.35 / mg NO_3/l	id.
3	770[1]	9.40 / mg NO_3/l	id.
4a	95	2.15 / kg N	id.
4b	115	19.15 / kg N	id.
5a	75	3.10 / kg N	id.
5b	75	1.80 / kg N	id.
6	95	2.30 / mg NO_3/l	id.
7a	95	23.75 / mg NO_3/l	id.
7b	75-115[2]	3.20-24.25 / mg NO_3/l[2]	id.
7c	75-115[2]	6.75-33.35 / mg NO_3/l[2]	id.

1. Including loss of margin of the cultivation of beans (margin taking contract work into account).
2. Depending on the harvest date of the maize / sowing time of the catch crop and subsequent N uptake and saving of N fertiliser in the next crop.

Environmental side effects / pollution swapping

When destroyed green manures, including catch crops, are left unincorporated on top of the soil, mineralised N may be partly lost to the air as ammonia (NH_3) instead of being leached as nitrate.

The sowing of the green manures and, if required, an additional treatment to destroy and incorporate the crop into the soil, costs energy (fuel) and thus increases the emission of CO_2. The crop can be destroyed mechanically or chemically with an herbicide, which has an environmental impact.

Feasibility

Apart from their compulsory presence after maize is grown on sandy and loess soils, catch crops are not cultivated on a large scale in the Netherlands. The crop rotation is often too intensive, leaving few opportunities for a successful catch crop; many main crops are not harvested any earlier than autumn. However, to be effective, the catch crop should be sown before the end of September and preferably even before the beginning of September. Therefore, the main crop must be harvested relatively early. It is estimated that a successful catch crop can be grown on no more than about 45% of the cultivated area of ware potatoes on sandy soils in the southeast of the Netherlands.

Catch crops are also host plants for parasitic nematodes and increase the infection degree of soil-borne nematodes that also infect other crops. This is specifically a problem on sandy soils, resulting in the limited adoption of green manures by farmers (depending on the nematodes infection of the soil).

Mode of implementation

Aside from their use on fields where maize is cultivated, catch crops are not widely used on arable land in the Netherlands. A much larger implementation of catch crops would require an earlier harvest of the main crop, and the availability of species that are more tolerant to producing at relatively low temperatures and that are not hosts for plant parasitic nematodes. Their use could be increased by introducing new plant species and/or plant breeding. Furthermore, an earlier harvest of the main crop could be pursued, without the loss of yield, by growing earlier maturing varieties or, although less promising, by using different cultivation techniques.

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Description
Catch crops are sown following the harvest of the main crop or undersown in the main crop. In temperate humid climates, catch crops have proven to be a useful tool for the abatement of soil erosion, nutrient leaching and soil organic carbon losses.

Rationale, mechanism of action

N uptake
During late summer and autumn, catch crops can take up mineral nitrogen remaining after the harvest of the previous main crop and mineralised nitrogen from soil organic matter and, eventually, from crop residues and applied manure. Catch crops reduce the soil mineral nitrogen in the soil profile, which is prone to leaching during winter and early spring. Depending on the species of catch crop, the weather circumstances and N availability in the soil, a well-established and early sown catch crop can take up 50 to 200 kg N ha^{-1} (Sørensen, 1992; Thorup-Kristensen, 1993; Geypens and Honnay, 1995; Vos and van der Putten, 1997; Destain *et al.*, 2010). Including catch crops in rotations reduces nitrate leaching by 70% (Tonitto *et al.*, 2006). In long-term rotation experiments with catch crops, nitrate concentrations in leached water were nearly always less than 50 mg L^{-1}. Furthermore, leached water quantities were smaller due to transpiration by the catch crop in autumn (Constantin *et al.*, 2010).

Cover crops
Catch crops function as cover crops. Roots improve soil aggregation and the aboveground biomass covers the soil and transpires water, protecting the soil from wind and water erosion. The catch crop cover also suppresses weeds and regrowth of the harvested crop (Brust *et al.*, 2011). Some catch crops may decrease the population pressure of nematodes or other pest species, while other catch crops are host plants and enhance multiplication of the pest species. Therefore, the position of a catch crop in a rotation has to be well considered.

Nutrient release
Catch crops are incorporated between late autumn and early spring. Once the catch crop has been incorporated, mineralisation begins as soon as weather circumstances allow it. The release of mineral N from the catch crop is an advantage if the next crop is able to take it up immediately. This implies that fertilisation of the next crop should be reduced. However, if the next crop is sown long after incorporation of the catch crop and the released N cannot be taken up sufficiently, there is a risk of nitrate leaching or denitrification in spring.

On the other hand, the reduction of the soil mineral nitrogen pool by a catch crop also reduces the N availability for the succeeding crop, as a fraction of the assimilated N would otherwise be retained in the rooting zone and be available for the succeeding crop. This effect has been termed pre-emptive competition (Thorup-Kristensen, 1993). However, the assimilated N increases the N availability for the succeeding crop, as a fraction of this nitrogen is mineralised and thus returned to the plant's available soil mineral nitrogen pool. Based on those considerations, Thorup-Kristensen (1993) found that the combined effect of catch crop N uptake on N availability for a succeeding crop can be expressed as:

$$N_{eff} = (m - r) * N_{uptake}$$

With:

N_{eff}	The difference in soil mineral nitrogen available for the next crop between fields with and without catch crops.
m	The fraction of catch crop N mineralised after incorporation.
r	The fraction of catch crop N that would remain available as soil mineral nitrogen for the next crop if no catch crop was sown.
N_{uptake}	The catch crop N yield.

The retention factor r depends on the depth and date of the N uptake. N taken up in early autumn and at great soil depth is much more likely to be lost and will thus have a lower r value than nitrogen available at some other times (e.g. in early spring in the topsoil).

Furthermore, the retention factor r depends on:
- The amount of precipitation during winter: the more precipitation, the more N will be leached.
- The soil type: heavier soils have higher retention factors.
- Root depth of the next crop: the deeper roots reach, the more N remains available for the next crop.

The mineralisation coefficient m differs among catch crop species and soil types and also depends on weather circumstances. Catch crops with low C:N ratios will release N faster than catch crops with high C:N ratios. The C:N ratio depends mainly on catch crop species, but can also be affected by incorporation date, sowing date, nutrient availability and weather circumstances during growth. Vigil and Kissel (1991) found that the C:N ratio explained 75% of the differences in N release from eight different crops. Thorup-Kristensen (1994) and Justes *et al.* (2009) found significant correlations between organic C and N contents and the net N mineralisation from incorporated catch crops. Incorporation of catch crop residues with high C:N ratios can induce N immobilisation.

In long-term experiments, Berntsen *et al.* (2006) and Constantin *et al.* (2011) found that incorporation of catch crops with higher C:N ratios did not result in relevant amounts of extra N mineralisation during the first years, but that the amounts of extra N mineralised increased yearly, probably due to additional N released from the increased amounts of soil organic matter. Incorporation of catch crops with lower C:N ratios resulted in relevant amounts of extra N mineralisation from the first year onwards, but these amounts remained constant during the duration of the experiment.

Non-frost-resistant catch crops can also release N before incorporation, during decay of the biomass after the first period of frost, which can lead to N losses if the next crop is sown late. It is therefore advisable to choose frost-resistant catch crops like ray grass if there is a late crop following a catch crop incorporated in spring. On the other hand, it is advisable to choose non-frost-resistant catch crops like mustard or phaecilia if incorporation is done in autumn (on heavy soils): they take N up more quickly and release N more slowly.

In addition to nitrogen, catch crops retain and recycle other nutrients like phosphorus.

Soil organic matter
Catch crops produce organic matter, which contributes to the build-up of soil organic matter after incorporation. Constantin *et al.* (2010) found a positive linear relationship between the yearly increase of soil organic carbon (= effective organic carbon) and the incorporated amount of carbon for different catch crops. Incorporation of catch crops can reverse the decline of soil organic carbon following the removal of spring barley straw (Mutegi *et al.*, 2011).

Carbon mineralisation from catch crop roots is generally slower than carbon mineralisation from the aboveground biomass (Rasse *et al.*, 2005), which cannot always be explained by differences in the C:N ratio (Mutegi *et al.*, 2011). Timmer *et al.* (2004) found that the effective organic carbon content was 35% for roots, while only 20% for aboveground biomass. Through rhizodeposition, carbon can also be translocated from the roots to the soil organic matter during the growing season (Mutegi *et al.*, 2011).

Fodder
Depending on catch crop yields, edibility of the catch crop species, sowing date of the next crop and weather circumstances at harvest date, catch crops can also be harvested to serve as animal fodder.

Applicability

Sowing date
Catch crops can be cultivated in any cropping system as long as there is enough time for ample development and uptake of nutrients. In the moderate marine climate of northwestern Europe, catch

crops can best be cultivated after cereals or other early harvested crops (e.g. some vegetables), as it is generally advised to sow catch crops before 1 September to obtain sufficient N uptake and reduce N losses during winter (Herelixha *et al.*, 2002). Compared to bare fallow treatments, Nett *et al.* (2011) observed a significant reduction in the soil mineral N content only under early sown catch crops and not under late sown catch crops. Other field experiments have shown that catch crop dry matter yields decrease faster with sowing date than N yields do, as N concentrations in the biomass increase (Goffart *et al.*, 1997).

Nevertheless, Vos (1992) and Vos and van der Putten (1997) found linear relationships between aboveground catch crop N yield and sowing date for combined data from different empirical studies concerning N yields of catch crops:

$$N_{aboveground} = 522 - 1{,}8 * sowing\ date \qquad \text{(Vos, 1992)}$$

$$N_{aboveground} = 960 - 3{,}4 * sowing\ date \qquad \text{(Vos and van der Putten, 1997)}$$

With $N_{aboveground}$ in kg N ha^{-1} and sowing date in days counted from 1 January.

The effects of sowing date on catch crop N yield also depend on catch crop species. The faster a catch crop is established, the smaller the differences in N yields between earlier and later sown catch crops (Vos and van der Putten, 1997; Nett *et al.*, 2011).

Climate and weather conditions
Weather conditions during and shortly after sowing of the catch crop are crucial to obtaining high catch crop N yields. Late summer drought can cause delayed germination, resulting in effects similar to those for late sown catch crops.

In drier climates, soil moisture depletion by catch crops can negatively influence the next main crop. Undersowing the catch crop in the main crop can also induce problems with soil moisture availability for both the main crop and the catch crop. Furthermore, establishing the catch crop under the main crop is not always successful.

Fertilisation
In Flanders, the environmental policy allows farmers to apply animal manure after harvest of winter cereals at a rate of 60 kg total N ha^{-1} from slurry, if they sow a catch crop before 1 September (on light textures) or before 15 October (on heavy textures). Farmers claim that fertilisation stimulates catch crop growth, which enhances the benefits of catch crops. However, studies have not determined whether fertilising catch crops affects N losses during winter. Ninane *et al.* (1995) and Destain *et al.* (2010) found an increase in total N yield of 100 kg N ha^{-1} for white mustard when it was fertilised with 80 kg N ha^{-1} mineral fertiliser. Others (Vos and van der Putten, 2001) have proven that a higher fertilisation is not always efficient: catch crop N yield did not increase with 50 kg N ha^{-1} for catch crops fertilised with 70 kg N ha^{-1} compared to catch crops fertilised with 20 kg N ha^{-1}.

Effectiveness and costs
Quick establishment associated with a deep rooting system for the catch crop improves its effectiveness. The N uptake by grasses in autumn is normally lower than for some other catch crops like yellow mustard or phacelia. On the other hand, grasses are frost-resistant and take up some nitrogen during winter. Other catch crops are less frost-resistant and will release some nitrogen during winter.

The costs of a catch crop are relatively low and include the price of the seeds, the field preparation and the sowing itself. Apart from benefits on a large environmental scale, farm-scale financial benefits include fertiliser input reductions and higher crop yields.

The part of N retained by catch crops that becomes available for the succeeding crop reduces fertiliser costs in spring. The fertiliser replacement factor expresses the ratio between the amount of nitrogen fertiliser and the amount of catch crop N that have to be applied/incorporated to result in a similar increase in N uptake by the succeeding crop. Vos and van der Putten (2001) found a fertiliser replacement factor equal to 0.61. Therefore, after incorporating a catch crop with a yield of 100 kg N ha^{-1}, the mineral fertiliser application to the succeeding crop could be reduced with 61 kg N ha^{-1}. However, a general reduction of the fertilisation rate cannot be defined, as fertiliser replacement factors and catch crops N yields (see part 0) show high variation.

The remaining part of the N taken up by the catch crop will be immobilised in newly formed organic matter, resulting in increasing N mineralisation and decreasing long-term fertiliser needs. Therefore, long-term experiments with catch crops have not resulted in decreasing yields from the main crops (Tonitto *et al.*, 2006), and even increased yields for sugar beets and winter wheat, when oil radish was sown as a yearly catch crop (Constantin *et al.*, 2010).

Environmental side effects/pollution swapping

N_2O emission

Incorporation of catch crops helps to maintain soil organic matter content and sequester the greenhouse gas (GHG) CO_2. The emission of other GHGs such as N_2O could also be affected due to the presence or later incorporation of catch crops. During autumn, emissions are expected to decrease if a catch crop is sown, since the availability of nitrate (as an electron donor) and soil moisture contents are lower. Cavigelli and Robertson (2000, 2001) also showed that catch crops affect denitrifying bacteria. Compared to bacteria on bare fallows, denitrifying bacteria under catch crops are less sensitive to O_2 and have a lower N_2O:N_2 ratio. After catch crop decay due to frost or after incorporation, emissions are expected to increase due to a higher availability of carbon (as electron acceptor) or even nitrate (as electron donor) after incorporation. From autumn to spring, Premrov *et al.* (2009) found higher dissolved organic carbon concentrations in shallow groundwater under white mustard than under fallow or bare fallow. Mørkved *et al.* (2006) found an increase in N_2O emissions when the sap of plants was added to soils with reduced O_2 availability. Petersen *et al.* (2011) found higher N_2O emissions for oil radish treatments compared to bare fallows during winter and after incorporation. The positive effect of the incorporated oil radish on N_2O emissions was smaller for reduced tillage than for conventional tillage. In their long-term experiments, however, Constantin *et al.* (2010) did not find significant differences in N_2O emissions between treatments with and without catch crops.

Pesticides

Catch crops might stimulate weed and nematode suppression and therefore reduce the number of pesticide and herbicide applications. However, in some cases, herbicides must be used to terminate the growth of the catch crop.

Feasibility

Only bad weather conditions can hinder the sowing of a catch crop and dry spells after sowing can retard the development of the catch crop.

Mode of implementation

In some countries or regions, like Flanders, farmers receive a subsidy to cover the costs of the seed and soil cultivation. To obtain that subsidy, the catch crop must be sown before 15 October, which is too late to get the most beneficial effects from the catch crop.

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B: Application time (extend closing period)

Northern Ireland

Description
The closed period for organic and inorganic fertiliser spreading relates to restrictions on the time of year farmers are allowed to spread fertiliser on their land. The current closed periods in Northern Ireland are described below. In addition, the application of organic and inorganic fertiliser is strictly regulated outside of the current closed period.

Rationale, mechanism of action
Organic and inorganic fertilisers pose a significant risk to water quality on agricultural land if they are spread when there is limited uptake of nutrient by plants and/or there is a high risk of runoff coinciding with applications. The closed periods in Northern Ireland largely coincide with periods when crop uptake is limited during the late autumn and winter months. During these months, low soil moisture defect and high frequency of rainfall significantly increase the risk of fertiliser application resulting in water pollution, due to the occurrence of runoff.

Time frame
15 September through 31 January

Applicability
- The land application of chemical fertiliser to grassland is not permitted between 15 September and 31 January of the following year.
- The land application of chemical fertiliser to any land is not permitted between 15 September and 31 January of the following year for crops other than grass unless there is a demonstrable crop requirement between those dates.
- The land application of organic manure, excluding farmyard manure and dirty water, to any land is not permitted between 15 October and 31 January of the following year.
- The land application of farmyard manure to any land is not permitted between 31 October and 31 January of the following year.

Effectiveness and cost-effectiveness
The initial evidence supporting the implementation of a closed period in Northern Ireland was based on modelled data demonstrating the number of safe days per month available for slurry spreading (see figure below). Safe days were defined as those with no rainfall within 48 hours of application and a soil moisture deficit below field capacity. More recent data from an experimental grassland field site in Northern Ireland was modelled using a model from Vadas *et al.* (2007) in order to elucidate the reduction in phosphorus export in surface runoff as a result of the closed period (Table 2).

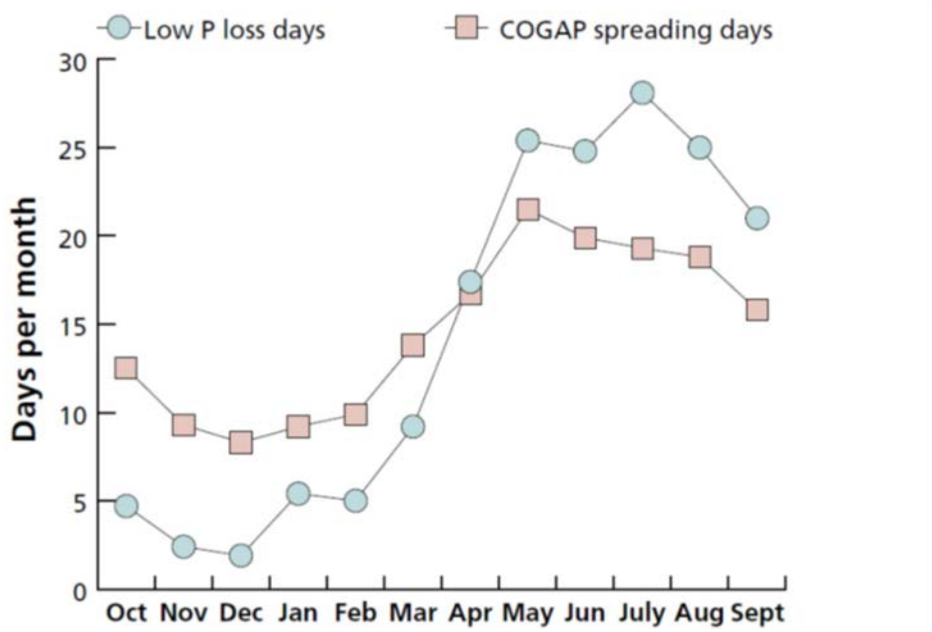

Figure 13 *Comparison of spreading days based on the Code of Good Agricultural Practice (COGAP) with number of days per month with low potential losses of phosphorus following application of organic manure to drained grassland at Crichton Royal, Dumfries (data from McGechan, 2002).*

Effectiveness on groundwater
No data available

Effectiveness on surface water

Table B.1
Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the phosphorus loads to surface water.

Soil type	Hydrological field conditions	Land use	System boundary conditions	P-load to surface water			Type of study	Author(s) reference
				Before (kg P ha^{-1})	After (kg P ha^{-1})	Reduction (%)		
Sandy clay loam	Poorly drained	grassland	Surface runoff	8.95	6.78	24	Modelling study using a four-year historical data set	McConnell, 2010

Costs

Table B.2
Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Specific circumstances	Costs			Cost-effectiveness		Author(s) reference
		Total	*Depreciation*	*Maintenance*	*€ kg^{-1} N-reduction*	*€ kg^{-1} P-reduction*	
1	75 dairy cows requiring 22 weeks slurry storage (~40 ha)	7599	6599	1000	No figure available	86.35	Ferris *et al.* (in prep**)**

Environmental side effects / pollution swapping

As a result of slurry storage, this mitigation measure results in an increase in NH_3 and CH_4 emissions.

Feasibility

This is a straight forward mitigation measure to implement once farmers have the capital funds required to increase slurry storage capacity. However, problems can occur if bad weather persists outside of the closed period, limiting farmers' opportunities to empty their tanks before the start of the next closed period.

Mode of implementation

Under the Nitrates Action programme (Northern Ireland) 2010 regulations, strict adherence to the closed period for slurry spreading is mandatory on all farms in Northern Ireland. To implement this measure, where necessary, farmers were provided with significant capital grants to fund the building of slurry storage tanks.

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The Netherlands

Description

1. Mineral fertiliser nitrogen (N) and manures rich in mineral N (slurries and liquid fractions) can only be applied in the Netherlands in periods when the risk of nitrate leaching is small, to avoid excessive losses of N to the environment.
2. Mineral N fertiliser dressings can be split instead of applied once, to reduce the risk of N losses and to adjust rates to crop demand and the variable supply of N from the soil.

Rationale, mechanism of action

If manure or mineral fertiliser N are applied in autumn or winter, the mineral N, as well as the N that mineralises from the organic N fraction, will generally not be taken up by a crop. This mineral N will leach, runoff or denitrify due to the prevailing precipitation surplus during winter. These losses can be minimised by postponing the application to times shortly before cultivation of a crop (in spring) or right after a cut (as in grassland, i.e. during spring and summer) or, in case of manures applied to arable land, by combining the application with the cultivation of a green manure (in late summer).

Splitting mineral N fertiliser dressings reduces the risk of N losses due to leaching and denitrification in rainy periods during the growing season, especially in shallow rooting crops on soils that are susceptible to leaching (i.e. coarsely textured soils with little organic matter and/or a limited rooting depth).
Splitting also allows N rates to be adjusted to soil and weather conditions, such as N mineralisation that tends to vary across fields and years. The required N rates can be based on the observed soil mineral N content during the growing season or on the N status of the crop (e.g. as reflected in the nitrate content of the petioles). Such improvements to the synchronisation of N supply and demand can prevent overdosing of N. This results into a smaller N surplus and less residual SMN in autumn and hence a smaller loss to the environment.

Time frame

- Application of manure in spring and summer: the emission to groundwater and surface waters is reduced in autumn and winter.
- Splitting the N rate: the emission is reduced during the growing season if a precipitation surplus would occur in rainy periods (e.g. in field production of vegetables in autumn).
- Improvement of the synchronisation of N supply and demand: reduction of the emission in autumn and winter.

Applicability

The application time of manures and mineral fertiliser N is legally controlled in the Netherlands. It is forbidden to apply slurry between 1 August and 1 February on arable land, and between 1 September and 15 February on grassland. An exception is made for application on arable land in August if a catch crop is sown before 1 September. On arable land, solid manures, such as farmyard manure, can be applied for the whole year on clay and peat soils, but on sandy soils and loess soils even solid manures cannot be applied between 1 September and 1 February. Mineral fertiliser N can generally not be applied between 15 September and 1 February. Some exceptions are made for crops grown in autumn.

Splitting the N rate is common practice in several crops, especially in grassland, many vegetable crops and strawberries. Besides improving the N use efficiency, splitting is meant to control crop development. Generally the benefit of splitting to reduce N losses is highest in shallow rooting crops that are grown at the end of summer and in autumn when the risk of a precipitation surplus increases.

N splitting systems consisting of conditional, indicator-based post-emergence N applications are available for maize, potatoes, several vegetables crops, strawberries and flower bulbs. For potatoes, some systems other than SMN-based systems are available. These alternatives are based on monitoring petiole nitrate content and/or plant biomass.

A new system developed for potatoes and leeks is based on monitoring the crop with a radiation reflection sensor. N requirement of crops can thus be derived from their canopy reflection. Crop sensing may also be suited and further developed for other crops.

Effectiveness and cost-effectiveness

Effectiveness on groundwater

Table B.3

Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater: application time of manure.

ID	Soil type	Hydrological (field) conditions	Land use	System boundary conditions	NO_3 (mg/l) or N-load (kg ha^{-1})	Autumn	Spring	Reduction (%)	Number of years	Type of study
1	Sandy soil	Groundwater level 0.7-1 m below surface	Maize production	Soil	Apparent N recovery[1]	20%[1]	29%[1]	34%	6	Field trials
2	Clay soil		Arable land	Soil	N fertiliser replacement value	5%[2]	49%[3]-65%[4]	90-92%	3	Field trials
3a			Arable land	Soil	N fertiliser replacement value	19-20%[5,6]	50-62%[5,6]	67%		Modelling study
3b			Arable land	Soil	N fertiliser replacement value	21-23%[5,7]	60-75%[5,7]	68%		Modelling study
3c			Arable land	Soil	N fertiliser replacement value	23%[8]	39%[8]	41%		Modelling study
3d			Arable land	Soil	N fertiliser replacement value	24-32%[9]	48-61%[9]	33-61%[9]		Modelling study

1. At a total average N rate of cattle slurry of 239 kg N per ha applied in autumn versus 249 kg N per ha applied in spring.
2. At a total average N rate of pig slurry of 307 kg N per ha applied in November.
3. At a total average N rate of pig slurry of 144 kg N per ha applied in March/April.
4. At a total average N rate of pig slurry of 168 kg N per ha applied in May.
5. Variation depends on the application method (affecting the losses by ammonia volatilisation).
6. Cattle slurry.
7. Pig slurry.
8. Farmyard manure of cattle.
9. Solid poultry manures. Variation depending on the type of poultry manure.

Table B.4

Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater: variable split N rate versus fixed N rate.

ID	Soil type	Hydrological field conditions	Land use	System boundary conditions	NO_3 (mg/l) or N-load (kg ha^{-1})	N rate		Reduction (%)	Number of		Type of study
						Fixed	variable		Years	trials	
4a[1]	clay soil		arable land	soil	total N rate	228	207	9%	3	14	Field trials
4b[1]	loess soil	deep groundwater	arable land	soil	total N rate	255	203	20%	2	2	Field trials
5a[2]	sandy soil	dry sand soil	arable land	soil	total N rate	207	181	13%	2	6	Field trials
5a[2]	sandy soil	dry sand soil	arable land	soil	N surplus[6]	14	-9		2	6	Field trials
5a[2]	sandy soil	dry sand soil	arable land	root zone 0-30 cm	residual soil mineral N after harvest	18	11	39%	2	6	Field trials
5b[2]	reclaimed peat soil	dry sand soil	arable land	soil	total N rate	198	170	14%	2	6	Field trials
5b[2]	reclaimed peat soil	dry sand soil	arable land	soil	N surplus[6]	-13	-25		2	6	Field trials
5b[2]	reclaimed peat soil	dry sand soil	arable land	root zone 0-30 cm	residual soil mineral N after harvest	12	11	8%	2	6	Field trials
6[2]	sandy soil	dry sand soil	arable land	soil	total N rate	203	168	17%	2	4	Field trials
6[2]	sandy soil	dry sand soil	arable land	soil	N surplus[6]	5	-19		2	4	Field trials
6[2]	sandy soil	dry sand soil	arable land	root zone 0-60 cm	residual soil mineral N after harvest	41	32	22%	2	4	Field trials
7[1]	clay soil	dry sand soil	arable land	soil	total N rate	213	150	30%	2	4	Field trials
8a[1]	sandy soil	dry sand soil	arable land	soil	total N rate	258	255	-	2	2	Field trials
8b[2]	sandy soil	dry sand soil	arable land	soil	total N rate	250	180	28%	1	1	Field trials
8c[2]	reclaimed peat soil	dry sand soil	arable land	soil	total N rate	205	210	-	1	1	Field trials
8d[1]	clay soil	dry sand soil	arable land	soil	total N rate	225	170	24%	2	4	Field trials
9[3]	sandy soil	dry sand soil	field production vegetables	soil	total N rate	180	95[7]	50%	2	2	Field trials
9[3]	sandy soil	dry sand soil	field production vegetables	soil	N surplus[6]	-103	-151		2	2	Field trials

ID	Soil type	Hydrological field conditions	Land use	System boundary conditions	NO_3 (mg/l) or N-load (kg ha^{-1})	N rate		Reduction (%)	Number of		Type of study
						Fixed	variable		Years	trials	
9[3]	sandy soil	dry sand soil	field production vegetables	root zone 0-60 cm	residual soil mineral N after harvest	40	18	55%	2	2	Field trials
10[4]	clay soil		arable land	soil	total N rate	100	72	28%	3	5	Field trials
10[4]	clay soil		arable land	soil	N surplus[6]	-48	-73		3	5	Field trials
11[5]	clay soil		field production vegetables	soil	total N rate	70	105	-35%	2	2	Field trials

1. Ware potatoes.
2. Starch potatoes.
3. Leeks.
4. Spring-sown onions.
5. Iceberg lettuce.
6. Total N fertiliser rate minus (measured) N removal at harvest.

Costs
Applying manure at another time will not necessarily affect application costs. However, postponing manure applications to spring on heavier soil types may require adjusted equipment with a much lower wheel pressure, thus negatively affecting the costs. Moreover, when manures are applied in late summer instead of autumn in order to facilitate an effective sequestration of manure-N by a vigorous green manure crop, this may require concessions to the length of the growing season of the preceding main crop and hence its yield potential. For the cattle or pig farmer, some extra storage capacity may be necessary as the manure must be stored longer.

Splitting the N rates requires tractors to drive over the fields more often and hence more fuel consumption. Variable N rate systems also involve costs for required labour, sampling and analyses. Costs of only sampling and analysis vary and depend, among others, on the type of variable N rate system and number of samplings during the growing period. The costs amount to about €35 per ha on average.

In some cases, the application of a variable split N rate system caused some yield reduction, but in other cases yield was increased by it. Therefore an effect on yield can be omitted from the cost calculation.
For potatoes, the average saving of N fertiliser amounts to about 30-35 kg N per ha, implying a reduction of fertiliser costs of about €35 per ha. So, on average, the costs of sampling and analysis are equivalent to the reduction of fertiliser costs.

Environmental side effects / pollution swapping
Application of manures after wintertime can cause damage to the soil structure, especially on clay soils but also on wet sandy soils, due to the heavy application machinery. A poor soil structure can restrict the crop's root development and may result into a lower utilisation of N, more residual SMN in autumn and hence a higher loss of N to the environment.

Splitting the N rate increases the emission of CO_2 due to the need for tractors to drive over the fields more often and more fuel consumption.

Feasibility
Application of manures after wintertime is technically possible and is common practice in arable farming on sandy soils and in grassland farming on any soil type. On tilled clay soils, however, the application of manure with heavy machinery is restricted to avoid damage to the soil structure. Therefore alternative application methods using lighter equipment have been and are being developed.

Splitting the N rate is feasible or even recommended for grassland, a number of arable crops and many vegetable crops. It is not useful for all crops and a few crops can even respond negatively to splitting. Knowledge of the crop's N uptake pattern and its N requirements in different growth stages is an important condition for splitting. Incorrect splitting (by uninformed decisions) can cause severe N deficiency in an early growth stage of the crop.

Variable N rate systems used to adjust the N rate to growth conditions can be applied in potatoes and several vegetables crops. The reliability of the systems largely depends on the measurement error.

Mode of implementation
Manures are only applied in the legally allowed periods in the Netherlands. On sandy soils, manures are mostly applied in spring. On clay soils, they are less often applied in spring. Instead, they are mostly applied on clay soils in August, after the harvest of cereals, followed by a green manure crop.

Splitting a fixed N rate is quite common for a number of arable crops and many vegetable crops. Combinations of splitting while using variable N rates, however, are not yet widely implemented in the Netherlands, because of the extra labour and costs of sampling and analysis.

Moreover, not all farmers have sufficient confidence in these conditional N application systems. Nevertheless, farmers' in variable split N rate systems is increasing due to the reduction of permitted N application standards evolving from the EU Nitrates Directive Action Programme. Variable N rate systems based on canopy reflectance are especially receiving a lot of attention at the moment, but they need to be further implemented in practice.

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Description
According to Newell Price *et al.* (2011), there are four methods in the UK that fall under the category of application time: 1) reduction of length of grazing day/season (Method 35); 2) avoiding the spread of slurry of poultry manure (Method 69); 3) avoiding the spread of FYM (Method 72); and 4) avoiding the spread of manufactured fertiliser (Method 26) at high-risk times.

Rationale, mechanism of action
Reducing the time animals spend grazing will reduce the amount of urine deposited in the field as 'hot-spots', which will reduce the amount of nitrate leaching and N_2O emissions to air (1). So will avoiding spreading of slurries, poultry manures, FYM & manufactured fertiliser (2-4) with 'high' readily available N contents at times when there is a high risk of surface runoff or leaching.

Time frame
The time frame in which reductions to N/P leaching will occur should be immediate.

Applicability
Livestock farms where animals graze outside in spring and autumn (1). All farms that produce or use FYM, poultry slurry or fertiliser and have drained and/or sloping land (2-4).

Table B.5

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater.

ID	Land use	System boundary conditions	NO_3 (mg/l) or N-load (kg ha^{-1})	Before	After	Reduction (%)	Type of study	Author reference
1	Dairy[a] Grazing[b] Mixed[c] farming	D2/C1 Farm scale	N **(kg N ha^{-1})**	15-50[a] 7-25[b] 20-50[c]	12-40 5.6-20 16-40	20%	Modelling study	Newell–Price *et al*. (2011) Mitigation methods-users guide (WQ0106)
2	Dairy[a] Combinable crops[b] Roots[c]	D2/C1 Farm scale	N **(kg N ha^{-1})**	15-50[a] 20-40[b] 25-45[c]	12-40 16-32 20-36	20%	Modelling study	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
3	Dairy[a] Grazing[b] Mixed[c] Comb[d] crops	D2/C1 Farm scale	N **(kg N ha^{-1})**	15-50[a] 7-25[b] 20-50[c] 20-40[d]	14.25-47.5 6.65-23.75 19-47.5 19-38	5%	Modelling study	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
4	Dairy[a] Grazing[b] Mixed[c] Comb crops[d] Comb roots[e] Horticulture[f]	D2/C1 Farm scale	N **(kg N ha^{-1})**	15-50[a] 7-25[b] 20-50[c] 20-40[d] 25-45[e] 20-35f	14.25-47.5 6.65-23.75 19-47.5 19-38 23.75-42.75 19-33.25	5%	Modelling study	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)

Effectiveness on surface water

Table B.6

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the nitrogen loads to surface water.

ID	Land use	System boundary conditions	Surface water N-load			Type of study	Author reference
			Before	After	Reduction (%)		
1	Dairy[a] Grazing[b] Mixed[c] farming	D2/C1 Farm scale	15-50[a] 7-25[b] 20-50[c]	12-40 5.6-20 16-40	20	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
2	Dairy[a] Combinable crops[b] Roots[c]	D2/C1 Farm scale	15-50[a] 20-40[b] 25-45[c]	12-40 16-32 20-36	20	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
3	Dairy[a] Grazing[b] Mixed[c] Comb[d] crops	D2/C1 Farm scale	15-50[a] 7-25[b] 20-50[c] 20-40[d]	14.25-47.5 6.65-23.75 19-47.5 19-38	5	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
4	Dairy[a] Grazing[b] Mixed[c] Comb crops[d] Comb roots[e] Horticulture[f]	D2/C1 Farm scale	15-50[a] 7-25[b] 20-50[c] 20-40[d] 25-45[e] 20-35f	14.25-47.5 6.65-23.75 19-47.5 19-38 23.75-42.75 19-33.25	5	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)

Table B.7

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the phosphorous loads to surface water.

ID	Land use	System boundary conditions	Surface water P load			Type of study	Author reference
			Before	After	Reduction (%)		
1	Dairy[a] Grazing[b] Mixed[c] farming	D2/C1 Farm scale	0.2-0.8 0.05-0.5 0.2-0.8	0.18-0.72 0.045-0.45 0.18-0.72	10%	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
2	Dairy[a] Combinable crops[b] Roots[c]	D2/C1 Farm scale	0.2-0.8 0.02-0.8 0.02-0.9	0.1-0.4 0.01-0.4 0.01-0.45	50%	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
3	Dairy[a] Grazing[b] Mixed[c] Comb[d] crops	D2/C1 Farm scale	0.2-0.8 0.05-0.5 0.2-0.8 0.02-0.8	0.19-0.76 0.0475-0.475 0.19-0.76 0.019-0.76	5%	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)
4	Dairy[a] Grazing[b] Mixed[c] Comb crops[d] Comb roots[e] Horticulture[f]	D2/C1 Farm scale	0.2-0.8 0.05-0.5 0.2-0.8 0.02-0.8 0.02-0.9 0.01-0.7	0.18-0.72 0.045-0.45 0.18-0.72 0.018-0.72 0.018-0.81 0.009-0.63	10%	Modelling	Newell–Price *et al.* (2011) Mitigation methods-users guide (WQ0106)

Costs

Table B.8

Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Land use	Costs	Cost efficiency		Author reference
		€ / year	€ kg^{-1} N-reduction	€ kg^{-1} P-reduction	
1[a]	Dairy farm	6187	2062-619	309,350-77,338	Newell–Price *et al.* (2011)
1[b]	Grazing	4125-2593	2946-519	825,000-51,860	Newell–Price *et al.* (2011)
1[c]	Mixed	1178	294-118	58,900-1425	Newell–Price *et al.* (2011)
2[a]	Dairy farm	153	51-15	1530-383	Newell–Price *et al.* (2011)
2[bc]	Combinable crops Combinable roots	212	53-24	21,200-471	Newell–Price *et al.* (2011)
3	Dairy[a]	153	204-61	15,300-3825	Newell–Price *et al.* (2011)
3	Grazing[b]	118-153	437-94	61,200-4720	Newell–Price *et al.* (2011)
3	Mixed[c] Comb crops[d]	177	177-79	177,000-3933	Newell–Price *et al.* (2011)
4	Dairy[a] Horticulture[f]	118	157-47	118000-1475	Newell–Price *et al.* (2011)
4	Grazing[b]	35-82	234-28	16400-700	Newell–Price *et al.* (2011)
4	Mixed[c]	353	353-141	17650-4413	Newell–Price *et al.* (2011)
4	Comb crops[d] Comb roots[e]	943-1002	1002-419	501,000-10477	Newell–Price *et al.* (2011)

Environmental side effects / pollution swapping
Reducing grazing time would lead to 20% increases in NH_3 emissions and also lead to increases in methane emissions. The amount of FIOs and BOD would be expected to decrease (Newell–Price et al, 2011). Better timing of slurry application would reduce the losses of readily available N and P by 20% and 50%, respectively. Better timing of FYM and fertiliser applications would also decrease losses from land, but only by 5%. Not applying slurries, manures and fertilisers when they are most easily transported to water courses would also decrease the likelihood of transfer of FIOs and result in lower BOD. However, application of FYM to dry soils in the summer months would be expected to marginally increase ammonia emissions (Newell–Price et al, 2011).

Feasibility
1) Reduction of grazing day/season would increase labour and associated costs of forage production and manure management.
2 & 3) Sufficient slurry or FYM storage facilities are necessary to allow for greater choice of timing of applications to land.
4) Farmers would have to delay the first spring application of fertiliser until the soils were drier, which could impact their yield.

Mode of implementation
This is a voluntary measure(s) communicated by stakeholder engagement activities with CSFO/NE.

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C: Buffer strips

England and Wales

Description
A buffer strip is an unfertilised grass strip along the land contour, in valley bottoms or on upper slopes that is used to interrupt runoff. Buffer strips can be permanent or temporary and can be of any shape. Buffer strips adjacent to water courses are termed riparian buffer strips (methods 13 & 14 in Newell *et al.,* 2011).

Rationale, mechanism of action
The reduction in N losses is thought to be due to less available N in the soil profile as the buffer strip receives no fertiliser. P is reduced through the interception of upslope runoff and any associated p-bound sediment. The denser and rougher vegetation within the strip/zone slows the runoff and allows it to infiltrate (as soils should be less compacted within the buffer strip). It also allows any sediment with any associated particulate P to be carried away with the runoff and deposited within the strip.

Time frame
Once established, effects should be immediate.

Applicability
A 10 metre buffer strip is required along surface waters within NVZ areas where organic manures are used. In other areas, this is a voluntary measure available under stewardship scheme. It is applicable within all farming systems, though it is usually associated with arable systems. Fencing is required to protect the buffer strip/zone if it is established on farms with livestock.

Effectiveness and cost-effectiveness

Effectiveness on groundwater
No suitable UK studies were found about the effects of buffer strips on groundwater.

Table C.1
*Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the **nitrogen** loads to surface water.*

ID	Land use	System boundary conditions	Surface water N-load			Type of study	Author(s) reference
			Before	After	Reduction (%)		
1 & 2	Dairy	D2/C1 Farm scale	15-50	1.5-5	90	Modelling	Newell–Price *et al.* (2011)
	Grazing	D2/C1 Farm scale	5-25	0.5-2.5	90		Newell–Price *et al.* (2011)
	Mixed	D2/C1 Farm scale	20-50	2-5	90		Newell–Price *et al.* (2011)
	Comb crops	D2/C1 Farm scale	20-40	2-4	90		Newell–Price *et al.* (2011)
	Comb roots	D2/C1 Farm scale	25-45	2.5-4.5	90		Newell–Price *et al.* (2011)
	Pigs out	D2/C1 Farm scale	100-150	10-15	90		Newell–Price *et al.* (2011)
	Horticulture	D2/C1 Farm scale	20-35	2-3.5	90		Newell–Price *et al.* (2011)

1. Buffer strip.
2. Riparian Buffer strip.

Table C.2

*Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the **phosphorous** loads to surface water.*

ID	Land use	System boundary conditions	Surface water P load			Type of study	Author(s) reference
			Before	After	Reduction (%)		
1 & 2	Dairy	D2/C1 Farm scale	0.2-0.8	0.16-0.76	20-80	Modelling	Newell–Price *et al.* (2011)
	Grazing	D2/C1 Farm scale	0.05-0.5	0.04-0.49	20-80		Newell–Price *et al.* (2011)
	Mixed	D2/C1 Farm scale	0.2-0.8	0.16-0.76	20-80		Newell–Price *et al.* (2011)
	Comb crops	D2/C1 Farm scale	0.02-0.8	0.016-0.796	20-80		Newell–Price *et al.* (2011)
	Comb roots	D2/C1 Farm scale	0.02-0.9	0.016-0.896	20-80		Newell–Price *et al.* (2011)
	Pigs out	D2/C1 Farm scale	1-3	0.8-2.8	20-80		Newell–Price *et al.* (2011)
	Horticulture	D2/C1 Farm scale	0.01-0.7	0.008-0.698	20-80		Newell–Price *et al.* (2011)

1. Buffer strip.

2. Riparian Buffer strip.

Costs

Table C.3

Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Land use	Costs	Cost efficiency		Author reference
		€ / year	*€ kg^{-1} N-reduction*	*€ kg^{-1} P-reduction*	
1 (BS)	Dairy	1176.47	87-26	29,412-1838	Newell–Price *et al.* (2011)
	Grazing	58.82	13-3	5882-147	Newell–Price *et al.* (2011)
	Mixed	588.24	33-13	14706-919	Newell–Price *et al.* (2011)
	Comb crops	941.18	52-26	235294-1471	Newell–Price *et al.* (2011)
	Comb roots	4117.65	183-102	1029412-5719	Newell–Price *et al.* (2011)
	Pigs out	1411.76	16-11	7059-588	Newell–Price *et al.* (2011)
	Horticulture	1176.47	65-37	588235-2101	Newell–Price *et al.* (2011)
2 (RBS)	Dairy	4000.00	296-89	100000-6250	Newell–Price *et al.* (2011)
	Grazing	764.71	170-34	76471-1912	Newell–Price *et al.* (2011)
	Mixed	2705.88	150-60	67647-4228	Newell–Price *et al.* (2011)
	Comb crops	2823.53	157-78	705882-4412	Newell–Price *et al.* (2011)
	Comb roots	12470.59	554-308	3117647-17320	Newell–Price *et al.* (2011)
	Pigs out	5294.12	59-39	26471-2206	Newell–Price *et al.* (2011)
	Horticulture	3294.12	183-105	1647059-5882	Newell–Price *et al.* (2011)

Environmental side effects / pollution swapping

Variable effects on controlling nutrients are dependent on specific site conditions, can improve habitats on land (and in water-stream shading), and have the potential for carbon sequestration with soils in the buffer. See Stutter *et al.* (2012) Journal of Environmental Quality 41: 297-303. It could also lead to a reduction in FIO, if livestock were previously present.

Mode of implementation

A 10 metre mandatory buffer strip is required along surface waters within NVZ areas where organic manures are used. In other areas, this is a voluntary measure available under a stewardship scheme.

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Denmark

Description

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Rationale, mechanism of action

Arable land is taken out of production and fertilisation is stopped. The mechanism for N-effect is reduced leakage due to the stopping of fertilisation.

The mechanism for P is diversified: reduction of surface runoff from the fields upstream of the buffer strip, reduced leakage, and stabilisation of the river banks (reduced erosion).

Time frame

The effect on N-leakage occurs from year 1. The effect on P loss from surface runoff appears from year 1. The other effects appear over a period of approximately 25 years (DMU, DJF, 2011).

Applicability

A buffer strip of up to 10 metres is mandatory along all water courses. It has been estimated that about 50,000 ha of arable land has been taken out of intense production and transferred to extensive grassland.

Effectiveness and cost-effectiveness

Table C.4

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater.

ID	Soil type	Land use	System boundary condition	N-load (kg ha^{-1}) reduction	Reference
1	No differentiation	Change from arable land to non-fertilised grassland	Root zone	App. 50 kg N ha^{-1}	2)
2	No differentiation	Change from arable land to non-fertilised grassland	Root zone	Average 34 kg N ha^{-1} (differs from app. 10 kg N ha^{-1} to app. 51 kg N ha^{-1}) depending on coverage before establishing the buffer strip)	4)

Effectiveness on surface water

The N-reduction from the root zone to primary surface water recipient (normally the river) is probably very low. In the water planning, no reduction is included (i.e. root zone effect = surface water effect).

Table C.5

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the phosphorus loads to surface water.

ID	Transportation path	Land use	System boundary condition	Surface water P-reduction	Type of study	Author(s) reference
1	Leaching	Change from arable land to non-fertilised grassland	Primary recipient	0.03-0.15 kg P ha^{-1} y^{-1}	Model based	1
2	Surface runoff	Change from arable land to non-fertilised grassland	Primary recipient	A total effect of 4-30 tonnes P y^{-1}	Modelling study	1
3	Reduced river bank erosion	Change from arable land to non-fertilised grassland	Primary recipient	A total effect of 11-83 tonnes P y^{-1}*	Field studies	1
4**	No differentiation	Change from arable land to non-fertilised grassland	Primary recipient	1.4-4.8 kg P ha^{-1} y^{-1}		2

* To obtain this effect, 10% of the river banks must be planted to stabilise the banks and reduce bank erosion.

** The estimated effect used in the Danish RBMP (ref. 2) is based on a preliminary study from NERI. New field studies, especially on the effect of buffer strips on bank erosion, have revealed new information (and shown a smaller effect), which is not reflected in the RBMPs.

Costs

Table C.6

Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	€ kg^{-1} N-reduction	Author(s) reference
1	3.3	2) a unit cost for all general measures

Environmental side effects / pollution swapping
In the long run, buffer strips may strengthen biodiversity along water courses.

Mode of implementation
A 10 metre buffer strip on each bank is mandatory along all Danish water courses.

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The Netherlands

Buffer strips

Description

Natural riparian buffer zones
Natural flood plains and natural riparian buffer zones only exist alongside a few brooks or streams in the eastern and southern parts of the Netherlands. Most streams in the Netherlands are manmade, and all larger rivers have been canalised. There are some restoration projects in which natural river courses (meanders) are being reestablished to some extent. Therefore, natural riparian buffer zones are exceptional but do exist.

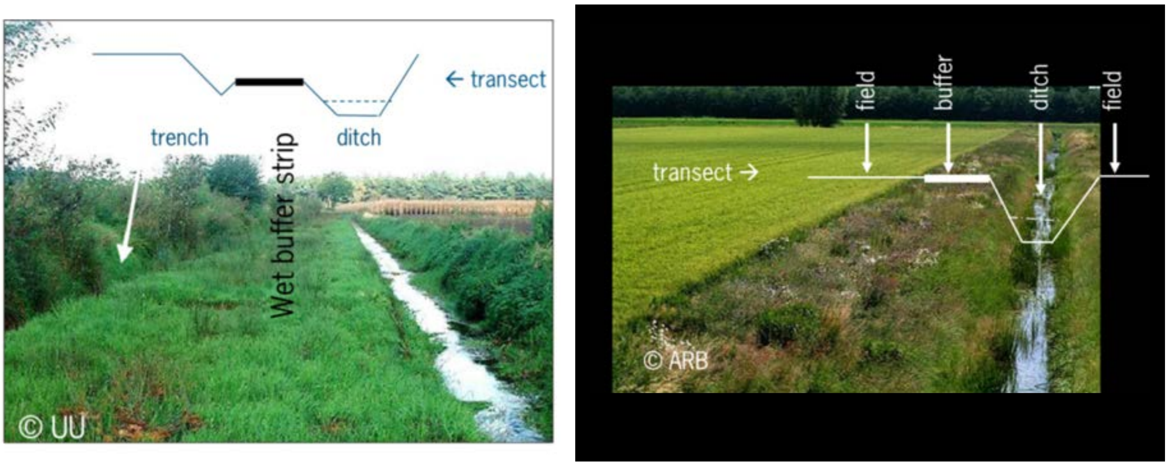

Figure C.1 *Transect and photos of a wet (left) and dry (right) buffer strip. Sources: University of Utrecht and Actief Randenbeheer Brabant.*

The majority of buffer strips (BS) in the Netherlands are manmade. Here we distinguish between two types of BS: dry and wet.

Manmade marsh or wet buffer strips
To create a wet BS (Figure C.1, left), the cross-section of the stream needs to be altered (i.e. top soil needs to be removed before installing the BS). Wet BS are mostly installed for water storage purposes (i.e. to prevent peak discharge). At low discharge levels, only the narrow deeper part of the surface water profile carries water, while at high discharge levels the wider shallower part is also involved. This wider shallower part is then designed and maintained like a constructed wetland to become a wet BS, and may then also contribute to other goals (e.g. reducing nitrate loads from neighbouring fields, reducing pesticide loads by spray drift from treated fields adjacent to the water body, biodiversity, and beauty of the landscape). This type of BS is expected to be less effective in reducing P-loads, because it is wet, which hampers adsorption to the soil. Wet BS have been implemented by many water boards in parts of their management area (water storage and biodiversity). As a consequence, they are exceptional or non-existent next to the smallest of ditches for which farmers are responsible.

Manmade dry buffer strips
<u>Narrow legal uncultivated strips</u>
In the Netherlands, a dry BS is simply a strip of the field next to the ditch (or stream) where no fertiliser (including manure and slurry) or pesticides are applied, and where, for that reason, the main arable crop is not grown (no production zone; but animals may graze). The original cross-section remains where dry BS (Figure C.1, right) are installed.

Legislation requires farmers to maintain strips without cultivation (no tillage, arable crop, fertiliser, pesticide), ranging from 0.25 metre (grassland), 0.5 metre (cereals) or 1.0 metre (root crops) to a maximum of 5 metres wide (for some fruit trees). These widths are based on protection against pesticide drift associated with spraying direction and groups of crops. Nonetheless, many farmers still start ploughing right at the edge of the ditch. By the end of the winter, they often dig small furrows from the field edge into the ditch to get rid of excess water (see runoff). Only in a small part of the upper brook catchments, often associated with high nature value, are 5–metre-wide dry BS required next to the main stream.

Extra-legal wider strips
In addition to narrow legal uncultivated strips, wider dry BS have not been widely implemented in the Netherlands. There are several regional projects in which BS are being or have been implemented based on either large government subsidies (partly national, partly EU), or subsidies from regional authorities (province, water board). They are sometimes also supported by the EU (e.g. Actief Randenbeheer Noord Brabant, Hoekse Waard, Hunze en Aas). Their width generally varies between 2 and 6 metres. On arable land, these strips are generally sown with grass or species-rich mixtures of grass and herbaceous flowers to promote functional agro-biodiversity (reduce pest pressure, stimulate pollination) and the beauty of the landscape. On grassland, the original grass sward remains and the species composition in the BS develops over time in accordance with the decreasing soil fertility status of the strip due to harvesting (2-4 times/year).

Rationale, mechanism of action

Direct losses
Dry BS contribute to the reduction of pesticide drift and direct fertiliser and soil losses, simply by forcing the farmer to maintain a larger distance to the ditch during application and tillage. They also stabilise ditch banks, which prevents erosion. In contrast to other countries, animals are generally not kept away from BS in the Netherlands, because this would require too much fencing (or the replacement thereof). In some areas, cows still drink from the ditch, but they cannot enter the ditch because the carrying capacity of the ditch bottom is too low. So the Dutch miss this advantage of buffer strips.

Wet BS may reduce pesticide loads deposited by drift onto the main stream if the wet has fallen dry. However, this is not the case when the wet BS carries water. So a wet BS may also contribute to the reduction of pesticide drift as long as it increases the distance between the crop edge and the water body in the main stream during spraying application. This reduction will be less than that of a dry BS with the same width due to the periods during which a wet BS is submerged. The same holds for direct losses of fertilisers and soil particles.

Surface runoff and erosion
Generally speaking, surface runoff (SR) and erosion are the most important transport routes for P. These entry routes may contribute to pesticides loads as well. Contrary to spray drift, pesticide loads with SR and erosion depend on the mobility and persistence of the chemical compound. However, quantitative information on the magnitude of pesticide loads by runoff and erosion from flat fields is still lacking (while there is information about the other loads spray drift and drainage). As BS are renowned for their capacity to filter out solid material from surface runoff flow, this is an important transport route to address with respect to BS effectiveness. We expect higher effectiveness of dry BS for **solids**, compared to wet BS, basically for the same reasons as with direct losses: the wet BS will be carrying water for at least part of the time. Although especially large particles may sediment in the wet strip, the finer part of the SR particle load (generally with relatively high content of contaminants), may stay in the water column and be moved to the surface water system.

Although most fields in the Netherlands are flat, SR does occur; not only due to gentle slopes in small parts of the country, but also in other fields, particularly due to soil saturation (typically during the second half of the winter). Of course any prolonged period with high rainfall would cause SR as well. The agricultural areas of the Netherlands that are most subject to SR are peat grasslands with ditches 30-60 m apart and water level <60 cm below surface, heavy riverine clay grasslands with shallow trenches (<50 cm deep and 10-40 m apart), and other mineral soils compacted by treading, tillage and heavy wheel loads. The latter category is particularly worrisome, because this is an ongoing process that will increase the problem. In general, BS are most effective at reducing nutrient and pesticide loads if SR occurs, and indeed it seems logical to expect the same for lowlands, like large parts of the Netherlands. However, in contrast to sloping areas, it is not obvious when and where exactly it occurs in the case of lowlands. SR from flat fields follows a very erratic pattern that is hard to predict. Although a recent PhD thesis (Appels, 2013) shows it is possible, we cannot expect to have hot spot maps for all Dutch fields in the short-term. Therefore, generic introduction of BS would not be very cost effective for reducing SR loads. It would be more cost effective to invest in specifically designed buffer patches to reduce concentrated surface runoff flow, where exactly this occurs, rather than a BS along the full length of the stream. Besides, alternative measures to reduce SR, such as pipe drainage, are often more effective (Noij *et al.,* 2008).

Groundwater flow
In flat lowlands with permeable soils and abundant artificial drains, like the Netherlands, groundwater flow (GF) is the most important transport route for nutrients to surface waters. As for nitrates, flow depth is crucial for BS effectiveness. According to Hill (1996), the optimal flow depth for reducing nitrate loads with BS in flood plains is 1-3 m below the soil's surface. His findings were partly corroborated by experimental research in the Netherlands conducted by Noij (2012a): they found low BS effectiveness for N, both for shallow GF (<1 m bss) and deep GF (>3 m bss). However, no BS effectiveness was found for the intermediate location either, where substantial GF was expected (between 1 and 3 m bss). This was explained by folded loam layers diverting GF away from the ditch. According to their modelling study(Noij 2012b), BS effectiveness for N in the Netherlands varies between 7% and 25%, mainly determined by the distance between ditches (more precisely: the ratio between BS width and the distance between ditch and water divide, which equals the relative area covered by BS).

The effectiveness of BS with respect to P and GF is entirely determined by shallow flow (if not surface runoff). In cases with deep GF, Noij *et al.* (2012b, 2013) found no measurable effect of BS on P-loads, simply because hardly any P-load was detected. In contrast, they found a clear BS effectiveness of 60% (relative P-load reduction) on the location with 2% slope and very shallow flow (<1 m BS). Although shallow flow also occurred at the peat location, the BS was not effective for P at this location, because of the low P status of the soil (compared to its chemical buffering capacity). Noij *et al.* (2013) argued that BS will only be effective for mitigating P-loads if the original P status of the top soil and the level of discharge via shallow GF are high. Such a situation exists on wet soils (high groundwater levels) with high P status due to historically accumulated manure surpluses in eastern and southern sandy soil areas (coined P leaking soils).

Saturated GF is less relevant for pesticides for two reasons. Firstly, most of the pesticides with a high leaching potential and/or a high persistence are banned from the Dutch market. Secondly, compared to SR, erosion and preferential flow, saturated GF is a slow process with relatively long travel times, thus enabling sufficient decomposition. We expect saturated groundwater flow to make a negligible contribution to total pesticide loads to surface water.

However, an exception should be made for preferential groundwater flow to pipe drains, especially on clay soils, which are predominantly used for arable agriculture and horticulture in the Netherlands. For the whole of pesticides applied to Dutch agricultural crops, annual pesticide loads by pipe drainage exceed the annual loads by spray drift. Still, the pesticide loads by spray drift make the largest contribute to the impact on the aquatic ecosystem, because they are peak loads.

Time frame
As for direct losses, a BS can be expected to have immediate effects. For surface runoff, this is also largely true because it is also a fast transport route.

Yet, we expect some increase in BS effectiveness for soluble P fractions in SR, with accumulating net withdrawal and decreasing P status (for an explanation, see the next paragraph). However, if the BS is frequently loaded with soil particles in sloping areas, buffering capacity could decline and sediment should be removed. Biomass removal is also a condition for maintaining or increasing effectiveness for P (Roberts, Stutter *et al.*, 2012; Noij, Heinen *et al.*, 2013).

We now restrict ourselves to dry BS and GF. Our modelling showed (Noij 2012b) that the effectiveness of BS for N increases with time, levelling off after a time period that depends on its width: the wider the BS, the longer the period before the steady state is reached. For example, at the deeply permeable sandy soil location where we measured no statistically significant effect, the model indicates that it takes about 10 years to reach a steady state effect of 18%. Yet, 90% of the ultimate effect was already reached after the four-year measuring period. The increase of the BS effect is primarily due to the hydrological time lag, and to a lesser extent to the declining organic N content of the BS soil.

The time frame is entirely different for P because the BS effect is determined by the difference in P status between field and BS. As the BS treatment continues, accumulated net P withdrawal by the harvested grass increases while soil P status in the BS declines. Assuming a stored available amount of P in the top soil of, for example, 1000 kg.ha-1, and a net P withdrawal by grass, decreasing from 25 to 10 kg.ha-1.yr-1 P (note this is without N fertiliser!), it might take hundreds of years to completely deplete the stored amount of P. Therefore it will take a long time for BS to reach equilibrium and final effectiveness. Nevertheless, we immediately found an effect of 60% at the shallow flow location! Apparently the P-mining or phytoextraction in the BS immediately affects the most labile P fractions that are most susceptible to uptake and leaching (Koopmans, G.F., W.J. Chardon, P.A.I. Ehlert, J. Dolfing, R.A.A. Suurs, O. Oenema and W. H. van Riemsdijk, 2004. Phosphorus Availability for Plant Uptake in a Phosphorus-Enriched Noncalcareous Sandy Soil. J. Environ.Qual. 33:965-975. Van der Salm, C., W.J. Chardon, G.F. Koopmans, J.C. van Middelkoop and Ph.A.I. Ehlert, 2009.Phytoextraction of Phosphorus-Enriched Grassland Soils. J. Environ. Qual. 38:751-761).

Applicability
From a practical or agro-technical point of view (i.e. without considering the economy or cost-effectiveness) dry buffer strips are widely applicable in the Netherlands. In general, it is easier to implement dry BS in grassland areas, because the farmer has all the equipment for cutting and clearing the grass, and the animals for utilising it. This is true as long as grazing within the BS is accepted. Our modelling study confirmed that grazing obviously reduces the effectiveness of a BS, but fencing it off would be costly and hamper grass cutting and harvesting. In addition to the necessary activities and equipment for maintaining the BS, farmers with arable land tend to be worried about weeds. Nevertheless, regional projects have shown that dry BS can be successfully implemented as long as farmers get a reward (varying from €0.30-0.90 per m).

The acceptability of BS strongly depends on the intensity of the farm. Our cost-effectiveness study showed that the opportunity costs of BS are minimal for extensive dairy farms (self-sufficient for roughage; manure can be used on the farm; Noij *et al.*, 2008). However, if the implementation of BS implies the need to purchase extra fodder and reduce grazing, the costs sharply increase to €50 per ha. Costs may even rise to €100 per ha if the farmer needs to export extra manure from the farm (transportation costs) if the BS are no longer accepted as farmland for the manure legislation. Also, within the context of an arable farm, it is easier to accept BS for less intensive fields with staple crops, compared with more intensive fields (e.g. with vegetables).

The main argument against the introduction of BS is the costs. On average, a 1-metre-wide BS corresponds with 1% of agricultural area in the Netherlands, due to the high density of water courses (Table 1). Wet BS are only considered for the larger ditches, which are maintained by water boards in areas where peak discharge control is necessary. The difference between the first and second rows in Table C.7 shows that only one-fourth of the water courses are larger ditches in sandy areas.

Table C.7

Proportion (%) of the agricultural area in different landscape regions of the Netherlands that would be occupied by generically installed buffer strips on both sides of the water course for different BS widths (Gaast and Van Bakel, 1997).

Landscape region	Buffer strip width		
	2 m	*5 m*	*10 m*
Sandy soil area, excl.[1]	0.5	1.3	2.6
Sandy soil area, incl.[2]	2.0	5.1	10.2
Sandy soil area[2] Noord-Brabant	2.5	6.2	12.4
Sandy soil area[2] Gelderland	1.6	4.0	8.0
Moraines	0.0	0.0	0.0
Boulder clay	0.6	1.5	2.9
Central rivers area	1.3	3.3	6.5
Sea clay area	2.0	5.1	10.1
Low moorland area	3.9	9.9	19.7
High moorland area	1.6	4.0	8.0
Reclaimed high moorland	1.1	2.8	5.6
Dunes	0.0	0.0	0.0
Beach ridges	1.9	4.9	9.7
Loess and cretaceous	0.3	0.9	1.7

1. Excluding shallow trenches (<50 cm deep) and ditches that fall dry during summer.

2. Including shallow trenches (<50 cm deep) and ditches that fall dry during summer.

Effectiveness and cost-effectiveness

Except for the specific case with much shallow flow and high soil P status, the effectiveness of BS in the Netherlands is on the edge of cost effective, as far as nutrient load reduction is concerned. In practically all cases that we modelled (Noij *et al.*, 2008), we found more cost effective alternative measures (source measures, hydrological measures, end-of-pipe measures such as constructed wetlands). However, we argue that BS should not be judged solely on their potential to mitigate nutrient and pesticide loads to surface waters, but should be designed for multiple purposes, such as enhancing biodiversity, increasing the beauty of and access to the landscape, creating stable ditch banks (i.e. reducing dredging costs) and reducing peak discharges (in case of wet buffers). BS are often installed with flower-rich herbaceous mixtures for functional agro-biodiversity (pest control and pollination), beauty of the landscape and ecological connectivity, by creating the green veins of an intensively used landscape.

A crucial aspect of their cost-effectiveness is the cost of the area they occupy, and the type of farm they belong to. We calculated hardly any costs for dairy farms that are self-sufficient in roughage. However, in cases where the BS area would be subtracted from the available farm area for calculating manure surpluses, the costs would sharply increase due to the need to import extra fodder and export manure from the farm.

Table C.8

Effect of mitigation option for specific circumstances on NO_3-N concentration in groundwater.

ID	Soil type FAO (2002 & 2008)	Hydrological field conditions	Land use	System boundary conditions	NO_3-N (mg/l)	Ref. strip	Buffer strip	Reduction (%)	# of years	Type of study
1 Beltrum	Sand: Gleyic podzol	No pipe drainage; ditch partly dry during summer (distance 60 m); <1% slope; GWL 40-140 cm BS; aquifer depth 20 m, calculated flow depth to ditch <7 m	Fodder maize, grass winter crop	Upper groundwater 50-150 cm BS	Average GW concentration	25.8	8.7	66	4	Field study
2 Loon op zand	Sand: Haplic podzol	No pipe drainage; permanent ditch (distance 150 m); no slope; GWL 70-180 cm BS; deep aquifer with loam between 1 and 4 BS	Grassland permanent grazing	Upper groundwater 50-150 cm BS	Average GW concentration	5.1	0.4	92	3	Field study
3 Winterswijk	Sand on boulder clay: Eurtric gelysoil	No pipe drainage; ditch partly dry during summer (distance to top of slope 80 m); 2% slope; GWL 30-200 cm BS; aquifer depth <1 m	Grassland rotational grazing	Upper groundwater 20-100 cm BS	Average GW concentration	4.5	2.2	52	4	Field study
4 Zegveld	Peat: Terric histosol	No pipe drainage; ditch (distance 60 m); no slope; GWL 25-80 cm BS; aquifer depth 5.2 m	Grassland rotational grazing	Upper groundwater 20-80 cm BS	Average GW concentration	7.7 (11.8)[2]	8.6 (13.2)	-12.8 (-12.1)	4	Field study
5 Lelystad	Silty clay loam: Calcaric fluvisol	Pipe drain 8 m distance; ditches 300 m distance	Maize	40-120 cm BS	Average GW concentration	0.9	0.2	75	3	Field study

1. Ranges refer to depth of suction cups.

2. Between brackets: total soluble N.

Table C.9
*Effect of mitigation option on the nitrogen loads (total N) to surface water (**bold** is statistically significant). Specific circumstances (type of study and number of years) are the same as in Table 2. (Sources: Noij 2012a; Noij 2012b).*

ID	Average concentration measured in reservoirs		Flow weighted Nt-concentration (mg/l) measured in reservoirs		
	Absolute reduction Nt (mg/L)	Reduction (%)	Ref. Strip	Buffer Strip	Reduction (%)
Beltrum	-2.3	-15	14.0	16.4	-17
Loon op Zand	0.4	6	8.0	7.4	10
Winterswijk	-3.8	-62	3.3	7.1	-48
Zegveld	**1.4**	**15**	4.0	3.0	10
Lelystad	0.2	5	2.4	2.1	14

Table C.10
Effect of mitigation option on the P loads (total P) to surface water (bold is statistically significant). Specific circumstances (type of study and number of years) are the same as in Table 2. (Sources: Noij 2012a; Noij 2012b).

ID	Average concentration measured in reservoirs		Flow weighted Nt-concentration (mg/l) measured in reservoirs		
	Absolute reduction Nt (mg/L)	Reduction (%)	Ref. Strip	Buffer Strip	Reduction (%)
Beltrum	0.01	12	0.078	0.066	15
Loon op Zand	0.00	0	0.53	0.50	17
Winterswijk	**0.23**	**57**	0.54	0.21	61
Zegveld	0.04	17	0.25	0.22	13
Lelystad	0.00	-4	0.034	0.028	4

Costs

The cost-effectiveness ranges from €0 to 20 per kg N (Table 4). For P, there was only one situation in the field study where the BS was effective. In this situation, CE was €22 per kg P.

Table C.11

Costs of mitigation options for different areas and specific circumstances.

ID	Specific circumstances	Total costs[1] € ha^{-1} yr^{-1}	Reference load[2] kg ha^{-1} yr^{-1}		Buffer strip effectiveness[3] (BSE) for N and P (%) and cost-effectiveness (CE) in € kg^{-1} N or P reduction[4]																					
					Beltrum deep sand				Loon op Zand interrupted sand				Winterswijk shallow sand						Zegveld Peat				Lelystad Central clay	
					BSEN		CEN		BSEN		CEN		BSEN		CEN		BSEP[5]	CEP	BSEN		CEN		BSEN	CEN
					Low	High	Low	High	Low	High	Low	High	Low	High	Low	High			Low	High	Low	High		
arable farms			N	P																				
1	Central marine clay area	135	19.5	0.69																			0	0
2	Southwest marine clay area	41	15.7	0.32																			0	0
3	Southeast sandy area	40	28.4	4.22	7	22	6	20	9	22	6	16												
4	Northeast sandy area	22	29.1	1.64	7	22	3	11	9	22	3	8	11	13	6	7	60	**22**						
dairy farms																								
5	Clay (moderate)	0	15.7	7.9																			N/A.[6]	N/A
6	Peat (extensive)	0	6.1	1.42															14	25	0	**0**		
7	Sand (intensive)	12	19.1	1.3	7	22	3	9	9	22	3	7	11	13	5	6	60	15						

1. Determined with the MEBOT arable farm model and the DAIRYWISE dairy farm model (*Table S3 in* Noij *et al.*, 2008).
2. Determined with the ANIMO/STONE nutrient model (*Table S3 in* Noij *et al.*, 2008).
3. Taken from the modelling study in Noij (2012b). The calculated BSEN varies with ditch density and pertains to the long-term steady stage situation.
4. Calculated by combining the results from 1, 2 and 3.
5. Taken from the field study, Table 4.
6. Not analysed: the effectiveness is zero in well-drained cases with pipe drainage. However, grassland also occurs on clay without pipe drainage and/or on heavy clay with shallow trenches, especially in the large river area. We did not calculate the effectiveness for such circumstances.

Environmental side effects / pollution swapping

The installation of dry harvested grass BS implies extraction of N and P from the BS soil. BS may be grazed on cattle farms, but since the feed quality of the BS grass declines over time, we expect a larger part of the grass in the BS to remain for later cutting. N and P harvested with cut grass may be reused for young cattle, dry cows and beef cattle, or can be mixed through the roughage harvested from the entire field. As such, harvested dry BS contribute to the nutrient and C cycling of the farm, and do not have any negative environmental impact compared to the original use. It is more difficult for farmers of arable land to utilise the harvested grass next to arable crops. Part of it may remain on the adjoining field and contribute to the soil's organic matter, part of it may be given to farmers with cattle and part of it may be piled up and later removed together with roadside and bank litter by the water board. Some extra emission of GHG may be expected, due to decomposition of the biomass from BS (be it in a pile, in the soil or in a ruminant).

There is a different situation for wet BS. Biomass growing in the wet strips is not removed as regularly as that growing on dry BS: maybe once every 1-2 years, particularly reeds. Water boards combine these activities with their normal cleaning operations and the recovered biomass is treated as usual (i.e. it remains close to the water courses). Sometimes it is spread over the nearest arable land, and other times it is piled and spread later or removed. Especially when it is piled, GHG emission may be expected. If nutrient loads from nearby fields reach wet BS, the nitrate loads contribute to GHG emissions, because of the N_2O emissions associated with denitrification (Hefting 2006). These emissions can then be expected to have increased compared to a situation without wet BS.

Feasibility

It is feasible as long as it is rewarded. However, according to upcoming EU Common Agricultural Policies, farm income subsidies under the first pillar will become partly (30%) conditional. One of the conditions is that 5% of the farms be reserved as Ecological Focus Areas (EFA). The Dutch government is now studying what landscape elements to include as EFAs. Buffer strips are one of the more probable categories under consideration. The feasibility of BS will increase with the acceptance of these policies.

Mode of implementation

For legally compulsory BS, see *Narrow legal uncultivated strips*. For the influence of upcoming EU policies, see Feasibility. Further introduction of BS in the Netherlands will depend on subsidy-based regional initiatives stimulating voluntary implementation. These regional subsidies also partly depend on second pillar money from the EU (Rural Development, in Dutch *POP gelden*). The national category for funding this project is ILG (Investeringsbudget Landelijk Gebied), which is provided through provinces, often in cooperation with the water boards. An important drawback of regional subsidies is their temporary character, which jeopardises participation by farmers.

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D: Controlled drainage

The Netherlands

The Netherlands is positioned in the confluent deltas of the Scald, Meuse, Rhine and Ems rivers. In large areas of these flat, low lying and often wet soils, the excess precipitation and/or seepage are drained by an intensive network of trenches, tile drainage and ditches. Recently, controlled drainage was reinvented to preserve water for dry periods as an adaptation to climate change and to reduce the emission of nutrients (Van Bakel, Van Boekel and Noij, 2008; Stuyt *et al.,* 2012; Stuyt, 2013).

Description
Controlled drainage systems actively vary drainage levels to regulate the amount of water to be drained from the fields and the resulting groundwater levels in the fields. These resulting groundwater levels depend on the actual situation, the nearby (precipitation) and long-term (drought) weather expectations and the required agricultural management.

The drainage level is regulated by raising or lowering the water levels in the ditches or in the tile drainage systems itself. In the latter case, a technical device controls the required drainage levels. The drainage system only drains water when the groundwater level exceeds the drainage level (i.e. the level of the adjustable weir or adjusting pipe). Water level management to a summer and a winter level is the simplest as well as the most widely applied form of controlled drainage. On the other hand, weather predictions, in combination with online and automated measured groundwater levels as well as measured moisture content or the measured pressure head in the root zone, can be used for real-time control of the drainage levels. In all cases, from simple to complex, the farmer’s management goals determine the actual management. These goals may be to:
1. Improve drainage to increase rideability and workability and prevent wet damage.
2. Retain water in anticipation of drought.
3. Maintain a water supply in dry periods to prevent water shortage.
4. Reduce peat degradation to slow down soil subsidence.
5. Reduce nutrient emissions to groundwater and surface water.

Rationale, mechanism of action
Changes in the drainage level influence the pathways and residence times of the soil water and transported solutes and particles. These changes result in other drainage fluxes and other nutrient loads. The effects on the nutrient loads are determined by the changes in drainage fluxes, as well as by changes in the residence time and changes in the moisture content in the unsaturated zone. Thereby, changes in physical, chemical and biological retention, transformation and decay processes modify the nutrient concentrations. Think of the decomposition of organic matter (N and P), nitrification and denitrification (N) and sorption/desorption (P).

In general, the drainage level should be lowered to reduce phosphorous emission, but should be raised to some extent to reduce the emissions of nitrogen and nitrate. To optimise water management, the drainage level has to be lowered in cases of excess water and has to be raised when a water shortage is expected, but always within the constraints determined by the agricultural management (e.g. the type of crop(s), the required soil tillage, harvesting), the fixed drain base and the technical possibilities. The optimal management strategy for achieving these combined goals still has to be determined, but will vary depending on the local situation (i.e. the field’s properties).

Time frame
Reductions (and increases!) in N/P leaching due to changes in drainage levels occur almost instantaneously. The effect depends on both the situation and the amount of change.

Applicability
Drainage is implemented almost everywhere in the Netherlands where it is effective: in wet and moderately dry soils. Controlled drainage can be implemented as an adaptation to climate change in situations with (temporarily) drought periods and can be implemented in all situations with excess

water during long yearly periods to control nutrient emissions. Controlled drainage is applicable to all land uses and all soils with (structural) excess water.

Effectiveness and cost-effectiveness
Controlled drainage influences the availability and quality of water. The effect on water quality depends on the management goal(s), which may differ over time.

Controlled drainage influences the emissions of both N and P to the groundwater and, especially, to the surface water. It is assumed that a choice can be made between reducing nitrate emissions to the groundwater and reducing nitrogen emissions to the surface water.

- Lowering the drainage level increases nitrate emissions; raising the drainage level decreases nitrate emissions.
- Lowering the drainage level significantly reduces phosphorus emission (deeper drainage with relatively high nitrogen concentrations); raising the drainage level increases phosphorus emissions (shallower drainage with relatively high nitrogen concentrations), especially in wet soils.
- Lowering or raising the drainage level is not expected to result in changes (the increase in nitrate concentration compensates for the decrease in shallow drainage), but locations with an increase or a decrease should also be expected.

Table D.1
Effects of the construction of controlled drainage in already drained areas for different soils and hydrologic conditions on the nitrate emission to groundwater, nitrogen emission to surface water and phosphorus emission to surface water. A + means a positive effect (i.e. a decrease in emissions).

ID	Sand			Clay			Peat
	Wet	Moderately dry	Dry	Wet	Moderately dry	Dry	Wet
NO_3	N/A	+	N/A	N/A	+	N/A	N/A
N	N/A	+	N/A	N/A	+	N/A	N/A
P	N/A	0	N/A	N/A	0	N/A	N/A

- The field was already drained, so wet and dry are not relevant.
- It is assumed that the phosphorus emissions largely occur through the subsoil.
- Because the field had been drained, minor effects on phosphorus emissions were expected.

Table D.2
Effects of the construction of controlled drainage at a greater depth in already drained areas for different soils and hydrologic conditions on the nitrate emission to groundwater, nitrogen emission to surface water and phosphorus emission to surface water. A + means a positive effect (i.e. a decrease in emissions).

ID	Sand			Clay			Peat
	Wet	Moderately dry	Dry	Wet	Moderately dry	Dry	Wet
NO_3	N/A	+	N/A	N/A	+	N/A	N/A
N	N/A	+	N/A	N/A	+	N/A	N/A
P	N/A	+	N/A	N/A	+	N/A	N/A

- The field was already drained, so wet and dry are not relevant.
- It is assumed that the phosphorus emissions largely occur through the subsoil.
- Because the field had been drained, minor effects on phosphorus emissions were expected.

Table D.3

Effects of the construction of controlled drainage at a greater depth in not yet drained areas for different soils and hydrologic conditions on the nitrate emission to groundwater, nitrogen emission to surface water and phosphorus emission to surface water. A + means a positive effect (i.e. a decrease in emissions).

ID	Sand			Clay			Peat
	Wet	Moderately dry	Dry	Wet	Moderately dry	Dry	Wet
NO_3	--	--	N/A	--	--	N/A	N/A
N	0	0	N/A	0	0	N/A	N/A
P	++	++	N/A	++	++	N/A	N/A

- Construction of controlled drainage is not applicable to dry soils.
- Significantly lower nitrate concentrations and loads to the groundwater are expected (due to the lowered groundwater levels).
- Lowering the drainage level significantly decreases the phosphorus emission.
- The increase in nitrate concentration compensates for the decrease in shallow drainage, so nitrogen emissions are not expected to change.
- Because tile drainage is used almost everywhere it is useful in the Netherlands, the implementation of controlled drainage in not yet drained soils is of very minor importance.

The effects of controlled drainage on the emissions of nutrients are theoretically known but still need to be quantified. It appears to be very difficult to extrapolate the results of the sparse field experiments to other situations. Effects at regional and national scales are equal to the totalled or averaged local effects. Because controlled drainage is not effective and/or applicable everywhere, the maximum effect on regional and national scales will be smaller than the maximum local effect. Controlled drainage is considered to be a potentially suitable measure, but in practice results could be lower than expected.

Measured effectiveness on surface water

Table D.4

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the nitrogen loads to surface water.

ID	Soil type	Hydrological field conditions	Land use	BC	Surface water		Type of study	Author(s) reference
					Nitrogen load			
					Kg ha^{-1}	Reduction (%)		
1	Fine sand on loam	Drained, net leakage, heterogeneous soil, soil gradient, groundwater 1.5-0.0 m-gl	Carrots, salsify, potato, maize	TD	Ref. nm Drain: 27-40 Contr. drain: 33-67	??	Field experiment	Stuyt *et al.,* 2012
2	Fine sand above loam	Drained, net leakage, heterogeneous soil, soil gradient, groundwater 1.5-0.0 m-gl	loam	TD	Ref. nm Drain: (level 1.2 m-gl) 1.6-5.4 Contr. Drain: (level 0.9 m-gl) 0.4-3.9 Deep Drain: (level 1.2 m-gl) 1.8-5.9 Deep contr drain: (level 0.9 m-mv) 0.7-4.2	??	Field experiment	Schipper and Van der Schans 2012

Table D.5

Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the phosphorous loads to surface water.

ID	Soil type	Hydrological field conditions	Land use	BC	Surface water		Type of study	Author(s) reference
					Phosphorus load			
					Kg ha^{-1}	Reduction (%)		
1	Fine sand on loam	Drained, net leakage, heterogeneous soil, soil gradient, groundwater 1.5-0.0 m-gl	Carrots, salsify, potato, maize	TD	Very small	??	Field experiment	Stuyt *et al.,* 2012

Estimated costs

Table D.6
Cost of mitigation option for different areas and specific circumstances.

ID	Total	Maintenance
	€ per year	€ per year
1	3000	100

Mode of implementation
The effectiveness of the measure at regional and national scales is determined by the degree of implementation. The latter depends on the implementation process (e.g. voluntary vs. compulsory, stakeholder engagements, knowledge transfer, local vs. national, instruments and facilities).

In the Netherlands, several field experiments are examining the very promising use of controlled drainage to quantify its effects and optimise its management. At the same time, farmers are being encouraged to voluntarily implement its use.

Controlled drainage has not been identified as a possible part of policy implementation in all northwestern European countries.

Table D.7
Cost of mitigation option for different areas and specific circumstances.

Controlled drainage	NL	DK	UK [1)]
NO_3			
Nitrogen	O[1]	O	O
Phosphorus	O	O	O

1. England and Wales.

2. O = optional.

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E: Soil tillage

Denmark

Description
Tillage in the autumn before a spring crop is not allowed until after 1 November in clay soils and after 1 February in sandy soils.

Rationale, mechanism of action
Tillage in the autumn may increase mineralisation of organic nitrogen in crop residues and thereby increase the risk for nitrate leaching during the following winter.

Time frame
Effect from year 1

Applicability
Applicable in areas that will be sown with spring crops the following spring. The Danish Water plans (ref. 1) estimate that this measure can be applied to an area of 110.000 ha.

Effectiveness and cost-effectiveness

Effectiveness for the root zone

Table E.1
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater.

ID	Soil type	Land use	System boundary condition	N-load (kg N ha^{-1})	Reduction (kg N ha^{-1})	Reference	Type of study
	All	Crops grown in spring	Surface water	N-load	6.7/year	1	
1	All	Crops grown in spring	Root zone	N-load	10/year	3	Field measures

Effectiveness in surface water
The effectiveness in surface water (final recipient =coastal waters) will be modelled using the root zone effect and the N-reduction from the root zone to the final recipient. The reduction percentage differs between catchments, so the modelling is performed on a catchment scale (e.g. a root zone effect of 30 kg N ha^{-1} and a reduction of 2/3 = a marine effect of 10 kg N ha^{-1}).

Effect on phosphorus loss
The effect on phosphorus loss is limited and estimated to total 1 tonne per year (ref. 1).

Table E.2
Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Specific circumstances	Cost-effectiveness	Author(s) reference
		€ kg^{-1} N-reduction	
1	No indication	app. €13	6
2	No indication	app. €3.5*	1

* Average cost for all general measures.

Environmental side effects / pollution swapping
None

Feasibility
Some exceptions are necessary (e.g. in organic farming where autumn tillage is required for weed control).

Mode of implementation
The measure is implemented through a statutory order (i.e. a mandatory measure).

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4. DCE 2012: Virkemidler til N-reduktion – potentialer og effecter (DCE 2012: Measures for N-reduction – potentials and effects).
5. DCE 2012: Effecter på P-overskud, P-tab og naturindhold af yderligere N-virkemidler ud over Grøn Vækst (DCE 2012: Side effects of N-measures on P surplus, P loss and natural habitats).
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Contact person(s)

Denmark

Description
If grasslands are ploughed in the autumn, there is a high risk of nitrate leaching during the following winter. By postponing the ploughing to spring before sowing the next crop, this risk of nitrate leaching is reduced.

Rationale, mechanism of action
Change of ploughing time from autumn to spring.

Time frame
Effect from year 1.

Applicability
A better use of N released from the ploughed grass. In Denmark, grass is not allowed to be ploughed between 1 July and 1 February.

Effectiveness and cost-effectiveness

Table E.3
Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater.

ID	Soil type	Land use	System boundary condition	N-load (kg N ha^{-1})	Reduction (kg N ha^{-1})	Reference
	All	Rotational grass (rotated every 3 years)	Root zone	N-load	15.3/year	1
1	All	Rotational grass (rotated every 3 years)	Root zone	N-load	36/year	3

Effectiveness in surface water
The effectiveness in surface water (final recipient =coastal waters) will be modelled using the root zone effect and the N-reduction from the root zone to the final recipient. The reduction percentage differs between catchments, so the modelling is performed on a catchment scale (e.g. a root zone effect of 30 kg N ha^{-1} and a reduction of 2/3 = a marine effect of 10 kg N ha^{-1}).

Environmental side effects / pollution swapping
None.

Mode of implementation
The measure is implemented through a statutory order (i.e. a mandatory measure).

References

1. Naturstyrelsen, 2011: Virkemiddelkatalog (Nature Agency, 2011: Catalogue of measures).
2. DMU, 2007: Virkemiddelkatalog (NERI 2007: Catalogue of measures).
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5. DCE 2012: Effecter på P-overskud, P-tab og naturindhold af yderligere N-virkemidler ud over Grøn Vækst (DCE 2012: Side effects of N-measures on P surplus, P loss and natural habitats).
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Contact person(s)

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The Netherlands

Tillage is the mechanical modification of soil structure. The results of tillage depend on the characteristics of the soil that is being tilled (e.g., texture, structure, moisture, friability, plasticity). Conventional, inversion tillage by mouldboard ploughs or disc ploughs (which flip over a layer of soil, burying surface residues) may lead to soil degradation. Negative effects of tillage are:

- Risk of forming crusts on the soil surface and compacting soil below the depth of tillage (i.e. the formation of a tillage pan)
- Deteriorating soil structure (resulting in decreased infiltration and storage of precipitation and irrigation water)
- Accelerated decomposition of soil organic matter (negative from a long-term perspective)
- Increased susceptibility to runoff and water and wind erosion

Description

Soil cultivation and management to reduce the risk of extremes of water logging and drought, to reduce runoff, to improve the efficient use of soil nutrients, to increase crop production and thereby to reduce the nutrient emissions to the water system.

Methods of reduced tillage are: 1) conservation tillage systems (returning crop residues to the soil surface), 2) plough less/reduced/minimum tillage (non-inversion tillage using discs or tines to cultivate the surface for seedbed preparation), and 3) no tillage (direct drill into stubbles).

Rationale, mechanism of action

Soil tillage (or reduced soil tillage) by minimal or no cultivation maintains organic matter and preserves good soil structure (minimal cultivation also breaks up surface crusts). It is often supposed to be particularly effective when the soil surface is mulched with crop residues. In the Netherlands, however, the soil's organic matter contents are very good and we expect additional organic matter to have a minimal effect.

As a result of limited mixing, organic matter accumulates in the upper soil layer. Organic matter improves all the soil's properties (biological, chemical and physical).

Soil organic matter forms food for soil organisms that are crucial to the cycling of nutrients, so the accumulation of organic matter leads to increased biological activity (and biodiversity). However, microbial activity tends to be slower than in soils with conventional tillage because the surface mulch in conservation tillage systems tends to remain in larger particle sizes that take longer to break down. The accumulation of organic matter near or at (e.g. mulch) the soil surface also reduces soil temperature, which slows microbial activity. In particular, the nitrogen behaviour is largely determined by biological activity, so the accumulation of organic matter has an important effect on nitrogen dynamics, rooting pattern, crop production and the efficient use of nutrients.

Mulching also reduces transpiration, leading to an increase in the moisture content of the upper soil layer. Soil organic matter breakdown products glue soil particles together into stable soil aggregates. These aggregates make the soil porous and resistant to compaction and erosion. The resulting soil conditions improve infiltration and increase moisture levels in the soil (i.e. increase the retention of water) as well as the biological activity and diversity in the soil. They also promote the efficient use of nutrients. This reduces runoff, erosion and the consequent loss of nutrients (especially P). Increased infiltration prevents nitrogen loss through microbial denitrification in wet soil conditions, but also can increase the leaching of mobile nutrients in the soil, especially nitrate. The increased moisture level increases crop growth, drought tolerance and nitrate uptake (and reduces the leaching of nitrate).

Because reduced soil tillage is less intensive, the compaction of soil layers (i.e. the forming of tillage pans) can also be prevented. However, in soils that have accumulated extremely high levels of phosphorus near the soil surface, rotational ploughing (e.g. once in 10 years) may benefit water quality.

Time frame
It takes some years to reach the improved soil structure and increased crop yields that result from the conversion from ploughing (conventional tillage) to minimal or no cultivation systems. Small reductions in nitrate leaching occur almost immediately through reduced mineralisation of soil organic matter in the autumn, although there are likely to be small increases in drainage volumes.

This effect increases to a small extent over some years, as long as the soil structure improves and the soil organic matter increases. Conversion from ploughing (conventional tillage) to minimal or no cultivation systems in the short-term also decreases the surface runoff and total N and (especially) total P concentrations in surface runoff. Again, this effect increases over some years. In the long-term, however, the total P concentrations in the runoff may rise somewhat due to an increasing amount of phosphate near the soil surface.

Applicability
Reduced soil tillage is not targeted to specific areas or sub-basins, but has to be adapted to the individual farmer's farm management (and requires careful control of compaction and weeds). Reduced soil tillage is, of course, the practice in (permanent) grassland and orchards, but major changes can be achieved in crop rotation systems (arable crops, horticulture and rotating maize/grassland).

Effectiveness and cost-effectiveness
The effect of reduced tillage and direct drilling depends on the crop species as well as the soil type and the hydrologic conditions. The best results seem to be obtained on the heaviest clay soils (the most difficult soils to prepare with conventional soil tillage methods).

The leaching of nitrate seems to increase with more intensive cultivation, particularly when carried out in autumn. Reduction of soil tillage (especially in autumn) has a positive effect on preventing nitrate leaching. Reduced soil tillage also reduces the runoff of phosphorus. This effect is dependent on the reduction in runoff/erosion and the concentrations of dissolved phosphorus (highly determined by the phosphate content of the soil at/near the soil surface).

A lot of research on this topic is currently being conducted in the Netherlands (Boonekamp, 2012; Haan *et al.*, 2011b; Talsma and Kooiman, 2012). Most projects recently began and have only preliminary results. Older, finished projects and foreign studies (Soane *et al.*, 2011) indicate varying results dependent on the specific realisation and location-bound properties (e.g. soil, climate). Haan *et al.* (2010) demonstrated that applying no organic matter resulted in reducing nutrient concentrations but, after some years, also resulted in reduced agricultural production.

The effects of measures for reducing or preventing superficial runoff (e.g. blocking runoff or infiltration trenches) may be relatively large, and in theory these measures reduce runoff up to 100%. The effect on the concentrations in the surface water depends on the amount of runoff and the nutrient concentrations therein. Measurements of the latter are scarce. Koopmans (2012) intensively measured these concentrations over successive years on heavy clay soil at Waardenburg. As expected, the differences between the years were enormous: during wet years (without cracking), runoff through trenches was found to be the major drainage process for this soil. Extreme events caused up to 50% of the total nutrient losses. In runoff from sandy soils with very high phosphorous contents in the province of Limburg, Noij *et al.* (2009) measured concentrations that were typically above 25 mg/L N and 10 mg/L P. Medians were 10 mg/L N resp. 5 mg/L P. Compared to the calculated diffuse emissions, this results in substantial contributions of 3 kg N and 1.5 kg P, especially for phosphorus. Measurements in the 'Achterhoek' region (Appels, in prep.) gave comparable results. Reducing runoff can result in considerable contributions to improving the surface water quality.

Table E.4

Measures to increase soil quality.

Nr.	Measure	Effect	Applicabilityu	Regulation	References
19	Soil tillage during good conditions and with low ground pressure (to prevent compaction)	++	0	0	Geel *et al.*, 2009; Vermeulen and Wel, 2008
20	Use fixed bridle paths	+	0	+	Vermeulen and Mosquera, 2009; Soane *et al.*, 2011; Vermeulen *et al.*, 2010
21	Non-inversion tillage	+	0	0	Weide *et al.*, 2008
22	Conservation tillage systems returning crop residues	+	0	0	Postma *et al.*, 2010, Haan *et al.*, 2010
23	Composting crop residues and bring compost back on the field	+	0	0	Iepema *et al.*, 2008, Dam, 2007

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Contact person(s)

Frank van der Bolt (hydrology and water quality)
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F: Wetland restoration / constructed wetlands

Denmark (Constructed wetlands)

Description
See below.

Rationale, mechanism of action
Constructed wetlands (CWs) are constructed to optimise the natural processes for denitrification and/or sedimentation of phosphorus. In Denmark, only restored wetlands have been used as a measure to remove N from drainage and river water.

Time frame
The reduction of N and P will be effective from year 1.

Applicability
To be cost effective, the CW should receive drainage water from a considerable area (e.g. 100 ha drained field to 1 ha CW).

Two types of CWs (surface and subsurface flow) are presently being tested under Danish conditions (19 plants), so the results reported in this factsheet are preliminary and may be changed by the end of the test.

Effectiveness and cost-effectiveness

Table F.1
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the N losses from the root zone or NO_3-concentration in groundwater.

ID	Soil type	Hydrological field conditions	Land use	System boundary condition	N-load (kg N ha^{-1})	Reduction (kg N ha^{-1})	Type of study
1	Not relevant	Drained area	Any crop	Effects are calculated in the outlet form the plant	N-load	All year: 20-50% of incoming N Summer: 35-80% of incoming N Winter: 15-25% of incoming N	Field measures

Phosphorus
CWs are known to have a very good effect on removing particulate phosphorus, depending on their design. Studies about how to optimise their effects are being conducted in the Danish test plants, so no reliable results are ready to be presented.

Environmental side effects / pollution swapping
Correctly established, the CW can have a positive effect on biodiversity, with habitats for flora and fauna.

Feasibility
The mitigation option is presently being tested under Danish climate conditions.

Mode of implementation
Presently not relevant.

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Contact person(s)

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Northern Ireland (Constructed wetlands)

Description
A constructed farm wetland is defined as ‘one or more shallow, free surface flow constructed cells containing emergent vegetation, which is designed to receive and treat lightly contaminated surface water runoff from farm steadings, in such a manner that any discharge from the wetland will not pollute the water environment’.

Table F.2
Rationale, mechanism of action.

Water treatment process	Factors that optimise the process
Settling of suspended particulate matter by gravity	Low flow velocity, low wind speed, low disturbance, long residence time
Physical filtration of suspended solids by wetland biomass acting as a hydrological baffle to incoming flows	High vegetation density, low flow velocity
Uptake and breakdown of nutrients by plants and micro-organisms	Longer residence time, contact with high densities of micro-organisms and plants, readily available organic matter
Accumulation and increase of organic matter, which is important for nutrient cycling	Low flow velocity, availability of adsorption sites
Aerobic and anaerobic microbial mediated processes, such as nitrification and denitrification, important for the cycling of nitrogen and reduction of sulphur	Presence of oxidising and reducing conditions, high density of a variety of micro-organisms, around neutral pH, high temperature
Chemical precipitation of phosphorus in and sorption on soils	Many available sorption sites, pH, redox potential
Predation and natural die-off of pathogens	High diversity and density of natural predators (e.g. protozoan), exposure to sunlight

Time frame
This varies with the residence time of the constructed wetland. In the case of the example in Tables 1-4, residence time was approximately 70-100 days.

Applicability
- Livestock handling areas where livestock are held occasionally for less than 24 hours,
- Roof drainage from pig and poultry housing,
- Concrete areas that are lightly contaminated as a result of vehicle and occasional livestock movements,
- Machinery washings (unless contaminated with pesticides or veterinary medicines),
- Winter run–off from silage pits (but not silage effluent) between 1 November in one year and 30 April in the next,
- Baled silage storage areas on steading.

Effectiveness and cost-effectiveness

Effectiveness on groundwater
The constructed wetlands in this scenario are used to reduce the nutrient concentration of dirty water prior to discharge to surface water. However, it also removes the requirement to store and apply dirty water to land and thereby reduces the risk of nutrient leaching to groundwater. The benefits from this were not assessed in the research on constructed wetlands done in Northern Ireland.

Effectiveness on surface water

Table F.3
Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the nitrogen loads to surface water.

ID	Soil type	Hydrological field conditions	Land use	System boundary condition	Surface water N load			Type of study
					Before	*After*	*Reduction (%)*	
1	Clay	Moderated to poorly drained soils	All farming systems	River	24.2 kg NH_3-N yr^{-1}	0.89 kg NH_3-N yr^{-1}	96.3	Field measure

Table F.4
Effect and cost-effectiveness of mitigation option for different areas and specific circumstances on the phosphorus loads to surface water.

ID	Soil type	Hydrological field conditions	Land use	System boundary condition	Surface water P load			Type of study	Author(s) reference
					Before	*After*	*Reduction (%)*		
1	Clay	Moderated to poorly drained soils	All farming systems on heavy to medium drained soils	River	270.1 kg TP $year^{-1}$	21.7 kg TP $year^{-1}$	92	Field measure	Forbes *et al.*, 2011

Table F.5
Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Specific circumstances	Cost (€/year)			N load (kg N ha^{-1})	Reduction kg N ha^{-1}	Author(s) reference
		Total	Depreciation	Maintenance	€ kg^{-1} N-reduction	€ kg^{-1} P-reduction	
1	Dairy farm*	3995	2507.50	1487.5	€171.38 kg^{-1} NH_3-N	€16.10 kg^{-1} P	Forbes *et al.*, 2011

* The 180-cow dairy unit has a dirty yard area of approximately 3000m^2 and produces 5.0 m^3 dairy parlour washings each day.

Environmental side effects / pollution swapping
N_2O, CH_4 and CO_2 emissions may be increased by the establishment of the wetlands.

Feasibility
Wetlands are considered to be low-cost engineering solutions that are generally simple to construct but can require a significant capital investment outlay. A limiting factor in the feasibility of using them to treat dirty water is the area of land required to achieve the >90% reduction in N and P. In the case of the example used in Tables 1-4, the five-pond wetland system required 1.2 ha of land.

Mode of implementation
Uptake of constructed wetlands to treat dirty water is a voluntary measure and to date there has been limited uptake.

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Contact person(s)

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The Netherlands (Wetland restoration)

Description
Development or restoration of wet buffer strips along upstream rivers and streams, or isolated wet areas in an agricultural landscape.

Rationale, mechanism of action
Runoff water from agricultural areas containing nutrients will pass the wetlands before entering the discharge system (ditches, streams, rivers). Due to temporary storage and the delayed travel time, nutrient retention processes will be enhanced and nutrient concentrations will decrease. For nitrogen, the main retention process is denitrification. In addition to the increased residence time, this removal process is also promoted by the favourable conditions in the wetlands and buffer strips, such as organic matter availability, the presence of macrophytes and higher temperatures. Furthermore, the higher residence time and lower flow velocities enable settling of particulate phosphorus and thus removal from the water phase. Finally, nutrients are stored in vegetation biomass; whether this is a temporary or permanent storage depends on the management of the vegetation.

Time frame
After construction or restoration of the wetlands and wet buffer strips the increase in nutrient retention can start immediately. Processes related to hydrological conditions (residence time, flow velocity) show a direct effect. After the first growing season, enhanced denitrification and vegetation uptake are in effect.

Applicability
In principle, all runoff and drainage water containing nitrogen and phosphorus can be treated in wetlands. Maintenance of the wetland, removal of the sediments and harvest of the plant products are needed to maintain high nutrient retention.

Effectiveness and cost-effectiveness

Effectiveness on groundwater
N/A.

Effectiveness on surface water

Table F.6

Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the nitrogen loads to surface water.

ID	Soil type	Hydrological field conditions	Land use	System boundary condition	Surface water N load			Type of study	Author(s) reference
					Before	After	Reduction		
1	Sand	Strijbeekse beek: drained, flat, wet, shallow groundwater level (0.5–1.0)	Permanent Grassland, Arable land	Ditch (D1,D2)	24.5 kg N ha^{-1} y^{-1}	22.7 kg N ha^{-1} y^{-1}	7.5% (3.5 – 11)	Field measures	Stowa (2008)
2	Sand	Raalterwetering: Undrained, flat	Grassland, Urban area	Ditch (D1,D2)	1.0 (0.5-2) mg/l N	0.5 (0.3-1) mg/l N	50%	Field measures	Stowa (2008)
3	Clay	Constructed wetland: drained, flat, wet, shallow groundwater level (0.5–1.0)	Horticulture, Arable land	Ditch (D1)			15%	Field measures	Grontmij (2012)
4	Sand	Gooiersmars: (un)drained, flat, wet, shallow groundwater level (0.5–1.0)	Grassland, Arable land	Ditch (D1,D2)	5606 kg N y^{-1}	4226 kg N y^{-1}	25%	Modelling (field measures)	De Klein (2008)

Table F.7

Effect and cost-effectiveness of mitigation options for different areas and specific circumstances on the phosphorous loads to surface water.

ID	Soil type	Hydrological field conditions	Land use	System boundary condition	Surface water P load			Type of study	Author(s) reference
					Before	After	Reduction		
1	Sand	Strijbeekse beek: drained, flat, wet, shallow groundwater level (0.5–1.0)	Permanent Grassland, Arable land	Ditch (D1,D2)	0.5 kg P ha^{-1} y^{-1}	0.5 kg P ha^{-1} y^{-1}	100%	Field measures	Stowa (2008)
2	Sand	Raalterwetering: Undrained, flat	Grassland, Urban area	Ditch (D1,D2)	0.4 (0.1-0.5) mg/l P	0.3 (0.1-0.4) mg/l P	75%	Field measures	Stowa (2008)
3	Clay	Constructed wetland: drained, flat, wet, shallow groundwater level (0.5–1.0)	Horticulture, Arable land	Ditch (D1)			0%	Field measures	Grontmij (2012)
4	Sand	Gooiersmars: (un)drained, flat, wet, shallow groundwater level (0.5–1.0)	Grassland, Arable land	Ditch (D1,D2)	388 kg P y^{-1}	270 kg P y^{-1}	30%	Modelling (field measures)	De Klein (2008)

Table F.8
Cost-effectiveness of mitigation option for different areas and specific circumstances.

ID	Specific circumstances	Total costs	Author(s) reference
1	Strijbeekse beek: Wet buffer strip	€42,000 km^{-1} buffer strip	Stowa 2008

Environmental side effects / pollution swapping
Denitrification results in harmless N_2 gas (80% of the atmosphere). However, a small part of the nitrogen (0.5-2%) will be transformed into N_2O, which is a potent greenhouse gas. Storage and burial of particulate P in sediments is generally effective and permanent, especially when binding compounds are present (e.g. iron, calcium, aluminium). When harvested, aquatic vegetation on the wetland can be used for multiple purposes. If the biomass is not harvested, the storage of nutrients is mostly temporary and nutrients will be released again after the growing season.

Feasibility
Wetlands can be developed in all agricultural areas near vulnerable surface waters. However, the main constraint is usually the claim on the available land. In a highly populated country like the Netherlands, space is scarce and land represents a high value. The feasibility increases when wetlands are developed for multiple purposes. In addition to nutrient removal, this can be hydrologic retention and/or nature development.

Mode of implementation
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