Identification of most promising measures to reduce nitrate pollution of water sources

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To safeguard human health and keep drinking water sources safe for consumption, the European Union (EU) maintains a maximum concentration guideline of 50 mg/L for nitrate (NO_3) in ground and surface waters. Nitrate in groundwater and surface waters originates primarily from nitrogen fertilisers, manure storage and spreading operations in agriculture, and from sewage waste and septic systems. Directives to reduce NO_3 concentrations, such as the Drinking Water Directive, the Water Framework Directive, and the Nitrates directive, have not as yet achieved a consistent level of implementation and effectiveness across all Member States. As a consequence, limits for NO_3 are still exceeded in some areas with vulnerable water resources. Diffuse pollution of nitrogen from agriculture is the main obstacle to meeting the Drinking Water Directive targets for NO_3.

Various measures and good agricultural practices have been developed and implemented in practice at farm level in the EU. These measures and practices have been successful in some regions but not in all. There is a huge diversity within the EU in farming systems, climate, geomorphology, hydrology, soils, education level of farmers, quality of extension services, and type of water supplies, which means that site-specific measures and good practices are required to decrease NO_3 pollution of drinking water resources. Various measures and good agricultural practices have been developed and implemented in practice at farm level in the EU. These measures and practices have been successful in some regions but not in all. In this report we review the effectiveness of management measures for reducing NO_3 losses to ground- and surface water resources. We combined (i) a synthesis of existing review papers, (ii) a meta-analysis of available data from literature and (iii) practice-based knowledge from nine case studies across Europe.

Results from reviews and meta-analyses that assessed the effects of different measures on NO_3 losses and soil NO_3 concentrations showed that the amount of literature available greatly differed for the various practices. Most measures described in literature were effective to some extent at reducing the risk of NO_3 losses to water bodies. There was overwhelming evidence that the use of non-legume cover crops is an efficient practice, with reductions in NO_3 leaching from 35% to 98%. The effect does however diminish when legumes are used. Besides cover crops, the use of (nitrification) inhibitors is also effective. For biochar, the effect differs from none at all, to considerable reductions in NO_3 leaching. Changes in tillage systems on average did not lead to significant reduction in NO_3 losses. Rather, for losses through leaching a significant

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increase was even reported. Switching to organic farming often includes no-till practices and did seem to reduce NO_3 losses. However, there was considerable variation in the results, and when losses were expressed per unit of produce, losses were often increased due to lower yields by organically managed farms.

In the meta-analysis 53 studies and 278 observations on a variety of measures were included. Because of a lack of studies and the absence of a solid, uniform type of pairwise comparisons (treatment group vs. control group), it was impossible to incorporate studies on topics such as implementation of balanced N fertilization, adaptations of N application timing or rate, restricted grazing, changes in crop rotations, and mulching. The results show that implementation of a vegetative buffer, the use of cover crops, and application of (nitrification) inhibitors lead to a significant decrease in NO_3 losses. For the other analysed measures (tillage, controlled drainage, biochar, and changes in application method), no significant average effect was recorded in the compiled database. Moreover, although some of the measures had a significant effect on NO_3 losses, including 'measure type' as an explanatory variable in the meta-analysis model did not significantly improve it. This indicates that the variation of the effect explained by the different measures is limited.

For the case study assessment, questionnaires were sent to experts involved with the FAIRWAY case studies. Results are summarised below (Table 1). In general, there was a wide variety of measures described. Optimizing the rate and timing of fertiliser and manure applications were measures that were applicable throughout (almost) all the case studies. With a highly rated effectivity, applicability and adoptability, as well as a relatively low cost these are measures that can be taken easily and may yield quick results. Compared to the literature review and the meta-analysis, there were several measures that were absent in the questionnaire results. Implementation of biochar and nitrification inhibitors was not reported by the experts. Measures on drainage or irrigation management were not reported either. Another difference between the measures included in the literature review and meta-analysis on one hand, and the response from the case study questionnaires on the other is that the measures from the latter seemed to focus more on the farm-scale. Measures on outreach, information sharing, whole-farm assessments and large-scale N input reductions were reported.

The main conclusions of the report are:

- The use of non-legume cover crops appears an effective way to reduce NO_3 losses. This effect is often diminished when legumes are included. Application of DCD also seems to be effective as a measure and cost-benefit analyses show that this can be profitable. For other measures, such as biochar and changes in tillage practices, the results differ.
- The success of the implementation of a measure often varies per farm and per location. It is subject to differences in topography, climate, and other farm management practices. Farm-tailored solutions are therefore likely to yield result.
- Implementation of measures to reduce NO_3 losses should not only consider the effectiveness, and costs, but also the adoptability and possible (unwanted) side-effects.

Table 1 – Overview of the measure types applied and studied within the FAIRWAY case studies, with indications on effectivity, cost, applicability, and adoptability.

Measure type	Country[1]	Target[2]	Effectivity[3]	Cost[4]	Applicability[5]	Adoptability[6]	Notes
Changes in cropping system or crop rotation	NL, SLO	GW/SW/NUE	++	€	++	++	May improve soil health/quality, decrease chance of diseases.
Changes in fertilization timing	NL, DK, GR, ROM, SLO	GW/SW	+++	€	+++	+++	e.g. no manure spreading in the fall or splitting fertiliser applications. Expenses may increase if it demands more labour or requires additional manure storage space.
Changes in application method	GER, DK	GW	++	€	++	++	Effectivity may depend on the farm; may decrease other N losses such as greenhouse gases.
Changes in application dose (reduced input, balanced fertilization, or optimal fertilization)	NOR, POR, GER, DK, GR, SLO	GW/SW/NUE	++	€	+++	+++	May require soil testing. May be mandatory.
Cover crops	DK, GR, ROM, SLO	GW/SW	+++	€€	++	++	May increase soil OM content. Cost varies based on farm type. Less applicable/adoptable in Slovenia.
Reduced tillage	NOR	SW	++	€€	+++	++	May prevent soil erosion.
Buffer strips (either between crops and waterways, or between rows of crops)	NL, FR, GR, ROM, SLO	GW/SW	++	€€	++	+	May contribute to landscape diversity but decrease crop yields. Implementation costs differ per country.
Grassed waterways	NOR	SW	+++	€€€€	+	+	May reduce erosion and contribute to landscape diversity. Reduces the amount of cropland
Farm-scale nutrient management tools	GER	NUE	*	€	+++	+++	Farmers may be obliged to use these tools.
Outreach and information events	GER	NUE	*	€	++	++	Effectivity depends on farm type and farmer knowledge.
Other	GR	GW/SW	?	?	?	?	Grassland and grazing management; improved fertiliser storage; no data available yet.

[1] Abbreviations for the various participating countries: NL – Netherlands; SLO – Slovenia; DK – Denmark; GR – Greece; ROM – Romania; GER – Germany; FR – France; NOR – Norway.
[2] Target of the measure: groundwater (GW), surface water (SW), nitrogen use efficiency (NUE).
[3] Effectivity is evaluated as Low (+, 5-10% load reduction), Moderate (++, 10-25% load reduction), High (+++, >25% load reduction), Variable (*), or Unknown (?).
[4] Implication costs are evaluated as Low (€, < €10/ha), Moderate (€€, 10-50/ha), High (€€€, €50-100/ha), Very high (€€€€, > €100/ha), or Unknown (?).
[5] Applicability is evaluated as No (+, on < 25% of the land), Partly (++, on 25-75% of the land), Yes (+++, on > 75% of the land), or Unknown (?).
[6] Adoptability is evaluated as No (+, in < 25% of the cases), Partly (++, in 25-75% of the cases), Yes (+++, in > 75% of the cases), or Unknown (?).