

# Toolbox of cost-effective strategies for on-farm reductions in N losses to water

*N-TOOLBOX KBBE-2008-1-2-08*

## Implementing water protection policy at the farm level in the European Union: lessons from the N-Toolbox case studies



**Date: September 2013**

## ***Contributors***

The following people have contributed to the development of this summary of case studies from the N-TOOLBOX project.

Julia Cooper, Andrew Carmichael, and Kate Gascoyne - Newcastle University

Geert-Jan van der Burgt, Bart Timmermans, and Petra Rietberg, Louis Bolk Institute

Hanne Kristensen, Aarhus University

Miguel Quemada, Technical University of Madrid

## Table of Contents

1 Background and summary of strategies .....	3
Summary of strategies .....	5
1. Manure storage and handling solutions .....	7
2. Livestock management .....	7
3. Pasture management for reduced N losses.....	8
4. Balanced N application rates .....	8
5. Best management practices for manure use on land.....	8
6. Strategies for irrigated land .....	9
7. Efficient N cycling at the field level.....	9
8. Runoff, drainage and wastewater management .....	10
2 Farmer engagement and testing NDICEA: perspectives from four countries .....	11
Spain.....	11
United Kingdom .....	13
The Netherlands.....	16
Denmark.....	18
3 Key lessons from the farmer engagement aspect of the project.....	21

## 1 Background and summary of strategies

### *Why the N-TOOLBOX project?*

In 2008 the European Commission released a call for proposals under the workprogramme topic: Novel approaches for reducing nitrogen losses. The objective of the programme was to improve uptake of the Nitrates Directive at the farm level. The consortium (Newcastle University, Louis Bolk Institute, Technical University of Madrid, and Aarhus University) responded to the call by developing a project that combined a review of the state of the art in technologies to reduce losses of N to water, with the upgrading of a user-friendly software package for simulating field-scale N dynamics, and the testing of strategies with farmers. The project has generated a number of outputs, many of which can be found on the website ([www.ntoolbox.eu](http://www.ntoolbox.eu)). Key outputs include:

1. A catalogue of strategies for reducing N losses from production systems within the EU that have been identified as major contributors to pollution of water by nitrates. This is available both as an interactive web-tool and as a PDF document. A summary of the strategies are presented below in chapter 1.
2. An adapted and enhanced version of the NDICEA model for use as an advisory tool by farmers attempting to comply with the Nitrates Directive. The model is now adapted for Spanish, UK, Dutch and Danish conditions, and can be downloaded for free from [www.ndicea.nl](http://www.ndicea.nl).
3. Documentation of the results from testing, monitoring and assessing the effect of the N-TOOLBOX approach on levels of nitrates in water leaching from case study farms.

This document is a short summary of key findings and experiences from the on-farm case study component of the project.

### *Background*

The movement of nitrates into groundwater and surface water from agricultural sources has been identified as a major environmental and health issue within the European Union. The Nitrates Directive (91/676/EEC) was adopted in December 1991 as a tool to address this issue and the Water Framework Directive (2000/60/EC) was more recently implemented with one of its key aims to provide “good status” for all waters by 2015. The Directives particularly focus on preventing the eutrophication of fresh and marine waters (and associated risks to human health), which has become a major problem in many regions of intensive agricultural production in Europe.

A number of research projects have been supported within the EU Framework Programmes aimed at **a)** identifying the causes of nitrate pollution of groundwater and surface water, **b)**

testing innovative approaches to reducing N losses to the environment, and **c)** developing simulation models that can be used as decision support/advisory tools for farmers. There is now a need for a coordinated effort to move forward and assess, verify and test practical measures that can be implemented to reduce losses of N to the environment. In this report we publish a number of case studies that can be used as a “blueprint” for implementing water protection policy at the farm level across the EU. The case studies demonstrate:

- the strategies used to engage the farmer in the process,
- the role of decision support tools, and
- the actual innovations used to reduce N losses from the farm

The N-TOOLBOX case studies targeted 4 annual cropping systems (one in each of the participating countries) that have been flagged as contributing significantly to nitrate pollution within the EU.

- **Vegetable production systems** in Denmark have resulted in contamination of groundwater with nitrates during their wet winters due to high use of N fertilizers and low N use efficiency of crops. This applies to both organic and conventional farms that have been targeted in the case studies.
- **Arable crop rotations** in the UK have lead to excessively high nitrate contents in groundwater and surface water. In many cases these rotations are on livestock farms where manure is used as an N source, and clover rich leys are produced in short rotations with arable crops. Nutrient management approaches that consider soil N supply and legume N, as well as nutrients provided by manure and fertilizers, are essential in these systems to avoid excessively high levels of soil nitrate during the growing season. These systems are the focus in the UK.
- **Large-scale vegetable production systems** on dry sandy soils have lead to excessively high nitrate contents in groundwater in The Netherlands. Intensive land use for cash crops, harvests in the critical fall period, unknown soil-N mineralization and lack of green manures in the rotation are dominant factors causing leaching of nitrogen. These systems have been the focus for activities in The Netherlands.
- **Irrigated systems** in Spain are particularly susceptible to groundwater pollution because irrigated crops are abundantly fertilized and as intensive irrigation leads to very fast movement of fertilizer N from the soil surface to deep soil layers. As a result aquifer contamination from nitrate leaching is largely related to intensive irrigated agriculture especially below cereal/maize based cropping systems. Nutrient and water management strategies need to be implemented to prevent leaching of nitrates to groundwater in these systems which will be the focus in Spain.

### *The NDICEA model*

The NDICEA model for arable and horticultural crops ([www.ndicea.nl](http://www.ndicea.nl)) has been developed and tested for decision support on farms in the Netherlands, Spain, UK, and Denmark as well as Germany, France and California. The model simulate effects of changes of management on N leaching at the field scale based on inputs of soil type, region, crop rotation etc. and simulates the effects on N leaching, crop N uptake, soil organic matter N etc. in a relatively simple and easy-to-understand way.

In the case studies the NDICEA model was used at three different stages in the process of engaging and implementing the N-TOOLBOX approach on farms.

1. The simulation outputs for the NDICEA model were used as a basis for discussions, dissemination and knowledge transfer among scientists, advisors and farmers.
2. The NDICEA model was used to simulate N dynamics in some case studies based on data inputs of soil type, crop rotation etc. under the farmer's current management practice.
3. The NDICEA model was used in other case studies to demonstrate and select alternative strategies to reduce N leaching. The simulations were advanced to include calibration with early-season measurements of soil N to give decision support in-season for the selection of N-TOOLBOX strategies e.g. reduction of fertilizer rates.

### **Summary of strategies**

One of the main outputs of the N-Toolbox project was a “catalogue of N loss reducing strategies” that was produced in PDF form and as an on-line version, both of which are available on the N-Toolbox website ([www.ntoolbox.eu](http://www.ntoolbox.eu)). These strategies have been divided into the 8 categories which are shown in the decision tree in Figure 1. This decision tree can be used to help users identify which set(s) of strategies are most appropriate for their system, and is the basis of the on-line version of the catalogue. A summary of the strategies within each category is listed on the following pages.

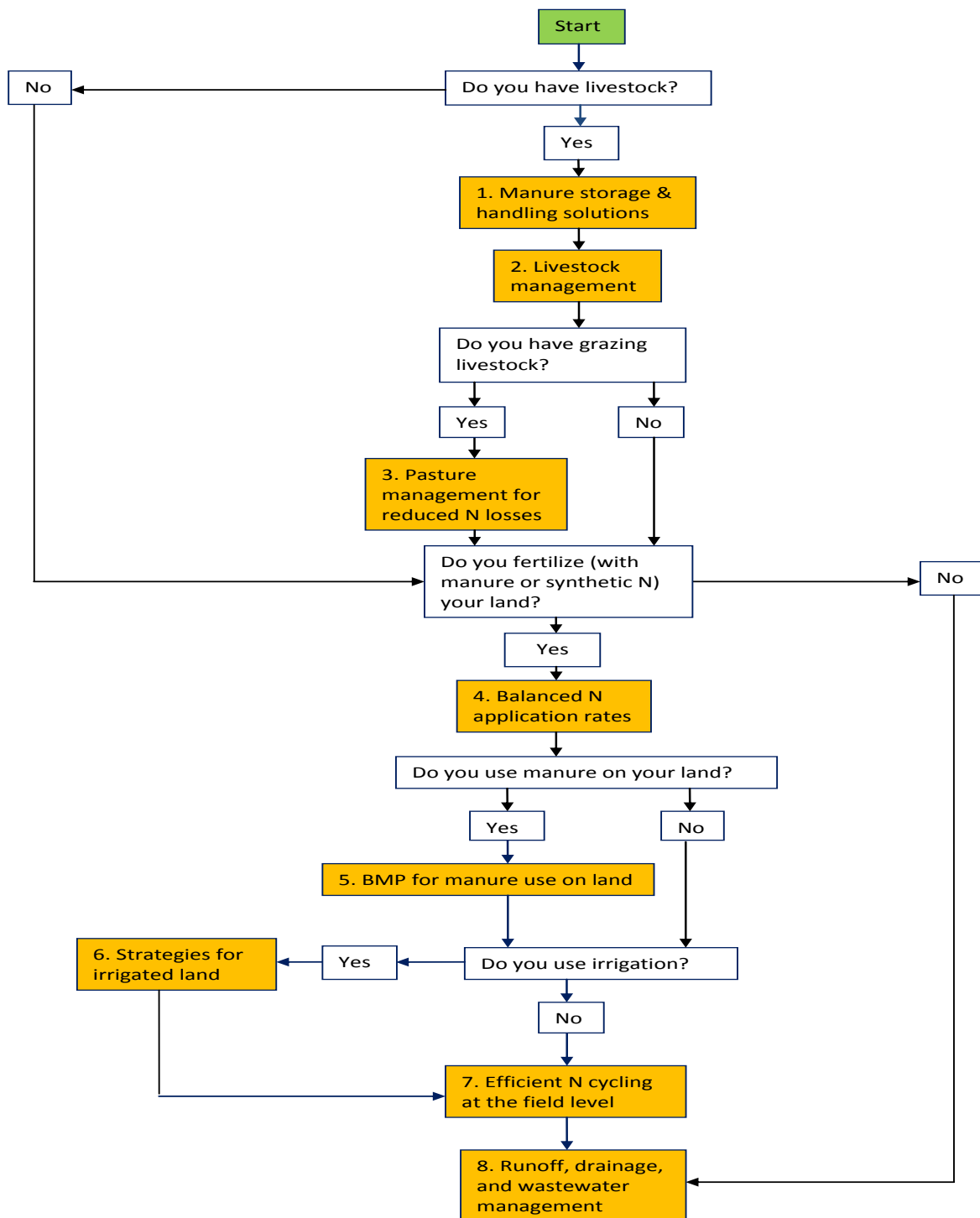


Figure 1. N-TOOLBOX decision tree for identification of sub-sets of N loss reducing strategies for specific production systems

## 1. Manure storage and handling solutions



- ✓ enhance manure storage capacity
- ✓ compost manure or bedding livestock on high C materials
- ✓ locate solid manure heaps away from watercourses and field drains
- ✓ cover solid manure storage areas
- ✓ store solid manure on a concrete pad with a runoff collection system
- ✓ separate solid and liquid fractions of manure
- ✓ anaerobically digestion of slurry

## 2. Livestock management



- ✓ decrease the number of young cattle and reduce the cattle turnover rate
- ✓ reduce the levels of dietary N
- ✓ phase feeding
- ✓ balance dietary nitrogen and carbohydrates to optimize rumen function



### 3. Pasture management for reduced N losses

- ✓ reduced damage to soil structure by moving feeders & troughs
- ✓ exclude livestock from surface waters
- ✓ increase the clover content of the sward
- ✓ reseed older, permanent swards
- ✓ reduce stocking densities on pastures
- ✓ use nitrification inhibitors



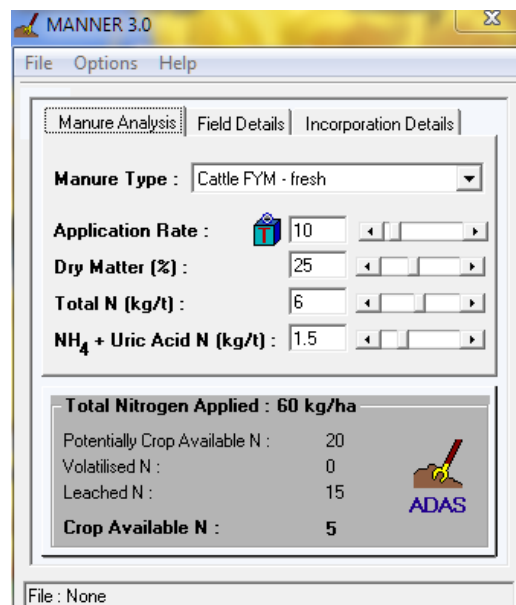
### 4. Balanced N application rates



- ✓ optimise fertilizer rates
- ✓ use in season estimates of crop N status

### 5. Best management practices for manure use on land

- ✓ do not apply manure to high-risk areas
- ✓ apply manure to land when conditions are optimum
- ✓ manure testing
- ✓ accurately estimate manure N release over the growing season
- ✓ regular maintenance and calibration of manure application equipment



## 6. Strategies for irrigated land

- ✓ adjust the quantity of water applied to match crop needs
- ✓ fertigation
- ✓ upgrading the existing irrigation to a more water use efficient system



## 7. Efficient N cycling at the field level



- ✓ split fertilizer or manure applications
- ✓ cultivate land for crop establishment in spring rather than autumn
- ✓ use a catch crop
- ✓ incorporate residues with a high C:N ratio into the soil to promote immobilisation of N
- ✓ use of N fixing green manure crops in the rotation
- ✓ slow- or controlled-release fertilizers
- ✓ rotate N efficient and inefficient crops

## **8. Runoff, drainage and wastewater management**

---

- ✓ **yardworks for clean and dirty water separation**
- ✓ **sedimentation ponds**
- ✓ **artificial wetlands to treat dirty water**
- ✓ **riparian buffer strips**



## 2 Farmer engagement and testing NDICEA: perspectives from four countries

In each of the four partner countries we tested the N-Toolbox approach on farms. This involved:

1. identifying a target region/area where nitrate pollution was a known risk
2. engaging with farmers in the area and identifying individuals who were interested in working with scientists to test and evaluate some N loss reducing strategies on their farms
3. selecting some strategies expected to reduce N losses and/or improve N use efficiency on the case study farms
4. monitoring N dynamics on the case study farms
5. interpreting results of the case studies and reporting back to participating farmers
6. evaluation of the engagement of farmers and the role of NDICEA

In this chapter we report on how these steps were implemented in each country. The focus is on how the implementation of strategies for reduction of nitrate leaching was perceived by farmers, and how they were engaged in the testing and evaluation.

### Spain

#### *Selection of target region and strategies*

In Spain a national stakeholder advisory group (SAG) was set up for the project. This group advised the scientists on the best target areas for on-farm case studies. Two areas in Central Spain were selected where systems are based on maize production, and irrigated systems have been identified as a major source of nitrate pollution. A key point raised by the SAG was that: in irrigated systems both nitrogen and water management need to be optimised for successful reductions in leaching. The key message used to engage farmers was that it is possible to maximize profit by reducing fertilizer rates if water and fertilizer management are adapted to crop needs. Identification of suitable farms was mainly based on advice from local advisory services and contact with local farmers.

#### *Engaging farmers*

From the meeting with the stakeholder group we also received the following input:

- i) advisors have a large influence on the decisions taken by farmers, therefore, collaborating with advisors was very important to engage farmers

- ✓ irrigated systems need water and N management-based solutions
- ✓ emphasize economic benefits to farmers
- ✓ work closely with local advisors
- ✓ offer farmers a shortlist of possible strategies

ii) it was preferable to identify a short list of relevant strategies to prevent nitrate losses in irrigated systems and discuss it with farmers, rather than to present the detailed catalogue of strategies in full to the farmers

Farmers were shown nitrogen balances that had already been done in agricultural systems in the area demonstrating that N applications were often excessive. This was further emphasized when results



from experiments done by local advisors were shown to farmers, showing that beyond the optimal rate there was no crop response to N fertilizer. The farmers were already familiar with the problem of excess fertilizer application, but they really appreciated that the problem was approached as a strategy to reduce costs.

*The role of NDICEA*

Scientists, together with advisors and farmers, designed a fertilizer rate experiment in 2010. Yield and nitrate leaching were measured and results were discussed with the farmers. Farmers really wanted to know: where is the fertilizer going? NDICEA was very useful to answer this question. Farmers were very interested in learning

**NDICEA answers the question: where has my N fertilizer gone?**

**Advisors had an important role in knowledge transfer and tools like NDICEA reinforced the technical value of their message.**

about the N balance on their own farm. They had already heard about nitrate leaching, volatilization and denitrification, but looking at figures of their own agricultural systems was very useful to design specific strategies for their farm.

## *Farmers' response*

**The role of NDICEA in farmer engagement was to serve as a starting point for discussion, and also to provide a handy tool for comparing the effect of the potential strategies on the different components of the N cycle.** It is also important to emphasize that farmers were not willing to learn how to use NDICEA, but interested in participating in discussions about its outputs. Advisors were interested in learning how to use NDICEA, and they found it a useful tool to conduct N balances in agricultural systems and to support recommendations to farmers

Reducing N fertilizer application was always a topic in the discussions with farmers. The main concern stated by farmers about reducing fertilizer rates was that in fields with a large degree of variability, some areas of the field may end up under-fertilized. Increasing fertilizer application ensures that the entire farm will reach the potential yield, even if they are aware that in some areas they are applying a fertilizer surplus. This is a concern that it may be possible to address in the future using precision farming technologies.

## **United Kingdom**

### *Selection of target region and strategies*

N-Toolbox case study activities in England were focussed on optimising fertilizer recommendations. This strategy was chosen from the N-Toolbox catalogue partly because the project coordinator had considerable experience with soil testing for determining nitrogen supply and optimising fertilizer recommendations, and also because it was identified as a strategy that would require minimal investment by the farmer and could result in an economic benefit.



The Eden Valley region of northwest England was chosen as a focus area for N-Toolbox case study activities because this region is a Nitrate Vulnerable Zone and has also been selected by the Department of Environment, Food and Rural Affairs as one of only three “demonstration test catchments” in England.

- ✓ **work with existing networks of farmers and other stakeholders**
- ✓ **don't inundate farmers with requests to participate in projects**

*Engaging farmers*

The research group had never carried out on-farm activities in this part of England, so it was a challenge to identify potential cooperating farmers; however, through a number of networks (government contacts, a private charity working on Eden River water quality,

**Farmers selected in the project tended to be those who are already progressive and engaged; it is difficult to know whether lessons learned from this group will be transferable to the wider farming community.**

a local farmers network, word of mouth) it was possible to identify four willing farmers/managers for the 2009/2010 season, three of whom carried on with the work in the second season. There were a range of decision-making styles among the farms: from farms with trained agronomists, to others who relied on advisors or made fertilizer rate decisions themselves. Table 1 lists the crops grown on the study fields on each farm during 2010 and 2011 and the primary source of information the farmers use to come up with their fertilizer rates each year.

**Table 1. Crops grown in N-Toolbox case studies in each year in the Eden Valley of England, and the predominant fertilizer recommendation system used by the farmer/manager during the project**

Farm number	Crop 2010	Crop 2011	Fertilizer recommendation system
1	Winter wheat	Winter barley <sup>1</sup>	RB209/PLANET <sup>2</sup> ; some SOYL satellite mapping
2	Spring barley	Winter barley	RB209
3	Winter barley	Winter barley	Farmer experience
4	Spring barley <sup>3</sup>		Farmer experience

*Role of NDICEA*

The farmers quickly grasped the purpose of the NDICEA software tool and were engaged and interested when it was demonstrated. The use of the tool provided a useful stimulus for discussion about soil N dynamics in their fields and what factors could be controlling these dynamics. Cases where the tool did not accurately predict actual N dynamics i.e. where soil mineral N measurements did not match the model predictions, proved to be particularly useful for stimulating discussions and debate. So the accuracy of the model did not prove to

<sup>1</sup> At Farm 1 only, winter barley was grown in 2011 in the same field as the winter wheat from 2010.

<sup>2</sup> RB209 is the official fertilizer recommendation guide published by the UK Department of Environment, Food and Rural Affairs; PLANET is the software package which provides RB209 recommendations.

<sup>3</sup> Farm 4 did not grow winter barley so was not included in the 2011 studies.

be particularly important when using it as a demonstration tool in the context of the farmer meetings.

#### *Farmers' response*

The use of the case studies served to dispel some of the assumptions about fertilizer use on farms and N losses. None of the farmers believed that they were over-using nitrogen inputs (due to cost and need for efficient uptake) and this was proved so in the trials. In fact, two of the three host farms in the 2010-2011 trials were under-using N inputs according to the results.

**While NDICEA was useful as a demonstration tool, none of the farmers involved felt that they would use this tool on their own to make decisions about crop and fertilizer management on their farms.**



Farmers had different reasons for using the N rates that they normally did. The farmer using the least N on his arable crops said that he knew that he would get a higher yield if he used more, but was afraid that on a beef finishing and sheep breeding farm, with a wet climate, he would not have the time or the expertise to manage the pests and diseases or apply the plant hormones that would be needed. The more focussed arable farm with an agronomist working on the farm was able to deal with these issues and was interested in producing maximum yields as part of a mixed farming estate; therefore he tended to fertilise for the maximum economic yield. The college farm had a number of rotation and staffing issues that limited their arable management options, but they were interested in improving the efficient management of N.



## The Netherlands

### Selection of target region and strategies

The combination of horticultural production and sandy soils in The Netherlands makes management of nitrogen particularly challenging. Researchers worked closely with advisors to identify farmers interested in trying out strategies to reduce their N losses. In the first meeting at each farm, the objectives of the project were presented and the farmers were invited to select strategies from the measures catalogue which were feasible in their situation. Several measures of the N-toolbox were discussed and successfully experimented with by the researchers and farmers. Nevertheless, some agronomic and economic



limitations to the application of N-toolbox measures became apparent during the N-toolbox project.

One of the measures which proved useful was the NDICEA nitrogen dynamics model. NDICEA simulations showed that most of the nitrogen loss occurs during winter. This can possibly be reduced by changes in the fertilizer

management aiming at a better match between crop demand and nitrogen availability, and by sowing catch crops in autumn after the main crop.

Slow release nitrogen fertilizers can be of help synchronising the N-dynamics of soil and plant. However, on the sandy soils in this project, certain slow release fertilizers, such as Entec, have an acidifying effect. This meant that the use of slow release fertilizers as a strategy was not appropriate for these systems.

- ✓ **slow release fertilizers were not appropriate in the sandy soil**
- ✓ **catch crop establishment can be poor if planted too late**
- ✓ **farmers are concerned about nematode risks when growing green manures**

Planting catch crops after the main crop harvest was a possible strategy. The interaction with farmers and the trials in the field revealed some important drawbacks to the use of catch crops and green manures. First, the timing of planting is crucial: sowing a green manure after September 20<sup>th</sup> in The Netherlands seems to be useless because growing conditions for most crops are too poor. We experienced that the Japanese oats sowed after a root crop harvested at the end of September, did grow poorly. Consequently, it did not take up much nitrogen.

Second, farmers are well aware that many green manure species enhance nematodes. Knowledge about which nematode is enhanced by what green manure is widespread and taken into account by selecting the green manure, but, as a farmer summarized: ***“The perfect green manure does not exist.”*** Costs, fear of nematodes and timing issues seem to be the most important limitations for widespread adoption of green manures in arable farming throughout The Netherlands.

### *Engaging farmers*

**Even though the more progressive farmers seemed to be involved, it was the relatively easy to implement and low-risk N-toolbox measures they selected to be applied (e.g. changing the amount of fertilizer applied, the type of fertilizer, and the timing of the application). More complex adjustments, such as adapting the rotation or switching crops, were not made.**

Farmers who were engaged in this project were interested in nitrogen dynamics and judicious nitrogen management. Often, they were already applying fertilizers quite carefully, and aiming to minimize losses of nitrogen. They used nitrogen budget calculations. Farmers wanted to see further benefits from a measure, more than just reducing the risk of nitrogen leaching, as showed by the quote of one of the growers involved. ***“This implies that there should be a real incentive for farmers – either a carrot or a stick – to truly adopt measures from the N-toolbox, especially the more radical ones.”***

### *Role of NDICEA*

NDICEA as a decision support tool was mainly used by the researchers who are already familiar with the model. They used it in two ways: first, to better understand the system at stake and to evaluate proposed methods to the farmers, and second, to show farmers the effects of different amounts or types of fertilizer used. The model could adequately describe the nitrogen dynamics of the fields in the study, so it helped the researchers to get an overview of N losses from the different systems. For the farmers the model and the presentation of the nitrogen dynamics were completely new. Although they were all very interested, acceptance of the results by farmers is not always assured.

**The nitrogen budgeting calculations in use by extension services are year to year independent calculations. NDICEA showed that it is worth while taking the longer management history into account to evaluate N balances properly, but the complexity of the processes makes it more difficult to accept the results.**

## Response of farmers

The farmers were motivated to be part of a process developing knowledge and documenting experiences. As one of the pilot farms pointed out: ***“A measure should yield something... should be of benefit to us. For example, seeding a green manure costs money and time, but there are some species which are beneficial for us because they decrease the amount of nematodes in the soil. This is why we do it. Though from a governmental perspective, reduction of nitrogen leaching should be our main focus.”***

### Denmark

#### Selection of target region and strategies

Intensive vegetable crop rotations were the focus of activities on both organic and conventional farms. These farms were targeted because of prior knowledge about the use of high fertilizer rates and low nitrogen use efficiency in these systems. A local organic vegetable advisor from the stakeholder advisory group, also played a key role in identifying target farms. This advisor had observed that many organic farmers were using high rates of manure after incorporation of winter green manures in spring and it was leading to a high risk of leaching. The Ntoolbox strategy of reduced fertilizers was implemented and directed to both organic and conventional farmers. By measuring soil mineral N to 1.5-2 m depth and NDICEA

- ✓ winter green manures and spring manure applications can increase N leaching risk - even on organic farms
- ✓ NDICEA can illustrate for farmers the excess N levels in their soil
- ✓ fertilizer rates can be reduced
- ✓ conventional farmers were introduced to autumn catch crops

**Many strategies not only reduce N losses, but have other benefits for farmers or the environment.**

modelling of the availability of soil nitrogen in the crop root zone, farmers were shown the nitrogen availability to the crop over the season, and the possibility to save on spring applications of fertilizer.

## Engaging farmers

**The fact that farmers were promised information about soil nitrogen over time in the root zone of their fields was clearly a factor that stimulated the farmers' interest in the project.**

Researchers visited the farms and discussed the idea of reducing fertilizer rates for the benefit of the environment and the farmer's profits. The farmers saw an opportunity to get in depth knowledge about nitrogen dynamics in their fields. The actual crops under investigation were selected in cooperation with the farmers and the

advisor. NDICEA was demonstrated to the farmers by the advisor, who was keen on using the model in his daily advisory activities, and who wanted to test the model for decision support. Further he cooperated in his own national demonstration projects directly with Geert-Jan van der Burgt from Louis Bolk Institute on testing the NDICEA model. In the Ntoolbox project, cooperation was further established with the advisor on the setup of field trials and sampling at the farms.



**The joint activities from both the Ntoolbox project and the advisory service on implementing strategies to reduce nitrogen leaching were clearly important for the engagement of the organic farmers.**

**The Danish national advisory service is now working to implement NDICEA as an advisory tool on Danish farms.**

### *Role of NDICEA*

The farmers showed good interest in the demonstration of the NDICEA model, but did not seem interested in using it on their own, but in collaboration with the advisory service. This was

despite the fact that the farmers participating in the Ntoolbox project were exceptionally engaged and knowledgeable about the environmental and biogeochemical aspects of reducing nitrogen losses from their systems.

During the Ntoolbox project period the national advisory service initiated activities to implement the use of NDICEA in the advisory services for all agricultural crops. Direct cooperation was established between the national agricultural advisory service and the

Louis Bolk Institute to further adjust NDICEA for use on agricultural farms in Denmark. The Ntoolbox project contributed with knowledge and experience in this process, which built on the activities from several sides of the advisory and scientific landscape in Denmark.

The experience with the Ntoolbox approach in Denmark shows that it is possible by combined use of on-farm investigations and collaboration among farmers, the advisory service, national environmental authorities and scientists to engage farmers, and among stakeholders to develop and disseminate the ideas and support tools for reducing nitrogen losses from vegetable production. This extension of activities in Denmark depended on initiatives and activities coming from several stakeholders/sources over long time. The future impact on farmers' use of nitrogen and the water quality will depend on continuous effort and follow-up on the implementation of the Ntoolbox strategies.

#### *Farmers' response*

Two stakeholder advisory meetings were held to discuss the background for implementing the water frame directive, the idea of using Ntoolbox strategies for improving nitrogen use efficiency, the results from the field trials for soil nitrogen availability in the whole root zone with different fertilizer rates and catch crops, and to demonstrate NDICEA modelling

The issues were discussed among the participants including the farmers, the advisor and a representative from the national environmental authorities. In some cases the results clearly showed the high spring soil nitrogen availability from green manures and last year's residual soil N at one organic and one conventional

farm. This demonstrated to farmers that the spring fertilizer additions were more or less unneeded and could lead to excess nitrogen availability during the growing season and high nitrogen leaching losses during winter. In contrast, another organic farm was managed with lower fertilizer rates combined with winter green manures on a soil type with low leaching intensity.

This led to a much tighter nitrogen cycle with sufficient nitrogen availability over the season and low leaching losses.

**These differences were discussed among the participants and were clearly eye-openers with comments from farmers like "well, then we could have skipped the spring fertilizer application".**

### 3 Key lessons from the farmer engagement aspect of the project

- ✓ The expectation of knowledge transfer on nitrogen cycling and links to production yields specific to each farmer's own farm was a main driver for the engagement of farmers in the Ntoolbox project.
- ✓ The prospect of economic benefit from implementation of strategies was a key factor for engaging farmers.
- ✓ The nitrogen simulation model NDICEA was an important tool for knowledge transfer and stimulation of discussions on nitrate leaching with farmers.
- ✓ Farmers were interested in demonstrations using NDICEA, but not in their own use of the model. Advisors were keen on employing NDICEA for simulation of current or alternative practices for reduction of nitrate leaching.
- ✓ Farmers were most interested in easy-to-implement strategies like reduction of N fertilizer rates.