

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

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

## Final Report



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# N-TOOLBOX



practical solutions to nitrate pollution



## Executive Summary

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 was adopted in December 1991 as a tool to address this issue and the Water Framework Directive was more recently implemented. In spite of the best efforts of legislators in the EU and member states, water quality in many European surface and groundwater bodies remains below the desired standard. The NTOOLBOX project began in 2009 in response to a call from the EU for a project that would improve uptake of the Nitrates Directive at the farm level across the EU. The project brought together partners in the UK, The Netherlands, Denmark and Spain. The emphasis of the project was on the identification and testing of practical solutions to the problem of nitrate pollution within the agricultural sector.

The overall aim of this project was to develop a “toolbox” of cost-effective technologies to be implemented at the farm level to protect water from nitrate pollution. As well as identifying appropriate technologies, the project also aimed to document approaches to promoting uptake of the technologies. Each project partner worked on the ground with farmers to test out new strategies while at the same time noting the techniques that effectively engaged farmers in the problem-solving process.

Activities within the project focussed on three key areas: analysis of literature to identify the best strategies for reducing losses of nitrates to water from agriculture; improvement of the decision support tool NDICEA; and, test-driving the N-TOOLBOX of strategies on farms. The main output from WP1 was the document: **Innovative and cost-effective technologies to reduce N losses to water from agriculture in the EU: a catalogue of farm level strategies**. This document lists 39 strategies within 8 different categories, with the “win-win” strategies (methods that reduce N losses to water and save money) ranked highest. The document is available as downloadable pdf file on the project website ([www.ntoolbox.eu](http://www.ntoolbox.eu)) and has also been converted to an easy-to-use on-line tool.

In WP2 the software package **NDICEA** ([www.ndicea.nl](http://www.ndicea.nl)) was introduced to the project partners and adapted for use in each partner country. The geographic range of the software was expanded by adding environmental files (weather and soil data) from England, Spain and Denmark. The language of the interface was also amended to include Spanish as well as English, Dutch and German.

Working directly with farmers in WP3 was a new experience for many of the project partners. This was viewed as positive as it allowed the scientists to gain an improved appreciation of the practicalities of N management at the farm level. NDICEA proved very effective during farmer meetings as a stimulus for discussion about causes of N losses within a crop rotation, and for investigating strategies to reduce those losses. In WP4 the final stakeholder workshop brought together representatives from a number of Departments within the Commission (e.g. DG Agriculture, DG Environment, DG Climate and DG Research), as well as some national representatives. It provided a useful opportunity to present findings to key stakeholders and to identify further activities to add value to the work done within the N-TOOLBOX project.

## Project context and main objectives

### *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.

The annexes to the Nitrates Directive (91/676/EEC) already identify a range of technologies that can be adopted to reduce the movement of nitrates from agricultural sources into groundwater and surface water. Most importantly, the directive promotes the simultaneous introduction of

- *“crop rotation, soil winter cover, catch crops”,*
- *“use of fertilisers and manure, with a balance between crop needs, N-inputs and soil supply, frequent manure and soil analysis, mandatory fertilisation plans and general limitations per crop for both mineral and organic N fertilisation”*
- *“appropriate N spreading calendars and sufficient manure storage, for availability only when the crop needs nutrients, and good spreading practices”*
- *use of the “buffer effect of non-fertilised grass strips and hedges along watercourses and ditches”*
- *“good management and restriction of cultivation on steeply sloping soils, and of irrigation*

With a view to improving uptake of strategies like these, the coordination and support actions within the project were designed to fulfil the overall aim to:

***develop a “toolbox” of cost-effective technologies to be implemented at the farm level to protect water from nitrate pollution.***

In order to fulfil this aim, the following 3 specific objectives were formulated:

1. *To facilitate the implementation of policies for the protection of water from nitrate leaching from agriculture.*
2. *To identify innovative and cost-effective technologies which improve the efficiency of N use on the farm, and minimize losses of nitrogen to the environment (water and air)*
3. *To enhance the applicability of existing and newly developed technologies by assessment, verification and testing at the farm level.*

The project also set out to achieve the following measurable objectives:

1. Production of a catalogue of innovative and cost-effective technologies to be implemented in hotspots for N losses from farming systems in the EU.
2. Development of an improved NDICEA decision support tool (or an alternative where necessary) for N management at the farm level, using inputs from current EU projects on N modelling.
3. Testing of the N-TOOLBOX (catalogue and decision support tool) at the farm level in each of the four regions and production systems.
4. Monitoring of water quality, N use efficiency, farm scale costs/benefits, and policy level costs/benefits in each of the four regions and production systems.
5. Documentation of the implementation of the N-TOOLBOX approach at the farm level (production of case studies in a publishable form).

The N-TOOLBOX project focussed on the identification of system-specific solutions that can be incorporated into national action programmes to achieve the objectives of the Nitrates Directive. It delivered a set of tools that can be used for decision making at a range of levels, from an individual farm level, up to the national or European level to inform policy makers. These tools included: **a)** a catalogue of innovative and cost-effective technologies for reducing N losses from agricultural systems in pdf format and an on-line tool, **b)** an enhanced N management decision support tool for use at the farm level (NDICEA), and **c)** a series of case studies from partner countries summarizing experiences with implementing strategies and using NDICEA, at the farm level (available as pdf and on-line). In addition, a number of project outputs in the form of reports are included on the Project Publications section of the website.

## Main science and technology results from the N-TOOLBOX project

Activities within the project have focussed on three key areas: analysis of literature to identify the best strategies for reducing losses of nitrates to water from agriculture (WP1); improvement of the decision support tool NDICEA (WP2); and, test-driving the N-TOOLBOX of strategies on farms (WP3). Dissemination of project outputs to stakeholders, including farmers and policy makers, has been another key activity within the project (WP4). Details on all project science and technology results are outlined below.

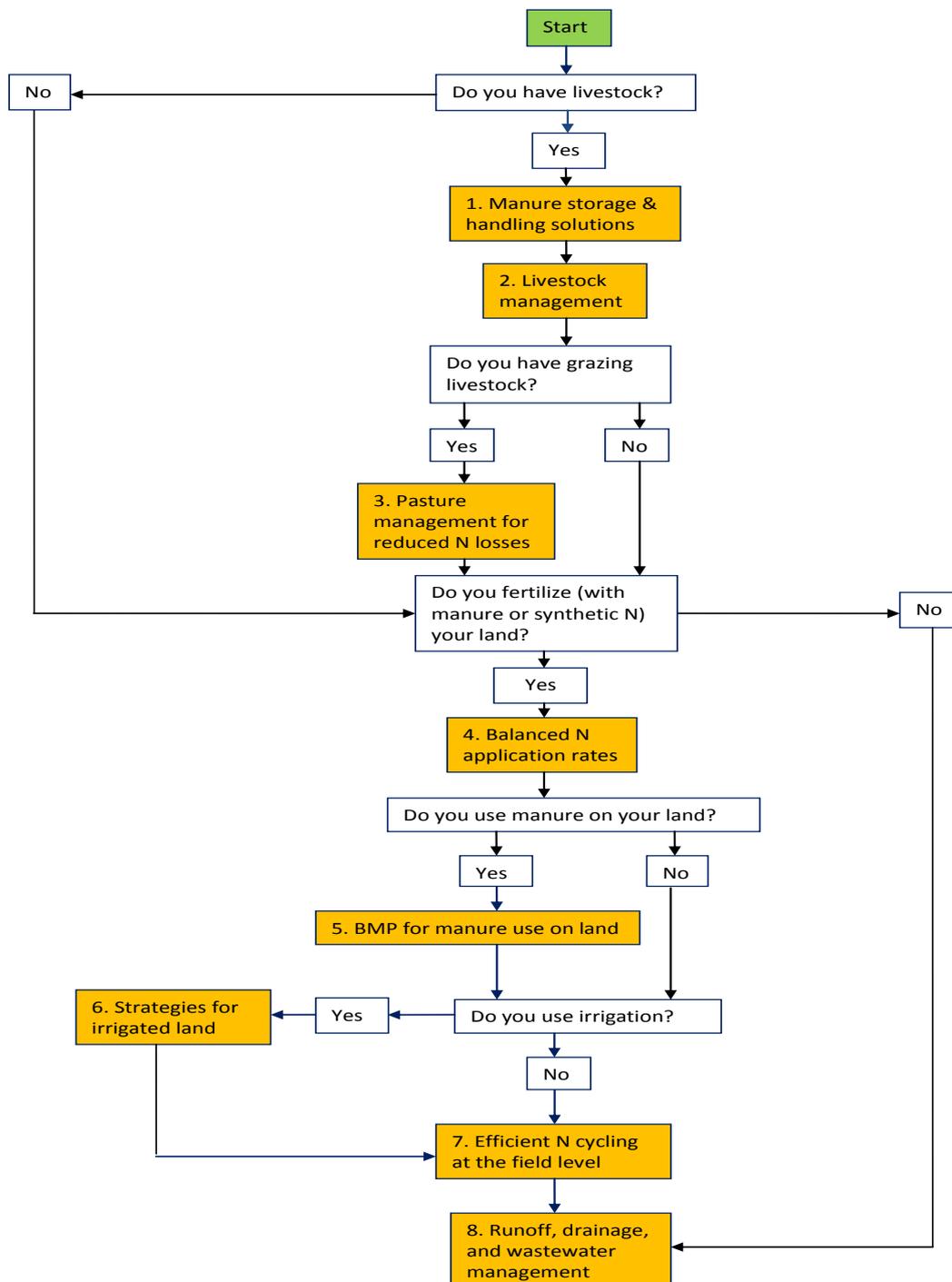


Figure 1. N-TOOLBOX decision tree for identification of sub-sets of N loss reducing strategies for specific production systems

## **WP1 Meta-analysis of innovative and cost-effective technologies to reduce N losses**

### *A catalogue of strategies*

The main output from WP1 was the document: **Innovative and cost-effective technologies to reduce N losses to water from agriculture in the EU: a catalogue of farm level strategies**. This document lists 39 strategies within 8 different categories, with the “win-win” strategies (methods that reduce N losses to water and save money) ranked highest. The document is available as downloadable pdf file on the project website ([www.ntoolbox.eu](http://www.ntoolbox.eu)) and has also been converted to an easy-to-use on-line tool.

One of the first steps taken at the beginning of the project was to come up with a framework for categorizing strategies to reduce N losses to water. This framework became known as the “decision tree”, and is shown in **Error! Reference source not found.**. The decision tree helps guide users to the most appropriate set of strategies for their farming system. Throughout the activities within WP1, the decision tree was used to help the scientists organize information and prioritize activities.

### *Irrigated systems meta-analysis*

In the initial proposal the team planned to conduct a detailed statistical meta-analysis on the various strategies identified, to help select those that have consistently proven to be effective at reducing losses of N to water from agricultural systems. A large database (containing over 1000 references) was compiled consisting primarily of peer reviewed articles that report the effects of various farming practices on nitrate leaching/losses.

After the database had been compiled, the project team discussed the value of conducting a meta-analysis on all the categories of strategies and it was agreed that:

- a) Not all strategies were suitable for a meta-analysis since they work in indirect ways to improve efficiency of N use on the farm and/or reduce the farm N surplus e.g. manure storage and handling solutions, livestock management (feeding strategies), and runoff, drainage and wastewater management. This makes extraction of data that is indicative of N leaching difficult. Although the papers collected in the Endnote library on these topics were not used for a statistical meta-analysis, results were reviewed and assessed when compiling the final version of the catalogue.
- b) For several strategies, meta-analyses have already been conducted. Tonitto et al. (2006)<sup>1</sup> conducted a meta-analysis on the use of cover crops in fertilizer-intensive cropping systems. Zhang et al. (2010)<sup>2</sup> have done a meta-analysis on the use of vegetated buffers to reduce

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<sup>1</sup> Tonitto, C., David, M.B., Drinkwater, L.E., 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agriculture Ecosystems & Environment* 112, 58-72.

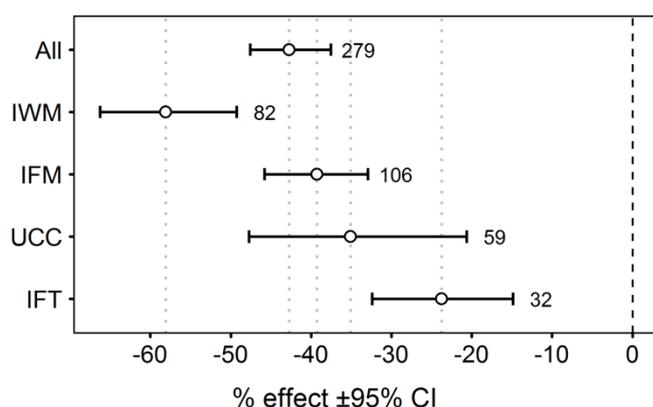
<sup>2</sup> Zhang, X.Y., Liu, X.M., Zhang, M.H., Dahlgren, R.A., Eitzel, M., 2010. A Review of Vegetated Buffers and a Meta-analysis of Their Mitigation Efficacy in Reducing Nonpoint Source Pollution. *Journal of Environmental Quality* 39, 76-84.

nonpoint source pollution, and Mayer et al. (2007)<sup>3</sup> did a meta-analysis on the effectiveness of riparian buffers to remove nitrogen. As described above, findings from these studies were assessed when compiling the final list of strategies in the catalogue.

A knowledge gap was identified in the area of strategies to reduce N losses in irrigated systems of production. For this reason it was decided to focus efforts on producing a meta-analysis in this specific area. A total of 61 papers were identified that will be suitable for a meta-analysis in this topic area. The analysis focussed on the following strategies within the category of irrigated systems:

1. Adjusting irrigation water to crop needs, including adjusting rates and timing
2. Adjusting fertilizer rate to crop needs in irrigated systems
3. Use of nitrification inhibitors in irrigated systems
4. Intercrop management (fallow versus cover crops)

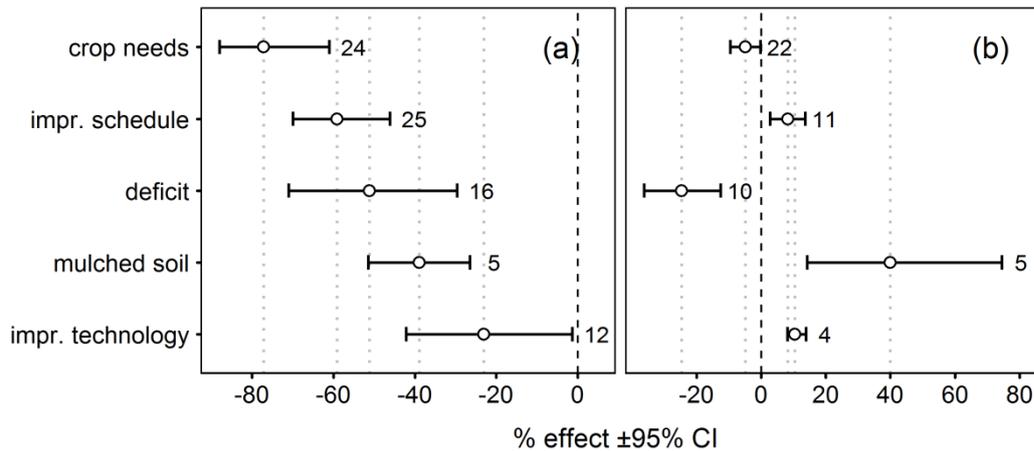
A manuscript has now been completed and submitted to the journal Agriculture, Ecosystems and Environment.



**Figure 2. Overall effect of all management strategies (All) and effect of each category of management strategy on nitrate leaching in units of percent change from the control. Mean values and 95% confidence intervals of the back-transformed response ratios are shown. IWM: improved water management; IFM: improved fertilizer management; UCC: use of cover crops; IFT: improved fertilizer technologies. Sample sizes (i.e. the number of control-treatment pairs) are shown on the right of the confidence intervals.**

Figure 2 shows the effect of the various management strategies on nitrate leaching relative to a control. You can see that on average the strategies reduce nitrate leaching by ~43% compared with standard practice. The most effective way to do this is to improve water management.

<sup>3</sup> Mayer, P.M., Reynolds, S.K., McCutchen, M.D., Canfield, T.J., 2007. Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality* 36, 1172-1180.



**Figure 3. Effect of the strategy Improved water management and various treatments within the strategy on nitrate leaching (a) and total yield (b) in units of percent change from the control. Mean values and 95% confidence intervals of the back-transformed response ratios are shown. The control irrigation rate for crop needs is excessive; the control rate for deficit was water application to crop needs. All other irrigation rates were the same for control and treatment. Sample sizes (i.e. the number of control-treatment pairs) are shown on the right of the confidence intervals.**

A more detailed analysis of this strategy is shown in Figure 3. It shows that first and foremost, irrigation water should be applied to meet crop needs, and not exceed this amount. When water is supplied in this way, losses of nitrate can be reduced by almost 80%! The other improved water management strategies also reduce nitrate leaching, but it should be kept in mind that these reductions are not relative to excessive irrigation (see figure caption for details).

Ideally, a strategy to reduce nitrate leaching should not have an adverse effect on yield. Figure 3b shows that yield is relatively unaffected by irrigating to meet crop needs, or improving the irrigation schedule or technology. Deficit irrigation, defined as a reduction in water application with respect to crop needs that leads to a significant yield reduction, is a common practice when water availability is limited. It implies less water percolation below the root zone but also a decrease in crop growth and N uptake. This is reflected in the results shown in Figure 3b, where crop yields are reduced by approximately 22% where deficit irrigation is used.

In contrast, the use of mulch has a beneficial effect on yield. Mulching, apart from numerous other agronomic advantages, enhanced crop N uptake due to an increase in soil temperature and N and water use efficiency leading to a reduction in NL. In addition to that, mulching protects the bed from direct infiltration of rainfall during the cropping season that may cause occasional NL. Various mulching materials exist (black PE films, cellulose, etc.) and the effect of them differs depending on permeability, biodegradability and other characteristics, but overall our meta-analysis, and other studies, have shown that mulched surfaces reduce quantities of nitrate leached in comparison with unmulched treatments.

The full results of the irrigated systems meta-analysis were provided to the Commission in report form (WP 1 Deliverable 1.5 Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems), and are also available in pdf form on the project website. It is expected that the results will also be published in a peer reviewed journal in 2013.

## ***WP2 Enhancement of the NDICEA decision support tool for reducing N losses in commercial farming***

In the N-TOOLBOX project partners outside of The Netherlands were introduced to the software package **NDICEA** ([www.ndicea.nl](http://www.ndicea.nl)) which was adapted for use in each partner country. The geographic range of the software was expanded by adding environmental files (weather and soil data) from England, Spain and Denmark. The language of the interface was also amended to include Spanish as well as English, Dutch and German. Project partners used NDICEA in their on-farm case studies (WP3) and through this experience became aware of the potential of this software, particularly as an educational tool.

One of the key scientific outputs of the project was the validation of the software using real field data from Spain, Denmark and the UK. The software was validated by comparing actual measured values for soil mineral N in topsoil and subsoil, with the values predicted by the model. The model performance was evaluated on datasets from these three countries by means of visual observation, RMSE and RSR from the soil nitrogen dynamics. A full report on this activity was provided to the Commission and is available as a pdf file on the project website (WP2 Deliverable 2.6 Evaluation of the NDICEA model, based on case studies in United Kingdom, Denmark, Spain and the Netherlands). Some of the key results from each country are outlined here.

### *Model validation in the UK*

Data from the Nafferton Factorial Systems Comparison trial in northern England were used in the validation procedure. This trial includes both organic and conventional crop rotations (Table 1), with organic and conventional fertility management practices superimposed on these rotations.

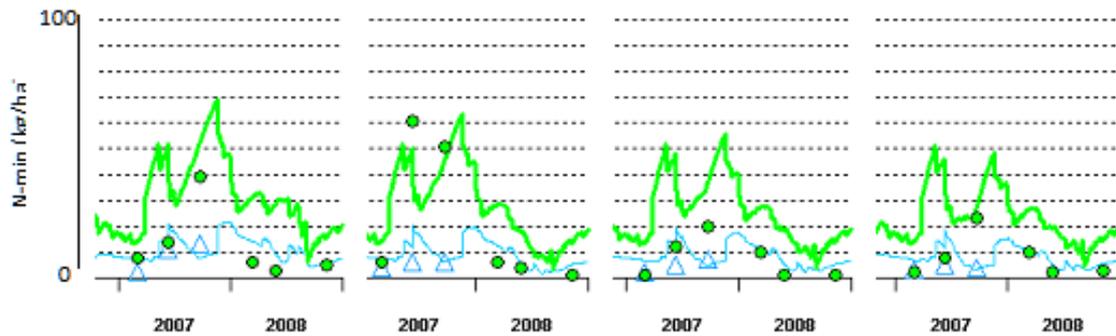
**Table 1. Sequence of crops grown in the conventional and organic rotations in the Nafferton Factorial Systems Comparison trials**

<b>Year</b>	<b>Conventional rotation</b>	<b>Organic rotation</b>
1	Grass/clover, full year	Grass/clover, full year
2	Grass/clover, year of ploughing	Grass/clover, year of ploughing
3	Winter wheat	Winter wheat
4	Winter wheat	White cabbage summer
5	Winter barley	Brown bean
6	Potato	Potato
7	Winter wheat	Summer barley

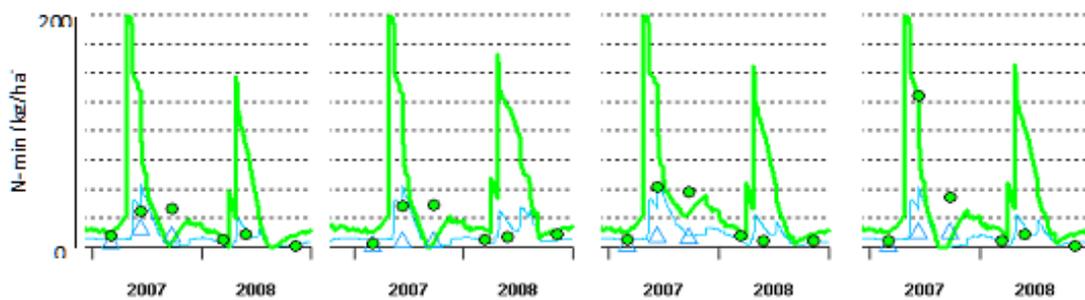
Simulations of treatments that used organic N inputs (i.e. all organic plots) were superior to those that used mineral N inputs (i.e. all conventional plots). This is demonstrated by the RMSE and RSR values shown in Table 2. For topsoil in the organically fertilized treatments, the RMSE ranged from 11.5 to 22.7 kg N/ha. An RMSE of 20 kg N ha<sup>-1</sup> or less was proposed by Van der Burgt et al (2006)<sup>4</sup> to represent acceptable model performance.

<sup>4</sup> Van Der Burgt, G.J.H.M., Oomen, G.J.M., Habets, A.S.J., Rossing, W.a.H., 2006. The ndicea model, a tool to improve nitrogen use efficiency in cropping systems. *Nutr. Cycl. Agroecosyst.* 74, 275-294.

These results are illustrated in Figure 4 which shows the simulations in the conventional crop rotation under organic management. The figure shows relatively good agreement between the measured and simulated values.



**Figure 4. Simulated versus observed concentrations of mineral nitrogen in the fully organic plots of the conventional rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.**



**Figure 5. Simulated versus observed concentrations of mineral nitrogen in the conventionally fertilized plots of the conventional rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.**

Results where mineral N inputs were used were not so good. RMSE values for the topsoil in these treatments ranged from 40.8 to 70.8 kg N/ha (Table 2). This is confirmed by the simulation shown in **Error! Reference source not found.** which shows consistent under-estimation of soil mineral N values in the topsoil for the June soil samples. These samples were taken relatively soon after N fertilizer application and should indicate higher mineral N than was measured, leading to the suggestion that the calculated nitrogen release out of fertilizer could be improved. There were some limitations to the data provided from the UK for validation. Timing of the soil sampling on soil inorganic nitrogen is important to realize a good model evaluation; two samples only, before sowing and after harvest, is not really enough to get a good assessment of model performance. In addition, when soil mineral nitrogen samples were taken during crop growth, model calculation and measured values sometimes showed big differences. This suggests that there is a need to improve the plant nitrogen uptake sub-model.

**Table 2. Root mean square error (RMSE) for topsoil and subsoil for all plots in the conventional rotation. C=conventionally fertilized, FC =fully conventional, O=organically fertilized, FO=fully organic. n=number of observations of mineral nitrogen, on which the calculation of RMSE is based.**

Name	RMSE topsoil	n	RMSE subsoil	n
C30A	66.38	6	17.23	3
C44A	68.95	6	18.49	3
C70A	59.8	6	14.59	3
C116A	70.8	6	20.17	3
FC28A	53.2	6	11.34	3
FC46A	52.79	6	14.92	3
FC68A	40.8	6	14.16	3
FC118A	61.64	6	17.34	3
O26A	18.63	6	8.42	3
O48A	11.48	6	6.3	3
O66A	18.7	6	5.55	3
O120A	14.55	6	7.36	3
FO32A	22.65	6	4.34	3
FO42A	13.34	6	4.64	3
FO72A	20.62	6	5.51	3
FO114A	19.6	6	5.13	3

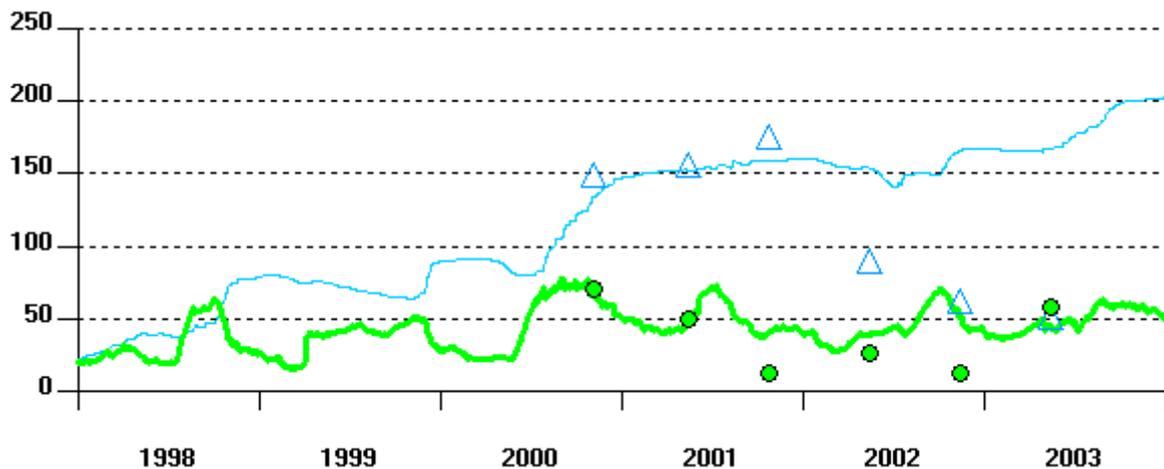
#### *Model validation in Denmark*

Data to test NDICEA's performance in Denmark were collected in an experiment published by Kristian Thorup-Kristensen (2006), titled: Effect of deep and shallow root systems on the dynamics of soil inorganic N during 3-year crop rotations. The experiment was realized in an existing organic crop rotation running since 1996 in Aarslev, Denmark. In this experiment, the impact of ten crop rotations, having various root patterns' sequences, on soil nitrogen dynamics were compared. Only organic inputs were used in these experiments.

**Table 3. Rotations used in field trials in Denmark**

Year	Rotation 1, 4, 5	Rotation 2, 3	Rotation 6, 7, 8, 9, 10
1	Green pea	Green pea	Green pea
2	Fodder radish	Fodder radish	Fodder radish
3	Spring barley	Spring barley	Spring barley
4	Grass/clover	Grass/clover	Grass/clover
5	Leek or red beet or white cabbage	Leek	Fallow
6	Spring barley	Spring barley	Fodder radish or ryegrass
7	Fallow	Rye grass or chicory	Leek or red beet or white cabbage

In the Danish dataset the soil mineral N of the topsoil was well described with RMSEs ranging from 13.3 to 28.1 kg N/ha. However, RMSEs in the subsoil were not so good, ranging from 28.6 to 75.8 kg N/ha. This might be caused by the depth of the subsoil, which was up to 2.5 meters for these experiments. The model performance could be improved by introducing a multi-layer soil sub-model instead of the actual two-layer soil sub-model. Figure 6 illustrates the N dynamics for rotation 1, showing that on two sample dates, soil mineral N was grossly overestimated by the model.



**Figure 6. Simulated versus observed concentrations of mineral nitrogen for treatment 1. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil. X-axis: kg mineral nitrogen ha<sup>-1</sup>. Y-axis: years.**

The reason for this lack of correspondence between observation and simulation is unknown. A possible explanation could be found in the depth of the subsoil, in this case 50-250 cm. In modelling the Danish system in NDICEA, the soil was divided in two compartments: 0-50 and 50-250 cm. For the subsoil, this implies that the nitrogen dynamics (leaching, capillary rise, plant uptake) of two meters of soil is averaged. The model could not take into account differences in nitrogen concentration within this two meters of soil. Gaining insight in nitrogen dynamics in soil between 50 and 250 cm below surface was exactly the objective of the study done by Thorup-Kristensen. He showed that plants can take up nitrogen that was leached down the soil profile. Since NDICEA is a two-layer model, these dynamics in the area of 50-250 cm below surface could not be shown. Including multiple layers would allow for a more precise modelling of nitrogen dynamics in deeper soil layers.

### **Model validation in Spain**

In irrigated maize production in dry areas in Spain, the risk of nitrogen leaching is high. However, there are technical opportunities to match crop nitrogen demand with nitrogen availability. Water management and a fertilization scheme are the instruments to improve nitrogen use efficiency and hence reduce nitrogen losses by leaching. This is why the Universidad Politécnica de Madrid has started research and evaluation projects in irrigated maize cultivation in the Albacete and the Aranjuez region. A dataset from Albacete was used in this report.

Spain, with its different climatic and soil conditions, needed an adaptation of the evapotranspiration calculation and a calibration of the scenarios to reach an acceptable model performance. If more Spanish datasets were studied, the NDICEA model could be enriched with standard Spanish soils and evapotranspiration data.

In a three-year experiment from 2003 to 2005, seven fertilizer treatments were compared with a zero treatment, resulting in eight treatments without replicates. The treatments are listed in Table 4. Maize was sown in the beginning of May and harvested in the beginning of October. Both seeds and crop residues were harvested, resulting in a very limited return of organic matter to the soil. The soil is a Calcixerolli – xerochrept with an Ap soil layer 0-25 cm and a Bk layer up to 40 cm. Root growth is supposed to be limited to 40 cm depth.

**Table 4. Treatments in the experiment used for model validation in Spain**

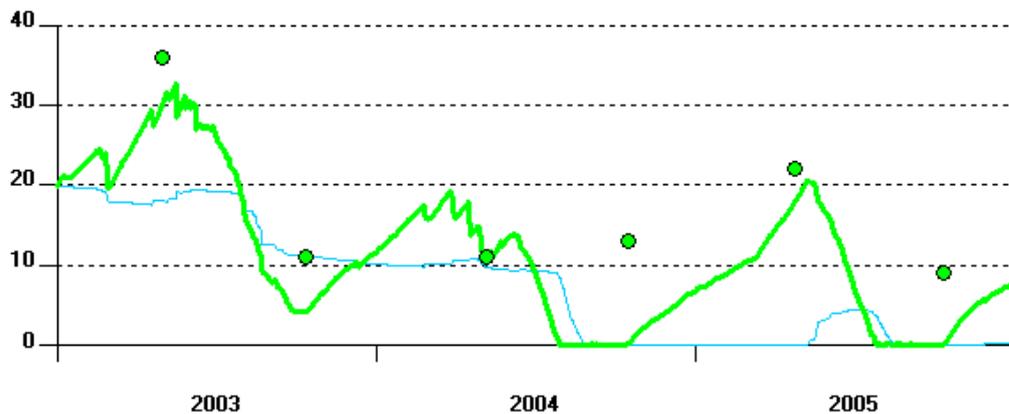
Name	Description
0	No fertilizer
40	40 kg N/ha artificial fertilizer, four weeks after sowing
120	120 kg N/ha artificial fertilizer, four weeks after sowing
200	200 kg N/ha artificial fertilizer, four weeks after sowing
280	280 kg N/ha artificial fertilizer, four weeks after sowing
360	360 kg N/ha artificial fertilizer, four weeks after sowing
280_2	140 kg N/ha artificial fertilizer, four weeks after sowing, 140 kg three weeks later
360_2	180 kg N/ha artificial fertilizer, four weeks after sowing, 180 kg three weeks later

**Table 5. RMSE of three series of simulations. Basic = original default model parameters. Cal = calibrated individually. CalAv = Average model parameters after calibration. n=6**

name	RMSE Basic	RMSE Cal	RMSE CalAv
0	12	7	8
40	21	5	6
120	37	16	16
200	23	8	9
280	39	11	14
360	54	23	25
280_2	32	8	9
360_2	53	23	25

The RMSE of the simulations with the default soil model parameters was mostly >20, and only satisfying for the zero treatment (Table 5, column 'Basic'). In all cases except for the zero treatment, simulated soil mineral N values were higher than measured values (data not shown).

Calibration considerably improved model performance in terms of RMSE (Table 5, columns Cal and CalAv). Only the two 360 treatments kept a RMSE > 20 kg N ha<sup>-1</sup>. Replacing the individual soil parameters by the average parameters slightly increased the RMSE, as expected, but the number of scenarios with an RMSE below 20 remained the same (6 out of 8, Table 5).



**Figure 7. Course of mineral N in treatment 0. Green line: simulated mineral N value topsoil. Blue line: simulated mineral N value subsoil. Green dots: measured mineral N values topsoil.**

After calibrating the soil parameters the model describes soil nitrogen dynamics at an acceptable level. In the modeling of this experiment it is not possible to find out why the calibration is needed, in other words, why the default soil parameters result in a structural shift. The model was build and until recently, only validated for north-west European soils and climatic conditions. In this arid area in Spain both soil and climate are different, and these factors can cause a structural shift in the model. Further investigations on other datasets are needed to find out why this shift occurred. Moreover, additional studies are needed to better adapt the model to Spanish conditions, for example by creating specific default values within the model.

### **WP3 Farm level assessment of N-TOOLBOX**

#### *On-farm case studies*

Working directly with farmers in WP3 was a new experience for many of the project partners. This was viewed as positive as it allowed the scientists to gain an improved appreciation of the practicalities of N management at the farm level. Farmers were attracted to the project by the promise of results specific to their farm on things like crop yield and soil N status. While the scientists and advisors enthusiastically adopted NDICEA as a learning tool, farmers were reluctant to use it themselves. However, NDICEA proved very effective during farmer meetings as a stimulus for discussion about causes of N losses within a crop rotation, and for investigating strategies to reduce those losses. A detailed report on the outcomes of WP3 has been provided to the Commission (**Farm level assessment of N-TOOLBOX in the UK, the Netherlands, Denmark and Spain**). In addition, the key results from the N-TOOLBOX project and the case studies have been provided in PDF format (**Implementing water protection policy at the farm level in the European Union: lessons from the N-Toolbox case studies**) and summarized on the N-TOOLBOX website.

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.

Some general conclusions can be drawn from the case studies in Spain, the UK, The Netherlands and Denmark.

- The case studies showed that despite current legislation and economic factors that encourage farmers to reduce N fertilizer rates to crops there is still a margin for reducing N application by about 20-100% in several cases. In other cases reductions beyond current levels will jeopardize yields and may increase N leaching due to poor crop growth.
- The strategies that showed most suitable for reduction of N leaching in the case studies included
  - balanced nitrogen application rates,
  - split dose applications,
  - slow release fertilizers,
  - crop rotations with alternating high and low N requiring crops, and
  - use of catch crops.
- Decision support tools like the NDICEA model provided a useful way for knowledge transfer and stimulation of discussions and decision making of farmers on the implementation of strategies for reduction of N leaching.
- Knowledge on soil inorganic N content in spring is important for decision making on implementation of strategies.
- Intensive vegetable production on sandy soils poses special challenges for reduction of N leaching that may call for more radical changes in the cropping systems.
- Organic vegetable production based on incorporation of green manure and fertilizer application may have high N leaching.
- Knowledge transfer from researchers to farmers/advisors is important to enable willingness of farmers to adopt new strategies to prevent nitrogen losses. Advisors have an important role in the knowledge transfer to farmers.
- The farmers in the case studies were open to apply strategies for N reduction, but that there needed to be clear advantages beyond “just preventing nitrogen leaching” to ensure taking decision of implementing such strategies. This was especially true for strategies that include risks (e.g. reduction of crop yield) and costs (e.g. sowing a green manure).
- Farmers/advisory service workshops and university classes were useful for dissemination and knowledge transfer on tools for reduction of N leaching and the NDICEA model.

### *Identification of knowledge gaps*

Another important output from the project was the report summarizing knowledge gaps in the area of N losses to water from agriculture (WP3 Deliverable 3.5.2 Gaps in knowledge and directions for future research to reduce N losses from agriculture in the European Union). This report explained how there are no “magic bullets” that will solve the problem of water pollution by nitrate from agricultural sources. Livestock producers are faced with particular challenges. Confined animal feeding operations (CAFOs) often produce nutrients in excess of the land area available for manure application. This is a fundamental problem with these systems - livestock production is often geographically separated from the land where the animal feed is produced. The problem can be addressed to some extent by improving the efficiency of feed nutrient use by animals, an area that

still needs more research. Farmers could take more control over the nutrient balance on their farms if they had access to simple decision support tools to help them optimize feed rations.

In more extensive, pasture-based systems, there are still environmental risks created when stocking densities are too high, or access to water courses is not restricted, or when animals are kept on the land during periods when net drainage is occurring (i.e. during the winters in northern Europe). Research can help improve the environmental profile of pasture-based systems by developing better models that include soil, animal and plant components. The development of simple decision support tools that warn the farmer when net drainage is about to begin, alerting him to the need to remove his animals from the pasture, could help farmers to become better land managers and reduce the risk of pollution from pastures.

As already identified in the on-farm case studies, there is still potential to reduce fertilizer N applications to crops. One area with great potential to improve the efficiency of fertilizer N supply to crops is precision agriculture. This includes remote and real-time sensing techniques that allow the farmer to match fertilizer applications to crop needs at a very precise scale (i.e. varying application rates per square meter, rather than per hectare). Equipment manufacturers and progressive farmers have shown great interest in this technology, but it is acknowledged that the agronomic information required to back up fertilizer rate decisions, is not always available. There is a real need for agronomists, soil scientists and crop scientists to work together with equipment manufacturers so that the full potential of this technology to balance fertilizer N supply with crop needs can be realized. There is also a need to develop this technology for use with vegetable crops, since to date the emphasis has been on major crops (winter wheat, maize etc.).

Private laboratories and scientists continue to persevere to identify a soil test that is predictive of N release from soil organic matter during the growing season. This is notoriously difficult, especially in regions with high rainfall, since the soil N cycle is dynamic with various gain and loss pathways that are influenced by moisture and temperature. Extensive research has been carried out already, and there is a need to compile the findings from across Europe to identify which tests are most likely to be effective, taking into account local soil and weather conditions. The way forward with these tests will likely be to link them to dynamic soil N models so that soil mineral N supplies over the growing season can be made available in real time to assist farmers with decision making about fertilizer N applications.

## Potential impact and main dissemination activities

The N-TOOLBOX project encompassed a broad range of activities expected to have an indirect and direct impact on a range of sectors within society.

The outputs of the project expected to impact on the farming community include the **website**, which provides a wealth of information about best management practices to reduce losses of N to water from farming systems. The catalogue of strategies is available on the website as a downloadable pdf file, as well as an on-line tool to help farmers to identify the best set of practices for their farm. There are also documented examples of N-TOOLBOX activities in the partner countries. It is hoped that farmers, advisors and policy makers will learn from the experiences gained during the on-farm case studies.

The information is available in five languages on the website (English, Spanish, French, German and Dutch) which should greatly increase the impact of the site. It is now essential that the N-TOOLBOX website link is made available on other websites, to improve site traffic and expand the potential impact of the project activities.

The NDICEA software tool has been expanded to allow use in Denmark, Spain and the UK. This has already had an impact on the various farmers who participated in the on-farm case studies during the project, as well as others who attended farmer meetings. Project partners also learned to use NDICEA as a teaching tool for MSc and undergraduate students. Student exposure to the software is expected to trickle out to the agricultural and research communities as the graduates use NDICEA in their future research and advisory roles.

The on-farm case studies allowed the scientists to interact directly with farmers, something that was a new experience for many of the participants. While the numbers of farmers that were reached in this way was relatively small, the impact of this activity is expected to be long-term. Scientists learned a new way of working that involved farmer consultation and adaptation of experiments to meet farmer needs. This new way of working will be carried over into future projects by many of the participating scientists. Good links and communication between the scientists and the participating farmers were established. The farmers involved are expected to be more open in the future to collaborating in research projects and more empowered to carry out research in consultation with scientists.

N-TOOLBOX partners delivered a total of 29 presentations in the four partner countries. Audiences for these presentations ranged in size from as few as 3 people, attending farmer training sessions on the use of NDICEA in Spain, to as many as 250 people at the Bio Veldag event in The Netherlands. Posters about the project and the NDICEA software package were presented at international meetings including the International N Workshop in Ireland and the International Fertiliser Society in the UK. A poster was also displayed at the Northumberland County Show in northern England, where it is estimated that 500 people were exposed to the information. Eight workshops were held: these had a relatively big impact in Spain where a total of 100 people participated, as well as The Netherlands where over 200 people attended workshops where NTOOLBOX was discussed. In the UK, workshops were smaller and focussed on transferring project results from on-farm case studies directly to farmers. They provided a wonderful opportunity to informally discuss issues relating to N pollution from agriculture, and to show our appreciation to the farmers.

A total of six theses were written based on N-TOOLBOX project activities. Considering the relatively small size of this project, and the fact that research was not its primary focus, this is an impressive achievement. These theses covered a range of topics including an economic analysis of strategies to reduce N losses to water in the UK, the uptake of N by deep roots of fodder radish in Denmark, and the decomposition rate of organic fertilizers in The Netherlands. Theses

The final N-TOOLBOX stakeholder workshop was held in Brussels in September 2012. This event brought together representatives from a number of Departments within the Commission (e.g. DG Agriculture, DG Environment, DG Climate and DG Research), as well as some national representatives. It provided a useful opportunity to present findings to key stakeholders and to identify further activities to add value to the work done within the N-TOOLBOX project. While numbers attending were not high, some useful comments were received and useful contacts made. Since then, the coordinator has been in touch with several of the participants to follow up on issues raised during the workshop.

### **Public website address and contact details**

The public website ([www.ntoolbox.eu](http://www.ntoolbox.eu) or [www.n-toolbox.eu](http://www.n-toolbox.eu)) is currently hosted within the Nafferton Ecological Farming Group's outreach website ([www.nefg-organic.net](http://www.nefg-organic.net)). The project website will be maintained within the NEFG site indefinitely.

Dr. Julia Cooper is the main contact person for follow up information on this project. She can be reached at:

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