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

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Report on:
Enhancement of the NDICEA decision support tool for reducing N losses in commercial farming

Geert-Jan van der Burgt & Petra Rietberg,
Louis Bolk Institute, The Netherlands

N-TOOLBOX

practical solutions to nitrate pollution

Evaluation of the NDICEA model

P.I. Rietberg
G.J.H.M. van der Burgt

Evaluation of the NDICEA model, based on case
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corresponding author: g.vanderburgt@louisbolk.nl

www.louisbolk.org

Preface

The NDICEA nitrogen and organic matter model, originally constructed to support organic arable farming in the Netherlands, has been developed into a tool for sustainable agriculture. To enhance the use in other countries, an evaluation of the performance of the model in England, Denmark and Spain has been realized. We thank Julia Cooper (University of Newcastle, Nafferton Ecological Farming Group), Kristian Thorup-Kristensen and Hanne L. Kristensen (Aarhus Universitet), and Miguel Quemada (Universidad Politécnica de Madrid) for providing datasets and supporting us in constructing reliable NDICEA input files. Moreover we acknowledge the the European Commission, Directorate General for Research, who co-funded this project (N-TOOLBOX-227156) within the 7th Framework Programme of RTD, Cooperation Theme 2 - Biotechnology, Agriculture & Food. At last we acknowledge the Dutch Ministry of Economic affairs, Agriculture and Innovation for their part in co-funding this project.

Contents

Summary

Within the N-Toolbox project the NDICEA nitrogen model, one of the key tools in the virtual Toolbox, has been improved and tested in England, Denmark and Spain. The model performance was evaluated on datasets from these three countries by means of visual observation, RMSE and RSR from the soil nitrogen dynamics.

In England the scenarios with organic fertilizer performed better than those with artificial fertilizer, leading to the suggestion that the calculated nitrogen release out of fertilizer could be improved. 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 enough. When soil mineral nitrogen samples were taken during crop growth, model calculation and measured values showed sometimes big differences. It is suggested to improve the plant nitrogen uptake sub-model.

In the Danish dataset the soil mineral N of the topsoil was well described, but that of the subsoil was not. This might be caused by the depth of the subsoil, which was up to 2.5 meters. The model performance could be improved by introducing a multi-layer soil sub-model instead of the actual two-layer soil sub-model.

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.

For the improvement of the model, equations from the EU-ROTATE_N model are used to describe root growth and nitrogen uptake in more detail.

Samenvatting

In het N-Toolbox project is het NDICEA stikstofmodel, één van de gereedschappen uit de stikstofgereedschapskist, verbeterd en getest in Engeland, Denemarken en Spanje. De prestaties van het model zijn getoetst op basis van visuele beoordeling, RMSE en RSR van de stikstofdynamiek.

In Engeland bleken de scenario's met organische mest beter te presteren dan die met kunstmest. Dit leidt tot de suggestie dat het vrijkomen van stikstof uit kunstmest nog onvoldoende adequaat in het model berekend wordt. De timing van de bemonstering van de grond op minerale stikstof is belangrijk om een goede modelevaluatie te kunnen doen. Twee keer per jaar, voor zaai en na oogst, is niet voldoende. In de gevallen waarin wel tijdens de teelt monsters zijn genomen was er soms een groot verschil tussen de gemeten en de berekende waarde. Een verbetering van het sub-model voor N-opname wordt kort besproken.

In de Deense dataset werd de stikstofdynamiek van de bovengrond goed beschreven, die van de ondergrond niet. De oorzaak hiervan ligt misschien bij de diepte van de ondergrond, tot 2,5 meter. De modelprestaties zouden dan verbeterd kunnen worden door over te gaan van een tweelaags bodemsubmodel naar een multi-laags submodel.

In Spanje, met ten opzichte van Noord-West Europa sterk afwijkende bodem- en klimaatcondities, was het nodig de evapotranspiratieberekeningen aan te passen en de scenario's te calibreren voordat er een bevredigend resultaat zichtbaar werd. Als er meer Spaanse datasets bestudeerd zouden worden zou dat kunnen leiden tot specifieke Spaanse bodemparameters en waterberekeningen.

Voor de verbetering van het model zijn algoritmes gebruikt uit het EU-ROTATE_N model om de wortelgroei en stikstofopname meer in detail te modelleren.

1 Introduction

Excessive leaching of nitrogen is associated with ground and surface water contamination and biodiversity loss in both aquatic and terrestrial ecosystems. Throughout Europe, intensive agriculture takes place in areas vulnerable to losses of nitrogen by leaching. Farmers and policy makers in those areas face the double challenge of minimizing such environmental losses while optimizing crop yields.

According to the European Nitrate Directive, nitrogen concentration in ground water should not exceed 50 mg/L. Reaching this target is a major challenge in areas vulnerable to nitrogen leaching. For example, in the Netherlands, the average nitrate concentration in ground water under sandy soils was 87 mg/L (RIVM 2008, data from 2003-2005).

Measures to prevent nitrogen losses have been studied extensively by scientists and extension workers. Implementation in practice, however, lags behind. The N-toolbox project aims at bridging this gap by discussing the practical applicability of possible measures to prevent losses and by monitoring pilot farms where such measures are applied.

Within the N-toolbox project, the NDICEA-model is used as a tool to enhance understanding of nitrogen dynamics in the field and support decision-making. The model can help to assess risks of nitrogen losses by leaching and denitrification. NDICEA, an acronym of Nitrogen Dynamics In Crop rotations in Ecological Agriculture, was constructed by Wageningen University and has been further developed by the Louis Bolk Institute.

The NDICEA-model is target oriented: crop yield and crop quality parameters (e.g. dry matter content, nitrogen content) are used as a basis for crop nitrogen uptake calculations. Mineralization of nitrogen from soil organic matter as well as organic inputs such as manure and compost is calculated, based on actual weather data and soil characteristics. NDICEA has a time step of one day. NDICEA model functioning is described in detail by Van der Burgt et al. (2006).

Until recently, NDICEA had been validated for a German agro-ecological system only (Van der Burgt et al. 2006b) and used in other conditions (Van der Burgt et al. 2006 a; Topps et al. 2006; Koopmans and Van der Burgt, 2005; Van der Burgt 2004). Potentially, it could serve as a tool in other countries and systems as well. The N-toolbox project aims at extending NDICEA model use to various pedo-climatic conditions and agro-management systems. The applicability of the model for use in other regions needs to be tested.

The purpose of this study is to evaluate the NDICEA model. In doing so, the modeling of mineral nitrogen in the topsoil is taken as a proxy for overall model performance. Does the model accurately predict mineral nitrogen availability in the topsoil? In order to answer this question, model calculations are compared with measurements of mineral nitrogen as explained in the methods section. The criteria used in the evaluation process are elaborated in that section as well.

In this study, the applicability of NDICEA is tested for four different agricultural systems. All data stem from regions targeted in the N-toolbox project: regions where intensive agricultural production is taking place on vulnerable soils, having a high risk of nitrogen leaching and contamination of ground and surface water. The case studies on which the evaluation of NDICEA is based are located in Northumberland, England; Aarslev, Denmark; and Albacete, Spain. The case studies are outlined in chapters 3 - 5. Chapter 6 contains a general discussion and the main conclusions. In chapter 7 the model adaptations as they are realized during the N-Toolbox project are briefly described. The introduced algorithms can be found in Annex 1.

2 Methodology

Short descriptions of the case studies on which the analyses are based, as well as the materials and methods used in the case studies, are given in chapters 3 - 5. Here, the calculations and criteria used in the evaluation are outlined. These were applied in all three cases.
Moriasi et al. (2007) reviewed literature on model evaluation of watershed simulations. They indicated that model evaluation is best achieved using a combination of both visual observation and quantitative assessment. In this paper, both methods were used. Simulation of mineral nitrogen in topsoil and subsoil by NDICEA wass compared with mineral nitrogen content observed in the field. Besides visual observation, the root mean square error (RMSE) and the root mean square error standard deviation ratio (RSR) were calculated.

2.1 Visual observation

Time versus nitrogen-leaching graphs, which is NDICEA-output, were observed to obtain an indication of the accuracy of the modeling. In addition, visual observation was used to assess whether the difference between observation and simulation is related to the timing of events. Theoretically, a high RMSE could result from a mismatch in timing (i.e. a nitrogen peak that is simulated to occur (slightly) earlier or later than observed) and not from a wrong estimation of the size of the soil mineral nitrogen content. Visual observation gave an indication of the nature and cause of the RMSE observed, although the limited number of observations of mineral nitrogen did not allow for the observation of a clear trend in mineral nitrogen.
In addition, NDICEA could model a mineral nitrogen content of the soil of zero. Theoretically this is possible, but this is very unlikely to happen. Therefore a mineral N level of zero in topsoil or subsoil was considered as an incorrect simulation. The number of times that a mineral nitrogen content of zero is modeled was counted and taken as a model performance.

2.2 RMSE

The RMSE is a statistic that has been widely used to evaluate model performance (Moriasi et al., 2007). For NDICEA, the RMSE had previously been used to evaluate model performance at several sites in The Netherlands. An RMSE of 20 kg N ha^{-1} or less was proposed by Van der Burgt et al (2006) to represent acceptable model performance. This is the size of deviation that farmers deem acceptable.
For each plot, the RMSE was calculated. For the Nafferton dataset, that contains data from four treatments in four repetitions, the RMSE was calculated as well for the four treatments – data of the repetitions are thus taken together. In all cases a distinction was made between subsoil and topsoil.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y^{sim} - Y^{obs})^2}{n}}$$

2.3 RSR

Moriasi et al. (2007) stress the need for dimensionless statistics to evaluate model performance. Those are especially useful when comparing different models. In addition, universal criteria for model performance evaluation can be used with dimensionless statistics.

The RMSE-observation standard deviation ratio (RSR) is such a statistic, in which the size of the RMSE is compared to the size of the standard deviation of the measurements:

$$\text{RSR} = \text{RMSE}/\text{STDEV}_{\text{obs}} = \sqrt{\sum_{i=1}^{n} \frac{(Y^{sim} - Y^{obs})^2}{n}} \Bigg/ \sqrt{\sum_{i=1}^{n} \frac{(Y^{obs} - Y^{mean})^2}{n}}$$

The lower the RMSE, the closer the simulated values are to the observed values. Singh et al. (2004, cited by Moriasi et al. 2007) consider an RSR of 0.5 or less low, and model performance ‘very good’. In addition, Moriasi et al. (2007) state that model performance is ‘good’ when the RSR is between 0.5 and 0.6, whereas an RSR between 0.6 and 0.7 indicates ‘acceptable’ model performance. Cameira et al. (2007) state that the RMSE ideally is lower than the standard deviation of the measured data. If the RMSE and standard deviation have the same values, the RSR is one. We considered an RSR of one or smaller acceptable, whereas we considered an RSR of 0.5 or less good.

3 Case 1: England

3.1 Introduction

Comparing organic and conventional agricultural systems is difficult, among others because they differ in both crop protection management and fertilization strategy. Differences in yield therefore cannot be easily ascribed to differences in pesticide use or use of manure or fertilizer. In at Nafferton Farm in Northumberland County (United Kingdom), an experiment was set up aiming at separating the effects of herbicides and pesticides from the effects of fertilizer type and amount in organic and conventional cropping systems.

3.2 Methods: collection and characteristics of the dataset

The experiment was executed from 2002-2008 on a sandy clay loam soil at Nafferton Farm which is located to the west of Newcastle-upon-Tyne in Northumberland County, United Kingdom. Four treatments were established: fully conventional (FC), in which both pesticides and artificial fertilizer were used, conventionally fertilized (C), in which artificial fertilizer was used, but no pesticides, fully organic (FO), in which animal manure was used without pesticides, and organically fertilized (O), in which animal manure was used and pesticides were allowed. The experiment was set up as a randomized complete block design with four repetitions. In addition, the experiment was set up on two adjacent locations, one with a typical organic crop rotation (OR), one with a conventional rotation (CR) Thus, 32 plots were used for our study.

Rotation & inputs

Conventional rotation

The conventional rotation is shown in Table 1. Schematic overview of the conventional rotation with the conventional and organic inputs are shown in Figure 1 and Figure 2. The inputs used in those rotations are shown in Table 2 and Table 3.

Table 1. Conventional rotation

1	Grass/clover, full year
2	Grass/clover, year of ploughing
3	Winter wheat
4	Winter wheat
5	Winter barley
6	Potato
7	Winter wheat

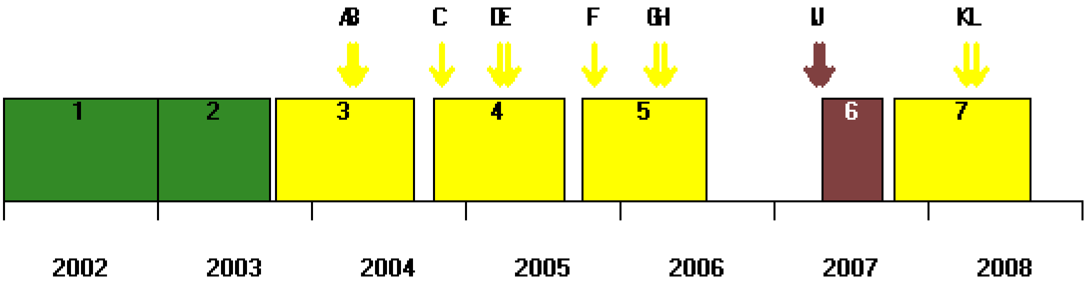


Figure 1 Schematic overview of the conventional rotation in place and timing of inputs in the conventional treatments (FC and C). Blocks indicate crops, arrows indicate timing of inputs.

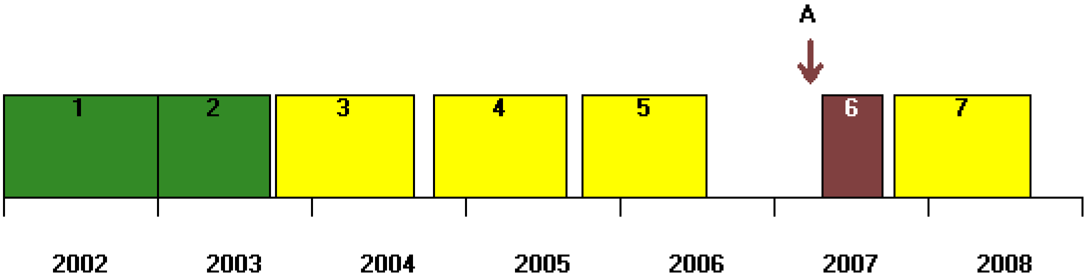


Figure 2 Schematic overview of the conventional rotation in place and timing of inputs in the organic treatments (FO and O). Blocks indicate crops, arrows indicate timing of inputs.

Table 2. Applications of artificial fertilizer (ammonium nitrate) in the conventional treatments (FC and C) in conventional rotation. Letters and numbers correspond with letters and numbers in Figure 1 .

		Date of application	N (kg/ha)
A	3	29-3-2004	50
B	3	16-4-2004	130
C	4	5-11-2004	0
D	4	21-3-2005	80
E	4	11-4-2005	130
F	5	2-11-2005	0
G	5	29-3-2006	50
H	5	16-4-2006	120
I	6	12-4-2007	0
J	6	25-4-2007	180
K	7	31-3-2008	50
L	7	24-4-2008	130

Table 3. Application of dairy manure compost in the organic treatments (FO and O) in the conventional rotation. Letters and numbers correspond with letters and numbers in Figure 2

		Date of application	N (kg/ha)
A	6	26-3-2007	170

OR Organic rotation

The organic rotation is shown in Table 4. Schematic overviews of the organic rotation with the conventional and the organic inputs are shown in Figure 3 and Figure 4. The inputs used in those rotations are shown in Table 5 and Table 6.

Table 4. Organic rotation

1	Grass/clover, full year
2	Grass/clover, year of ploughing
3	Winter wheat
4	White cabbage summer
5	Brown bean
6	Potato
7	Summer barley

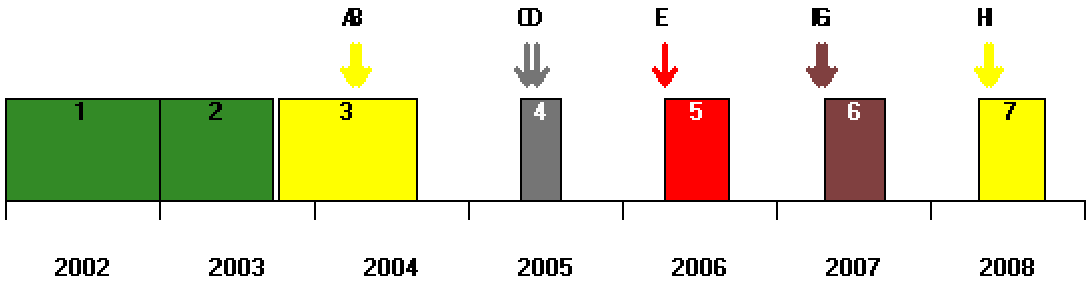


Figure 3 Schematic overview of the organic rotation in place and timing of inputs in the conventional treatments (FC and C). Blocks indicate crops, arrows indicate timing of inputs.

Table 5. Applications of artificial fertilizer (ammonium nitrate) in the conventional treatments (FC and C) in the organic rotation. Letters and numbers correspond with letters and numbers in Figure 3.

		Date of application	**N (kg/ha)**
A	3	29-3-2004	50
B	3	16-4-2004	130
C	4	18-5-2005	100
D	4	9-6-2005	160
E	5	10-4-2006	0
F	6	12-4-2007	0
G	6	25-4-2007	180
H	7	13-5-2008	60
I	7	22-5-2008	60

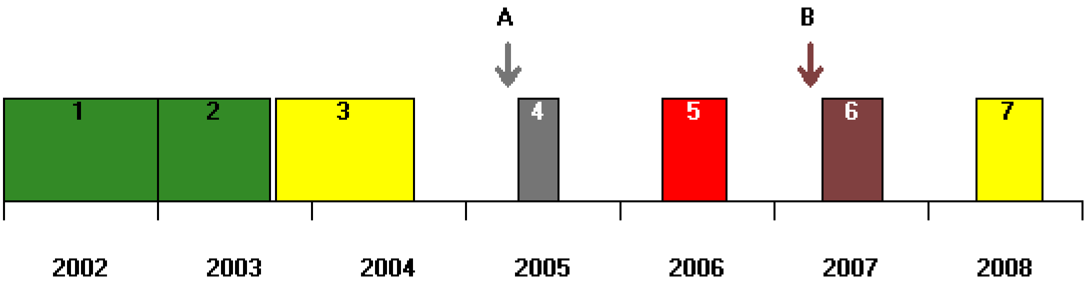


Figure 4 Schematic overview of the organic rotation in place and timing of inputs in the organic treatments (FO and O). Blocks indicate crops, arrows indicate timing of inputs.

Table 6. Application of dairy manure compost in the organic treatments (FO and O) in the organic rotation. Letters and numbers correspond with letters and numbers in Figure 4.

		Date of application	N (kg/ha)
A	4	11-4-2005	249
B	6	26-3-2007	170

For running the NDICEA model many crop and soil parameters need to be inputted. Some of these parameters were obtained from the Nafferton dataset (for example yield, N-content, sowing and harvest dates, fertilizer application dates and amounts). For other input parameters which were not available in the dataset, model averages or best guesses were used. All NDICEA parameters are available on request.

3.3 Results

3.3.1 RMSE of the conventional rotation

RMSE of topsoil was higher than 40 kg N ha^{-1} in all conventional plots, and below 20 kg N ha^{-1}in all but one organic plot (*Table 7*). In the subsoil, RMSE was below 20 kg N ha^{-1} in all cases, and below 9 kg N ha^{-1} in all organic plots (*Table 7*).

Differences between simulated and observed values were especially large in May and June (Table 8). In most cases simulated mineral nitrogen was higher than observed mineral nitrogen (Table 8). Simulation nitrogen content in the topsoil did not reach zero in the conventionally fertilized and fully conventional plots, and simulated nitrogen content in the subsoil reached zero once in one fully conventional plot. In both the organically fertilized and fully organic plots, simulated nitrogen content reached zero once in half of the plots and twice in the other half (not shown).

Table 7. 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.

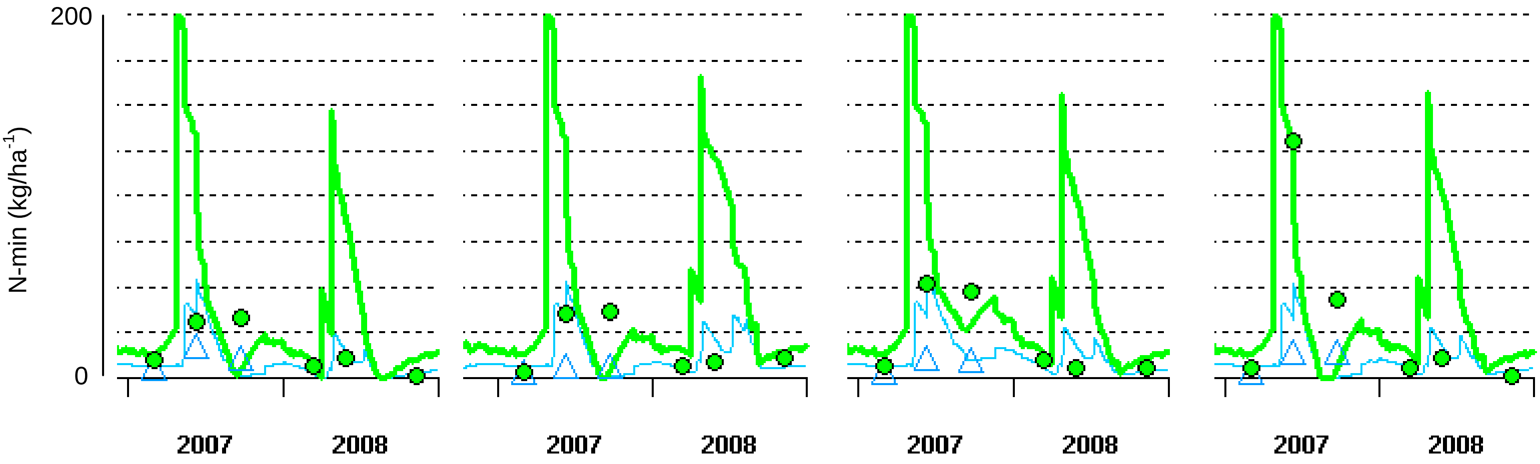
Name	**RMSE topsoil**	**n**	**RMSE subsoil**	**n**
C30A	66.38	6	17.23	3
C44A	68.95	6	18.49	3
C70A	59.8	6	14.59	3
C116A	70.8	6	20.17	3
FC28A	53.2	6	11.34	3
FC46A	52.79	6	14.92	3
FC68A	40.8	6	14.16	3
FC118A	61.64	6	17.34	3
O26A	18.63	6	8.42	3
O48A	11.48	6	6.3	3
O66A	18.7	6	5.55	3
O120A	14.55	6	7.36	3
FO32A	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

Table 8. Comparison of simulated and observed values of mineral nitrogen at different dates for all plots together. RMSE=root mean square error, sim.=simulated, obs.=observed, n=number of observations on which the calculation of RMSE is based, FC= fully conventional, C= conventionally fertilized, FO=fully organic, O=organically fertilized, number of observations whereby the difference between simulated and observed > 20 kg N ha^{-1}.

						# (sim. <obs.) >20					**% (sim. <obs.) >20**
Date	**n**	**# sim. <obs.**	**# sim >obs.**	**RMSE topsoil**	**RMSE subsoil**	**All**	**FC**	**C**	**FO**	**O**	
2-3-2007	32	0	32	8.1	5.6	0	0	0	0	0	0.0
11-6-2007	32	3	29	75.9	19.3	18	6	8	3	1	59.4
24-9-2007	32	21	12	21.8	7.0	6	2	3	0	1	18.8
12-3-2008	16	0	16	15.8		2	0	0	2	0	12.5
27-5-2008	16	0	16	71.5		9	4	4	1	0	56.3
11-11-2008	16	0	16	10.1		0	0	0	0	0	0.0

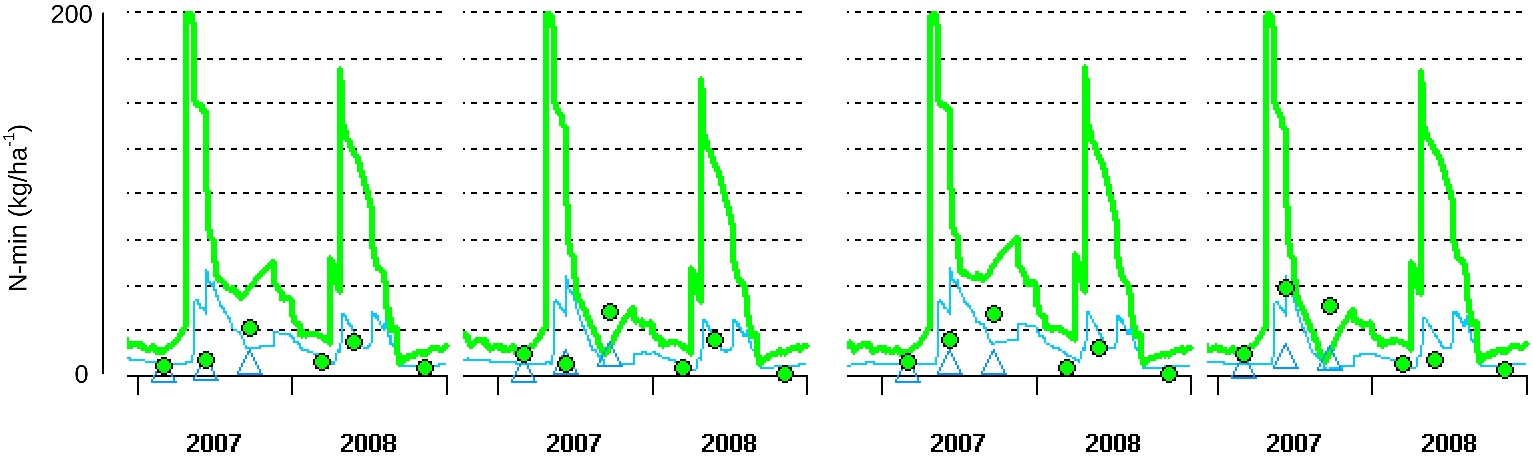
For the conventionally fertilized and fully conventional plots, graphical representation of the results is shown in Figure 5 and a. b. c. d.

Figure 6. Simulation and observation differed especially in June 2007 and May 2008 – the high peak in nitrogen availability modelled by NDICEA was not observed in the field. The model overestimated mineral nitrogen availability on almost all dates – though not in September 2007.



a. b. c. d.

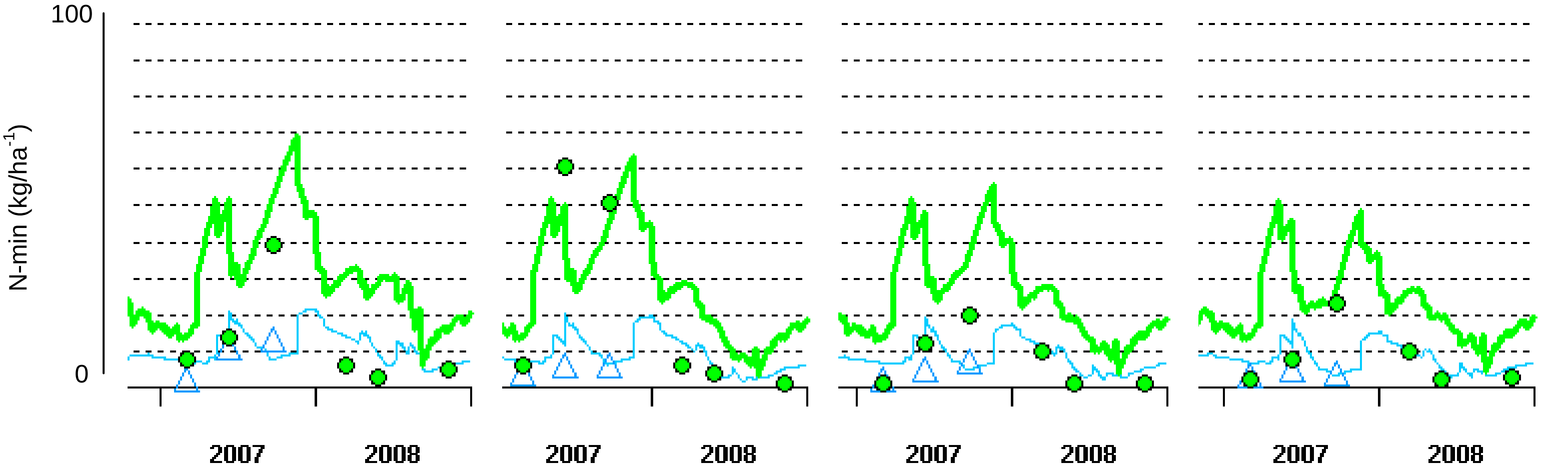
Figure 5 a-d. Simulated versus observed concentrations of mineral nitrogen in the fully conventional plots of the conventional rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.



a. b. c. d.

Figure 6 a-d. 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.

In the fully organic and organically fertilized plots, the deviation between simulated and observed mineral nitrogen content was highest in May 2007 and June 2008. However, the differences were not as large as in the fully conventional and conventionally fertilized plots. In the organically fertilized and fully organic plots available nitrogen is overestimated by NDICEA in almost all cases (Figure 7 and not shown).



a. b. c. d.

Figure 7a-d. 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.

3.3.2 RSR of the conventional rotation

RSR for the topsoil observations and simulations were below one for about half of the (fully) organic plots and for only one of the (fully) conventional plots. For the subsoil, RSR was below one for three (fully) organic plots only.

Table 9. Root means square error – standard deviation ratio (RSR) of topsoil and subsoil of all plots in the conventional rotation. n=number of observations on which the calculation is made.

Name	RSR topsoil	N	RSR subsoil	n
C30A	5.26	6	3.82	3
C44A	5.66	6	6.99	3
C70A	3.11	6	4.54	3
C116A	7.93	6	9.69	3
FC28A	4.01	6	1.74	3
FC46A	2.41	6	3.42	3
FC68A	0.82	6	2.23	3
FC118A	4.19	6	10.01	3
O26A	0.99	6	0.84	3
O48A	0.58	6	0.96	3
O66A	1.94	6	3.20	3
O120A	0.80	6	1.43	3
FO32A	1.68	6	0.74	3
FO42A	0.49	6	4.02	3
FO72A	2.62	6	2.19	3
FO114A	2.43	6	5.13	3

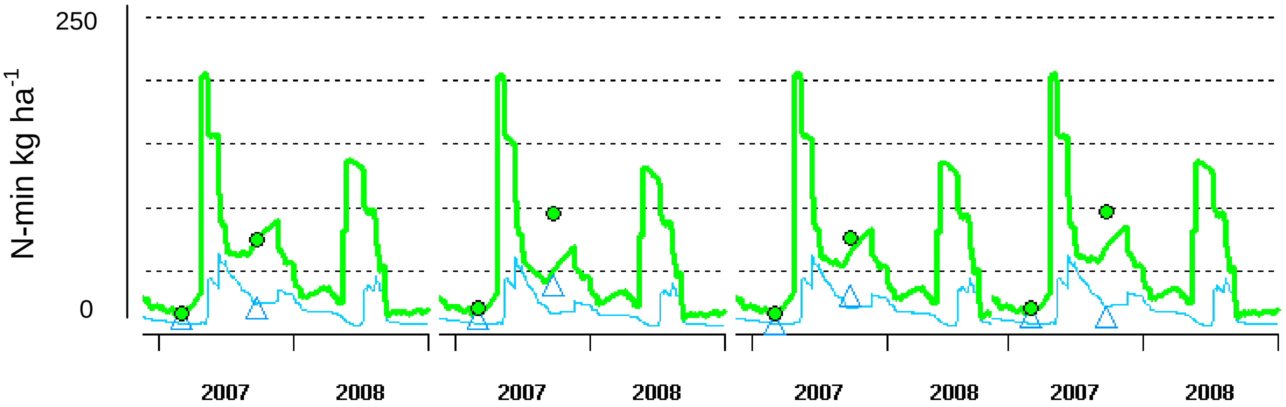
3.3.3 RMSE of the organic rotation

In all fully conventional plots and one conventionally fertilized plot RMSE was above 20 kg N ha^{-1}. In the fully organic plots, RMSE was above 20 kg N ha^{-1} in half of the cases and in three out of four plots in the organically fertilized plots. For all plots RMSE for the subsoil was below 14 kg N ha^{-1} (Table 10).

Table 10. Root mean square error (RMSE) for topsoil and subsoil for the organic rotation. n=number of observations on which the calculation is based. C=conventionally fertilized, FC=fully conventional, FO=fully organic, O=organically fertilized.

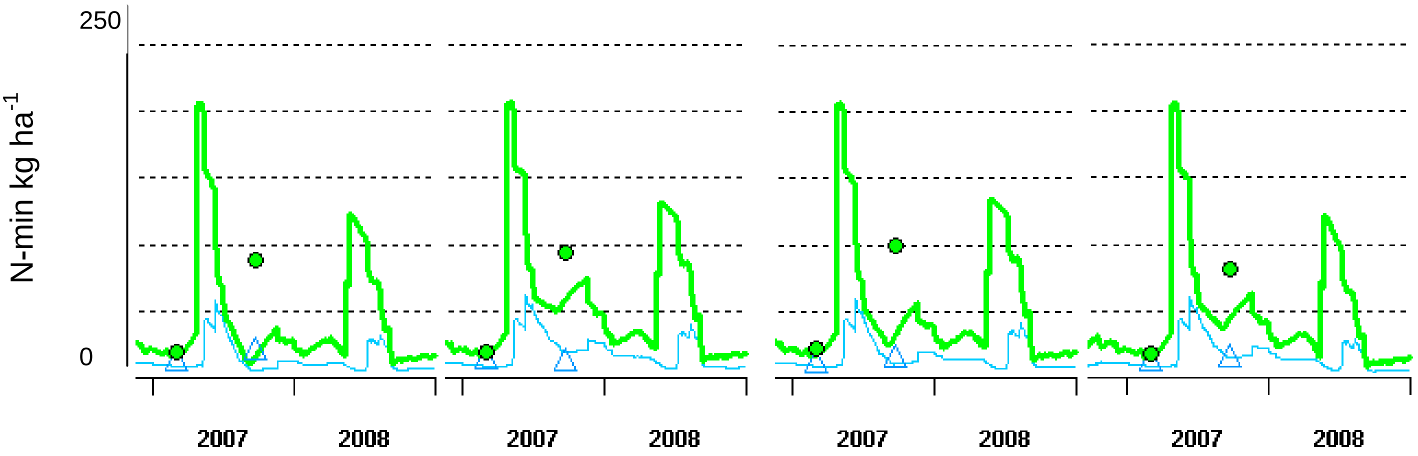
Name	RMSE topsoil	n	RMSE subsoil	n
C29A	0.9	2	4.43	2
C43A	7.85	2	5.11	2
C69A	31.88	2	13.72	2
C115A	19.3	2	8.17	2
FC27A	47.13	2	2.55	2
FC45A	26.24	2	1.86	2
FC67A	50.86	2	9.64	2
FC117A	24.53	2	6.21	2
FO31A	10.87	2	6.91	2
FO41A	20.15	2	5.88	2
FO71A	4.1	2	9.66	2
FO113A	29.86	2	0.94	2
O25A	29.12	2	0.71	2
O47A	26.89	2	2.25	2
O65A	4.43	2	1.43	2
O119A	23.7	2	1.3	2

In two of four fully conventional plots and in all conventionally fertilized plots a higher value was observed than is simulated by NDICEA (Figure 9 a-d and Figure 9 a-d).



a. b. c. d.

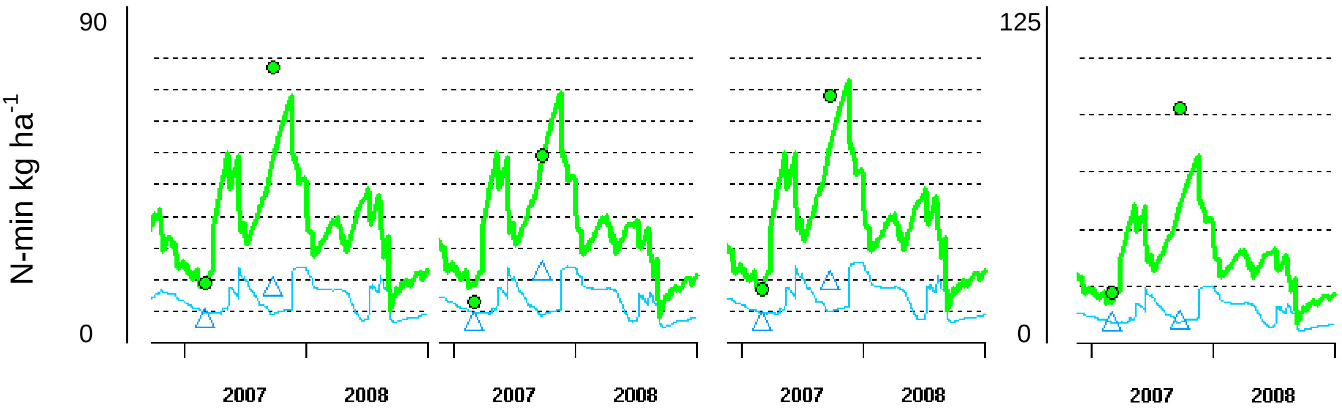
Figure 8 a-d Simulated versus observed concentrations of mineral nitrogen in the fully conventional plots of the organic rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.



a. b. c. d.

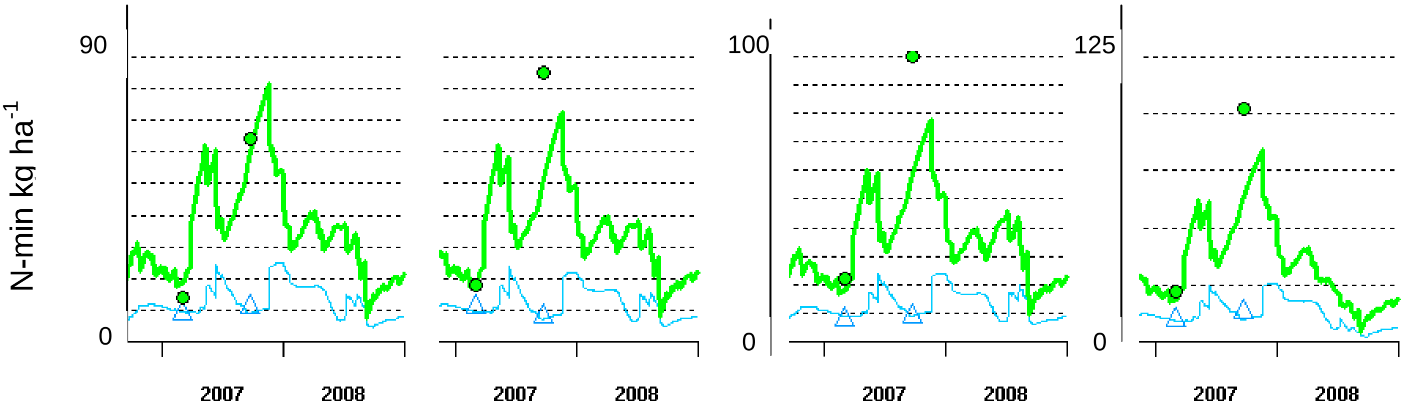
Figure 9 a-d. Simulated versus observed concentrations of mineral nitrogen in the conventionally fertilized plots of the organic rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.

In the fully organic and organically fertilized plots, a peak is modelled around the timing of the observation in September 2007 – but in five out of eight plots this observation is not as high as observed (Figure 11 a-d and Figure 11 a-d).



a. b. c. d.

Figure 10 a-d. Simulated versus observed concentrations of mineral nitrogen in the fully organic plots of the organic rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.



a. b. c. d.

Figure 11a-d. Simulated versus observed concentrations of mineral nitrogen in the organically fertilized plots of the organic rotation, 2007-2008. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil.

3.3.4. RSR of the organic rotation

For the topsoil of the conventionally fertilized and the fully conventional plots six out of seven plots have a RSR lower than one. For the fully organic and the organically fertilized plots this is five out of eight (Table 11).

For the subsoil of the conventionally fertilized and the fully conventional plots five out of seven plots have a RSR lower than one. For the fully organic and the organically fertilized plots this is six out of eight.

Table 11. Root means square error – standard deviation ratio (RSR) of topsoil and subsoil of all plots in the organic rotation. n=number of observations on which the calculation is made. n.d.=not determined, since the standard deviation of the observations was zero.

Name	RSR topsoil	n	RSR subsoil	n
C29A	3.08	2	0.31	2
C43A	0.19	2	0.33	2
C69A	0.17	2	1.32	2
C115A	0.36	2	n.d.	2
FC27A	0.71	2	0.41	2
FC45A	0.58	2	0.87	2
FC67A	n.d	2	0.52	2
FC117A	0.47	2	8.78	2
FO31A	4.66	2	0.44	2
FO41A	0.42	2	0.83	2
FO71A	1.60	2	0.35	2
FO113A	0.52	2	1.33	2
O25A	0.29	2	0.44	2
O47A	0.13	2	1.01	2
O65A	1.76	2	0.07	2

O119A	0.50	2	0.61	2

3.4 Discussion and conclusion

In the conventional rotation, NDICEA performed poorly in the conventionally fertilized and fully conventional treatments: in most cases RMSE > 20 kg N ha^{-1} and RSR >1. In the organically fertilized treatments, NDICEA performed better, and RMSE were < 20 kg N ha for almost all plots. RSR though was still > 1 in almost half of the cases. Remarkably, there is a pattern in the deviations between modelled and observed values. First, the date of measurement is important. Especially in June 2007 and May 2008, large differences between modelled and observed values were seen. In almost all cases, NDICEA overestimated soil nitrogen content compared to the observations in the field. In September 2007, differences between observed and modelled values were smaller (though still considerable in some cases), and NDICEA *under*estimated soil nitrogen content in two-thirds of the cases. Apparently, there is room for improvement for the modelling of the course of mineral nitrogen in soil in the growing season, especially after application of artificial fertilizer.

In the organic rotation, when looking at the RMSE, NDICEA seemed to model mineral nitrogen in the subsoil well but fails to do so acceptably in the topsoil. Especially in September 2007, NDICEA structurally underestimated topsoil mineral nitrogen content. However, when taking the standard deviation of the measurements into account by looking at the RSR, model performance was reasonable for both depths and throughout all treatments. It should be realized that the analysis of model performance in the organic rotation is based on two points in time only – which is a very limited number, especially given the large variation in mineral nitrogen during the course of a growing season.

When looking solely at the RMSE, NDICEA models seemed to be performing better in the organic rotation than in the conventional one; however, this is mainly due to the date of measurement – no measurements were taken in the organic rotation in May and June. At the points in time where measurements were taken in both rotations (March and September 2007), results for both rotations were similar.

Whether model performance is considered acceptable or good, depends on the criteria used for its evaluation. The two criteria used in this study did not lead to the same conclusion in all cases. In the conventional rotation, an RSR < 1 proved to be a stricter criteria than an RMSE < 20 kg N ha^{-1}. Due to the lower standard deviation in the measurements in the subsoil compared to those in the topsoil, the RSR in the subsoil was well above one whereas the RMSE was below 20 kg N ha^{-1} in most of the cases. In the organic rotation, it was the other way around: standard deviation in the topsoil was high, so that RSR was below 1 even though RMSE was above 20 kg N ha^{-1} in many cases. Even though a difference between modelled and observed values of 20 kg N ha^{-1} may be considered acceptable by farmers, the differences between RMSE and RSR point to the importance of taking into account the standard deviation of the observed values. RSR thus proved to be a useful additional measure for model performance.

4 Case 2: Denmark

4.1 Intro

Leaching of nitrogen is a dynamic process. Nitrogen that is lost from the topsoil could possibly be taken up by deep-rooting crops, if soil conditions are favorable to deep rooting. Designing a crop rotation including knowledge about rooting depth could improve nitrogen use efficiency and reduce leaching. This was the subject of an experiment in Denmark, on soils with a potential deep rooting capacity.

4.2 Methods: collection and characteristics of the dataset

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.

NDICEA was run for the years 1998-2006. From 1998-1999 'reference data' were used as input in NDICEA, thereafter measured data were used as input. These included soil parameters (type, thickness, pH and OM content), subsoil parameters (type and maximal root depth), crop data (planting and harvest date, DM production, rooting depth, DM distribution in the product, mass and nitrogen content of residues and roots). During the experiment, root growth was monitored with minirhizotrons at the end of the growing seasons.

Soil inorganic nitrogen-content had been measured throughout the experiment; samplings occurred three months after catch crops' sowing the first year (6th Nov. 2000), around vegetable planting the second year (18th May 2001) and after harvest (31st Oct. 2010), one month after barley's sowing the third year (27th May 2002) and after harvest (13th Nov. 2002), and also during the fourth year to assess the carry over effect of nitrogen over winter (12th May 2003). In total, soil mineral nitrogen was measured six times in each plot. Sampling and modeling depth were 0-50 cm and 50-250 cm.

4.2.1 Rotation & inputs

The first year started either with fodder radish or Italian ryegrass as a catch crop or without catch crop. The second year leek or red beet or cabbages was sown. The third year either barley alone or barley undersown with ryegrass or chicory was grown. The root systems' depth in each year was either limited (no catch crop or leek), medium (ryegrass or red beet) or deep (fodder radish, white cabbage or chicory). An overview of rotations in place is shown in Tables 12-14 and Figs. 12-14.

Table 12. Rotation 1, 4, 5. Numbers correspond with numbers in Figure 12.

1	Green pea
2	Fodder radish
3	Spring barley
4	Grass/clover
5	Leek or red beet or white cabbage
6	Spring barley
7	Fallow

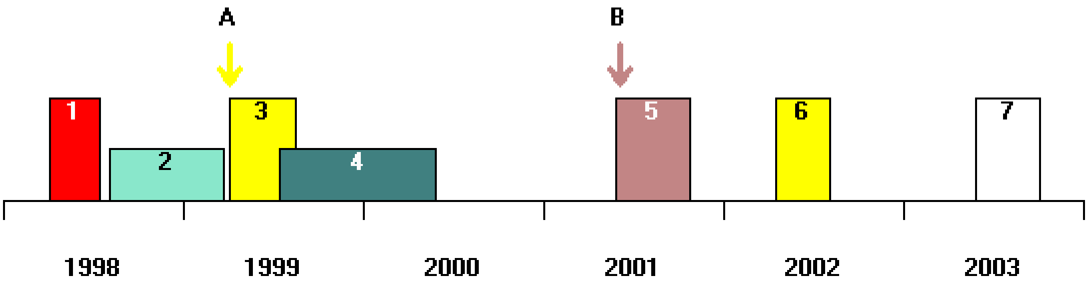


Figure 12. Schematic overview of the rotation in place and timing of inputs in rotation 1 and 4. Blocks indicate crops, arrows indicate timing of inputs.

Table 13. Rotation 2, 3. Numbers correspond with numbers in Figure 13.

1	Green pea
2	Fodder radish
3	Spring barley
4	Grass/clover
5	Leek
6	Spring barley
7	Rye grass or chicory
8	Fallow

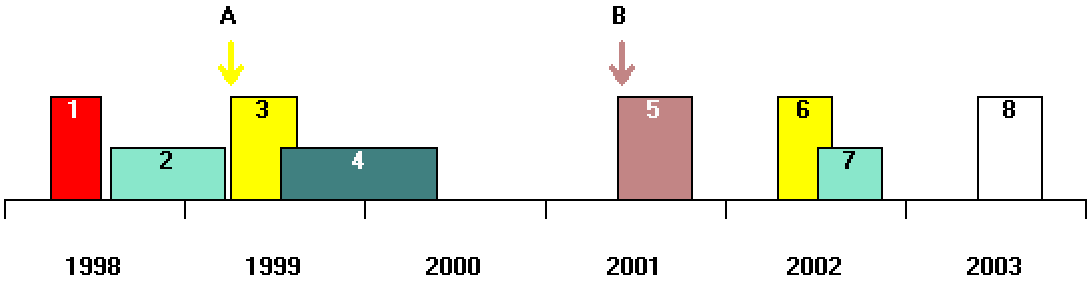


Figure 13. Schematic overview of the rotation in place and timing of inputs in rotation 2 and 3. Blocks indicate crops, arrows indicate timing of inputs.

Table 14. Rotation 6, 7, 8, 9, 10. Numbers correspond with numbers in Figure 14

1	Green pea
2	Fodder radish
3	Spring barley
4	Grass/clover
5	Fallow
6	Fodder radish or ryegrass
7	Leek or red beet or white cabbage
8	Spring barley
9	Fallow

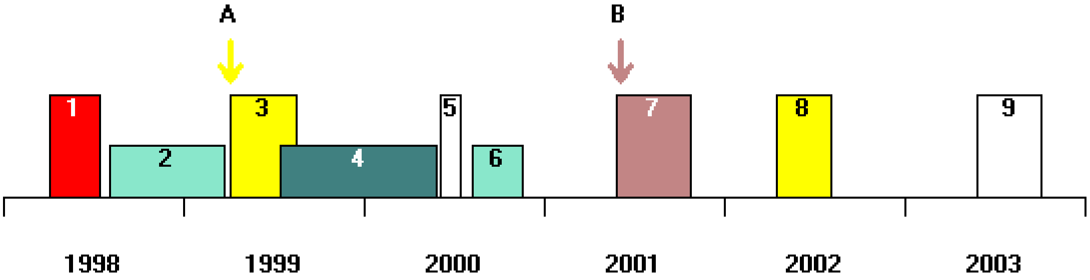


Figure 14. Schematic overview of the rotation in place and timing of inputs in rotation 6, 7, 8, 9 and 10. Blocks indicate crops, arrows indicate timing of inputs.

Organic inputs were the same for all treatments and are shown in Table 15.

Table 15. Inputs in crop rotations for all ten treatments

	Date of application	**N (kg/ha)**
Stable manure	5-4-1999	69
Chicken manure	5-6-2001	100

4.3 Results

4.3.1 RMSE

RMSE for all treatments is shown in Table 16.

Table 16. RMSE for all treatments

Treatment	RMSE topsoil	n	RMSE subsoil	n
1	20.84	6	70.79	6
2	15.39	6	58.53	6
3	18.65	6	65.01	6
4	15.77	6	55.85	6
5	13.32	6	28.64	6
6	28.09	6	68.81	6
7	25.25	6	59.43	6
8	19.66	6	75.77	6
9	24.88	6	56.34	6
10	18.08	6	41.77	6

RMSE was below 20 kg N ha^{-1} in six out of ten treatments in the topsoil, and higher than 28 kg N ha^{-1} in all treatments in the subsoil. During the six-year rotation, N-shortage was modelled once in plot six, seven and eight for topsoil only.

Deviations between simulated and observed values were not the same at all moments in time (Table 17). Especially in November 2011, the difference between observed and simulated values in the topsoil was relatively large (RMSE: 33.5 kg N ha^{-1}, Table 17) and in 90% of the cases, mentioned difference exceeded 20 kg N ha^{-1}. In addition, at this date simulated values were higher than observed values for all treatments. Thus NDICEA structurally overestimates mineral nitrogen availability compared to the measured values. This was the case in May 2002, too, although the differences between observed and simulated values were small (RMSE: 13.5 kg N ha^{-1},Table 17). For the other dates, this did not hold.

Table 17. Difference between simulated (sim.) and observed (obs.) values at different dates. Data from different treatments are summarized. n=number of measurements on which the calculation of RMSE and the percentage of RMSE > 20 kg N ha^{-1} is based.

Date	# sim.<obs.	# sim.>obs.	RMSE topsoil	RMSE subsoil	# (im.>obs.)>20	n	(sim.>obs.)>20 (%)
5-11-2000	16	4	10.4	50.8	5	12	42
15-5-2001	20	0	20.5	31.8	5	13	38
25-10-2001	7	13	20.6	52.7	11	20	55
15-5-2002	3	17	13.5	52.9	6	20	30
15-11-2002	0	20	33.5	70.8	18	20	90
15-5-2003	10	10	16.0	86.8	12	20	60

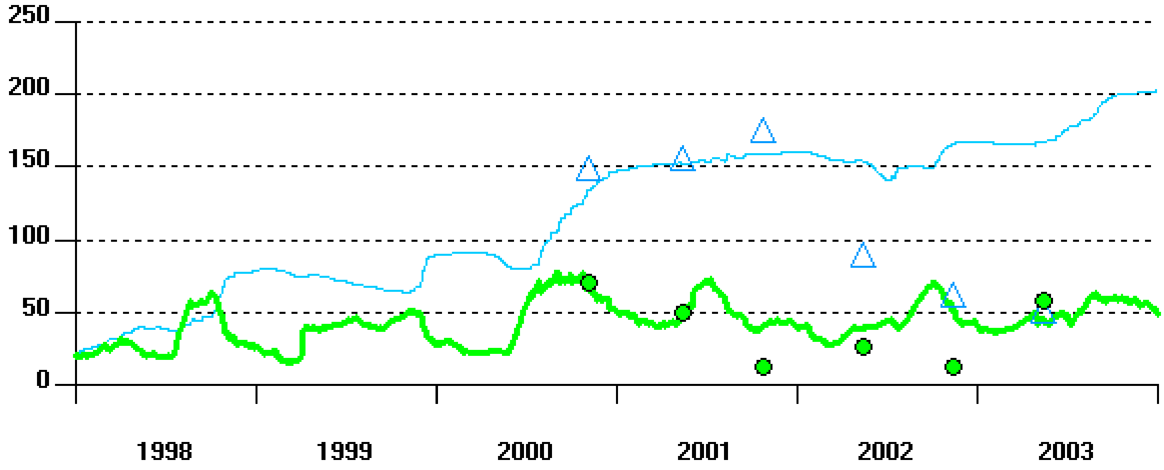


Figure 15. Simulated versus observed concentrations of mineral nitrogen for treatment 1. Green line: topsoil, blue line: subsoil, green circles: measurements in topsoil, blue triangles: measurements in subsoil. X-axis: kg mineral nitrogen ha^{-1}.Y-axis: years.

RSR

The RSR was below one for the topsoil in all treatments except for treatment six, and above one for the subsoil in all treatments except for treatment five (Table 18).

Table 18. Root mean square error (RMSE), standard deviation (SD) and RMSE-SD-ratio (RSR) for subsoil and topsoil for ten treatments.

Treatment	Depth	RMSE	SD	RSR
1	top	20.8	24.6	0.85
1	sub	70.8	52.9	1.34
2	top	15.4	22.7	0.68
2	sub	58.5	54.0	1.08
3	top	18.7	25.0	0.75
3	sub	65.0	60.3	1.08
4	top	15.8	21.9	0.72
4	sub	55.9	46.8	1.19
5	top	13.3	21.6	0.62
5	sub	28.6	56.6	0.51
6	top	28.1	25.2	1.12
6	sub	68.8	32.3	2.13
7	top	25.2	26.0	0.97
7	sub	59.4	24.4	2.44
8	top	19.7	24.6	0.80
8	sub	75.8	60.3	1.26
9	top	24.9	27.8	0.89
9	sub	56.3	46.2	1.22
10	top	18.1	26.4	0.68
10	sub	41.8	31.9	1.31

4.4 Discussion and conclusion

For the topsoil, the modelled and observed data were well in accordance: RMSE was below 20 kg N ha^{-1} in the majority of the cases and RSR was below one in almost all cases. NDICEA thus proved to model soil mineral nitrogen in the topsoil well for the system in which the data were collected. This is important since the mayor part of nitrogen is taken up in topsoil.

NDICEA did not model soil mineral nitrogen content well for the subsoil: RMSE was above 20 kg N ha^{-1} in all cases and RSR was >1 in almost all cases. Thus, in this Danish system, NDICEA should not be relied on for the modelling of subsoil mineral nitrogen content.

Moreover, the calculation of mineral nitrogen content of topsoil and subsoil are linked, notably the calculations of leaching and crop uptake.. Thus, poor model performance for the subsoil might point to inadequate mechanistic description of nitrogen transformation processes in both topsoil and subsoil. Evaluating the mechanistic performance of the NDICEA model however is beyond the scope of this report.

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.

5 Case 3: Spain

5.1 Introduction

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.

5.2 Methods: collection and characteristics of the dataset

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 19. 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 19 Treatments in the experiment

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

Soil sampling for soil mineral N analysis was done twice a year at the start and the end of crop growth, resulting in six measurements in each treatment.

The crop was irrigated every 1-3 days, in 2003 and 2005 with 18.3 mm each turn and in 2004 with 13.3 mm each turn. In 2005 there were more irrigation days with less water applied each time.

Fresh yield was measured from product (kernels) and crop residue, and from the product the dry matter content was analyzed. From both, nitrogen content was measured.

For building the NDICEA scenarios, real product yield and nitrogen content were used. For the crop residue, due to the lack of dry matter analysis, the dry matter yield was estimated using results of the Aranjuez experiment as default values. In the Aranjuez experiment the dry matter content of the residue was measured.

For NDICEA a topsoil of 40 cm was used and the subsoil was supposed to reach up to 60 cm depth. In the subsoil no root growth was modeled. In NDICEA, evapotranspiration is usually calculated according to Makkink (1957). However, this approach lead to high calculated surpluses of water that were not accordance with practical experience from farmers. On the farms were the data for this study where obtained, the advanced Penman-Monteith-equation (Monteith, 1973) is used to calculate evapotranspiration. When incorporating this equation in NDICEA, calculated water surpluses were better in accordance with practical experience. Thus, evapotranspiration was calculated to Penman-Monteith, as is common practice in FAO-studies. The Penman-Monteith approach implied that environment-files were adapted to include additional parameters; the crop factor for transpiration was increased from 1.1 to 1.2 and the evapotranspiration from bare soil was increased from 0.25 to 0.3.

For all scenarios, the calibration function of NDICEA was used. This can be done when there is a consistent difference between simulation and reality. Calibration will then result in a consistent (i.e. in all treatments the same direction) change of the parameters in question. This calibration was done in two steps. First the eight scenarios were calibrated, resulting in changed values of the ten model parameters included in the procedure. Second, the average of the obtained parameter values in ‘Cal’ was calculated and this average value for each parameter was used in all eight scenarios.

5.3 Results

5.3.1 Visual observations

In Figure 16 the course of mineral N in top- and subsoil is given. In 2004 and 2005 the level of available N reached zero, indicating a modelled N shortage, which should not occur. The shortage was around 10 kg in 2004 and 15 kg in 2005 (Figure 17). All other treatments did not show a calculated N shortage (graphs not shown).

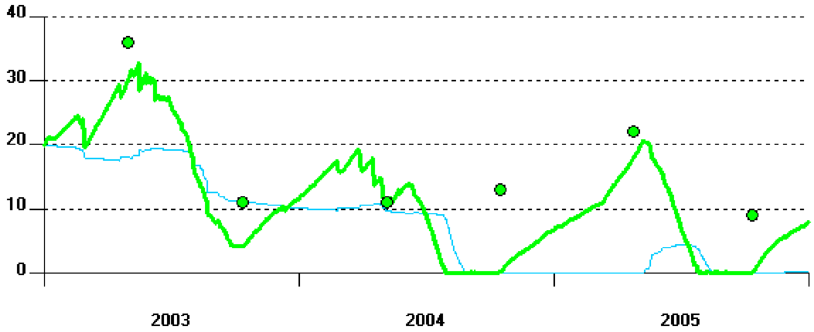


Figure 16. Course of mineral N in treatment 0. Green line: simulated mineral N value topsoil. Blue line: simulated mineral N value subsoil. Green dots: measured mineral N values topsoil.

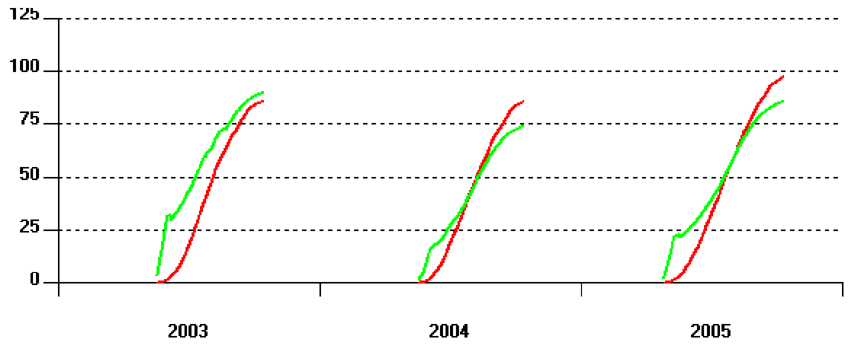


Figure 17. Cumulative nitrogen uptake (red line) and nitrogen availability (green line) of treatment 0, in kg N ha^{-1}.

5.3.2 RMSE

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

Table 20. 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

Calibration considerably improved model performance in terms of RMSE (Table 20, columns Cal and CalAv). Only the two 360 treatments kept a RMSE > 20 kg N ha^{-1}. 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 20).

In Table 21 the default values and the average calibrated values of the ten soil parameters included in the calibration procedure are given. Most important differences between default and average values are in Nleach1 and IAgeFresh.

Table 21. Default and new average values of calibrated soil parameters.

Parameter*	Default	Average
Text	0,78	0,80
Nleach1	0,85	1,10
IAgeOld	24	22,80
IAgeYoung	4	10,39

IAgeFresh	1,4	2,1
Nleach2	0,85	0,84
MaxWaterUptake1	0,75	0,78
C/N	8,3	6,79
A/D	0,45	0,35
Denitr	0,1	0,10

* For information about the parameters, contact the authors

5.3.3 RSR

The RSR is presented in Table 22. The STDEV was close to ten in all treatments. Four out of eight treatments had an RSR below one. The two ‘360’ treatments with a high RMSE also had a high RSR.

Table 22. RSME, STDEV and RSR of the CalAv scenarios of the treatments. RMSE and STDEV in kg N ha-1, others without dimension

Treatment	RSME	STDEV	RSR
0	7,56	10,37	0,73
40	5,55	10,77	0,52
120	16,26	10,94	1,49
200	8,83	10,13	0,87
280	14,17	9,87	1,44
360	24,79	9,63	2,58
280_2	9,04	10,27	0,88
360_2	24,8	9,44	2,63

5.4 Discussion and conclusion

The number of measurements (n = 6) to validate the model was very limited, and there were no measurements during crop growth. This reduced the value of this evaluation.

The input for the model showed one shortage: crop residue had to be estimated because dry matter content was not measured. This has influenced the results, and this influence might be structural if, for example, product/residue ratio in reality increases or decreases with product yield level.

Without calibration, the model results were poor. The zero treatment showed a little N shortage, and all fertilized treatments showed a higher simulated soil mineral N level than measured. Seven treatments have a RMSE above 20 kg N ha^{-1}. Since seven out of eight treatments show this shift towards a too high N availability, calibration made sense. After calibration and using the average soil parameter values, model performance was considerably improved. In the zero treatment the N-shortage is still present but did not exceed 15 kg ha^{-1} year $^{-1}$ in two out of three years.

In the calibration procedure Nleach1 rose from 0.85 to 1.1 and IAgeYoung rose from 4 to 10.39. Nleach1 describes the leaching of nitrogen out of the topsoil, and model performance is in this case better when this process is higher than default for this soil type. IAgeYoung stands for the (virtual) initial age of the young soil organic matter, one of the three soil organic matter pools in NDICEA. A higher value resulted in a lower speed of mineralization of nitrogen in the topsoil out of this organic matter pool. Both changes resulted in a lower mineral N content in the topsoil and thus in a better match between measured and simulated values.

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.

6 General discussion and conclusion

So far, NDICEA has been used in the Netherlands in various projects, by various farmers and farm advisors and by students. In other countries the model has been used less extensive (Denmark, UK, France, Spain). The original validation of the model was done with a German dataset (Van der Burgt et al, 2006). Within the N-Toolbox project, the NDICEA model was improved and the model could be validated on datasets from England, Denmark and Spain. The criteria used here for judgment of the accuracy of this model are:

- Visual: is the pattern of modeled nitrogen dynamics followed by the measurements (qualitative)
- Simulated soil mineral nitrogen level never becomes zero (quantitative)
- RMSE (quantitative)
- RSR (quantitative)

This study showed that not all criteria may lead to the same conclusion. It occurred, for example, that RMSE was acceptable while RSR was not, and vice versa. Theoretically, visual judgment can be acceptable while the RMSE is too high, due to a small shift in time of real and modeled processes. This, however, was not observed in this study. Overall judgment thus depends on the relative importance given to each of the criteria and the boundaries set.

The presence of a modeled lack of nitrogen seems to be a hard evaluation criterion, but if the same margin is allowed as is accepted for RMSE (20 kg N ha^{-1}) it is less ‘hard’

Out of the Nafferton datasets two potential structural model shortcomings arise. First, the modeled level of available nitrogen during crop growth often was higher than the level measured. This might be due to the way in which nitrogen uptake is modeled. Crop nitrogen uptake in NDICEA is calculated independent from crop nitrogen availability. In reality, however, more nitrogen may be taken up in the initial phases of growth, if this nitrogen is available. Such additional nitrogen uptake in early stages, a phenomenon known from field studies, may lead to a shift in nitrogen uptake and an overestimation of mineral nitrogen still present in the soil. Possibly, NDICEA could be improved by relating the calculation of nitrogen uptake by plants to calculated nitrogen availability. Second, the release of nitrogen from artificial fertilizer seems not to be well-described. The model algorithms make the mineral fertilizer N (nitrate, ammonia or urea) fully available the day after application. Volatilization is taken into account, but a delayed release because of for example lack of moisture or a delay for the turn-over from urea and ammonia to nitrate is not modeled. This can lead to a strong overestimation of plant-available nitrogen shortly after application.

The same observations were found in many Dutch NDICEA scenarios (Van der Burgt, data not published), so these two points indeed seem important to address to improve model performance.

The Nafferton and the Spanish datasets show a shortcoming in the system of model evaluation. If there are only two soil mineral nitrogen measurements each year, in spring (before sowing) and in fall (after harvest), model evaluation on RMSE and RSR can be good. At the same time, the period of the most intensive nitrogen dynamics, during crop growth, is not checked by means of measurements and is not validated. This is the main reason why it could not be seen whether NDICEA does or does not describe the release of nitrogen from artificial fertilizer well in the Spanish case. That is not very satisfying. Mineral nitrogen in soil has a seasonal dynamics – in order to capture this dynamics, multiple measurements are needed. Based on this study we would recommend to do more than two soil mineral N samplings each year, and to include measurements during crop growth.

The Danish dataset is well described by NDICEA as far as the topsoil is considered. For the subsoil, a wide gap between modeled and measured soil mineral nitrogen levels occurred in some scenarios. Since nitrogen uptake is predominantly realized in the topsoil, model performance seems acceptable. Nevertheless, the very interesting process of nitrogen uptake out of deeper soil layers could not be modeled in NDICEA. An explanation for this shortcoming is not found, but it might be related to the depth of the subsoil. In the NDICEA work so far in The Netherlands, Germany and England, subsoil goes down to 50 – 100 cm. In the Danish situation the subsoil goes down to 2.50 meter. In model terms this implies that all the processes of 50 (depth topsoil) up to 250 cm below ground level are considered as one ‘pool’, so an effect of different nitrogen levels at different depths cannot be modeled. This may be more problematic in a deep soil profile than in a rather shallow soil profile. To tackle this problem, the NDICEA model could be build up as a multi-layer soil model. The algorithms for this approach could be derived from the EU-rotate N model (Rahn et al., 2007).

The Spanish data were collected on a location with a fundamentally different soil and climate. After including the Penman-Monteith approach to evapotranspiration and after calibration, model performance was sufficient. The treatments with the highest N-input still nevertheless had a high RMSE and RSR.
In this case, model performance was better using the Penman-Monteith equation for evapotranspiration. In this approach, wind speed and air humidity are taken into account. This leads to a better estimation of evapotranspiration especially under conditions in which wind speed is (very) high and air humidity (very) low. We expect that the Makkink approach will perform sufficiently under north-west European conditions. For the Makkink approach, less environmental parameters (such as wind speed and air humidity) are needed, since in this approach only temperature and global radiation are used. These records are available at much more weather stations than wind speed and air humidity This is a clear advantage of using the Makkink approach in stead of the Penman-Monteith approach.
Calibration was possible and was needed to come to an acceptable model performance. This can be due to different soil characteristics compared to north-west European soils. To incorporate these characteristics as default values for Spanish soils in NDICEA, more Spanish datasets should be modeled and analyzed.

Overall we conclude:

- The NDICEA model can be used in England, Denmark and Spain
- It is strongly recommended to use the model in combination with a validation scheme with sufficient soil mineral N measurements spread over the season
- Under arid conditions the Penman-Monteith equation for calculating evapotranspiration should be used instead of the Makkink equation.

- Model performance could be improved by changes in the crop sub model, by adaptations in the release of nitrogen out of artificial fertilizers and by creating a multi-layer soil sub model.

7 Adaptations in the NDICEA model

One of the tasks in the N-Toolbox project was a further development of the NDICEA model. This has resulted in a number of adaptations in the calculation procedure and in the interface. In the list below, the adaptations from NDICEA 5 towards NDICEA 6 are briefly described. In Annex 1 the corresponding algorithms can be found.

- The calculations are done in steps of one day instead of one week. Consequently, the environment files are transformed to daily records instead of weekly records.
- In NDICEA 5, two modules could be used: a ‘field’ module and a ‘rotation ‘module. The rotation module is skipped and only the field module is left. The rotation calculations can still be done. By placing the whole rotation in the future the average weather conditions are used, and by using the new ‘repeat calculations’ button the results of the second cycle can be observed. This is equivalent to the former ‘rotation’ module. This procedure is described in the manual.
- England, Denmark and Spain are introduced in the land choice menu.
- In England four regions are introduced in the automatic weather download structure of the model: North, East, South, West England.
- In Denmark five regions are included in the automatic weather download structure of the model: Nort-Jylland, Ost-Jylland, Syd-Jylland, Fyn and Seeland.
- Spanish and Danish are added as language choice. The language choice can be made independently from the country and region choice.
- The maximum number of years is extended from 10 to 12.
- Artificial fertilizer is split up into several types of nitrogen fertilizer, related to the chemical composition of the nitrogen: nitrate, ammonia, urea.
- The speed of root depth growth is made temperature dependent. A time lag period is introduced for each crop, being the number of day degrees calculated from day of sowing above which root growth starts. Data and algorithms for these adaptations were obtained from the EU-ROTATE_N model (Annex 1).
- Root density in top- and subsoil, and with this N-uptake out of the two layers, is made crop-dependent. Data and algorithms for these adaptations are obtained from the EU-ROTATE_N model (Annex 1).
- Crop water uptake (and nitrogen uptake) in crops which are harvested dry (cereals, pulses) is changed. In the new calculation water uptake factor goes linearly down from 1.00 to 0.00 between starting ripening date and half-way harvest date (Annex 1).
- From all applied nitrogen fertilizers the volatilization is calculated and shown in the mineral balance (Annex 1).
- To view the results of the calculations in more detail, a zoom function is introduced in the result graphs.
- Irrigation is separately visible in the precipitation graph.
- Minor adaptations were made in the crop database, the green manure database and the fertilizer database.

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Annex 1: Algorithms introduced in NDICEA version 6.0 and 6.1

Rootgrowth

The root growth model has been restructured and is now the same as root development in the EU-ROTATE_N model. All the parameters described below are hidden for normal users. As far as needed, the algorithms from EU-ROTATE_N are adapted to a two-layer soil model.

DDGLG

The day-degree lag period. Root growth starts when a minimum of day-degrees (Temperature sum) is reached. DDGLG defines this minimum and is a crop-related parameter.
Day-degree $= \sum_{1}^{i}(T)$ when $T>0$
Where
day of sowing = day 0
T = temperature in degrees Celsius

STDPT (cm)

The starting depth is the depth of sowing or planting. This is the depth where root growth starts; it is a crop parameter with values between 1 (for example onions) and 6 (for example potatoes).

TMIN (Degrees Celsius)

The minimum temperature for root growth is defined by TMIN. If actual temperature is below TMIN, root depth growth is zero for that day or period. TMIN is a crop parameter.

DPTGR (cm)

The depth growth of the roots depends on the temperature sum Tsum (day degrees) and is crop dependent by means of the depth growth parameter.
Root depth at day i is described as
$RD^i = STDPT + (DPTGR * (Tsum^i - DDGLG))$ when $Tsum^i > DDGLG$;
else root depth at day i = 0

DISTR

The distribution parameter influences which part of the roots is present in the topsoil and which part in the subsoil: the root fraction of each soil layer. As long as root depth growth has not reached soil layer 2, root fraction in topsoil is 1.00 and in subsoil 0.00 .
Root fraction in topsoil RF1 at day i is described as
RF1 = ((-(1/DISTR) * exp(-DISTR * min(RD,THL[1]))) + (1/DISTR)) * ((-(1/DISTR) * exp (-DISTR * RD)) + (1/DISTR))^-1 if RD >0; else RF1 = 0
Where
DISTR = root distribution parameter (-)
RD = root depth at day i
THL[1] = thickness of soil layer 1

Root fraction in the subsoil RF2 is described as
RF 2 = 1.00 – RF1 when RF1 > 0.00 , else RF2 = 0
When the roots reach maximum rooting depth, defined by soil or crop, root development stops and root fractions stays what they are.

Crop growth

GREHA

Water uptake (and hence nitrogen uptake) in dry harvested crops such as cereals and dry pulses in the last phase of growth is changed. Crop water uptake factor cc in the old NDICEA version was going down from 1.00 to 0.50 between ripeningDay and harvestDay. In the new version water uptake goes down to 0.00 halfway ripeningDay and harvestDay. The dry harvested crops are symbolized by the parameter GREHA, with GREHA = 0 for cereals and dry pulses and GREHA = 1 for all other crops.

For crops with GREHA = 0:
If day^i >ripeningDay, then
cc day^i :=1-((Day^i -ripeningDay)/(0.5*(harvestDay-ripeningDay)))
where
cc = water uptake factor (range 0 – 1)
ripeningDay = daynumer when ripening period starts
harvestDay = daynumber of harvest

TBASE (Degrees Celsius)

The minimum temperature for crop growth is defined by TBASE. If the actual temperature drops down below TBASE, crop growth (water uptake, nitrogen uptake) is zero during that day or period.

Volatilization

Volatilization of nitrogen out of artificial fertilizer was not modelled in NDICEA so far. It is now introduced. The amount of volatilization is dependent on

- temperature after application of the fertilizer
- soil pH
- rainfall after application of the fertilizer
- soil CEC
- yes or no incorporation in the soil of the applied fertilizer
- Type of fertilizer used.

Nitrogen volatilization is calculated as a reduction of the potential N-volatilization:

NV = AN * PNV * NVF
where
NV = calculated nitrogen volatilization (kg/ha)
AN = Applied nitrogen (kg/ha)
PNV = Potential nitrogen volatilization (part, range 0 – 1)
NVF = Nitrogen volatilization factor

PNV is based on the type of nitrogen and on the way it is applied and is given in Table 23.

Table 23 PNV in dependance of fertilizer type and incorporation in the soil

Fertilizer type	Incorporation	PNV
Urea	no	0,40
Urea	yes	0,10
Ammonium sulfaat	no	0,60
Ammonium sulfaat	yes	0,30
Ammonium nitraat	no	0,30
Ammonium nitraat	yes	0,20
Anhydrous ammonia	yes	0,05

NVF depends on temperature, pH, rainfall and CEC as follows:
NVF = TF * pHF * (average (RF, CECF))
Where
TF = temperature correction factor, range 0-1
pHF = pH correction factor, range 0-1
RF = rainfall correction factor, range 0-1
CECF = CEC correction factor, range 0-1

TF is calculated in two steps.
First the Reference Day Number RDN is calculated. For each day the Reference Day Factor RDF is calculated in dependence of temperature:

$RDF = 0$ if $T < 1$

$RDF = -0.08 + 0.081 * T - 0.0015 * T^2$ $(1 < T < 25)$

$RDF = 1$ if $T > 25$

$RDN = MIN(5, \sum RDF)$

After calculating the RDN (1-5), for each day within the RDN number of days after fertilizer application the Temperature Factor Day TFD is calculated:

$TFD^i = -0.08 + 0.081 * T - 0.0015 * T^2$ for $1 < T < 25$

If $T < 1$, $TFD = 0$

If $T > 25$, $TFD = 1$

where

T = day temperature

Temperature Factor TF is calculated as

$TF = \sum TFD / RDN$

pHF

The pH correction factor is given in Table 24.

Table 24 pH correction factor

Range	pHF
pH < 3.5	0
3.5 < pH < 8.2	-0.71 + 0.21* pH
pH > 8.2	1

RF

The Rainfall correction factor RF is calculated in three steps.

First the Reference Day Number RDN is calculated. For each day the Reference Day Factor RDF is calculated in dependence of temperature:

$RDF = 0$ if $T < 1$

$RDF = -0.08 + 0.081 * T - 0.0015 * T^2$ $(1 < T < 25)$

$RDF = 1$ if $T > 25$

$RDN = MIN(7, \sum RDF)$

Second, after calculating the RDN (1-7), for each day within the RDN number of days after fertilizer application the daily rainfall correction factor can be found in Table 25. The value per day depends on the amount of rainfall or irrigation.

Table 25 Daily rainfall correction factors DRCF

	RDN						
Rainfall per day	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**
0	0,636	0,132	0,086	0,057	0,043	0,029	0,017

1	0,502	0,098	0,064	0,042	0,032	0,021	0,013
2	0,178	0,072	0,047	0,031	0,024	0,016	0,009
3	0,330	0,054	0,035	0,023	0,017	0,012	0,007
4	0,276	0,040	0,026	0,017	0,013	0,009	0,005
5	0,235	0,029	0,019	0,013	0,010	0,006	0,004
6	0,206	0,022	0,014	0,009	0,007	0,005	0,003
7	0,184	0,016	0,011	0,007	0,005	0,004	0,002
8	0,167	0,012	0,008	0,005	0,004	0,003	0,002
9	0,155	0,009	0,006	0,004	0,003	0,002	0,001
10	0,146	0,007	0,004	0,003	0,002	0,001	0,001
11	0,139	0,005	0,003	0,002	0,002	0,001	0,001
12	0,134	0,004	0,002	0,002	0,001	0,001	0,000
> 12	0,120	0,000	0,000	0,000	0,000	0,000	0,000

Third, the overall rainfall correction factor RF is calculated is the sum of the selected values out of Table 25:

RF = $\sum_{1}^{RDN} DRCF$

CECF

The CEC correction factor is calculated out of the CEC:

CECF = 1 – 0.023 * CEC

In Table 26 the data are shown.

Table 26 CEC and CECF for different soil types

Soil type	CEC	CECF
fine sand	5	0,885
coarse sand	3	0,931
sandy clay loam	18	0,586
loamy fine sand	8	0,816
clay loam	29	0,333
light clay	32	0,264
loess loam	30	0,31
silty clay loam	25	0,425
loam	35	0,195
fine sandy loam	12	0,724
silty clay loam	35	0,195
silt loam	15	0,655
basin ckay	35	0,195
oligotrofic peat	40	0,08
meso & eutrofic peat	40	0,08