

# MiNiAC, a model to simulate mineral nitrogen dynamics in arable crop rotations

Model description and verification of version 1.00

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# Table of contents

	page
1. Summary	1
2. Introduction	3
3. Model description	5
3.1 System description	5
3.2 Model structure	5
3.3 Included subroutines	5
3.4 Programming style	8
3.5 Compilation instructions	8
4. Model parameters	9
4.1 Data types	9
4.2 Data files	9
5. A set of parameters for the experimental station: Vredepeel	11
5.1 Weather data 2001-2002	11
5.2 Soil parameters	11
5.3 Crop rotation	14
5.4 Crop management: fertilization, crop residues and irrigation	14
6. Model verification	17
6.1 Nitrogen in the crop	17
6.2 Water tension in the soil	17
6.3 Water content in the soil	19
6.4 Mineral nitrogen in the soil	19
7. Notes on the development of MiNiAC	21
7.1 Water transport models	21
7.2 Crop model	21
7.3 Mineralization model	21
7.4 Denitrification	21
8. Discussion and conclusions	23
9. Literature	25
Appendix I. Input files	5 pp.

# 1. Summary

Agricultural practices on the sandy soils in the Netherlands result in a deterioration of groundwater quality. Progress on the reduction of nitrate emissions are made but the European target value of 50 mg nitrate-N L<sup>-1</sup> is still hard to meet on arable farms. As combining cultural practices to increase N-efficiencies and minimize leaching require several years to be tested, additional and explorative exercises can facilitate this process. One possible aid could be the development of a model, which can perform these explorative exercises and in addition make predictions on nitrate emissions to the groundwater. We developed such a model by coupling existing models. The combined model consists of a model to simulate one-dimensional water transport in the soil (SAWAH) and a model to simulate crop growth, including nitrogen demand (LINTUL). Several additional processes were included of which mineralization was the most important one and the model was adapted to simulate crop rotations. Feed back processes on water and/or on nitrogen shortages were not included.

Two-year experimental data from the experimental farm Vredepeel were used to verify the model.

The model predicted slightly higher soil water tensions than were measured. The simulated water content of the soil was also higher than the measured water content. However, the simulated mineral nitrogen content of the different soil layers was in good agreement with the measured nitrogen content. Although the model predicts higher soil water tensions than were measured which may affect the predicted N-leaching, at this point the results indicate that the model can be used to explore the effects of different, not yet practices fertilization strategies on the nitrogen emissions to the groundwater. The boundary conditions of the model however, need to be respected.

## 2. Introduction

The emission of nitrogen (N) from agriculture to groundwater, surface waters and atmosphere is a significant problem in the European Union (EU, Carton & Jarvis, 2001). In the Netherlands, agricultural practices, which result in a deterioration of groundwater quality, have become a serious problem on the sandy soils throughout the country (Neeteson *et al.*, 2001). The Dutch government developed a system to implement the target value for nitrate concentrations in the groundwater of 50 mg/L. This Mineral Accounting System (MINAS) however, may not lead to the intended concentrations for arable farming systems (Buck *et al.*, 2000). Besides the question how to achieve the target value, the Government has no method to evaluate that the target level is met. Measuring nitrate levels in the groundwater as a way to evaluate the nitrate concentrations below arable farms is an elaborate and expensive way and therefore not possible to perform on every arable farm. Therefore, experimental farms are used to study the effects of different fertilization strategies on the groundwater quality (De Haan & Kroonen-Backbier, 2002; Pulleman, 2002). These farms however, have also difficulties to meet the target value for nitrate (Van Den Berg & Pulleman, 2003). Although many different culturing practices are combined to increase N-efficiencies and minimize N-losses, the target value was only occasionally met in the three-year period in which the groundwater quality was monitored. These results request additional efforts to develop arable cropping systems which on one hand meet the target value and on the other hand produce marketable crops and thus have economic perspectives to be practiced by farmers. One additional research strategy could be the use of model calculations in order to evaluate long term effects of different culturing practices on both N-emissions to the groundwater, on yield and on soil fertility (organic matter content).

In this study we developed a simulation model that is able to simulate a rotation of arable crops, including cover crops. The model was developed by coupling existing models for the water balance and for the growth of individual crops. Simple concepts of mineralization and N-uptake by crops were incorporated so that the model was able to simulate the Mineral Nitrogen dynamics in Arable Crop rotations (MiNiAC).

The development of MiNiAC targeted several goals. First, it should be a (relatively) simple tool. Second, it should assist in identifying and quantifying the different sources of leached nitrogen. Third, it should assist in a scenario study in which farming practices could be related to the reduction or the increase of nitrogen leaching. Fourth, it should assist in a risk analysis whereby the risk of nitrogen loss and the risk of nitrogen shortage for crop production could be assessed for different management strategies.

MiNiAC meets these goals by simulating the nitrogen balance of an arable field. It relates the balance to the farming practice by allowing the cropping of one or more crops in a time sequence, the usage of predefined fertilizers, irrigation strategies, and the management of crop residues. Farming activities, which are not taken into account, are tillage practices, and pest and weed management.

## 3. Model description

### 3.1 System description

MiNiAC describes the mineral nitrogen flows into, inside and out of a soil layer, considering all nitrogen forms ( $\text{NO}_3$  or  $\text{NH}_4$ ) in the model as nitrogen (N). The volume of the layer is defined by the input parameters. The layer itself is divided into 2 or more sub-layers for computation of vertical mass flow. A water layer on top of the soil is included which may contain rainwater and mineral nitrogen from deposition.

Two mineral nitrogen sources are used as input, i.e. deposition and fertilization (including manure). Net mineralization of organic materials in general will be positive but may become negative after incorporation of organic materials with high carbon to nitrogen ratio (C/N ratio). Two sinks of nitrogen are considered, i.e. uptake by plants and nitrogen leaching below a predefined depth. Denitrification processes are not included in the model because for the given location potential denitrification is negligible (Zwart *et al.*, 2001).

LINTUL-SAWAH simulates the nitrogen flows dynamically during a period of farming activity. This period should start before the planting of the first crop and may end on any later date. Several crops may be grown on the field in a sequence. Cropping activities such as planting, harvesting, irrigation, fertilization and crop residue management are related to time. At the start of a simulation, organic matter is described as one pool with a predefined initial age. During the simulation, new organic materials from crop residues or organic fertilization become new decomposing materials, pools, with their own relative mineralization rate expressed in the initial age. Thus, organic matter in the soil is considered to be distributed among different materials/pools, each decomposing independently from each other with their own speed.

### 3.2 Model structure

The model uses the Fortran Simulation Environment (FSE) convention for numerical integration (Van Kraalingen, 1995). The FSE driver functions by repetitive calls to the timer, weather system, nitrogen-crop-growth model and output of results subroutines. Within one time step it calls the model first for initiation, secondly for rate calculations and thirdly for integration.

The model consists of different sub-models, a model to simulate water transport SAWAH (Simulation Algorithm for Water flow in Aquatic Habitats, Ten Berge *et al.*, 1992, Ten Berge *et al.*, 1995) and a model to simulate crop growth and nitrogen uptake, LINTUL (Spitters & Schapendonk, 1990). The water transport simulation model has an internal self regulating time step whereas the crop growth model has a fixed time step of one day.

Several control statements are included at the end of each time step. Main control statements are to check the water and nitrogen balances.

### 3.3 Included subroutines

#### *FSE driver*

The FSE driver controls the integration loop. It handles the time management as well as the weather data. The FSE driver is programmed and documented by Van Kraalingen (Van Kraalingen, 1995). The original FSE 2.01 driver may be used, however, for clarity and the possibility to batch processing the model without requests for interactive input, a modified the FSE 2.01 driver is included. The following modifications were carried out:

1. The FSE 2.01 driver was split into subroutines, namely driver, weather system and output controls.
2. The time controls, integration controls and file handling parameters were declared as common.
3. The requests for 'enter' after warning or error messages from the weather system were removed to facilitate batch calculations.
4. The FSE driver has been transformed into a Quickwin Application, which allows the usage of more than one window and which is especially handy during validation and calibration of the model.

5. A function was included to convert double precision time, as outputted by RDxTIM, to FSE time. This function uses a reference year, extracted from STTIME (Starting TIME).
6. The modified FSE 2.01 driver uses dates in stead of Julian day numbers as input for STTIME and FINTIM (FINAL TIME). If IYEAR (initial year of simulation) is less then the year of STTIME, a year shift occurs for all input dates and weather data, analogous to the original FSE driver, which uses Julian day numbers for STTIME and FINTIM.

### *Libraries*

Three static libraries are used in the model:

- TTUTILS (Van Kraalingen & Rappoldt, 2000),
- PGPLOT (<http://www.astro.caltech.edu/~tjp/pgplot/>) and
- the Quickwin library of Visual Fortran.

TTUTILS is used for reading data and for the use of some numerical functions such as INTGRL. PGPLOT is used for graphical output and can be removed if no graphical output is required. The Quickwin library is used in the adjusted FSE driver. The program will be compiled as a Quickwin application that allows for output to more than one window.

### *LINTUL with adjustments*

LINTUL (Spitters & Schapendonk, 1990) is a simple crop growth model, which simulated dry mass increase with a time step of 1 day. At the start of the growing season of a crop, it simulates the increase of LAI in time exponentially. At a given LAI or a given temperature sum, the increase of LAI is computed by multiplying the dry mass partitioned to the leaves with the specific leaf area (SLA). The SLA is assumed to be constant during the growing season. This LAI increase is then added to the existing LAI. The daily dry matter production is calculated through the LAI, the daily radiation and the light use efficiency (LUE). Finally the dry matter is partitioned into leaves, stems, roots and storage organs with known partitioning functions depending on temperature sums.

Three major adjustments to LINTUL have been made:

1. LINTUL has been extended in such a way that a crop rotation in time with different crops can be handled with different sets of crop parameters during the simulation period.
2. Nitrogen demand is implemented in the model. The potential amount of nitrogen in the crop is calculated through a table function with nitrogen content of the total dry mass and of dead dry mass. The N-demand (NDEMAND) at time  $t$  is calculated as the difference between the amount of N (in the total biomass of the crop, NDM) at time  $t$  and the amount of N at time  $t-1$  (Godwin & Jones, 1991).

$$NDEMAND_t = NDM_t - NDM_{t-1} \quad 1$$

3. The actual nitrogen uptake rate is implemented in the model in a very simple way. The actual nitrogen uptake rate is considered as a sink strength, calculated as the minimum of the NDEMAND and the available nitrogen. It is assumed that nitrogen uptake from a layer is proportional to the amount of available nitrogen present in that layer.

There are several implications due to this simplistic approach. First, the nitrogen uptake does not depend on the root length density, which represents the uptake capacity of the crop. Second, a layer can be exhausted for nitrogen, which is not likely to happen in reality. Third, the model can not deal with the effect of nitrogen shortages on dry mass production. When the nitrogen demand is not met, the N-shortage is cumulated and produced as an output variable.

In spite of these shortcomings this approach served our purposes.

### *SAWAH with adjustments*

Water transport is simulated using the model SAWAH (Simulation Algorithm for Water flow in Aquatic Habitats, Ten Berge *et al.*, 1992, Ten Berge *et al.*, 1995). SAWAH is a relatively simple one-dimensional water transport model that simulates water fluxes for saturated and unsaturated soils. The model requires the standard parameters of Van Genuchten to describe the soil hydraulic properties (Van Genuchten 1980).

The soil surface and the groundwater determine the boundary conditions for SAWAH. Rain and irrigation water is placed as a uniformly distributed water layer on top of the soil. This water may percolate into the soil, remain on top

or, if a predefined threshold is reached, run off. When the topsoil is dry, the top boundary is determined by an evaporation front, which moves slowly downwards when the topsoil dries out. The lower boundary water tension (hPa) is equal to the vertical distance (-cm) from the bottom of the lowest compartment to the groundwater level. Adjustments to SAWAH have been made for a better estimation of the time step for dummy integration. Oscillations occurred in the original model when the water content of a compartment was close to saturation. The model switched to and from saturated and unsaturated fluxes, which differed in direction. The adjustment was made to optimize the time step which then reduces the chance of unstable oscillations. This was done by the introduction of the Bisection Method (Press *et al.*, 1990) to determine the largest allowable time step.

The original model SAWAH does not compute potential evapotranspiration. Therefore, the evapotranspiration subroutine of Van Kraalingen & Stol (1997) has been included. This subroutine uses the Penman equations for evapotranspiration (Penman, 1948 and 1956). For each specific crop the crop coefficient to translate the Penman reference transpiration to the specific transpiration, is used (Feddes, 1987).

Water uptake by the crop is included in the model according to the water uptake described in SUCROS97: Simulation of crop growth for potential and water-limited production systems (Van Laar *et al.*, 1997). Roots are assumed to be uniformly distributed over the soil layer and water uptake depends on the relative amount of water available for uptake. The actual water uptake is calculated in the same way as the actual nitrogen uptake.

#### *Mineralization*

Carbon and nitrogen from organic matter are decomposed by micro-organism. There are many different mathematical and numerical models to describe these processes. In this study we used a relatively simple model described by YANG (1996) and Yang & Janssen (2000):

$$Y_t = Y_0 * e^{(-R*(f*t)^{(1-S)})}$$

2

in which  $Y_t$  and  $Y_0$  are the total quantity of organic C at time  $t$  and zero respectively,  $R$  is the average relative release rate during the first year,  $f$  is the temperature correction factor and  $S$  denotes the initial speed of 'aging' of the substrate. The parameters  $R$  and  $S$  are based on experimental data and the standard values presented by YANG (1996) are used in this study. The N mineralization is calculated as a result of the C-release, by multiplying the C-released with the C/N ratio of the organic matter. In the C-release and N-mineralization calculations, two processes are included: 1. Immobilization of N due to newly formed microbial biomass and 2. A biosynthesis efficiency (dissimilation / assimilation or D/A) depending on the type of micro-organism involved.

At the start of the model each layer of the soil is defined to be a pool and all pools decompose according to equation 2. There is no interaction between pools. The module may initiate new pools at times of new inputs like fertilization or crop residues from harvest. All pools exist till the end of the run. The maximum number of pools needs to be set in the source.

There are three time depended processes which affect the C-release and N-mineralization:

1. Temperature: a temperature correction function  $f$  is applied (Yang, 1996). The function assumes that the standard parameters for the speed of decomposition are obtained at 9°C.
2. Soil moisture content: a correction function for soil moisture is used, which reduces decomposition in dry and extremely wet soils (Reddy *et al.*, 1979 cited by Antonopoulos, 1999).
3. A reduction factor for decomposition is included to handle situations in which immobilization is greater than the mineral N content available. Thus, negative values for the mineral N content of a layer are avoided.

#### *Fertilization*

At fertilization, new pools are added to the mineralization module. Inorganic fertilizers are also handled by the same module. These contain 100% inorganic N and no carbon. Therefore, inorganic fertilizers are treated as fully mineralized pools in the mineralization subroutine.

#### *Deposition*

Deposition is computed from a fixed concentration in the rainwater multiplied with the daily rainfall. The concentration is calculated from the average yearly rainfall and yearly deposition measurements (Milieuenatuurcompendium, 2003).



### *Nitrogen Mass Flow*

Nitrogen mass flow is simulated by multiplying the nitrogen concentration in a sub-layer with the water flux, away from the sub-layer. Within this process, accuracy is obtained by a dummy integration with a smaller time step. This time step allows for a maximum nitrogen flux of 1/100<sup>th</sup> of the nitrogen content of the source layer. When this criterion is not met an error message is plotted to the screen and the run is terminated.

### *Nitrogen balance*

This module computes the nitrogen balance and gives an error message if any imbalance greater than 0.1 kg N ha<sup>-1</sup> occurs.

### *Output of results*

An subroutine has been included for output of results. The subroutine may write tables or graphic output to one or more windows or files. For graphic output, the PGPLOT library (<http://www.astro.caltech.edu/~tjp/pgplot/>) is used.

## **3.4 Programming style**

The different subroutines all perform their own initialization, rate calculations and state calculations, as is common in FSE driven programs. Parameters which are used by more than one subroutine, are exchanged by using 'common blocks'. The declarations of these parameters are written in an include file. An 'include 'common.inc' statement will make these parameters available to new subroutines. This programming style makes replacement of subroutines easier. Secondly, this approach requires consistent use of parameter definitions, thus making it easier to read the source code. Disadvantages are that it is unknown which subroutine is owner of a parameter and whether a parameter is already updated for the current time. Therefore, the order in which subroutines are called may become important.

## **3.5 Compilation instructions**

Compilation works fine with the supplied Visual Fortran project settings that are basically standard Quickwin application settings. You may receive the following warning that may be ignored:

LINK : warning LNK4098: defaultlib "libc.lib" conflicts with use of other libs; use /NODEFAULTLIB:library

It is advised to turn off any optimizations. Optimizations yield little gain, while sometimes results differ with those from non-optimized compilations.

## 4. Model parameters

Seven input files contain the parameters and their values for the different subroutines. The data types that are used in the input files are described below. Examples of the input files have been given in Appendix I.

### 4.1 Data types

Four data types are used: reals, integers, character strings and time data (dates).

- Reals and integers are numbers with or without floating points, respectively. A real must contain a dot. Scientific notation may be used using, e.g. 3.5E-7. Integers don't contain a dot, again the scientific notation may be used.
- Character strings are always given between single quotes.
- Dates may be formatted according to the following formats:
 

jjjj/mm/dd	e.g. 1994/08/31
jjjj-mm-dd	e.g. 1994-08-31
dd/mmm/jjjj	e.g. 3/sep/1994, also 3/september/1994
dd-mmm-jjjj	e.g. 3-sep-1994, also 3-september-1994

Single values are given in the format 'parameter=value' e.g.  
Param = 10.

Some data is read as an array i.e. a list of values. Arrays may be formatted as a comma separated list or in table format e.g.

```
Array1 = 10/jan/1994,29/jul/1994,15/sep/1994
Array2 = 10.,5.,6.
```

Or

Array1	Array2
10/jan/1994	10.
29/jul/1994	5.
15/sep/1994	6.

For more information on data types and formats, the reader is directed to the TTUTILS manual (Van Kraalingen & Rappoldt, 2000.)

### 4.2 Data files

#### *CONTROL.DAT*

This file contains the filenames of the different input files. This release uses names presented in the next chapters, however, they may be altered. Filenames can not be changed in reruns.

#### *RERUNS.DAT (Optional)*

If it is necessary to run the model repeatedly with new parameters sets, writing a reruns file may be useful. 'RERUNS.DAT' may contain new sets of changed parameters, previously defined in any of the input files, described below. Sets of parameters are separated by a semicolon and may only contain the adjusted parameters. The Model is 'rerun' after each semicolon with the new parameters. Output is directed to the same output files, however will be named rerunsset1, -2 etc.

*TIMER.DAT*

This file contains the time and weather data.

*CROPS.DAT*

The CROPS.DAT contains a table that describes the cropping sequence and the handling of crop residues. An error message will be produced at initiation of the model when a crop is planted before STTIME in the TIMER.DAT or before the previous crop is harvested. The model does not simulate inter-cropping. All other parameters, which are crop related, are set in the LINC.DAT file.

*LINC.DAT*

LINC.DAT contains a table with crop codes and names, and for each code a parameter set. Parameter names end with the crop code. Adding a new crop to the database may be done by adding a new, unique, crop code with the crop name to the crop code list and adding a new set of parameters ending with the new crop code. For example, if the new crop code is 'ZZ' the new specific leaf area parameter becomes 'SLATBZZ'.

*SAWAH.DAT*

This parameter file contains parameters for SAWAH. The file is slightly adjusted from the one described by Ten Berge *et al.* (1992).

*FERTILISER.DAT*

FERTILISER.DAT contains two tables, one to describe the fertilizer parameters and one to describe the actual fertilizer management.

*Weather data*

Weather data are retrieved by the FSE weather system. This library, weather.lib, reads files with the name 'country\_code-station\_number.year' (example for 1994 from station number 2: NLD2.994) as given in the TIMER.DAT. The weather files contain daily weather data for one year.

## 5. A set of parameters for the experimental station: Vredepeel

This chapter describes a parameter set for the experimental station Vredepeel, located in North Limburg, the Netherlands. This parameter set has been used for the verification of the model (Chapter 6). Vredepeel has a rotation of 8 years. Three different fertilizer strategies are tested on each rotation. Therefore,  $3 \times 8 = 24$  fields can be distinguished at Vredepeel. Within 2 fields fallow plots have been established for a two-year period (2001 and 2002), which are included in the simulations. This resulted in  $2 \times 2 + 24 = 28$  field to verify the model.

### 5.1 Weather data 2001-2002

Minimum and maximum temperature and the precipitation were measured at Vredepeel at a daily basis. All other weather data were retrieved from the Wageningen weather station. RIVM measured in 1999 an annual N deposition of 49 kg/ha (De Buck *et al.*, 2000, Milieuenatuurcompendium, 2003). The average rainfall in the Netherlands is 750 mm per year. The average temperature of 2002 at Vredepeel was 10.9 °C.

### 5.2 Soil parameters

Vredepeel is located on a sandy soil with 3-4 percent organic matter in the first 30 cm. Deeper down the organic matter rapidly declines to 1-2 percent at 30-60 cm and less than 1 percent below 60 cm. The C/N ratio is calculated from the organic C (0.54 \* fraction of measured organic matter of the field) and the measured N-content (of the same field). The bulk density of all fields is 1400 kg/m<sup>3</sup>.

#### *Space discretization*

Simulations were carried out for a soil profile of 70 cm. The profile was divided in 7 equal layers. It was presumed that N below 60 cm was lost for nutrient uptake (was leached) as no roots were expected to be lower than 50 cm depth and the capillary rise was insufficient to supply nitrogen from the groundwater.

#### *Mineralization*

Standard mineralization parameters, as given by Yang (1996), were used, bioefficiency of 8, initial speed of aging S of 0.46, DA of 2. A  $R_0$  of 0.037 was estimated from potential mineralization measurements. Potential mineralization measurements were fitted to equation 2, with the standard parameters mentioned above. The  $R_0$  was solved with the Microsoft EXCEL solver for the least sums of square. Measured field specific parameters were used for the organic matter content and organic nitrogen content. These parameters were measured at three depths (Table 1).

Table 1. Field specific mineralization parameters.

Field	Organic nitrogen (kg/kg soil)			Organic matter (kg/kg soil)		
	Depth (cm)					
	0-30	30-60	60-90	0-30	30-60	60-90
16.1	0.00137	0.0005	0.00025	0.039	0.018	0.008
16.2.A1	0.00096	0.00047	0.00011	0.037	0.017	0.006
16.2.A2	0.00096	0.0005	0.00014	0.039	0.017	0.006
17.1	0.00121	0.00069	0.00013	0.039	0.025	0.007
17.2.A1	0.00114	0.00051	0.00017	0.039	0.019	0.006
17.2.A2	0.00103	0.00085	0.00025	0.037	0.024	0.008
18.1	0.00133	0.00049	0.00015	0.039	0.019	0.006
18.2.A1	0.00107	0.00034	0.00011	0.037	0.014	0.004
18.2.A2	0.00113	0.00032	0.00014	0.037	0.031	0.005
18.2.A2.B	0.00113	0.00032	0.00014	0.037	0.013	0.005
18.2.A2.C	0.00113	0.00032	0.00014	0.037	0.013	0.005
19.1	0.00112	0.0004	0.00016	0.041	0.019	0.005
19.2.A1	0.00101	0.00034	0.00014	0.039	0.012	0.005
19.2.A2	0.00103	0.00028	0.00017	0.041	0.011	0.006
26.1	0.001	0.00057	0.0001	0.04	0.015	0.001
26.2.A1	0.00108	0.00043	0.0001	0.031	0.011	0.001
26.2.A2	0.00079	0.0003	0.0001	0.032	0.012	0.001
27.1	0.00118	0.0004	0.00031	0.041	0.02	0.006
27.2.A1	0.00123	0.00083	0.00024	0.042	0.026	0.01
27.2.A2	0.00105	0.00058	0.00019	0.041	0.021	0.011
28.1	0.00119	0.0003	0.0001	0.038	0.015	0.005
28.2.A1	0.00106	0.00033	0.00012	0.039	0.018	0.006
28.2.A2	0.00094	0.00045	0.00005	0.037	0.015	0.005
28.2.A2.B	0.00094	0.00045	0.00005	0.037	0.015	0.005
28.2.A2.C	0.00094	0.00045	0.00005	0.037	0.015	0.005
29.1	0.00097	0.00042	0.00012	0.032	0.013	0.006
29.2.A1	0.00122	0.00062	0.00016	0.035	0.02	0.007
29.2.A2	0.00106	0.00028	0.00013	0.034	0.014	0.007

*Water retention and conductivity*

The Van Genuchten parameters have been used. These were estimated using data from Vredepeel (Figure 1; De Vos *et al.*, 2002) by fitting the Van Genuchten curve using Microsoft EXCEL solver for the least sums of square. The boundary conditions for some parameters were included in the solver,  $WCST > VGR > 0$ , and  $K_s > 0$ . It has been assumed that the water retention parameters are not field specific. The parameters are given in Table 2.

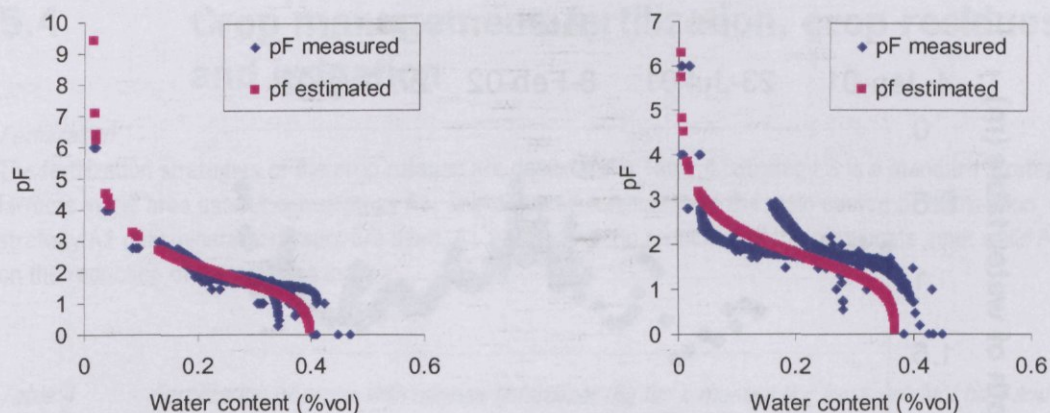


Figure 1. *pF* curve of the soil at 10-15 cm (left) and 35-40 cm depth (right). The measured data (De Vos *et al.*, 2002) are plotted as well as the Van Genuchten estimate.

De Vos *et al.* (2002) estimated the saturated conductivity at Vredepeel. The conductivity in the sandy soil is relatively high.

Table 2. *The Van Genuchten parameters.*

Depth (cm)	$\Phi_s$	$\Phi_r$	$n$	$\alpha$	$l$	$K_s$
	WCST (m <sup>3</sup> m <sup>-3</sup> )	VGR (m <sup>3</sup> m <sup>-3</sup> )	VGN (-)	VGA (cm <sup>-1</sup> )	VGL (-)	KST (cm d <sup>-1</sup> )
0-20	0.40	0.015	1.4	0.04	-2.25	15
20-30	0.40	0.015	1.4	0.04	-2.25	4.3
30-60	0.37	0.003	1.6	0.04	-1.77	8.5
60-90	0.35	0.0018	1.7	0.04	-1.70	3.8

#### Evaporation

The standard parameters for SAWAH for the conversion of potential evaporation to actual evaporation have been used (CSC2 = 0.1 cm<sup>2</sup> d<sup>-1</sup>, CSA = 0.005 cm<sup>2</sup> d<sup>-1</sup>, CSB = 1.0) (Ten Berge *et al.*, 1992; Ten Berge *et al.*, 1995).

#### Groundwater depth

The depth of the groundwater was measured and used as input in the model to control the lower boundary. Data have been given in Figure 2.

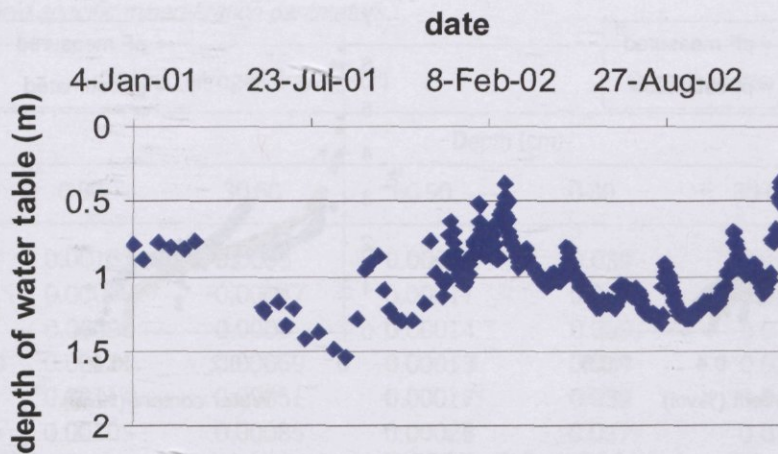


Figure 2. The groundwater table at Vredepeel as measured during the 2 years.

### 5.3 Crop rotation

Table 3 contains the crop rotation at Vredepeel. The use of green manure differed for the different fertilizer strategies, S, A1 en A2.

Table 3. Cropping sequence at Vredepeel, type of green manure and field number for S, A1 and A2 strategies.

Crop	Green manure	Green manure	Green manure A2	Field	Field
	S	A1		2001	2002
1 Early potato	None	None	Raphanus Sativus (Radish)	29	19
2 Sugar beet	None	None	Spring barley (1)	27	29
3 Silage maize	None	None	Spring barley	18	27
4 Peas & field beans (2,3)	None	None (2)	None (3)	26	18
5 Late potato	None	None	None	28	26
6 Sugar beet	None	None	None	17	28
7 Triticale / spring barley (4)	None	Triticale regrowth	Spring barley	16	17
8 Spring barley / carrots (5)	None	None	None	19	16

(1) 2001, no green manure

(2) 2001, in 26.2.A1 Tagetes instead of field beans because of nematode infestations

(3) 2001, in 26.2.A2 Tagetes, 2002, in 18.2.A2 Raphanus Sativus, both instead of field bean because of nematode infestations

(4) 2002, in 17.2.A2 spring barley instead of Triticale

(5) 2001, spring barley and 2002, carrots

## 5.4 Crop management: fertilization, crop residues and irrigation

### Fertilization

The fertilization strategies of the crop rotation are described in Table 4. Strategy S is a standard strategy most farmers in the area use. Under strategy A1, animal based fertilizers are the main source of fertilization, while under strategy A2 only mineral fertilizers are used. A1 focuses on the reduction of the phosphate input while A2 focuses on the reduction of the nitrogen input.

Table 4. Fertilization of crops with mineral N fertilizer ( $\text{kg ha}^{-1}$ ), manure ( $\text{kg fresh product ha}^{-1}$ ) and imported crop residues ( $\text{kg fresh product ha}^{-1}$ ) for strategy S, A1 and A2 in 2001 and 2002.

Crop	Field	Type	Date (2001)	S	A1	A2	Field	Type	Date (2002)	S	A1	A2
Spring barley/carrot	19	straw	2-Apr-01	2707	2707	2707	16					
		mineral f.	13-Apr-01	70	70	70		mineral f.	14-Jun-02	50	50	24
Early potato	29	pig slurry	16-Mar-01	20000			19	pig slurry	28-Mar-02	26000		
		ecoboost	16-Mar-01		40000			ecoboost	4-Apr-02		35000	
		carrots	6-Apr-01	23000	29000	29000						
		mineral f.	13-Apr-01			120		mineral f.	26-Apr-02			100
		mineral f.	18-May-01	85	38	70		mineral f.	31-Mar-02	51		54
		mineral f.	14-Jun-01	30	30	20						
		mineral f.	26-Jun-01			10						
Sugar beet	27	pig slurry	16-Mar-01	20000			29	pig slurry	28-Mar-02	26000		
		ecoboost	16-Mar-01		40000			ecoboost	4-Apr-02		40000	
		straw	6-Apr-01	2707	2707	2707		mineral f.	3-Apr-02			100
		mineral f.	13-Apr-01			80		mineral f.	26-Apr-02	95	22	
		mineral f.	18-May-01	68	16	81		mineral f.	26-Apr-02			78
Silage maize	18	cattle slurry	5-Apr-01	45000			27	cattle slurry	11-Apr-02	50000		
		ecoboost	16-Mar-01		35000			ecoboost	11-Apr-02		35000	
		mineral f.	2-May-01	50	30	30		mineral f.	23-Apr-02	40		
		mineral f.	4-May-01			120		mineral f.	25-Apr-02			122
Pea & bean	26	straw	28-Mar-01	2707	2707	2707	18	mineral f.	14-Mar-02	41	41	70
		mineral f.	2-Apr-01	78	78	78		mineral f.	5-Jul-02	92	54	
		mineral f.	6-Jul-01	54				mineral f.	14-Mar-02			41
Late potato	28	pig slurry	16-Mar-01	20000			26	pig slurry	28-Mar-02	26000		
		ecoboost	16-Mar-01		40000			ecoboost	4-Apr-02		40000	
		straw	6-Apr-01	2707	2707	2707		mineral f.	1-May-02			100
		mineral f.	24-Apr-01			120		mineral f.	21-Jun-02			
		mineral f.	18-May-01	81	32	65		mineral f.	31-May-02	73		55
		mineral f.	27-Jun-01	30	30			mineral f.	21-Jun-02	30	30	20
		mineral f.	6-Jul-01			40		mineral f.	2-Aug-02			20
Sugar beet	17	straw	5-Apr-01	2707	2707	2707	28					
		pig slurry	16-Mar-01	20000				pig slurry	28-Mar-02	26000		
		ecoboost	16-Mar-01		40000			ecoboost	28-Mar-02		40000	
		mineral f.	13-Apr-01			80		mineral f.	3-Apr-02			100
		mineral f.	18-May-01	77		73		mineral f.	2-May-02	84		
Triticale	16	mineral f.	21-Feb-01	81	81	81	17	mineral f.	14-Mar-02	80	80	
		mineral f.	13-Apr-01	60	60	60		mineral f.	19-Apr-02	60	60	



*Crop residues*

In principle, all residues remained on the field. It is assumed that 15% of the beet roots and carrots remains on the field as well as 5% of the maize stems. Unless grown as green manure, straw from spring barley was removed from the field and brought to fields where sugar beets were grown. Straw from triticale was removed in the standard cropping system but left in the A1 en A2 strategies.

*Irrigation*

Crops were irrigated during dry periods (Table 5). Each time, fields were overhead irrigated with 30 mm of water.

*Table 5. Field number and date of applied irrigation (30 mm per event).*

Field	Date					
16	11-Jun-01	26-Jun-01	3-Jun-02	11-Aug-02	15-Sep-02	
17	30-Jun-01	6-Jul-01	1-Aug-01			
18	4-Jun-02	16-Aug-02				
19	13-Jun-01	30-Jun-01	5-Jun-02	29-Jun-02		
26	29-May-01	16-Jun-01	24-Jun-01	25-Jun-02	15-Aug-02	24-Aug-2001 (1)
27	1-Jul-01	7-Jul-01	1-Aug-01			
28	20-Jun-01	27-Jun-01	9-Jul-01	29-Jul-01	29-Aug-01	
29	21-Jun-01	25-Jun-01	9-Jul-01	30-Jul-01		

(1) Only in 16.1 where beans were grown, not in 26.2.x where *Tagetes* was grown

## 6. Model verification

The model results after running with the previous described data sets for Vredepeel, have been compared with the measured nitrogen content in the crop, the measured soil water tension and water content, and the measured soil mineral nitrogen content.

### 6.1 Nitrogen in the crop

Differences in nitrogen uptake between different crops were nicely simulated (Figure 3). However, the model does not explain differences between the fertilization strategies S, A1 and A2 (except when planting dates differed). Measurements indicated differences in uptake between strategies up to 100 kg N/ha. This seems to be in agreement with the conditions of the model, as we did not include a feed back on dry mass production of nitrogen uptake due to limited available nitrogen. For two crops, sugar beets and peas, differences between years are not well explained.

For a number of crops, namely sugar beet, potato and peas, the allocation of photosynthesis products seems to be sensitive to nitrogen concentrations in the soil. The model does not simulate this process (see LINTUL with adjustments). The measurements indicated that the sprout/storage organ ratio differs a lot between years and fields. Besides dry mass allocation, crops may have suffered from additional stress factors such as weeds and pests.

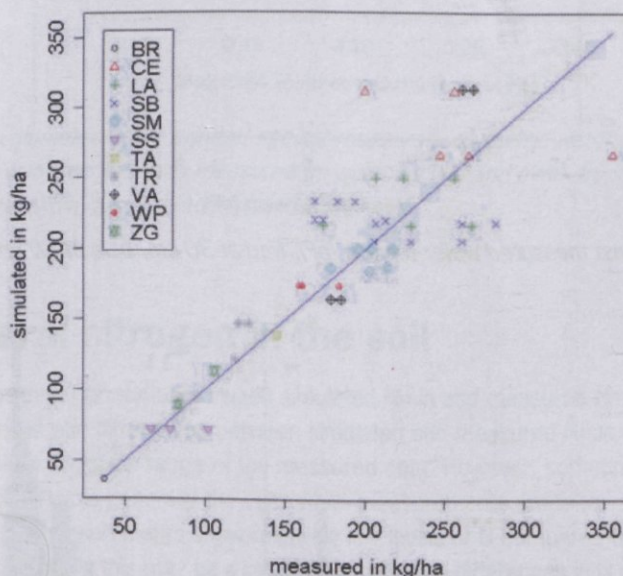


Figure 3. Simulated against measured nitrogen uptake. BR=Raphanus Sativus, CE=peas, LA=potato (late variety), SB=sugar beet, SM=silage maize, SS=field beans, TA=Tagetes, TR=triticale, VA=potato (early variety), WP=carrots, ZG=spring barley.

### 6.2 Water tension in the soil

Water transport is an important process when simulating nitrogen losses and it is often difficult to simulate. The water transport depends on the matrix suction, which is calculated from the pF-curve. In the model, the pF-curve is described by the Van Genuchten parameters. Obtaining correct Van Genuchten parameters is a delicate process.

The measured parameters to obtain the Van Genuchten parameters can vary largely, 100% is no exception. Simulating water transport close to air-dry and water-saturated conditions, at both ends of the pF-curve, usually results in increased deviation between measured and simulated soil water tensions. This is also found in this study, Figure 4, where variation increases close to pF 3 and pF 1.5. An other source of variation is hysteresis, meaning that matrix suction not only depends on the water content but also on the direction of change of the water content. This phenomenon is important on sandy soils as in Vredepeel and can be up to 15% in the plough layer (-030 cm) (Dekker *et al.*, 1999; De Vos *et al.*, 2002) but this is not taken into account in the model. Last but not least, preferential flow may cause a considerable error (Ritsema & Dekker, 2000). However, no measurements on hysteresis or preferential flow were conducted in this experiment.

Given these complications, Figure 5 may be considered as relatively good results. From these histograms may be concluded that the simulated soil moisture content is overestimated compared to the measurements, indicating that the simulated soil moisture content is wetter than the measured soil moisture content.

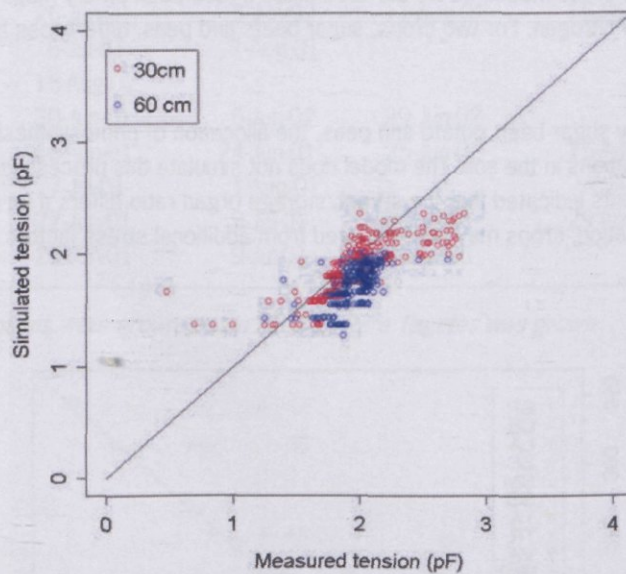


Figure 4. Simulated against measured water tension (pF). Red at 30 cm, blue at 60 cm soil depth.

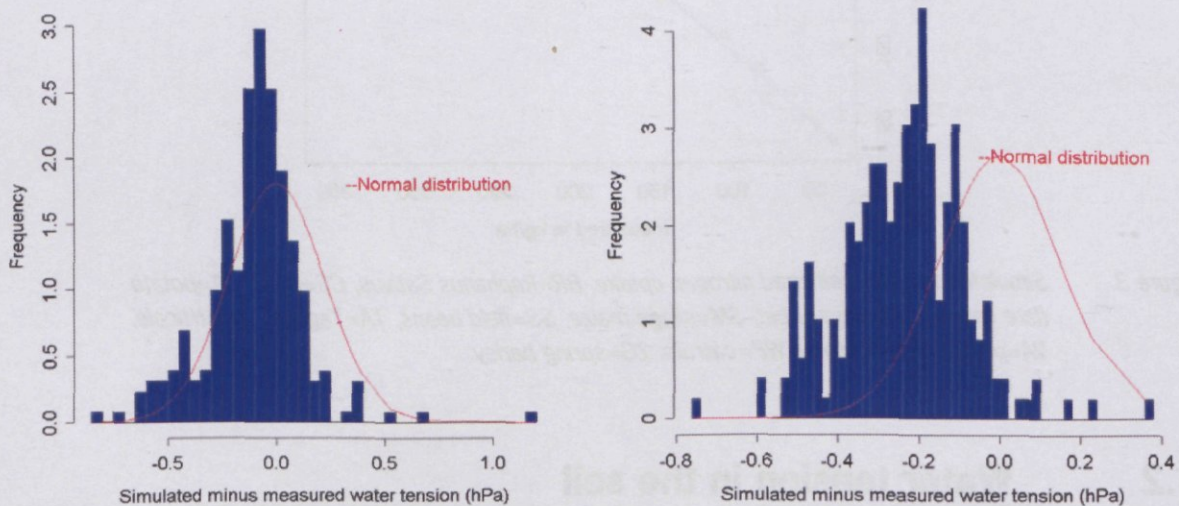


Figure 5. Histograms of the residuals in water tension for the two measuring depths, left 30 cm and right 60 cm below soil surface.

### 6.3 Water content in the soil

In the previous section it was seen from the water tension that soils are slightly wetter simulated than measured. This is confirmed by comparing simulated and measured water contents (Figure 6). As the wetness of the soil is simulated as the result of many processes, it is difficult to pin point which parameter causes the largest errors and therefore needs the most attention to be improved. Wetter conditions result in higher conductivity and subsequently in more water movement through the soil. This is likely to induce higher leaching as concentrations between layers are equalized by the water movement, favoring nitrogen transport toward deeper layers. At deeper layers concentrations tend to be lower.

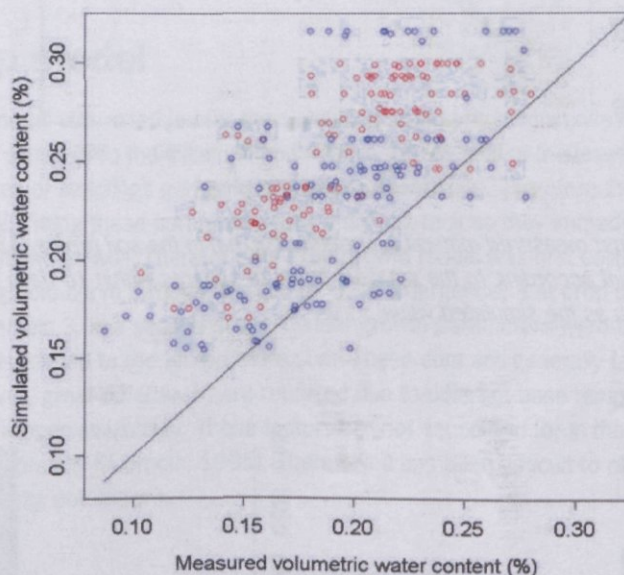


Figure 6. Simulated volumetric water content against measured volumetric water content. The measured volumetric water content was measured by weighing wet and oven dry soil samples that were taken for the  $N_{min}$  measurements (see below)

### 6.4 Mineral nitrogen in the soil

Figure 7 shows a relatively good correlation between simulated  $N_{min}$  and measured  $N_{min}$  in both 0-30 cm zone and the 30-60 cm zone. No systematic differences between simulated and measured  $N_{min}$  were found (Figure 8). Most of the simulations are within a 50 kg/ha range of the measured data. However, sometimes simulations and measurements are far apart. This is generally the case when measurements are taken shortly after mineral fertilizers were applied. Some of these measurements show relatively low levels of N compared to those one might expect from the application rates. Possibly this may be a result of locally high differences in N concentrations, which in some fields is aggravated by a row application of the fertilizers. A second source of variation between simulated and measured N contents in the soils may be the inaccurate estimation of nitrogen uptake by the crop. This is especially true for sugar beets, potato and peas, as was discussed previously.

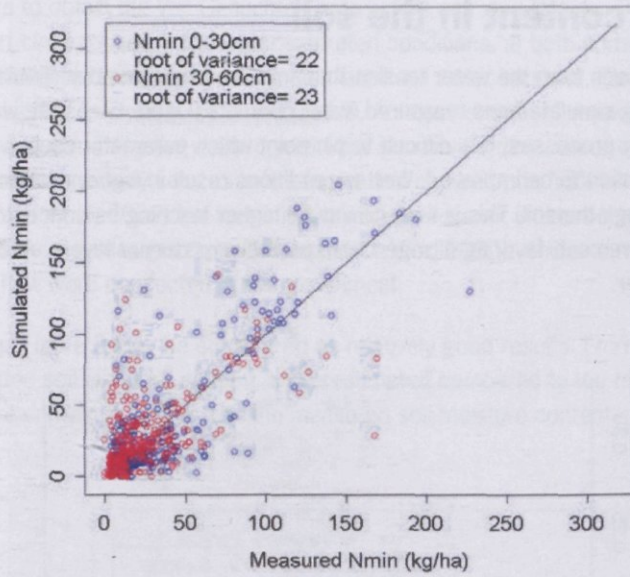


Figure 7. Simulated against measured mineral N contents (kg/ha) in the soil profile 0-30 cm and 30-60 cm. The closest point according to the smallest sums of squares within 10 days from the sample date as been chosen as the simulated value.

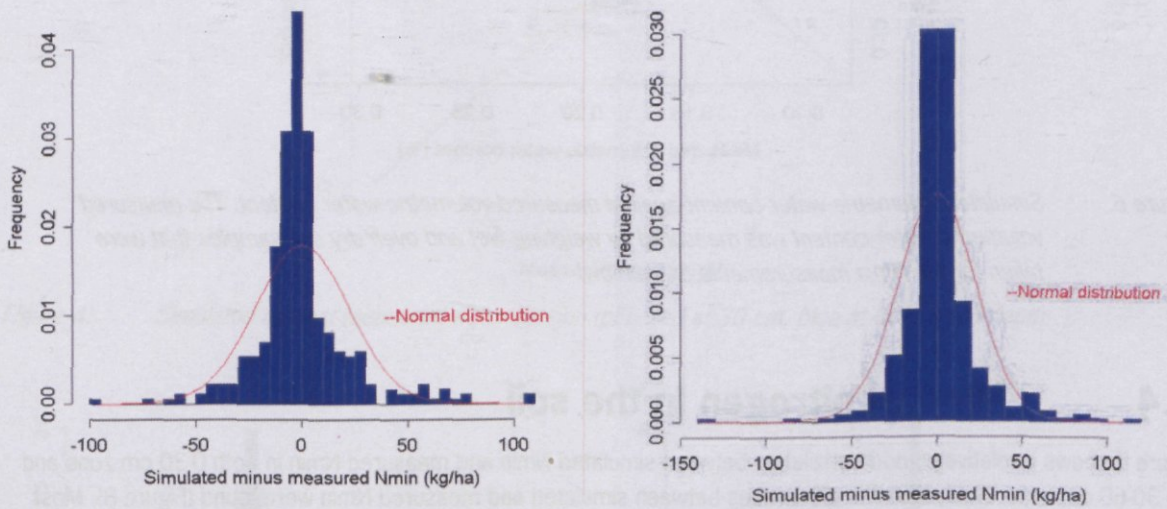


Figure 8. Histograms of residuals of previous figure, left for depth 0-30 cm, right for 30-60 cm.

## **7. Notes on the development of MiNiAC**

### **7.1 Water transport models**

Simplicity of the model was one of the goals when building this model. During the development different models to simulate water transport were tested, from simple balance calculations to tipping bucket and finally a process oriented water transport model. The importance of the water transport model for modeling the fate of nitrogen was clearly seen from the improvements when moving to a more sophisticated model for water transport.

### **7.2 Crop model**

The LINTUL-crop growth model was extended for the simulation so that more than one crop could be simulated in time. The model was very sensitive to the initial LAI and relative growth rate of the leaves. Estimations from sowing densities and initial leaf area of seedlings generally produced poor results. Therefore these parameters were adjusted to fit a proper LAI. Fitting these parameters was a difficult task as they immediately affected crop production and nitrogen uptake as well. Therefore the crop growth model was first calibrated using a fixed LAI which was derived by fitting a sigmoid curve through two points: 0. at emergence, 3 at crop closure. After crop closure, the LAI was assumed to remain 3. In a second stage the leaf growth parameters were adjusted to fit measured data. Partitioning of dry matter is related to the temperature sum. These data are generally taken from other experiments and from literature. However, great differences are reported due to different base temperatures, different cultivars or other factors such as nitrogen availability. These factors are not accounted for in the model, because of the complex relationships (Karvonen & Kleemola, 1995). Therefore it has been difficult to obtain accurate results for the partitioning of dry matter (data not shown).

### **7.3 Mineralization model**

Only potential nitrogen mineralization was measured in the laboratory. Parameter estimation for the mineralization model should be done on carbon release. As these data were not available, standard input data were obtained from Yang (1996). The relative mineralization rate determined from the laboratory measurements was reduced to match an average mineralization rate in the field of 80 kg ha<sup>-1</sup> in the first year. This amount was based on prior estimations for Vredepeel based on the measured mineral N accumulation in the fallow plots. At this rate, nitrogen did not accumulate neither was there shortage during the growing season.

### **7.4 Denitrification**

It was decided not to include denitrification as very little nitrate is denitrified at Vredepeel (Zwart *et al.*, 2001).

## 8. Discussion and conclusions

A relatively simple model on nitrogen dynamics for arable cropping systems has been presented. The model is capable of simulating more than one crop in a sequence in contrast to many other nitrogen models. It uses a water transport model based on differences in matrix potential, in contrast to the tipping bucket systems, which have narrow biophysical foundation. It uses a mineralization model, which can describe mineralization from one or more components, depending on the need of the user and the available data for validation.

MiNiAC requires is little more than the farming activities as input, making it easy to use the model in different farming situations without the need of intensive data collection. Extra parameters are restricted to a number of soil and crop parameters. Most of these are basic parameters, which are generally known, such as organic matter content, or can be derived from tables, such as the Van Genuchten parameters which can be obtained from the Staring reeks (Wösten *et al.*, 2001) when the soil particle distribution and the organic matter are known.

Interpretation of simulation results is never easy without knowing the source thoroughly. However, by keeping the interaction between different components to the minimum, we tried to ease the task of interpreting the results and we tried to reduce this handicap for any successor who might use the model.

The credibility of the model is derived from its components. The interactions of the components in this model have been tested on one experimental farm in the Netherlands for different management strategies during two different years. The first results fit relatively well with the measurements. Therefore, the model is suitable for assisting scenario studies and risk analysis at Vredepeel or comparable farming systems. How well the model behaves compared to other similar models such as RoTask is still to be determined. It is recommended to verify the model's behavior on other data sets before use.

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# Appendix I.

## Input files

```
*Example Control.dat
FILEOL = 'MODEL.LOG'      ! Log filename
FILEIR = 'RERUNS.DAT'    ! Reruns filename
FILEIT = 'TIMER.DAT'     ! Filename for time data
FILEI1 = 'crops.dat'     ! Filename for cropping sequence data
FILEI2 = 'sawah.dat'     ! Filename for water and soil parameters
FILEI3 = 'mineral.dat'   ! Filename for mineralization parameters
FILEI4 = 'linc.dat'      ! Filename for crop parameters
FILEI5 = 'bemesting.dat' ! Filename for fertilisation data
```

```
*Example timer.dat
STTIME = 1.              !start time
FINTIM = 365.            !finish time
DELT   = 1.              !time step (for Runge-Kutta first guess)
PRDEL  = 1.              !output time step
COPINF = 'N'             !Y/N whether to copy the input files to the output file
DELTMP = 'N'             !Y/N delete temporary output file
IFLAG  = 1101            !warnings to file, screen, errors to file, screen
WTRDIR = 'D:\jouke\amin-tmt\meteo\' !Directory with weather data
CNTR   = 'NLD'           !Country code
ISTN   = 1               !Station code
IYEAR  = 2002            !Year
```

```
*Example crops.dat
!Table of cropping sequence
!CROP = Crop code as listed in crop table, see linc.dat
!PLNTD = Planting date
!HARVD = Harvesting date
!RMxx = Fraction of removing of leaves, stems, roots, and storage organ at harvest.
CROP  PLNTD      HARVD      RMLV      RMST      RMRT      RMSO
'SB'  2001-04-16 2001-08-25  0.        0.        0.        0.85
'TR'  2001-08-26 2002-07-15  1.        1.        0.        1.
```

```

!List of crops which can be simulated.
CROPCODE =
  '00','No crop',    ! '00' is generic, don't change
  'PO','Potato'

!Parameter set for potato
PARVA =
2.6      ,! Average light use efficiency (g/Mj)
0.1      ,! initial leaf area index (m2 leaf area/ m2 soil)
2.       ,! base temperature for development (degrees C)
0.012    ,! initial relative growth rate of leafs (per degrees C * day)
0.       ,! % dry matter of dead leaves redistributed to the storage organs
0.5      ,! Extinction coefficient
5.2      ,! lai above which leaves die due to shading (m2/m2)
9.68e-4  ,! Relative leaf death rate due to development (per degrees day), 1. and 2, use
RDRT function
0.05     ,! Relative leaf death rate due to shading
1.2      ,! Transpiration rate, relative to Penman hypothetical grass, when LAI > 3.
280.     ,! Temperature sum for plant emergence (Degrees C day)
600.     ,! Temperature sum for death rate of leafs due to development (Degrees C day)
500.     ,! Max. rooting depth (mm)
0.       ,! nitrogen fixation as percentage of nitrogen needed for potential growth

!Partitioning of newly produced dry matter to leaves(LV) , stems(ST) roots(RT) and storage
organs(SO). Format (TSUM,FRACTION)
FLVTBVA = 0., 0.63, 270., 0.63, 393., 0.40, 420., 0., 4000., 0.
FSTTBVA = 0., 0.17, 270., 0.17, 393., 0.16, 420., 0., 4000., 0.
FSOTBVA = 0., 0.0, 270., 0.0, 393., 0.44, 420., 1., 4000., 1.
FRTTBVA = 0., 0.2, 270., 0.2, 393., 0., 420., 0., 4000., 0.

!Nitrogen concentration in the plant parts related to (TSUM) g nitrogen/g dry matter)
NCLVTVA = 0., 0.068, 125., 0.055, 218., 0.03, 250., 0.02, 4000., 0.02
NCSTTVA = 0., 0.040, 125., 0.034, 188., 0.018, 250., 0.012, 4000., 0.012
NCSOTVA = 0., 0.0158, 600., 0.0158, 1100., 0.017, 4000., 0.017
NCRTTVA = 0., 0.030, 63., 0.027, 188., 0.020, 250., 0.015, 4000., 0.015

!% change in light use efficient as a function of the temperature (degrees C)
LUETTVA = 0.,1., 100.,1.

!Specific leaf area (g/m3) as function of temperature sum
SLATBVA = 0.,0.0032, 270., 0.0032, 420.,0.0015, 5000.,0.0015

!Death rate leaves as function of temperature (DRDVO=1.) or temperature sum (DRDVO=2.)
RDRTVA = -20., 0.0, 10., 0.0, 15., 0.0, 30., 0.0, 50., 0.0

```

```

*Example sawah.dat
!SWIT3 : conductivity function option switch
!1: simple Rijtema, 2: extended Rijtema, 3: Van Genuchten, 4: Power function
SWIT3=3
!SWIT5 : time step option switch, 1=Variable time step, 2=Fixed time step (DTFX)
!SWIT5 = 1
!SWIT6 : soil moisture initialisation option switch
!1: hydrostatic equilibrium with groundwater, SWIT6=2: as specified below in WCLQTM
!3: at wilting point.
SWIT6 = 1
!SWIT7 : pressure head at lower boundary option switch:
!1: derived from groundwater level: ZWTB, 2: free drainage
SWIT7 = 1
!SWIT8 : moisture characteristic option switch.
!1: Driessen, 2: Van Genuchten, 3: linear interpolation on log scale
SWIT8=2

DTFX = 0.01 ! Fixed time step, units: d
DTMIN = 0.0000 ! Minimum time step, units: d
DTMX1 = 0.001 ! Maximum time step, units: d

LZ = 6 ! nth soil compartment below which leaching occurs
WLOQTI = 0.0 ! Ponding water units: m
WLOMX = 0.50 ! Maximum ponding water, units: m
IDRAIN = 0 ! nth soil layer in which drains or located.
ZEQTI = 0.00 ! Evaporation depth, units: m
CSC2 = 0.1 ! Effective soil vapour diffusivity, units: cm2/d
CSA = 0.005 ! Parameters for change of evaporation front, units: cm2/d
CSB = 1.0 ! Parameters for change of evaporation front, units: -

!Table with soil parameters per layer:


| Layer | TKL | WCLQTM | WCST | KST | VGL    | VGN   | VGR  | VGA |
|-------|-----|--------|------|-----|--------|-------|------|-----|
| 1     | 0.1 | 0.22   | 0.40 | 15. | -2.255 | 0.015 | 0.04 | 1.4 |
| 2     | 0.1 | 0.22   | 0.40 | 15. | -2.255 | 0.015 | 0.04 | 1.4 |
| 3     | 0.1 | 0.22   | 0.40 | 15. | -2.255 | 0.015 | 0.04 | 1.4 |
| 4     | 0.1 | 0.22   | 0.40 | 15. | -2.255 | 0.015 | 0.04 | 1.4 |


! TKL = Thickness soil compartments, units: m
! WCLQTM= Initial water content, units: m3 water/m3soil
! WCST = Saturated water content, units: m3 water/m3 soil
! KST = Saturated conductivity, units: cm/d
! VGL,VGN,VR,VGA: Van Genuchten parameters

!Table with date of irrigation and amount of irrigation in mm


| TIRRIG     | IRRIG |
|------------|-------|
| 2002-06-05 | 30.   |
| 2002-08-17 | 30.   |



!Table with groundwater levels.


| Dates       | Gwater |
|-------------|--------|
| 01/Jan/2000 | 0.79   |
| 04/Jan/2001 | 0.79   |
| 15/Jan/2001 | 0.89   |


```

## \* Example Mineral.dat

YNDEP = 49. !Yearly N deposition in kg/ha  
 YRAIN = 750. !Average yearly rainfall  
 BD = 1400. !Bulk density (kg/m3)  
 INDISS = 0.0 !Initial amount of Mineral Nitrogen (kg/ha) in the profile under study  
 DA = 2. !Disassimilation/Assimilation ratio of micro-organisms, 2 for fungi  
 CNM = 10. !C/N ratio micro-organisms, 10 for fungi, 5 for bacteria  
 PN = 0.00103 !Percentage Nitrogen in organic material  
 PSOM = 0.041 !Percentage of organic matter in soil  
 R9 = 0.087623 !Relative initial mineralization (Yang)  
 SOA = 0.2 !Speed of ageing (Yang)  
 YAVTMP = 10.9 !Yearly average temperature

## \*Example fertilisers.dat

## \*Fertiliser description table

\*FNAME = names of fertilisers

\*FCLIST= code list, codes must be 4 letter long and unique in the list

\*FPNM = fraction mineral nitrogen of total weight as given under FAP

\*FPN = fraction organic nitrogen

\*FPC = fraction C. Note that C is more or less 0.54 of the total organic weight.

\*FR9 = The initial relative mineralization rate in (YEAR\*\*(SOA-1)).

!(Green manure=1.39,Straw=1.11,Roots=0.80,FYM=0.82,SOM=0.057)

\*FSOA = Speed of aging, Green manure=0.64,Straw=0.66,Roots=0.67,FYM=0.49,SOM=0.46

FNAME	FCLIST	FPNM	FPN	FPC	FR9	SOA
'No fertilisation'	'NONE'	0.	0.	0.	1.	1.
'Mineral fertiliser'	'MINF'	1.	0.	0.	1.	1.
'Cow dung'	'CDUN'	0.0026	0.0023	0.0324	0.82	0.49
'Straw'	'STRA'	0.	0.005	0.527	1.11	0.66

## \*Fertiliser application table

\*FCODE contains fertiliser types from the fertiliser table

\*FAP is the application in kg/ha

\*TMAP is the time of application

TMAP	FCODE	FAP
2001-04-13	'CDUN'	2000.
2002-06-14	'MINF'	80.
2002-07-19	'MINF'	30.

\*Example weather data file: NLD1.001

\*-----\*

\* Country: Netherlands  
 \* Station: Wageningen  
 \* Year: 2001  
 \* Source: Dep. of Meteorology, Wageningen Agricultural  
 \* University.  
 \* Author: Peter Uithol  
 \* Longitude: 05 40 E  
 \* Latitude: 51 58 N  
 \* Elevation: 7 m.  
 \* Comments: Location Haarweg.

\*

\* Columns:

\* =====

\* station number  
 \* year  
 \* day  
 \* irradiation (kJ m<sup>-2</sup> d<sup>-1</sup>)  
 \* minimum temperature (degrees Celsius)  
 \* maximum temperature (degrees Celsius)  
 \* vapour pressure (kPa)  
 \* mean wind speed (m s<sup>-1</sup>)  
 \* precipitation (mm d<sup>-1</sup>)

\*-----\*

5.67	51.97	7.	0.00	0.00			
1 2000	1	831.	0.1	8.2	0.833	1.0	0.9
1 2000	2	1021.	4.4	8.3	0.925	1.7	0.3
1 2000	3	740.	7.2	9.2	0.979	4.8	2.4
1 2000	4	436.	4.5	9.3	0.888	3.2	9.5
:						:	
:						:	
1 2000	365	2117.	-1.6	2.5	0.621	3.2	8.2
1 2000	366	1776.	-3.0	1.2	0.556	2.8	0.0