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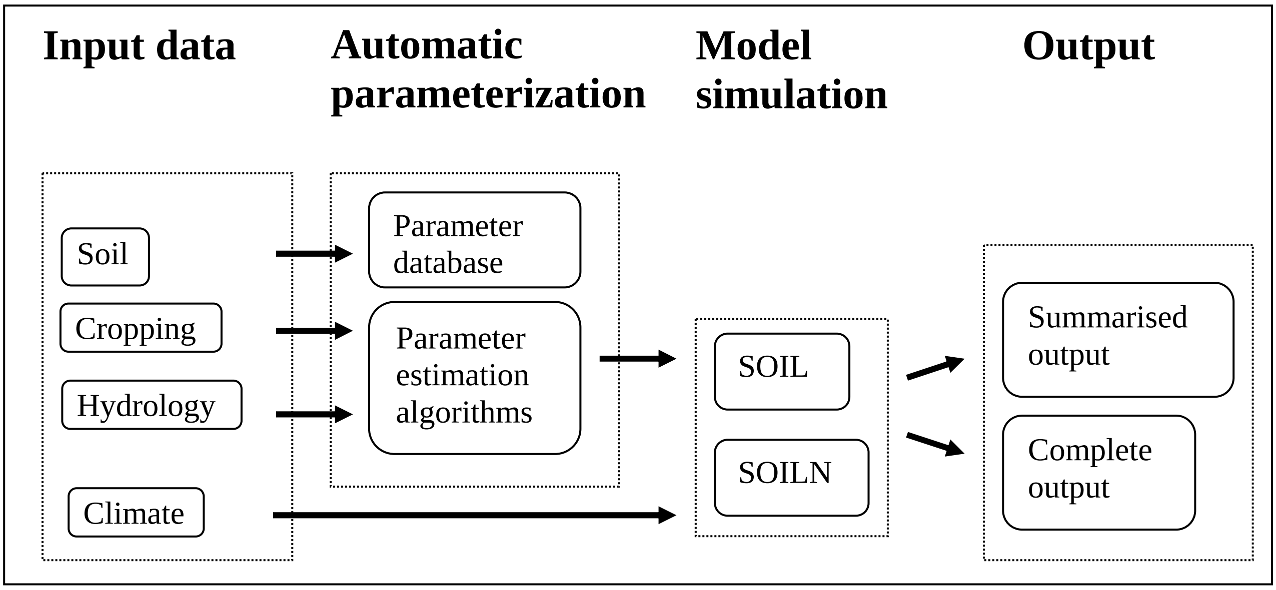
Technical description of SOILNDB (V. 3.0)

Teknisk beskrivning av SOILNDB (V. 3.0)



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Preface

Version 3.0 of SOILNDB is a successor of V.2.1 (Technical description: Larsson et al, 2004) and V 1.0 (technical description: Larsson et al. 2002). The development of this version was financially supported by the Swedish Board of Agriculture. Development of SOILNDB has also received funding from Swedish Environmental Protection Agency, the Foundation for Strategic Environmental Research, MISTRA and the Nordic Council of Ministers, which is gratefully acknowledged.

Contents

Summary

To effectively allocate resources to reduce nitrate leaching and the resulting adverse effects on the environment, it is of great importance to quantify the contribution from different agricultural management practices and different agro-environmental conditions. In this paper we present a decision support tool, SOILNDB that can be used to quantify nitrogen leaching losses from large areas of arable land where the availability of detailed data is limited. SOILNDB is also a useful tool for studying the effects of changes in agricultural management and land use on leaching, and for evaluating alternative management practices to minimise nitrogen leaching. The basis for SOILNDB is two widely used ‘research models’, SOIL and SOILN which describe water and heat fluxes, and nitrogen transformation and transport processes in the soil. A parameter database and parameter estimation algorithms are used to convert the input data in SOILNDB to parameter values for the SOIL-SOILN models. Model outputs can be presented either in a summarised form with yearly averages, or in more detail as time series with daily resolution.

Introduction

The increase in nitrate concentrations in groundwater, surface waters and coastal marine waters over recent decades is a subject of great concern because of the influence on eutrophication (e.g. Heathwaite, 1993; Owens, 1993) and because high nitrate concentrations in groundwater could lead to a deterioration in human health (e.g. O'riordan and Bentham, 1993). In many populated regions the largest source of nitrogen to these waters derives from arable land. To reduce nitrogen leaching losses from arable land, local authorities, national governments and international commissions have initiated several action plans. Consequently, the need for estimating nitrogen load from agriculture and its distribution, both on a local and regional level, has increased. Important objectives with such calculations may be; (i) to quantify N leaching from arable land and its temporal and spatial variation, (ii) to separate the contribution from arable land from other sources, (iii) to study the effects of changes in agricultural management and land use on the leaching losses, and (iv) to find and quantify alternative management practices which minimise nitrogen leaching losses.

For these objectives, simulation models are useful tools. Preferably, a model used for such calculations should be robust, meaning that it should rely on generally accepted scientific principles for the behaviour of the system described and that it should be thoroughly tested against experimental data under various agro-environmental conditions. On the other hand, it is also desirable that the model only requires a limited amount of input data since the availability of detailed data normally decreases with the increase in area. Also, it should be simple to use to reduce time and costs for the applications.

Management oriented models are often simplified, functional/empirical and easy to use while research models often are detailed, complex and normally quite difficult to use for management purposes (e.g. Håkanson, 1995; Addiscott and Mirza, 1998). However, an advantage of using an existing 'research' model for management purposes is that they often rely on more mechanistic descriptions of processes in the soil-plant system affecting nitrogen leaching. This increases the confidence in predictions of N leaching provided that relevant parameterisations can be made. An additional advantage of using an existing model is that the tests and parameterisations of these models (and of course also model development) already made in research applications can form the basis for the management applications. The extent, resolution and quality of data used for the parameterisations in research applications are normally quite high. Thus, the reliability of the results obtained for applied purposes will rely on the reliability of the model which, in turn, relies on previous evaluations of the model. An additional advantage of using a research model is that it can be utilised to relate research results, manifested through model development and parameterisation, to applications.

In Johnsson et al. (2002), a management oriented decision support tool to quantify nitrate leaching, SOILNDB, was presented. SOILNDB is based on the mechanistic research oriented models SOIL-SOILN, a parameter database and parameter estimation algorithms. In this technical description, we explain how the different parameter values in the parameter database were derived and we also describe in detail the parameter estimation algorithms.

System overview

SOILNDB (Fig 1.) is a Graphical Windows program which links input data to automatic parameterisation procedures for the water and heat model SOIL (Jansson and Halldin, 1979) and the nitrogen model SOILN (Johnsson et al., 1987). No conceptual or mathematical differences exist between the research versions of SOIL/SOILN and SOILNDB. Thus, the results produced by SOILNDB can be fully reproduced by the research versions. Both SOIL and SOILN include the possibility of choosing between different submodels for some processes. In such cases, the best tested submodels, or in some cases those that require least parameterisation, have been chosen. A compilation off the submodels in SOIL/SOILN used for SOILNDB are shown in Appendix 1 (Tables A1 to A4). With SOILNDB the time-consuming process of parameterisation, administrating model runs, and presenting model results is reduced, allowing a large number of calculations for various agro-environmental conditions (e.g. scenario calculations) to be made efficiently. One or a group of sites can be simulated, where each site should contain at least two years of data.

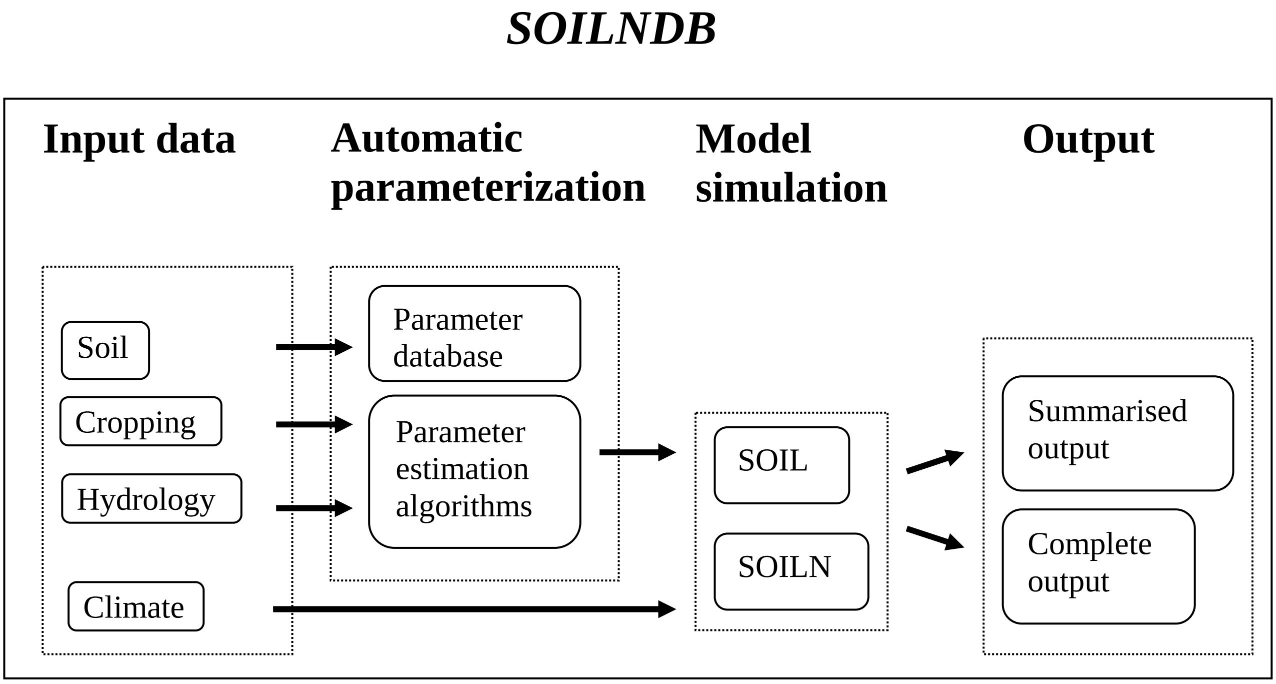

Fig. 1. Schematic description of the SOILNDB model system.

The requirements of input data for SOILNDB are more general, less detailed and less extensive than those required for direct use of the SOIL-SOILN models. A database is included in SOILNDB that contains parameter values for the SOIL and SOILN models for various situations, e.g., soil hydraulic properties for different soils, plant development and management parameters for different crops, etc. These values are based on previous applications of the models. SOILNDB also contains a number of parameter estimation algorithms. Also included in the system are presentations in summarised form of the outputs from the simulations. In the following sections, the main components of the system (models, input data, parameterisation procedures) are described in more detail.

The simulation models

The modelling approach consists of a coupling in series of a nitrogen transport and transformation model, SOILN (Johnsson et al., 1987), and a soil water and heat model, SOIL (Jansson & Halldin, 1979). The SOIL model provides driving variables for the SOILN model (i.e., infiltration, water flow between layers and to drainage tiles, unfrozen soil water content and soil temperature). The models have a one-dimensional vertical structure, with the profile divided into layers, which may vary depending on required numerical accuracy as well as physical and biological characteristics of the soil. The models have been extensively used, both as research tools and for applied purposes (e.g. Bergström and Johnsson, 1988; Bergström and Jarvis, 1991; Lewan, 1994; Johnsson and Hoffmann, 1996; Aronsson and Torstensson, 1998; Johnsson and Hoffmann, 1998; Hoffmann and Johnsson, 1999b; Hoffmann et al., 2000; Larsson, and Johnsson, 2003). Since both models are described in detail elsewhere (Jansson and Halldin, 1980; Johnsson et al., 1987), only a brief description will be presented here.

The SOIL model

The SOIL model is based on two coupled differential equations describing heat and water transport in a soil profile. Snow dynamics, frost, evapotranspiration, infiltration, surface runoff and drainage flows are included. The model uses standard daily meteorological data as input to predict soil water and heat conditions at any level in the soil profile. In the SOIL model, either free drainage or horizontal flow to groundwater and tile drains can be selected as bottom boundary conditions. With free drainage, a unit gravitational gradient is assumed as the driving force for vertical flow out of the lowest soil layer. No groundwater level is then simulated within the soil profile. With the other option, a groundwater level, net horizontal groundwater flow and flow to tile drains can be simulated. Saturated water flow to tile drains, q_{pipe}, is calculated when the groundwater table rises above the depth of the tile drains, z_{pipe}, according to the hydraulic gradient:

$$q_{pipe} = k_s A_{rel} \frac{z_{pipe} - z_{gw}}{L} \tag{1}$$

where k_{s} is the saturated hydraulic conductivity, A_{rel} is the ratio between the vertical area of the soil layer and the unit horizontal area, z_{gw} represents the depth of the water table and L the distance between the tile drains. Horizontal groundwater flow, q_{gr}, out of the one-dimensional soil profile is described with an empirical first order recession equation, so that when there is a groundwater level, z_{sat}, in the soil profile, outflow is given as:

$$q_{gr} = q_1 \frac{z_1 - z_{gw}}{z_1} \tag{2}$$

where q_1 represents a potential maximum flow rate per day and z_1 the depth where flow ceases (Jansson, 1991). Water flow between soil layers is described by Darcy's law and the law of mass balance, while the description of heat flow is derived from Fourier’s law. Parameter values in the SOIL model connected to hydraulic properties are assigned by the pedo-transfer functions described by Rawls et al. (1982) in SOILNDB, in which soil texture is given as input.

The initial water content is derived from the initial soil tension, which is uniform for the whole profile and set by the parameter ψ_{ini}. The flow of water in both partially frozen and unfrozen soil is calculated by combining Darcy's law and the law of mass balance. The soil water release characteristics is described with three cut and join functions (Jansson, 1991). In the dry range, above a threshold value Ψ_{x}, the water release is assumed log-linear:

$$\frac{\log(\psi/\psi_x)}{\log(\psi_{wilt}/\psi_x)} = \frac{\theta_x - \theta}{\theta_x - \theta_w} \qquad \psi_x < \psi < \psi_{wilt} \qquad (3)$$

while in an intermittent range, above a threshold value Ψ_{m}, it is described by the Brooks and Corey (1964) equation:

$$\left(\frac{\psi}{\psi_a}\right)^{-\lambda} = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad \psi_m < \psi < \psi_x \qquad (4)$$

and in the range close to saturation, by a linear expression:

$$\psi = \psi_m - \frac{(\theta + 4 - \theta_s)}{4}\psi_m \qquad \psi_0 < \psi < \psi_m \qquad (5)$$

where θ is the actual water content and Ψ is the actual tension, θ_{x} is the water content corresponding to the upper threshold tension (Ψ_{x}), Ψ_{wilt} and θ_{w} corresponds to the tension and water content at the wilting point, θ_{r} is the residual water content, θ_{s} is the saturated water content, Ψ_{a} is the air entry tension, λ is the pore size distribution index, and Ψ_{m} is the lower threshold tension corresponding to a water content of $\theta_{\mathrm{s}} - 4$. Above the lower threshold tension, Ψ_{m}, the unsaturated hydraulic conductivity, k_{w}, is described by the Mualem model (Mualem, 1976):

$$k_w = k_s\left(\frac{\psi_a}{\psi}\right)^{2+(2+n_{\mathrm{var}})\lambda} \qquad \psi_m < \psi < \psi_{wilt} \qquad (6)$$

where k_{s} is the saturated hydraulic conductivity and n_{var} is the tortuosity factor. When the water tension is between Ψ_{m} and Ψ, the hydraulic conductivity is described by:

$$k_w = 10^{\left(\log(k_w(\theta_s - 4)) + \frac{\theta - \theta_s + 4}{4}\log\left(\frac{k_{sm}}{k_w(\theta_s - 4)}\right)\right)} \qquad \psi_0 < \psi < \psi_m \qquad (7)$$

where k_{sm} is the saturated conductivity including macropores and $k_{\mathrm{w}}(\theta_{\mathrm{s}} - 4)$ is the hydraulic conductivity at Ψ_{m} calculated with *equation 4*.

The infiltration capacity is reduced when ice occur in the uppermost soil layer, and upward movement of water towards a frozen soil layer is minimized by the use of the lowest water content of the frozen soil layer or of the boundary between the adjacent soil layers.

Calculation of potential evaporation, transpiration, and evaporation of intercepted water is based on the Penman-Monteith combination equation (Penman, 1953; Monteith, 1965). The interception loss is partially determined by the surface resistance for intercepted water, r_{sint}, corresponding to the average distance within the canopy.

The root density is assumed to decrease exponentially from the soil surface to the root depth, where the exponential decrease is governed by the parameter, r_{frac}. Actual water uptake by roots from each layer is calculated according to a time-dependent depth distribution of roots and an empirical reduction function accounting for soil water availability. It is possible to account for compensatory uptake, governed by the parameter f_{umov}, if a deficiency occurs in some layers simultaneously as an excess of water exist in some other layer.

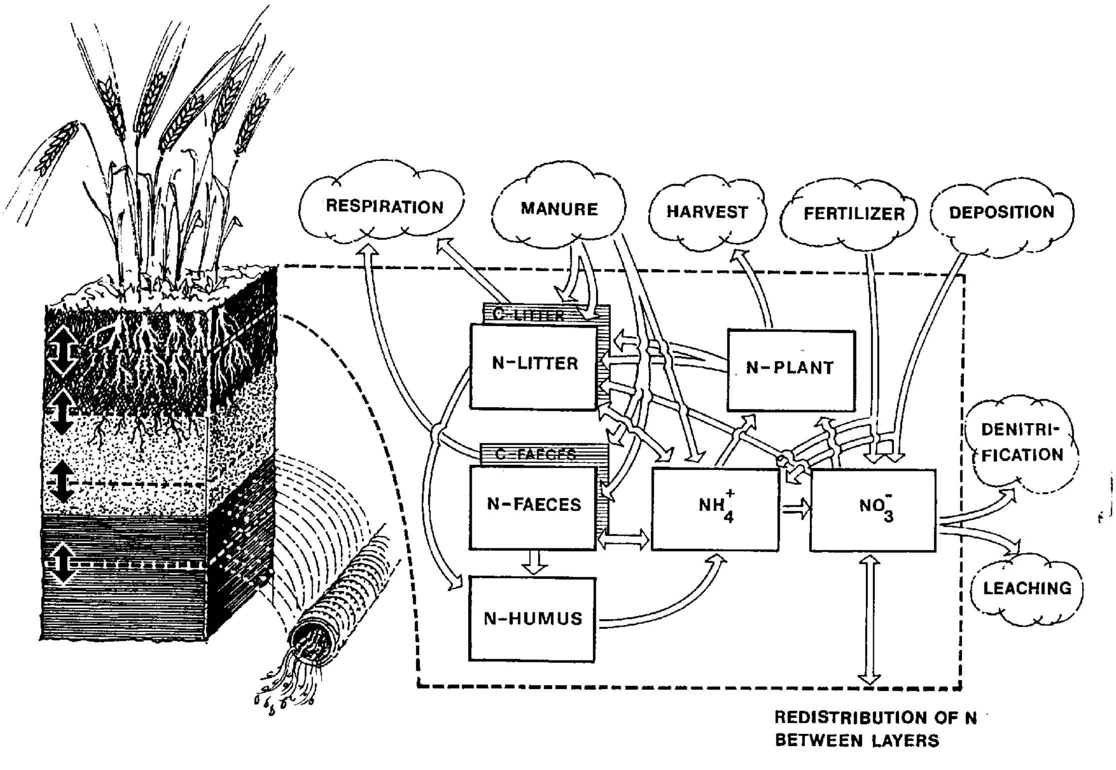

Fig. 2. Structure of the nitrogen model SOILN showing state variables (boxes) and flows (arrows) included in the model. The structure is replicated for each layer. Areas within the dotted line represent the top layer of the soil. Layers beneath have the same structure but have no direct input through fertilisation and deposition (Johnsson et al., 1987).

The heat flow equation, which is derived from Fourier's law, includes both the freezing and thawing of water and the convective effect of water flow. In frozen soils the water and heat equations are coupled using a freezing point depression function. The initial temperature is set uniform for the whole profile according to the parameter T_{ini}.

The SOILN model

The SOILN model includes all the major processes determining transport and transformations of nitrogen in arable soils (Fig. 2). Input of nitrogen can be in the form of ammonium- or nitrate-N as fertiliser, nitrogen fixation, manure or other organic fertiliser and atmospheric deposition, while harvest, leaching and denitrification constitute the output. Litter, faeces and humus comprise the organic-N fractions. The litter fraction represents non-decomposed material (e.g., crop residues, dead roots), microbial biomass and metabolites. The faeces component represents the digested fraction in manure, i.e., excluding bedding material or the organic part of N in other organic fertilisers. The humus component represents stabilised organic material derived from litter decomposition. Organic carbon pools are included for litter and faeces in order to regulate nitrogen mineralisation and decomposition.

The mineralisation, $N_{\mathrm{h}\leftrightarrow NH_4^+}$, of humus nitrogen, $\mathrm{N_h}$, in SOILN is calculated as a first-order rate process controlled by a specific mineralisation constant, k_h, and response functions for soil temperature, e_t, and moisture, e_m:

$$N_{h\rightarrow NH_4^+} = k_h \, e_t \, e_m \, \mathrm{N_h} \tag{8}$$

Decomposition, $C_{l,}$ of the soil litter carbon pool, C_l, (and similarly carbon in faeces) is described as:

$$C_l = k_l \, e_t \, e_m \, \mathrm{C_l} \tag{9}$$

where k_l is a specific rate constant. Decomposition products are partitioned into three fractions (Fig. 3.), one fraction is lost as carbon dioxide, another is stabilised as humus, and the remainder assimilated and recycled within the pool, as described by:

$$C_{l\rightarrow CO_2} = (1 - f_e) C_l \tag{10}$$

$$C_{l\rightarrow h} = f_e \, f_h \, C_l \tag{11}$$

$$C_{l\rightarrow l} = f_e (1 - f_h) C_l \tag{12}$$

where f_e is a synthesis efficiency constant and f_h is the litter carbon humification fraction. Decomposition of the organic litter (and faeces) carbon pools are governing the N mineralization from these sources according to:

$$N_{l\leftrightarrow NH_4^+} = \left[\frac{\mathrm{N_l}}{\mathrm{C_l}} - \frac{f_e}{r_o} \right] C_l \tag{13}$$

where $\mathrm{N}_{l\leftrightarrow NH_4^+}$ represents the litter mineralization rate, $\mathrm{N_l}$ is the litter N pool and r_o is the CN-ratio of micro organisms and humified products.

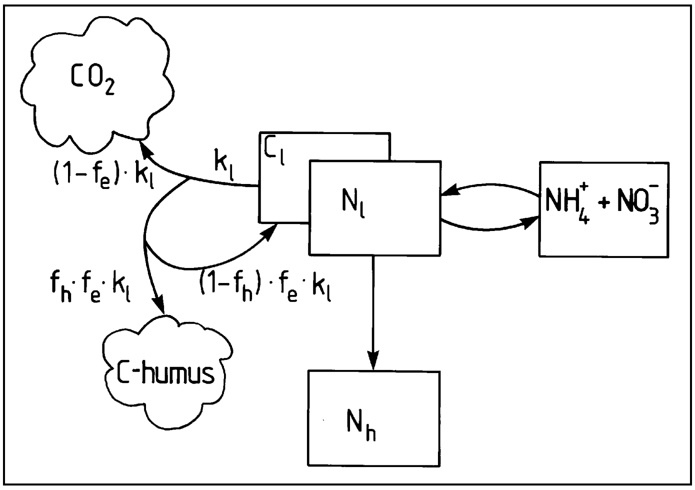

Fig. 3. Flow diagram illustrating the carbon and nitrogen balance associated with litter (or faeces) in SOILN. Explanations of parameter symbols are given in the text or in Johnsson et al., 1987.

A Q_{10}-expression is used for the soil temperature response function regulating all biological processes in the model. For all biological activity except denitrification, the effect of soil moisture is calculated based on the assumption that the activity decreases on both sides of an optimum soil moisture content range.

In SOILN, plant uptake of N is calculated from a time-dependent empirical function requiring specific parameter values for the different crops. A logistic growth curve is used to define a potential uptake demand during the growing season, which is distributed in the soil profile according to an assumed root distribution.

Denitrification is calculated as a first order rate process controlled by a potential rate and a response function accounting for the effects of soil temperature, soil oxygen status and soil nitrate content. The effect of oxygen status is indirectly expressed as a function of soil moisture content, which increases linearly from zero at a threshold water content and reaches a maximum of 1.0 at saturation. The effect of nitrate is given as a Michaelis-Menten type expression, i.e. a hyperbolic function controlled by a half-saturation constant.

Roots and harvest residues, left in the field, are incorporated into the soil litter pool at harvest respectively ploughing. Denitrification is calculated as a function of potential rate, soil temperature, soil oxygen status and soil nitrate content. Nitrate transport is calculated as the product of water flow and nitrate concentration in the soil layer from which the water flow originates, while ammonium is considered to be immobile in the soil profile.

Input data to SOILNDB

The basic idea of SOILNDB is that input data should be easy to obtain (or register) in ordinary agriculture. Consequently, the quantity of input variables in SOILNDB is considerably reduced and the level of resolution is also much lower compared to the requirement for the SOIL and SOILN models. The input for SOILNDB is categorised into “soil”, “climate”, “cropping system” and “local hydrology”. Input data can be given either directly by the user or be supplied in database form. Several pre made databases can be run in sequence without further user input other than needed to start the simulations.

Please note that most of the tables included in the text only are short versions of the more complete tables in the Appendix I. The text tables are only meant as help for understanding and to give some idea about magnitude and variation of the values.

Soil

The soil is selected either by choosing one of ten standard soil texture classes according to the USDA classification system or by choosing a soil from a database that can be maintained by each user of SOILNDB. In addition to soil type, user input also includes organic matter content for the topsoil and subsoil.

Climate

Meteorological data can be stored in a database by the user. Data required for a simulation are daily values of rainfall, air temperature, solar radiation (or solar duration or cloudiness), wind speed and vapour pressure (or relative humidity) and the latitude of the meteorological station, d_{lat}, used for calculating day length and global radiation. Nitrogen deposition rates can either be taken from a database by selecting a county in Sweden or the dry deposition rates and N concentration in rainfall can be given as input by the user.

Cropping system

Yearly input of crop and management information about: main crop, possible post crop (i.e. catch crops or undersown crops), yield, cultivation, and fertilisation. Each row in the cropping system table contains information about only one harvest. For crops with more than one harvest a new row should be written for each harvest and the harvest assigned its harvest number.

Main crops. Currently, there is an option to choose between the following main crops: spring wheat, spring barley, oats, spring rape, winter wheat, rye, winter barley, winter rape, potatoes, sugar beet, peas, horse bean, green forage, spring sown ley, clover rich ley (>25% clover), green manure ley (>50% clover), grass ley (<25% clover) and 'stubble fallow'.

Sowing date must be given for all annual crops. Sowing date for winter crops must be given on the crop 'main year' row (where also the harvest date is given). Perennial crops as leys have no sowing date, if it not is a 'spring sown ley' without a protection crop. Undersown leys are established as post crops to the preceding main crop, see below.

The number of harvests per year of the same main crop is limited to 4. More than one main crop can be grown in the same year if the preceding crop is finished with a ploughing event. Crops can be combined without restraint in the crop rotation.

Post crops. A post crop is an established crop growing after the (last) harvest of the main crop with exception for ordinary winter main crops. The following post crops are available: autumn sown catch crop, undersown catch crop (both are assumed as grass crops), winter oilseeds sown as a catch crop and undersown grass or clover dominated leys (see above).

Characteristics of the post crop is entered on a new row. The type of post crop is selected from a scroll list in a separate column. If the post crop is sown after the main crop, the sowing must take place after the harvest and cultivation of the main crop. It is possible to harvest the post crop on one occasion (i.e. undersown leys).

Yield. Target yields (kg ha$^{-1)}$ are given as input for all (both harvested and non-harvested) crops. Target yields are used for estimating plant N uptake and to estimate yield export. The gross yield (kg ha^{-1}) ('Harvest') must be given with a water content of 15% for cereals crops, peas and horse bean, 9% for rape seed crops, 79% for potatoes, 74% for sugar beets and 0% for leys and green forage crops, respectively. For green manure ley the estimated dry matter production at each cut should be given.

The exported target yield is calculated according to a *'Removal' percent factor* (default = 100%) given as input. If the removal factor is lower than 100% the exported target yield is equal to the target yield multiplied by the removal factor. A lower removal factor is normally used for non-harvested crops like green manure ley or fallow with a target yield required as input (to be used for estimating plant uptake) but where no plant material are taken away from the field. For example, a value of 0% would be used if no export would occur. A value of e.g. 30% could indicate that 30% of the nitrogen in the gross production (yield) on a green manure ley was lost by ammonia (or other) emission.

The target yield can be recalculated by using a removal factor larger than 100. If the removal factor is larger than 100 the new target yield is equal to the input target yield multiplied by the removal factor. However, the exported target yield is not affected of a removal factor larger then 100% target, i.e. the exported yield will remain equal to the original target yield given as input. A removal factor higher then 100 could be used to somewhat compensate for known and estimated harvest losses, for example of rape seeds. The effect will be that the amount of crop residues are calculated for the higher yield value and the nitrogen in the estimated yield loss is added to the residues, assuming the same C content as in crop residues.

Crop residues (straw etc.) may be exported (harvested etc) or left on field.. If crop residues are removed, the 'Remove Harvest residues' should be toggled to 'yes'.

If available, nitrogen contents (% N of d.m.) in *yield* respectively *crop residues* can be given for each harvest. If not, default values from the data base are used. The *post crop* yield (production) and nitrogen content can be given in the same way.

Cultivation. Two cultivation events are available for each main or post crop: stubble cultivation and ploughing. When a post crop is terminated, the cultivations must be given on the post crop row, not on the main crop row. When a ley is terminated the cultivations are given on the same row as the last harvest.

The stubble cultivation, which generally is comparably shallow, acts only on the actually above ground plant material (residues). 'Roots' are not affected. The fraction of above ground plant residues that will be incorporated into the litter pool is given by a stubble efficiency percent factor ('Stubble eff'). The cultivation depth for stubble cultivation is set to 0.1 meter.

Ploughing ends the actual crop and plant related variables are set to zero. All remaining 'roots' and 'residues' are transferred to the litter pool. Ploughing may not be omitted, while stubble cultivation is optionally. Ploughing depth is set to 0.25 meter in SOILNDB.

Be aware of necessary time intervals which must be respected for technically reasons. Cultivation must not take place earlier than the second day after harvest, and there must be at least 2 days between stubble cultivation and ploughing.

Fertilisation. The amount of ammonium respectively nitrate N (kg ha^{-1}) in commercial fertilisers should be separated in respectively columns in the cropping system table. Estimated nitrogen fixation can be given separately. The given estimate of ‘Fixated N’ will be added as ammonium-N to the uppermost layer. A choice can be made between a number of the most common types of manure (Appendix I:1). Alternatively, the user may specify the composition of the applied manure (i.e., NH_4-N concentration, c_{ammN}, organic N concentration, c_{orgN}, and C-N ratio in bedding in manure, CN_{fec}). To account for different volatilisation losses of NH_3 at manure application, f_{sloss}, various application techniques can be chosen from a database (Appendix I:2), or alternatively, the user may specify the fraction of ammonia lost implicitly.

Table 1. The thickness $\Delta z(l)$, fraction of potential denitrification in soil layers d_{frac}, Initial NO_3 and NH_4 content in each layer (NO_3) and (NO_4) with 5 respectively 6 layers.

5 layers				6 layers			
Δz(l) (cm)	d_{frac}	Initial NO_3 (g/m^2)	Initial NH_4 (g/m^2)	Δz(l) (cm)	d_{frac}	Initial NO_3 (g/m^2)	Initial NH_4 (g/m^2)
25	0.7	1.0	1.0	10	0.28	0.4	0.4
				15	0.42	0.6	0.6
25	0.3	0.05	0.05	25	0.3	0.5	0.5
25	0.0	0.3	0.3	25	0.0	0.3	0.3
25	0.0	0.2	0.2	25	0.0	0.2	0.2
200	0.0	0.0	0.0	200	0.0	0.0	0.0

Local hydrology

The user can choose between 5 (default) and 6 computational layers. The difference is that with 6 layers the uppermost layer is divided in two layers, 10 respective 25 cm thick, Table 1.

The user also has the possibility to choose between free drainage (default) and tile drainage. If tile drainage is selected, the following parameters must be set. L the distance between tile drains, z_{gw} the depth to tile drains and q_{gr} lateral groundwater flow.

Automatic parameterisation

Input data given to SOILNDB, as described above, determines the parameter values used for the underlying SOIL and SOILN models. This parameterisation is done automatically by the use of a parameter database and parameter estimation algorithms included in SOILNDB. The parameter database in SOILNDB is separated in two files, ‘parameters.mdb’ where most parameters and factors for parameter estimations are specified, and ‘climate.mdb’ where meteorological data is stored and some site-specific parameters related to climate are set (e.g. latitude and parameters related to the length of the growing period). The parameterisation of the SOIL model is based on previous applications with the research version of the model (e.g. Johnsson et al., 1987; Hoffmann and Johnsson, 1999b; Aronsson and Torstensson, 1998; Torstensson et al., 2000) and on the characterisation of the soils (see below). For the SOILN model, the parameter values are partly derived from literature surveys but mainly from applications where the model has been calibrated against measured data on various field sites with different agro-environmental conditions (see compilation by Hoffmann, 1999; Appendix I; Torstensson et al. 2000; Aronsson and Torstensson, 1998). Calibrations were typically performed against measurements on N concentration in drainage water, soil mineral N content at different depths, plant N uptake and N in grain exported at harvest.

Most of the 'parameters' that varies over time are written as time series to 'driving variable files', which are read by the models. With this approach, the number of occasions when the parameters can be changed is less restricted compared to the older version of SOILNDB. For example, the number of periods with nitrogen uptake and incorporation and the number of soil cultivation events per year are significantly increased. The groups of parameters included are: evapotranspiration, root development, nitrogen uptake, fertilisation and cultivation.

In the automatic parameterisation procedure, each row (harvest) in the cropping system table is analysed regarding crop type, yield, and dates for sowing, harvest and cultivation. From these data an indexed 'day table' containing dates for all necessary and actual events is produced. Day indexes not used are set to 'Nothing'. The maximum number of possible 'days' (indexes) is 24 per crop or harvest.

Day index 1 and 2 are used for establishment of winter crops during the sowing autumn. Index 3 to 8 are used to describe the development of the main crop from emergence until the day after harvest, index 9 to 16 are used for description of post crops or growth of weeds during the autumn and number 17 to 20 for the early spring period (in case of spring ploughing). Number 21 to 24 are used especially for stubble cultivation and ploughing. Each index is related to a defined assignment, for example day(3) is assigned the estimated date for emergence of a spring sown crop (or start of growth in spring for leys or winter crops), day(6) represent yellow ripeness of cereals, day(7) is the harvest day and day(23) is the date for ploughing.

Dates, in the day table, between sowing and harvest are set in accordance with crop specific 'Day offsets' (Table 2) taken from the parameters data base [Crop (Soil)]. These are mainly used in calculation of evapotranspiration. There are two groups of offset factors: offset_s1 to offset_s4, and offset_h1 to offset_h2.
The '_s-offsets' are number of days *after* the sowing date (or after start of the vegetation season in the case of perennial crops). 'Offset_h1' is the number of days *before* the harvest date, and 'offset_h2' is the number of days after harvest when the next growth of leys starts.
The period between sowing of an autumn sown post crop and its emergence is defined by ‘offset_c1’ [Postcrop (Soil)] (Appendix I:11)

Table 2. Definition of day offsets used to estimate dates different development stages etc. from applied sowing and harvest dates

Offset	Calculate day for:	Comments	Value, example: Oats
s1	Emergence/start of growth	All 'sown' crops	18
s2	Start stem elongation	All crops, harvest 1 in ley	30
s3	Max crop development	All crops, harvest 1 in ley	60
s4	Corresponds to S2	Leys, harvest 2-4	-
h1	Yellow ripeness/End of N uptake	All crops and harvests	22
h2	Start of growing for next harvest	Leys	-
r1	Max root depth in sowing autumn	Winter crops	-
r2	Max root depth in spring	All sown crops	40

Soil and hydraulic properties
For each of the 10 standard soil texture classes, the pedo-transfer functions described by Rawls et al. (1982) were used to assign values to parameters in the Brooks and Corey equation (i.e. the pore size distribution index, λ, the residual water content, θ_r, saturated water content, θ_s, and the air entry tension, ψ_a) and to the saturated hydraulic conductivity, k_s, used in the Mualem model (see Appendix I:3). The tortuosity factor, n_{var}, used in the Mualem model, was set to 1 (as defined by Campbell’s model) in all soils but the loamy sand (soil *a*) in the soils database where n_{var} was set to 5. The water content at wilting point, θ_w, and the upper limit for the use of the Brooks and Corey equation, ψ_x, was set to 1000 for the 10 standard soil texture classes. The saturated hydraulic conductivities including macropores, k_{sm}, are rough estimates based on previous applications with the SOIL model **(**Appendix I:3**)**. The coefficients in the empirical function for the temperature dependence in the hydraulic conductivity A_{0T} and A_{1T}, (set to 0.54 and 0.025, respectively), were set equal to default values given by the SOIL model for all soils.

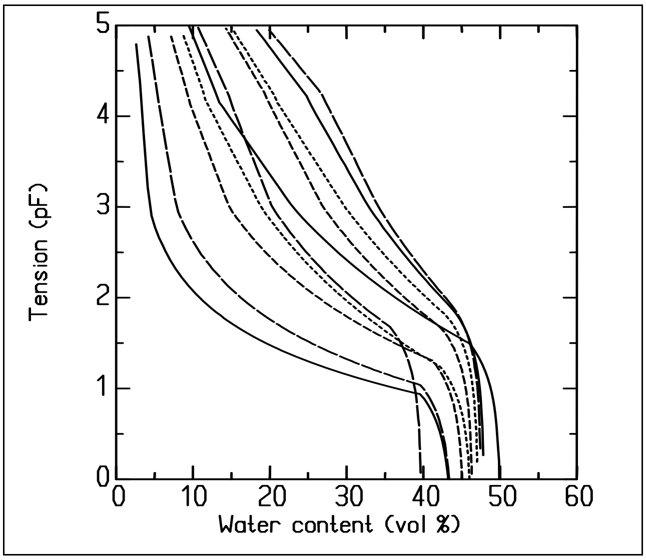

Fig. 4. Water retention curves (a) for the 10 soil texture classes (USDA) included in SOILNDB with: sand, loamy sand, sandy loam, loam, sandy clay loam, silt loam, clay loam, silty clay loam, silty clay, and clay following the arrow from bottom left to top right.

Properties related to snow and frozen soil

Parameters related to frozen soil in the SOIL model (i.e., the factor governing the decrease of unsaturated hydraulic conductivity due to freezing, fc_i, the fraction of the wilting point remaining as unfrozen water at –5°C, d_1, and the coefficient in the freezing point depression function, d_2) were set to default values given by the SOIL model for the sand. For all other soil texture classes (see Appendix I:4), the values were somewhat increased.

Most parameters related to snow properties were set to default values given by the SOIL model (see List of Symbols). However, the global radiation in the snow melt function, m_{Rmin} (default = 15^{-8} mm J^{-1}), was set to 10^{-8} in SOILNDB, which was also used by Borg and Jansson (1988) in an application at Lanna in southwest Sweden. The temperature coefficient in the snow melt function, m_T (default = 4 to 6 kg °C^{-1} m^{-2} day^{-1} for open fields), was set to 3, which was also used by Torstensson and Johnsson (1996) in an application at Mellby in southwest Sweden. The radiation melt factor for old snow, S_1, was set to 2.5, which is close to the default value (i.e. 2) used in the SOIL model. The liquid water coefficient in the snow density function, S_{dl} (default = 200 kg m^{-3}), was set to 100 kg m^{-3}, which was also used by Jansson and Gustafson (1987), and the water equivalent coefficient in the snow density function, S_{dw}, was set to 0.9 m^{-1}, which is in between the default value of 0.5 m^{-1} and 1.5 m^{-1} used by Jansson and Gustafson (1987).

Water balance

The parameters governing correction of precipitation due to errors in the measurement for rain, c_{rain}, and snow, c_{snow}, is read from the climate database. The default values given by the model (c_{rain} =1.07 and c_{snow} =0.14) and are based on the correction factors estimated for the climatic station used in the application described by Hoffmann and Johnsson (1999a). To obtain reasonable simulation results on discharge of water from the soil profile, the correction factors for snow and rain may need to be adjusted, especially for local conditions at site specific applications.

Parameters related to evapotranspiration for each crop are read from the parameters data base as breakpoints on a continuous description of how the parameter value develops over time.

For example, from emergence via different growth stages and harvest to ploughing. Dates, derived from the 'day table' mentioned above, and values for these breakpoints are written to the 'Cropdata.bin' driving file which is read by the SOIL model.

Within the SOIL model a linier interpolation between the breakpoints is made. With this method the number of brake points is no longer limited to 5 per year. For most main crops around 6 or 8 brake points per crop or harvest are used. The growth of post crops or weeds between main crop harvest and stubble cultivation and ploughing is also described.

The surface resistance for transpiration when intercepted water, r_{sint}, was set to 5 s m^{-1} for all crops. Some other parameters were set constant and assumed not to vary with crop (i.e. the albedo of vegetation and soil, a_{r}, set to 20, and the interception storage capacity per leaf area index (LAI), i_{LAI}, set to 0.2 mm LAI^{-1}.

The empirical coefficient regulating surface resistance, r_{ψ}, used to calculate soil evaporation was set to 200 s m^{-1} for all soils but for sand for which it was set to 100 s m^{-1}, in agreement with an application of the SOIL model on a loamy sand soil (Lewan, 1993). The contribution of LAI to the total aerodynamic resistance from measurement height to the soil surface, r_{alai}, was set to 50 s m^{-1} for all crops, and the extinction coefficient, k_{rn}, used for calculating net radiation at the soil surface from LAI, was set to 0.5 for all crops (Johnsson & Jansson, 1991).

Root development and root water uptake

Roots are assumed to develop stepwise from zero at emergence to a maximum root depth between 1 and 2 month later, and the distribution between soil layers is assumed to depend on crop and soil type. Root development and root depths (Table 3, and Table 4) are rough estimates based on studies and reviews by Haak (1993), Lewan (1993), and Myrbeck (1998).

Root development has its own ‘Root-day’ table. Index 1 and 2 are used for winter crops during the autumn of sowing, index 3, 5 and 10 for the main crop and index 11, 12 and 14 for post crops. For technical reasons in the SOILN model the maximum root depth is formally kept until the day of ploughing (Root-day(23)). The 'offset _r1' and 'offset_r2' [Crop(Soil); Postcrop(Soil)] are used to estimate the time from emergence, or start of growth, to the date for maximum root depth. The dates and values, for root development are included in the ‘Cropdata.bin’ driving file read by the SOIL model. The same root development is used by the SOILN model but the brake points are interpolated (linearly) by SOILNDB to a continuous (daily) curve and included, together with the potential nitrogen uptake (see below), in the ‘crop_N.bin’ driving file read by the SOILN model.

Root density is considered to decrease exponentially from the soil surface to the root depth, and to be deeper on more clayey soils and for perennial crops than for coarse textured soils and annual crops. The fraction of the exponential function remaining below the root depth, r_{frac}, that is to be allocated within the maximum root depth given by, z_{r}, was set to the default value given by the SOIL model (i.e. 0.05), while the corresponding parameter in SOILN, r_{fracN}, was set to 0.001. The critical tension for reduction of water uptake during dry soil conditions, ψ_{c}, was set to relatively high values (Appendix 1:3), allowing for water uptake during rather dry periods. The parameter for compensatory uptake, f_{umov}, was set to default in SOIL (i.e. 0.5).

Table 3. Maximum root depths for some different crops, $z_{r(5)}$, for the 12 standard soil texture classes (and the soils in the soils database) used in both the SOIL and SOILN models. For the complete lists of crops, see appendix: Root depth. The maximum root depth for the specific soils in the database relates to the soils with corresponding texture. The indexes in $z_r(i)$, refers to the dates, $t_{root(5)}$ respectively $t_{root(2)}$, defined in Table 4

Crop	Clay	Silty clay	Silty clay loam	Clay loam	Loam	Sandy clay loam	Loamy sand	Silt loam	Sandy loam	Sand	Sandy clay	Silt
Maximum root depth for main crops, $z_{r(5)}$, (m)												
Ley Green Manure	-1.4	-1.4	-1.3	-1.3	-1.2	-1.3	-1.0	-1.2	-1.1	-0.9	-1.1	-1.1
Ley, <25% Clover	-1.4	-1.4	-1.3	-1.3	-1.2	-1.3	-1.0	-1.2	-1.1	-0.9	-1.1	-1.1
Horse bean	-1.2	-1.2	-1.1	-1.1	-1.0	-1.1	-0.8	-1.0	-0.9	-0.7	-0.9	-0.9
Potatoes	-1.0	-1.0	-0.9	-0.9	-0.8	-0.9	-0.6	-0.8	-0.8	-0.5	-0.7	-0.7
Spring barley	-1.2	-1.0	-0.9	-0.9	-0.8	-0.9	-0.6	-0.8	-0.8	-0.5	-0.7	-0.7
Spring rape	-1.0	-1.0	-0.9	-0.9	-0.8	-0.9	-0.6	-0.8	-0.8	-0.5	-0.7	-0.7
Winter rape	-1.2	-1.2	-1.1	-1.1	-1.0	-1.1	-0.8	-1.0	-0.9	-0.7	-0.9	-0.9
Winter wheat	-1.2	-1.2	-1.1	-1.1	-1.0	-1.1	-0.8	-1.0	-0.9	-0.7	-0.9	-0.9
Maximum root depth in autumn for winter crops, $z_{r(2)}$, (m)												
All winter crops	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Maximum root depth in autumn for post crops, $z_{r(2)}$, (m)												
Autumn sown P-crops	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Catch Crop (undersown)	-1.0	-1.0	-0.9	-0.9	-0.8	-0.9	-0.6	-0.8	-0.8	-0.5	-0.7	-0.7
Undersown Ley >25%	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.0	-1.1	-1.1	-0.9	-1.1	-1.1

Table 4. Derivation of root development dates, $t_{root(i)}$

Crops	$t_{root(1)}$ [f]	$t_{root(2)}$ [f]	$t_{root(3)}$	$t_{root(5)}$	$t_{root(10)}$	$t_{root(23)}$	$t_{root(24)}$
Spring sown crops	—	—	$t_{s(1)} + s_1$ [c]	$t_{root(3)} + r_2$ [e]	$t_{sk(1)}+1$ [b]	t_{cu} [d]	$t_{cu} + 1$ [d]
Winter crops	$t_{s(1)} + s_1$ [c]	$t_{root(1)} + r_1$ [e]	$u_{st(1)}$ [a]	$t_{root(3)} + r_2$ [e]	$t_{sk(1)}+1$ [b]	t_{cu} [d]	$t_{cu} + 1$ [d]
Ley	—	—	$u_{st(1)}$ [a]	—	$t_{sk(i)}+1$ [b]	t_{cu} [d]	$t_{cu} + 1$ [d]
Post crops	$t_{sk(1)} + c_1$ [b]	$t_{root(1)} + r_1$ [e]	—	—	—	t_{cu} [d]	$t_{cu} + 1$ [d]

[a] where $u_{st(1)}$ is the start of the plant uptake period
[b] where $t_{sk(1)}$ is the harvest date and c_1 is *offset_c1*
[c] where $t_{s(1)}$ is the sowing date and s_1 is *offset_s1*
[d] where t_{cu} is the date for soil cultivation (e.g. ploughing)
[e] where r_1 and or_2 are the *offset_r1* respectively *offset_r1*
[f] for the calendar year of sowing of winter crops or autumn sown post crops

The coefficients for soil temperature influence on transpiration, t_1 and t_2, were set to default values given by the SOIL model (i.e. 0.8 and 0.4 respectively), and the parameters in the water tension response function for transpiration, p_1 and p_2, were set to 0.2 and 0 respectively.

Initial state of soil N and C content

Initial soil N litter, $N_{lom}(l)$, and humus, $N_{hom}(l)$, contents are calculated from the soil organic matter content, *SOM*:

$$N_{lom}(l) = \frac{\Delta z(l) * \rho(l) * SOM(l)\, c_{Com}}{r_{CN}}\, r_{lh} \tag{14}$$

$$N_{\mathrm{hom}}(l) = \frac{\Delta z(l) * \rho(l) * SOM(l)\, c_{Com}}{r_{CN}} \left(1 - r_{lh}\right) \qquad (15)$$

where $\rho(l)$ is the dry bulk density for the different soil layers, r_{lh} is the initial litter to humus ratio and c_{Com} is the fraction of C in soil organic matter, set to 0.58 (e.g. Brady, 1990). The *SOM* content is given as input for the uppermost layer(s), (0 to 25 or 0 to 10 and 10 to 25 cm), ‘Organic matter (topsoil)’, and the second layer (25 to 50 cm), ‘Organic matter (subsoil)’. The C/N ratio of soil organic matter, r_{CN}, is set to 10 and the initial litter to humus ratio, r_{lh}, is set to 0.005 in SOILNDB, while the bulk density is set to 1.35 and 1.45 g cm^{-3} for the top and sub soil, respectively, for all soils. Initial soil C litter content, $\mathrm{C}_{\mathrm{lom}}(l)$, is calculated from the soil organic matter content according to:

$$C_{lom}(l) = \Delta z(l) * \rho(l) * SOM(l)\, c_{Com}\, r_{lh} \qquad (16)$$

In the layers 50 to 75 cm and 75 to 100 cm, the initial *SOM* is assumed to be 20% and 10%, respectively, of the *SOM* in layer 25 to 50 cm, while the organic matter content at 100 to 150 cm depth is assumed to be negligible. Both initial NO3-N and NH4-N contents were set to 1, 0.5, 0.3, 0.2, and 0 g m^{-2} for layers 1, 2, 3, 4 and 5, respectively.

As an alternative to the calculations based on user defined organic matter content and the pre-defined mineral N amounts, the user may apply an own file containing initial amounts of mineral N and organic C and N for the different pools and layers.

Mineralization and decomposition of organic matter and related parameters

The litter specific decomposition rate, k_{l} (set to 0.035), and the related efficiency constant, f_{e} (set to 0.5), the litter carbon humification fraction, f_{h} (set to 0.2), the specific nitrification rate, k_{n} (set to 0.2), and the C/N ratio of micro organisms and humified products, r_{o} (set to 10), were all set to be equal to those used by Johnsson et al. (1987). The nitrate-ammonium ratio in the nitrification function, n_{q}, was set to 6 in SOILNDB, which is in between the value of 8 used by Johnsson et al. (1987) and 5 used by Torstensson and Johnsson (1996). Since no manure was applied in the experiment described by Johnsson et al. (1987), corresponding faeces-N parameters were set to be identical to those used by Borg et al. (1990), that is, the faeces decomposition rate, k_{f}, was set to 0.035, and the related efficiency constant, f_{efe}, was set to 0.5, and the faeces carbon humification fraction, f_{chf}, was set to 0.2. The humus-N mineralisation rate, k_{h}, is assumed not to vary with soil type, and was set to 0.00006 d^{-1}, which is slightly higher than the default value of 0.00005 d^{-1}. The increase in k_{h}, was set to match the plant N uptake and to keep a quasi-steady state in the humus pool in the test application of SOILNDB described by Hoffmann and Johnsson (1999a).

Table 5. Parameters related to water response functions for mineralisation and denitrification used in the SOILN model for some of the standard soil texture classes in the database. For a compete list if soils, see appendix: Soils in SOILN

Soil texture class for standard soils	$\Delta\theta 1$ (%)	$\Delta\theta 2$ (%)	xm	e_s
Sand	3	32	1	0.6
Sandy loam	8	18	1	0.6
Loam	10	16	1	0.6
Silt loam	14	13	1	0.6
Sandy clay loam	8	9	1	0.6
Clay loam	10	8	1	0.6
Clay	10	4	1	0.6

The soil moisture response function in SOILN is parameterised so that for each soil an optimal range of activity is achieved for soil moisture tensions between 100 to 500 cm water (e.g. Miller and Johnson, 1964; Stanford and Epstein, 1974). These tensions of 100 to 500 cm water corresponds to the parameter values of the water contents in the soil moisture response function defining ranges for increasing, $\Delta\theta 1$ and decreasing, $\Delta\theta 2$ biological activity (Table 5). The empirical constant, *xm*, in the soil moisture function, was set to unity for all soils, reflecting a linear response, and the coefficient defining the relative effect of moisture when the soil is saturated, e_s, was set to 0.6 for all soils (Johnsson et al., 1987).

Soil temperature effect on biological activity

The Q_{10}-function is used when the temperature is above 5°C with optimum activity at 20°C, (i.e. the switch TEMPR was set 'ON', and the parameter t_b was set to 20) and the Q_{10}-value, Q_{10}, reflecting the effect of temperature changes on biological activity, was set to 2 in accordance with measured data from laboratory studies (Lindén and Nouno, 1983). Below 5°C a linear decrease is assumed to 0°C, where biological activity is assumed negligible.

Denitrification

The parameter settings related to denitrification are based on an application for a barley crop on a loamy soil on a experimental field in central Sweden (Johnsson et al., 1987). The switch 'DENDIST' regulating the choice of 'sub-model' in SOILN is set to zero implying that the potential denitrification is divided in separate fractions for the different soil layers according to the parameter d_{frac}, set to 0.7, 0.3, 0, 0, and 0 for the soil layers from top to bottom in SOILNDB. The potential rate of denitrification, $k_d(z)$, was set to 0.1 and c_s, the half-saturation constant, which gives the effect of nitrate concentration on the denitrification, was set to 10. The water content activity range, θ_d in the function describing the effect of soil moisture on denitrification was set to 17 % which is roughly a mean of 10 % (used by Johnsson et al., 1987) and 26 % (used by Johnsson et al., 1991). The empirical constant, *d*, used in the function regulating the soil moisture effect on denitrification was set to 2.

Fertiliser, manure and deposition

Input of manure derived NH_4-N and faeces-N is estimated from the input information. The amount of N in faeces, N_{faeces}, in the soil at manure application is simply given by:

$$N_{faeces} = c_{orgN}(m) * M \qquad (17)$$

where c_{orgN} is the concentration of organic N in manure, as a function of manure type, m, and M is the applied amount. The net amount of NH_4-N applied to the soil with manure, N_{amm}, is calculated as:

$$N_{amm} = c_{ammN}(m) * M * \left(1 - f_{sloss}(m, a, t)\right) \tag{18}$$

where c_{ammN} is the concentration of NH_4-N in the applied manure, and f_{sloss} is the fraction of NH_4-N lost through volatilisation of NH_3 at application as a function of manure type m, application technique a and application date t. The values of f_{sloss} used in SOILNDB (Appendix I:2) were taken from Claesson and Steineck (1991). Appendix I:1 show all parameter values for c_{ammN}, c_{orgN} and C-N ratios used in SOILNDB.

Information about deposition of N presented in Appendix I:8 was taken from the Swedish Environmental Protection Agency (1997), and in SOILNDB the deposition is set according to the region selected.

Plant N uptake related parameters and coefficients

Crop N uptake and N removed as grain and straw at harvest are calculated from values of ‘target’ harvest yields, which are specified by the model user as input. However, if the amount of mineral N in the soil is insufficient for the N uptake corresponding to the target harvest yield, the simulated N uptake will be reduced proportionally and the target harvest yield will not be attained. The parameter for compensatory uptake of N, f_{umov}, was set to unity in SOILN (i.e. total compensation). The fraction of available mineral N for plant uptake and immobilization, f_{ma}, was set to 0.08 d^{-1}, which is equal to the default value used in SOILN.

In total it is possible to define 10 different nitrogen uptake periods (UP) in the present version of SOILNB. The uptake periods are indexed from 0 to 9. Each period has a specific characterization, however, all periods are not relevant for all crop and cultivation combinations. UP0 (Index 0) is used for winter crops during the autumn of sowing. UP1 to UP4 are used for the growing period of the main crop and UP5 for a post crop.

UP6 to UP9 are used to cover possible combinations of periods between harvest (main or post crop) and the first soil cultivation (and/or end of growing season) and between stubble cultivation and ploughing. The principle is that N uptake (in post crops, weeds or shed seed) may occur at any time until ploughing. Most combinations of autumn and spring uptake and cultivation are possible.

At, or some days later than the end of most of the N uptake periods ($u_{\mathrm{et(i)}}$), fractions of the N content in the crop will be transferred into the litter pool as 'roots' or above ground 'crop residues'. One example is the transfer of the dead 'roots' from a cereal crop at yellow ripeness (the end of N uptake). Sometimes the transfer is connected with soil cultivation (real incorporation) but can also be estimates of crop damaging effects of e.g. frost and thereby induced leaching of nutrients by rainfall from crop residues on the soil surface.

In the SOILN model, crop material (i.e. N and C) can be transferred into the litter pool in only two ways: roots at the end of a N-uptake period (UPET), and at PLOUGHING when above ground residues N stored in the LITABOVE pool is transferred to the litter pool. The root-N fraction is the fraction left from unity when: yield (HARHP), above ground residues (HARAR) and remaining N in crop material (HARLR) have been assigned fraction values and summed up, assigning must be made before each UPET event. The C/N-ratio of roots is given by CNROOT. Between UPET and ploughing the above ground residue N is stored in the LITABOVE pool, but the C/N-ratio (CNARES) is applied first at the ploughing day. The latest CNARES assigned before the ploughing is used for the entire N content in the pool unnoticed the origins of the actual N storage. At PLOUGHING, the total N content is transferred momentarily from the LITABOVE pool to the litter pool, while the remaining N in the crop (PLANT) is unaffected.

In order to handle these conditions in SOILNDB, the model will keep track of the estimated actual amounts of N in residues respectively roots with different origins and their N-amount weighted C/N-ratios during all uptake periods, until the ploughing. Prior to each transfer event, the estimated actual amount of N in the crop state variable PLANT is also calculated in order to estimate the values for the fraction parameters mentioned above.

One important effect of this new method for handling crop residues is that residues of the main crop with high C/N-ratios do not have to be dumped to the litter pool at one single event, causing a N immobilization shock seldom seen under field conditions. The transfer, except real physical cultivation events, of roots and residues from different crops into the litter pool is defined by coefficients in the database. A transfer of above ground residues must for technical reasons be made by a ‘fictitious ploughing event’ in the Manage_N.bin driving file (see below).

The description above can be exemplified by a cereal without a post crop. When the N uptake of the main crop is ended, approximately at yellow ripeness (= UPET), a fraction of root N given by the coefficient *deadrootN:rootN_ratio*, is transferred to the litter pool (in this case 100%). The day after the physical harvest a fraction of the above ground residues (as straw and chaff), defined by the *res_incorp_eff,* is transferred into the litter pool of the uppermost soil layer in order to, in some way, imitate the effect of leaching of e.g. N and C by rainfall but also the decomposition of residues that will occur at the soil surface. During the following period, between harvest and first cultivation, there will (in reality) mostly be a growth of weeds and/or shed seed. Therefore a new N uptake period (UP6) is started immediately after the main crop harvest. At the end of the new uptake period the straw and chaff from the cereal crop with high C/N-ratio will be 'mixed' with the weeds with low C/N-ratio before incorporation. The estimated N uptake in weeds is added to the remaining main crop residue N and the weighted C/N-ratio is calculated according to the estimated N amounts in the respective fraction.
If the first cultivation is a stubble cultivation, incorporation of the actual mix of residues could partly be further delayed during a following uptake period (UP7) by assigning the *'Stubble_eff’* coefficient a value <100 (%) in the cropping system table. At present, the default N uptake during UP7 is set to zero (see Database table [Crop (SoilN)]).

(In the SOILNDB code, the ploughing dates for 'real' cultivation events, stubble cultivation and ploughing, are always taken from index number 21 respectively 23 in the 'Day-table', described above.)

Manage_N.bin driving file. Parameter values concerning the end of each N uptake period and the following, fictitious or real, ploughing event are written to the 'Manage_N.bin' driving file and read by the SOILN model. The information includes: end date for the uptake period, UPET (u_{et}); ploughing date, PLOUGHDAY; ploughing depth, PLOUGHDEP; harvest fraction, HARHP (f_{hp}); above ground residue fraction to be transferred at the following ploughing date. HARAR (f_{ar}); remaining fraction HARLR (f_{lr}); C/N-ratio in above ground residues, CNARES (CN_{ares}) and C/N-ratio in roots transferred at u_{et}. The symbols within parentheses refer to symbol names used later in this description.

All "HAR_" parameters values, passed to SOILN, must be expressed as fractions of the actual estimated N content in the crop, PLANT. In some cases some of them are based on only a part (fraction) of the actual amount of residue N respectively root N in PLANT. The actually transferred part is calculated with help of other fraction coefficients, e.g. *deadrootN:rootN_ratio,* (f_{dr}) and *res_incorp_eff,* (f_{dres}) taken from the Crop(SoilN) database table, (Appendix I:10)

Estimated Plant N uptake and harvest

All concentrations and coefficients used for estimation of the amount of N in yield and residues are based on the dry matter content in yield. The exported dry matter target yield is calculated as:

$$S_{dry}(i,y,c) = S(i,y,c) * (100 - wc(c))/100 * MAX(f_{neth}(i,y),\ 1) \tag{19}$$

where S is the actual target yield (i.e. grain, seed or tuber) or target production (e.g. Green manure ley), given at the standard water content, wc is the standard water content for the actual crop (Table 6; Appendix I:9), (i) is the number of the uptake period (harvest) and f_{neth} is the removal fraction of the gross yield (the actually removed part, see Cropping System description above).

If there are known and quantifiable harvest losses of the main product (e.g. shed seed losses) it is possible to adjust (increase) the estimated N uptake by setting f_{neth} to a value larger then 1 (i.e. >100 % in the cropping system table). In such a case, the real crop N uptake (and 'gross yield' before shedding) may have been larger then the normally estimated N uptake calculated from the measured yield. The actual yield (removal) of N (see $\mathrm{N_{harv}}$ below) will still be the one given in the cropping system table.

A value of f_{neth} <1 will only decrease the removed yield of N (see $\mathrm{N_{harv}}$ below) and thereby increase the amount of N in remaining 'crop residues' (see below).

For all crops the target N yield, N_{Gharv}, above ground crop residue target N content, N_{res}, and target N content in root, N_{root}, for each harvest as a function of uptake period, i, crop type, c, and year, y, is calculated as:

$$N_{Gharv}(i,c,y) = S_{dry}(i,c,y) * c_N(i,c,y) \tag{20}$$

$$N_{res}(i,c,y) = S_{dry}(i,c,y) * f_a(c) * c_{Nres}(i,c,y) \tag{21}$$

$$N_{root}(i,c,y) = \frac{N_{Gharv}(c,i,y) + N_{res}(c,i,y)}{1 - f_r(c)} * f_r(c) \tag{22}$$

where c_N is the nitrogen concentration in the harvested product while c_{Nres} is the nitrogen concentration in above ground residues (i.e. straw, tops, stubble, chaff, stalks etc.), f_a is the ratio of above ground residues to grain dry matter biomass, and f_r is the fraction of N in roots of total plant, N.

Table 6. Parameters related to crop characteristics based on Swedish surveys (Hansson et al., 1987; Mattsson, 1991; Bengtsson et al., 1992; Haak, 1993; Mattsson, 1994; Hessel Tjell et al., 1999; Torstensson, 2003a, 2003b). "Grain" in the table is used for the harvested part of all main crops. For post crops it is used for the entire above ground production. "Straw" is the harvestable part of the above ground residues. N contents are given as % of dry matter and the residues/grain ratio is applied on the amount of dry matter in the harvested yield.

Main crops	Grain N content c_N (%)	Residues/ grain ratio f_a (-)	Residues N content c_{Nres} (%)	Water content in grain wc (%)	Straw/ residue ratio f_b (-)	RootN/plantN fraction f_r (-)
Ley, Green Manure	3.00	0.10	2.20	0	0.00	0.30
Ley, <25% Clov	2.50	0.10	1.80	0	0.00	0.30
Horse bean	4.50	1.20	1.40	15	0.00	0.20
Potatoes	0.95	0.26	3.90	79	0.00	0.13
Spring barley	4.15	1.30	1.00	15	0.39	0.20
Spring rape	4.18	4.15	1.43	9	0.40	0.20
Winter rape	4.18	3.23	1.43	9	0.40	0.20
Winter wheat	2.24	1.10	1.00	15	0.35	0.20
Post crops						
Catch Crop (grass)	2.00	—	—	0	—	0.40
Undersown Ley <25%	2.50	—	—	0	—	0.40
Undersown Ley >25%	3.00	—	—	0	—	0.40
Winter oilseed C-crop	3.00	—	—	0	—	0.40

The total target N uptake, N_{totup}, for each harvest is calculated as:

$$N_{totup}(i,y,c) = N_{Gharv}(i,c,y) + N_{res}(i,c,y) + N_{root}(i,c,y) \tag{23}$$

The target harvest yield, S, is the only compulsory parameter specified by the user, default values for the remaining parameters in equations 19 to 22 are all included in the SOILNDB database (Table 6; Appendix I:9). However, if actual values for c_N and c_{Nres} are available they can be inserted in the cropping system table.

For winter crops, the total target N uptake N_{totupw} is estimated in accordance with equations 20 to 23. The estimated value for target N uptake from emergence to end of growing season the autumn of sowing, $N_{totupw(0)}$ is taken from the database, (up_0; Table 7; Appendix I:10). For the main growing period, which is assumed to start, $u_{st(1)}$, at the beginning of the growing season, N_{totup} is approximated as:

$$N_{totup}(i,y,c) = N_{totupw}(1,y,c) - N_{totupw}(0,c) * f_{lrem}(0,c) \tag{24}$$

where f_{lrem} is a parameter regulating plant death during winter, currently set to 0.9, which signify that 10% of the plant N will be transferred to the litter pool with the C/N-ratio in roots ($CN_{\mathrm{root(0)}}$) at the end of the uptake period.

Harvest of annual crops

The exported N yield for annual crops (harvested only once per year) is estimated as:

$$N_{harv}(i,c,y) = N_{Gharv}(i,c,y) * MIN\left(f_{neth}(i,c,y),\ 1\right) + N_{res}(i,c,y) * f_b(c) \qquad (25$$

where f_{b} is the assumed harvestable fraction (Table 6) of the above ground residues (i.e. straw, etc.) If no harvest of crop residues is done, f_{b} is equal to zero. The exported target yield may be reduced by the net removal fraction f_{neth}.

For annual crops the harvested N fraction, f_{harv}, corresponding to the SOILN parameter HARHP written to the Manage_N.bin driving file described above, is given by:

$$f_{harv}(i,c,y) = \frac{N_{harv}(i,c,y)}{\left(N_{totup}(i,c,y) + N_{up}(1,p)\right)} \qquad (26)$$

Without a post crop the $N_{\mathrm{up(1)}}$ is equal to zero. The above ground residue fraction, f_{ares}, (corresponding to HARAR in Manage_N.bin) defining the fraction of plant N actually being transferred to the litter pool at the fictitious ploughing event following next to harvest, is calculated for all crops but ley according to:

$$f_{ares}(i,c,y) = \frac{N_{res}(i,c,y) * f_{dres}(i,c)}{\left(N_{totup}(i,c,y) + N_{up}(1,p)\right)} \qquad (27)$$

The fraction of remaining plant N after harvest, f_{lrem}, (corresponding to HARLR in Manage_N.bin) is estimated as:

$$f_{lrem}(i,c,y) = 1 - \left(f_{harv}(i,c,y) + f_{ares}(i,c,y) + f_a(c) * f_{dr}(i,c)\right) \qquad (28)$$

Leys (crops harvested more than once per year)

For ley crops, the target N uptake is calculated separately for each harvest. During the first year of the ley, the target N uptake is estimated in accordance with equations 19 to 23. The number of harvests is limited to 4 per year (UP1 to UP4). At each harvest the first year, fractions of both N in roots (f_{dr}) (dead roots) respectively above ground residues, f_{dres}, are, or may be, turned over (*deadrootN:rootN_ratio; res_incorp_eff;* Table 6) and transferred into the litter pool. Residue turn over is currently used only for Green manure leys where no yields are removed from the field but the crop is mowed 2-4 times during the growing period.

It is assumed that the major part of the storages of N (and C) in residues, N_{resL}, respectively roots, N_{rootL}, in the ley are built up during the undersowing autumn and the first year. Minor accumulations may also occur during autumn periods (after last harvest) in perennial leys. The turn over of root and residue N are compensated when the target N uptake in residues respectively roots are estimated (Equation 21 and 22), to get an accurate net build up of respective storage.

$$N_{resL}(i,c,y) = (1 - f_{dres}(i,c)\,) * N_{res}(i,c,y) \tag{29}$$

$$N_{rootL}(i,c,y) = (1 - f_{dr}(i,c)) * N_{root}(i,c,y) \tag{30}$$

The exported target yield may be reduced by the net removal fraction f_{neth}. For example in Green manure leys, the gaseous N losses (e.g. ammonia) from mowed crop residues could be imitated with a certain fraction of the gross production (N_{Gharv}) exported as 'harvested yield'. The exported N yield is estimated in accordance with equation 25.

Leys, second year and older

During the second and following years of a ley, only the exported yield plus the turn over fraction of roots (f_{dr}), are included in the target N uptake. Thus, no build up of N in plant is assumed to occur. After the last harvest of ley each year, N uptake will continue until the end of growing season or cultivation. N_{rootL} in equation 30 refer to the value estimated at the end of the vegetation season the presiding year (index (y-1)), after the autumn N uptake (UP6) and estimated losses during the winter.

$$N_{totup}(i,y,c) = N_{harv}(i,c,y) + N_{rootL}(c,y-1) * f_{dr}(i,c) \tag{31}$$

Harvest of ley (or crops harvested more then once per year)

In ley the fractions $f_{\mathrm{harv}}, f_{\mathrm{ares}}$ and f_{lrem} (equations 26 to 28) must be estimated from the total actual amount of N in the plant prior to each harvest. The total amount of roots and residue N remaining from earlier harvests, N_{remL}, is calculated (from equations 29 and 30) as:

$$N_{remL}(i,c,y) = N_{resL}(i-1,c,y) + N_{rootL}(i-1,c,y) \tag{32}$$

During the first year of ley the harvest fraction, N_{harv}, is estimated as:

$$f_{harv}(i,c,y) = \frac{N_{harv}(i,c,y)}{(N_{totup}(i,c,y) + N_{remL}(i,c,y))} \tag{33}$$

and the above ground residue fraction, f_{ares}, defining the fraction of plant N being transferred to the litter pool is calculated according to:

$$f_{ares}(i,c,y) = \frac{N_{resL}(i,c,y) * f_{dres}(i,c)}{(N_{totup}(i,c,y) + N_{remL}(i,c,y))} \tag{34}$$

The fraction of remaining plant N after harvest, f_{lrem}, is calculated according to equation 28.

For the following years of ley N_{remL}, refer to the value estimated at the end of the vegetation season the presiding year (index (y-1)), after the autumn N uptake (UP6) and estimated losses during the winter. The harvest fraction is estimated as

$$f_{harv}(i,c,y) = \frac{N_{harv}(i,c,y)}{(N_{totup}(i,c,y) + N_{remL}(i,c,y-1))} \tag{35}$$

At harvest, the above ground residue fraction, f_{ares}, is set to zero (no residue turn over). The fraction of remaining plant N after harvest, f_{lrem}, is calculated according to:

$$f_{lrem}(i,c,y) = 1 - \left(f_{harv}(i,c,y) + f_{ares}(i,c,y) + \frac{N_{rootL}(i,c,y-1) * f_{dr}(i,c)}{\left(N_{totup}(i,c,y) + N_{remL}(i,c,y-1)\right)} \right) \quad (36)$$

Post crops, weeds and shed seed after harvest

For post crops (UP5), growth of weeds or ley after (last) harvest (UP6), or if spring cultivation, in the spring uptake period (UP8) the target N uptake, N_{up}, is simply estimated as a function of crop, the available time for uptake, t_{UP}, and an estimated rate of 'daily N uptake' (g N $m^{-2}d^{-1}$) N_{upx}, (Table 8), taken from the database [*upax* in Crop(SoilN); Postcrop(SoilN)] . The potential uptake in autumn is estimated from the length of time available until end of vegetation season, but the N uptake is cut of at first cultivation date. For post crops the crop index (*c*) in equation 31 should be exchanged by the post crop index (*pc*).

$$N_{up}(i,c,y) = N_{upx}(i,c) * t_{UP}(i) \quad (37)$$

The target N uptake for post crops can also be estimated in a similar way as for main crops by assigning 'yield' and values of N concentration to the cropping system table. For uptake periods UP0, UP7 and UP9, the estimated crop specific values for the target N uptake, $N_{up}(i)$, is taken from the database (*up(i)* in [Crop(SoilN); Postcrop(SoilN)]). Uptake periods UP7 and UP9 are available for the periods between stubble cultivation and ploughing at autumn respectively spring cultivation. Currently, the default target uptake for both are set to zero.

If there is no cultivation in autumn (UP5, UP6 or UP7), a fraction ($1-f_{\text{lr(i)}}$) of the actual N content in the *Plant* state variable will die during winter and be transferred to the litter pool. The proportion between residue and root N from the actual uptake period is given by f_{r}. The C/N-ratios for these materials are given by $CN_{\text{ares(i)}}$ respectively $CN_{\text{root(i)}}$ in [Crop(SoilN)]. The remaining residues of the main crop (except for ley) are also transferred at the same time. The weighted C/N-ratio for residues is calculated from the actual C/N-ratio in the residues of the main crop and the estimated N contents in residues of the main crop and 'post crop', respectively.

Potential N uptake

Potential daily N uptake for the whole simulation are calculated within SOILNDB prior to the simulation and written to the 'crop_N.bin' driving file read by the SOILN model. In the same file, daily values for root depth for the N simulation are included.

For both main and post crops (UP1 to UP5), the uptake parameter, u_{a}, which is used to calculate the daily potential N uptake, is estimated for each harvest as:

$$u_a(i) = N_{totup}(i) * \frac{1 - e^{-u_c(i,c)*t_{UP}(i)}}{1 - \dfrac{N_{totup}(i)}{u_b(i,c)} * e^{-u_c(i,c)*t_{UP}(i)}} + u_b(i,c) + N_{up}(1,p) \quad (38)$$

where u_b and u_c are coefficients in the plant uptake function (see Table 7 and 8; Appendix I;10 and 11) and t_{UP} is the length of the uptake period, calculated simply by subtracting the start of the uptake period u_{st} from the end of the uptake period, u_{et} (calculated as harvest date minus *offset_h1,* see above). The coefficient N_{up}(1,p) is an estimation of the N uptake by the undersown post crop, *p*, during the main crop growing period. It is used (diverted from zero) only when an undersown post crop is growing together with the main crop. Currently the value is set to 1 g N m^{-2} for all undersown post crops (Table 8). For post crops (UP5) the crop index (*c*) in equation 38 should be exchanged by the post crop index (*p*).

For the uptake periods, UP0 (winter crops, first autumn) and UP6 to UP9, the uptake parameter u_a(i), is simply calculated as:

$$u_a(i,c) = N_{up}(i,c) + u_b(i,c) \tag{39}$$

Table 7. Examples of coefficients and parameters associated to plant N uptake and development for main crops. Only the coefficients for uptake period UP$_0$ and the first harvest (UP1) are presented. The values for harvest 2 to 4 in ley are similar.

Crop	up_0 (g N m^{-2})	u_{b0} (-)	u_{c0} (d^{-1})	CN_{root0} (-)	u_{b1} (-)	$upcx_1$ (-)	CN_{ares1} (-)	CN_{root1} (-)	deadrootN/ rootN- ratio$_1$ (-)	Res_ incorp_eff$_1$ (-)
Ley, Green Manure					0.2	11	16	20	0.3	0.8
Ley, <25% Clover					0.2	11	35	20	0.2	0.0
Horse bean					0.3	10	28	20	1.0	0.5
Potatoes					0.3	10	10	20	1.0	0.8
Spring barley					0.3	9	40	20	1.0	0.5
Spring rape					0.3	9	28	20	1.0	0.5
Winter rape	6.0	0.3	0.10	20	0.3	10	28	20	1.0	0.5
Winter wheat	2.0	0.3	0.11	20	0.3	10	40	20	1.0	0.5

Table 8. Plant N uptake and development parameters for post crops. The indexes 1 respectively 5 refers to uptake period UP1 and UP5

Crop	up_1 (-)	$upax_5$ (g N m^{-2} d^{-1})	u_{b5} (-)	$upcx_5$ (-)	f_{lr5} (-)	CN_{ares5} (-)	CN_{root5} (-)
Autumn sown C-crop		0.025	0.3	10	0.8	13	20
Catch Crop (grass)	1.0	0.050	0.1	10	0.8	18	20
Undersown Ley <25%	1.0	0.060	0.1	10	0.8	18	20
Winter oilseed C-crop		0.050	0.3	10	0.8	13	20

In order to achieve an acceptable adaptation of the uptake function at various length of the uptake periods and different crops, the coefficient u_c is estimated from a crop type and uptake period depending factor, u_{cx}, (*upcx* in Table 7 and 8) and the length of the available uptake period, $t_{UP(i)}$. Used only for uptake periods UP1 to UP6 (Eq. 38).

$$u_c(i,c) = \frac{u_{cx}(i,c)}{t_{UP}(i)} \tag{40}$$

For post crops the crop index (*c*) in equation 39 and 40 should be exchanged by the post crop index (*p*).

Cultivation of annual crops

During the time period between harvest and first cultivation, N uptake will continue in weeds or post crops (UP6 or UP5). The estimated potential N uptake is depending on the length of time available until the end of the vegetation season, but the uptake is terminated at first autumn cultivation date. The potential N uptake is estimated by equations 37 and 39. If the cultivation occurs in spring, another uptake period is started when the vegetation season begins (UP8). The definition of spring cultivation is that the cultivation is made later than the start of next vegetation season.

With a post crop (UP5), the amount of N in both above ground residues and roots in the plant will increase. The distribution between residues and roots is given by the fraction of N in roots of total plant N, $f_{r(p)}$, for the post crop. Without a post crop, the N uptake in weeds will only increase the amount of residue N, for simplicity and due to the dominance of young and fresh material. The last N uptake period before cultivation ends one day before the first cultivation date. The harvest fraction, f_{harv}, is set to zero.

Following annual crops, and assuming stubble cultivation is carried out, the remaining amount of main crop N in residues, N_{resM}, respective totally remaining N, N_{remM}, left from the residue transfer occurring after harvest (see above) is estimated as:

$$N_{resM}(i,c,y) = \left(1 - f_{dres}(i-1,c)\right) * N_{res}(i-1,c,y) \tag{41}$$

$$N_{remM}(i,c,y) = N_{resM}(i,c,y) + (1 - f_{dr}(i-1,c) * N_{root}(i-1,c,y) \tag{42}$$

The total amount of N in post crop, N_{upPc}, respectively the amount of N in residue, N_{resPc}, in the post crop are given by:

$$N_{upPc}(i,p,y) = N_{up}(1,p) + N_{up}(i,p,y) \tag{43}$$

$$N_{resPc}(i,p,y) = \left(1 - f_r(i,p)\right) * N_{upPc}(i,p,y) \tag{44}$$

Note that if no post crop is grown, $N_{up}(1,p)$ in equation 43 is zero, and the index p has the same value as 'c', referring to the main crop post harvest uptake periods UP6 to UP9 (N uptake in weeds or shed seed). The residue fraction, f_{ares}, as a function of main crop, c, and post harvest crop (post crop or weeds), p, is calculated as following:

$$f_{ares}(i,p,y) = \frac{f_{ste}(c) * \left(N_{resM}(i,c,y) + N_{resPc}(i,p,y)\right)}{N_{remM}(i,c,y) + N_{upPc}(ip)} \tag{45}$$

where f_{ste} is the stubble efficiency coefficient defining the fraction of above ground residue N being incorporated into the litter pool at the date of stubble cultivation. If the first cultivation is a ploughing, f_{ares} is estimated in the same way, but f_{ste} is always equal to 1.

The fraction of remaining plant N after stubble cultivation, f_{lrem}, is simply estimated as:

$$f_{lrem}(i,p,y) = 1 - \left(f_{harv}(i,p,y) + f_{ares}(i,p,y)\right) \tag{46}$$

As shown above, stubble cultivation is not assumed to cause any incorporation of root N into the litter pool. N in roots from the main crop and the post crop is still left in the plant, together with the remaining part of the above ground residue N. During the N uptake period between stubble cultivation and ploughing (UP7 respectively UP9) there might be further N uptake in weeds. At the following, and ending, ploughing event the residue fraction, f_{ares}, can be estimated as:

$$f_{ares}(i,p,y) = \frac{\left(1 - f_{ste}(c)\right) * \left(N_{resM}(i-1,c,y) + N_{resPc}(i-1,p,y) + N_{resPc}(i,p,y)\right)}{f_{lrem}(i-1,p,y) * \left(N_{remM}(i-1,c,y) + N_{upPc}(i-1,p,y)\right) + N_{upPc}(i,p,y)} \qquad (47)$$

The fractions of harvested and remaining N (f_{harv}, f_{lrem}) are both set to zero before the final ploughing event.

Termination of leys

During the time period between the last harvest and the first soil cultivation, N uptake will continue in the same way as for other crops. If the cultivation is made in spring another uptake period is started when the vegetation season begins (UP8).

The amount of N in ley residues (N_{resL}), the residue fraction (f_{ares}), and remaining plant N (N_{remL}) are calculated in the same way as for annual crops, by replacing N_{resM} and N_{remM} with the corresponding N_{resL} and N_{remL} respectively (equations 41, 42 and 45). The remaining amount of ley crop N in residues, N_{resL}, respective totally remaining N, N_{remL}, are updated by using equations 29, 30 and 32. The total N uptake in the post harvest growth, N_{upPc}, is estimated by equation 37. Note that the post harvest crop before first cultivation still is the ley, why the index '*p*' in equations 44 to 46 should be replaced by '*c*'.

The C/N ratio of above ground residues and roots

The C/N ratio of above ground residues, CN_{ares}, is an input parameter passed to the SOILN model by the Manage_N.bin driving file. At the harvest of the main crop it is given by:

$$CN_{ares}(i,c,y) = \frac{c_{Cres}(c)}{c_{Nres}(i,c,y)} \qquad (48)$$

where C_{Cres} is the carbon concentration in above ground residues (currently set to 40% for all crops). Following post harvest crop growth (post crops or weeds) the main crop residues are mixed by new fresh plant material, mostly with a lower C/N-ratio. The N weighed C/N-ratio in the actual mix of residues (index *w* in equation 46) with different origin is calculated as:

$$CN_{ares}(w,c,y) = \frac{CN_{\acute{a}res}(w-1,c,y) * N_{res}(w-1,c,y) + CN_{\acute{a}res}(i,c,y) * N_{res}(i,c,y)}{N_{res}(w-1,c,y) + N_{res}(i,c,y)} \qquad (49)$$

As the C/N-ratio of roots is not assumed to vary as much as the above ground residues, and are less well known, the C/N-ratio of roots are simply taken from the database for each N uptake period without any weighting procedure.

Outputs

Outputs from a simulation include both the detailed output files from the SOIL and SOILN models and a summarised output in tabular form given within the SOILNDB program. In the files from the SOIL and the SOILN models outputs from all model variables are given on daily basis and as a summary for the entire simulated period. The detailed output files from the SOIL and the SOILN models include two binary formatted files '.bin' files where outputs from all model variables are given on daily basis and two additional ASCII files '.sum' includes a summary of all parameter values used in the simulation.

Within the SOILNDB system, the results are presented in four groups "Input, output & change in storage", "Transport, concentration & discharge" and "Uptake & tillage per year" and "Uptake, fertilization & export per harvest". The output is displayed in tabular form covering yearly averages and whole-simulation averages. See Table 9, Table 10, Table 11 and Table 12 for the displayed variables.

Table 9. The data presented in the "Input, output & change in storage" table.

Input (kg/ha)	Total harvest export (kg/ha)	Losses (kg/ha)	Change in storage (kg/ha)	Mineralization (kg/ha)
Fertilization NO_3-N [+]	Target [+]	Denitrification [*]	Soil organic N [*]	Mineralization [*]
Fertilization NH_4-N [+]	Simulated [+]	Total transport in water [*]	Soil mineral N [*]	
Manure Organic N [+]		NO3 tranpsport 1 m [*]		
Manure NH_4-N [+]				
Fixation NH_4-N [+]				
Deposition NO_3-N [*]				

[*] Agrohydrological year
[+] Calendar year

Table10. The data presented in the "Transport, concentration & discharge" table, by agrohdrological years.

NO_3-N transport (kg/ha)	NO_3-N concentration (mg/l)	Discharge (mm)
Total	Streamwater (total)	Total
In surface runoff	Surface water	In surface runoff
To tile drains	Tile drain discharge	To tile drains
To groundwater	Groundwater	To groundwater

Table 11. The data presented in the "Uptake & tillage per year" table.

Plant uptake (kg/ha)	Soil cultivation (date)
Main crop, potential	last stubble date
Main crop, actual	last tillage date
Catch crop, potential	
Catch crop, actual	

Table 11. The data presented in the "Uptake, fertilization & export per harvest" table.

Plant uptake (kg/ha)	Total harvest export (kg/ha)	Input (kg/ha)
Main crop, potential	Target	Main crop, Fertilization NO_3-N
Main crop, actual	Simulated	Main crop, Fertilization NH_4-N
Catch crop, potential		Main crop, Manure Organic N
Catch crop, actual		Main crop, Manure NH_4-N
		Catch crop, Fertilization NO_3-N
		Catch crop, Fertilization NH_4-N
		Catch crop, Manure Organic N
		Catch crop, Manure NH_4-N

The result tables can be saved as files or printed out. For each simulation session, results are temporarily stored in a separate database. For convenience, the information concerning the chosen soil, climate and cropping system, given as input, are also presented and stored together with the simulation results.

If whole input databases are simulated in a batch, the simulation results are automatically saved in result databases.

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