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# Technical description of SOILNDB (V. 1.0)

Teknisk beskrivning av SOILNDB (V. 1.0)

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# Preface

This technical description was completed in March 2002, however most parts were printed before this date. As a consequence, the model description reflects the parameter values and the algorithms of the model as described by Hoffmann and Johnsson (1999a), and Johnsson et al. (2002). Important devolpment, resulting in changed parameter values, has been performed during 2000 and 2001, and will be described in an updated technical description.

We would like to thank Hans Johansson (Department of Soil Sciences, Division of Hydrotechniques) for skilful programming. This work was carried out within the Swedish Water Management Research Programme, VASTRA, financially supported by the Foundation for Strategic Environmental Research, MISTRA. Funding was also received from SLU, the Nordic Council of Ministers and the Swedish Environmental Protection Agency, 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 shell 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.

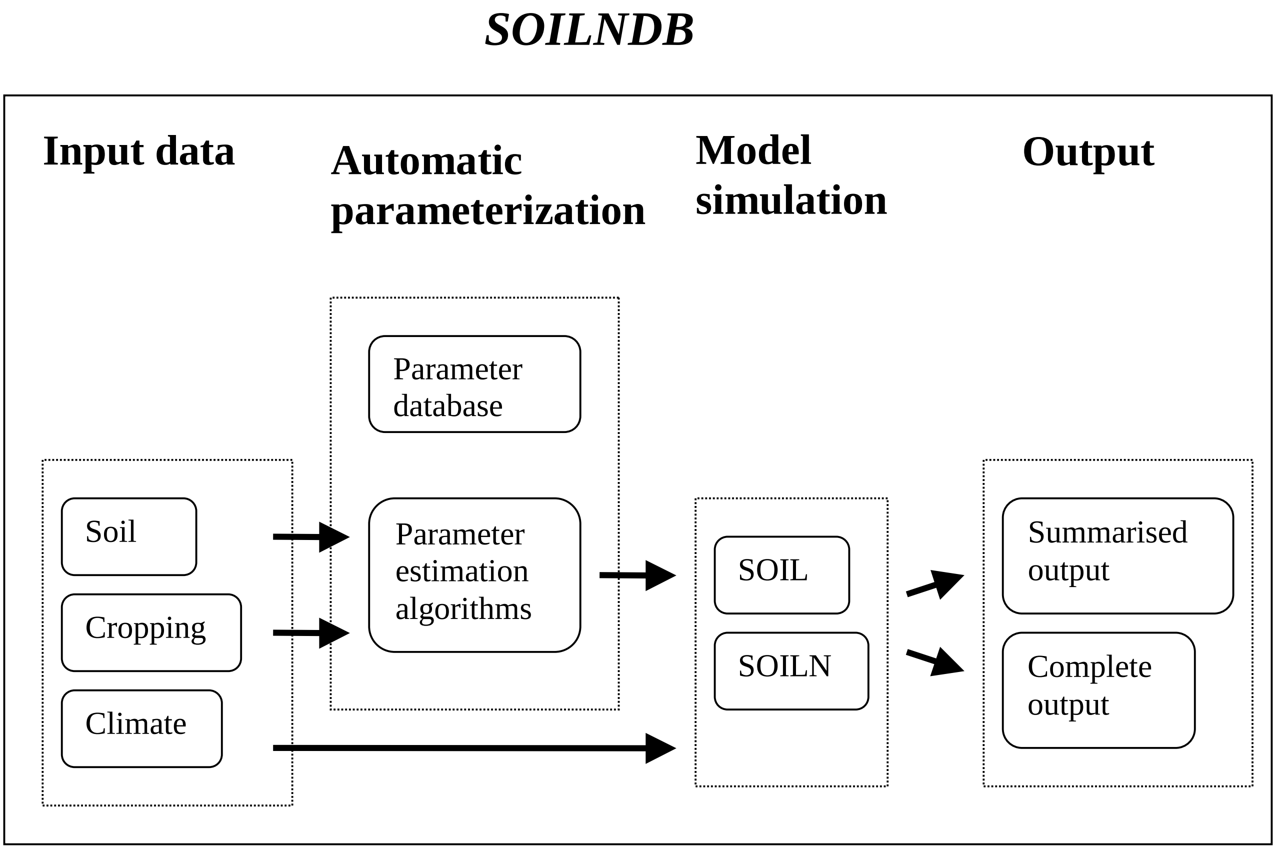


*Fig. 1. Schematic description of the SOILNDB model system.*

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). 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. As bottom boundary condition for water, a unit gravitational gradient is assumed as driving force for vertical flow from the lowest soil compartment. The initial water content is derived from the initail soil tension, which is uniform for the whole profile and set by the parameter $\psi_{\mathrm{ini}}$. 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 caracteristics is described with three cut and join functions (Jansson, 1991). In the dry range, above a threshold value $\Psi_{\mathrm{x}}$, the water release is assumed log-linear:

$$\frac{\log(\psi/\psi_x)}{\log(\psi_{wilt}/\psi_x)} = \frac{\theta_x - \theta}{\theta_x - \theta_w} \qquad \psi_x < \psi < \psi_{wilt} \qquad (1)$$

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

$$\left(\frac{\psi}{\psi_a}\right)^{-\lambda} = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad \psi_m < \psi < \psi_x \qquad (2)$$

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

$$\psi = \psi_m - \frac{(\theta + 4 - \theta_s)}{4}\psi_m \qquad \psi_0 < \psi < \psi_m \tag{3}$$

where $\theta$ is the actual water content and $\Psi$ is the actual tension, $\theta_x$ is the water content corresponding to the upper threshold tension ($\Psi_x$), $\Psi_{wilt}$ and $\theta_w$ corresponds to the tension and water content at the wilting point, $\theta_r$ is the residual water content, $\theta_s$ is the saturated water content, $\Psi_a$ is the air entry tension, $\lambda$ is the pore size distribution index, and $\Psi_m$ is the lower threshold tension corresponding to a water content of $\theta_s - 4$. Above the lower threshold tension, $\Psi_m$, the unsaturated hydraulic conductivity, $k_w$, is described by the Mualem model (Mualem, 1976):

$$k_w = k_s \left(\frac{\psi_a}{\psi}\right)^{2+(2+n_{\mathrm{var}})\lambda} \qquad \psi_m < \psi < \psi_{wilt} \tag{4}$$

where $k_s$ is the saturated hydraulic conductivity and $n_{\mathrm{var}}$ is the tortuosity factor. When the water tension is between $\Psi_m$ and $\Psi$, the hydraulic conductivity is described by:

$$k_w = 10^{\left(\log(k_w(\theta_s - 4)) + \frac{\theta - \theta_s + 4}{4}\log\left(\frac{k_{sm}}{k_w(\theta_s - 4)}\right)\right)} \qquad \psi_0 < \psi < \psi_m \tag{5}$$

where $k_{sm}$ is the saturated conductivity including macropores and $k_w(\theta_s - 4)$ is the hydraulic conductivity at $\Psi_m$ calculated with *equation 4*.

The infiltration capacity is reduced when ice occure 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, $r_{\mathrm{sint}}$, 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, $r_{\mathrm{frac}}$. 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 $f_{\mathrm{umov}}$, if a deficiency occures in some layers simultaneously as an excess of water exist in some other layer.

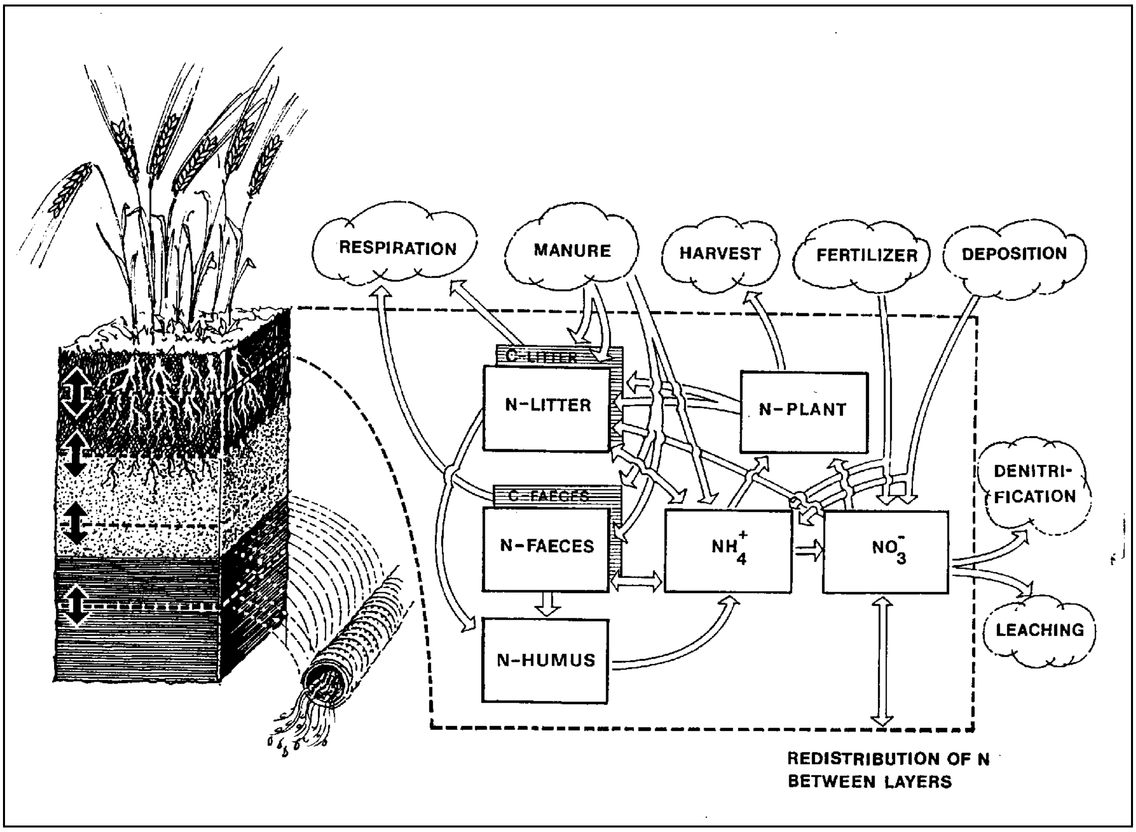


***Fig. 2.*** *Structure of the nitrogen model SOILN showing state variables (boxes) and flows (arrows) included in the model. The structure is replicated for each layer. Areas within the dotted line represent the top layer of the soil. Layers beneath have the same structure but have no direct input 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 $T_{\mathrm{ini}}$.

### *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 fertiliser, manure 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. 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, $k_{\mathrm{h}}$, and response functions for soil temperature, $e_{\mathrm{t}}$, and moisture, $e_{\mathrm{m}}$:

$$N_{h\rightarrow NH_4^+} = k_h\, e_t\, e_m\, \mathrm{N_h} \tag{6}$$

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

$$C_l = k_l e_t e_m \mathrm{C_l} \tag{7}$$

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:

$$C_{l\rightarrow CO_2} = (1-f_e)C_l \tag{8}$$

$$C_{l\rightarrow h} = f_e f_h C_l \tag{9}$$

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

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:

$$N_{l\leftrightarrow NH_4^+} = \left[\frac{\mathrm{N_l}}{\mathrm{C_l}} - \frac{f_e}{r_o}\right] C_l \tag{11}$$

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 microorganisms and humified products.

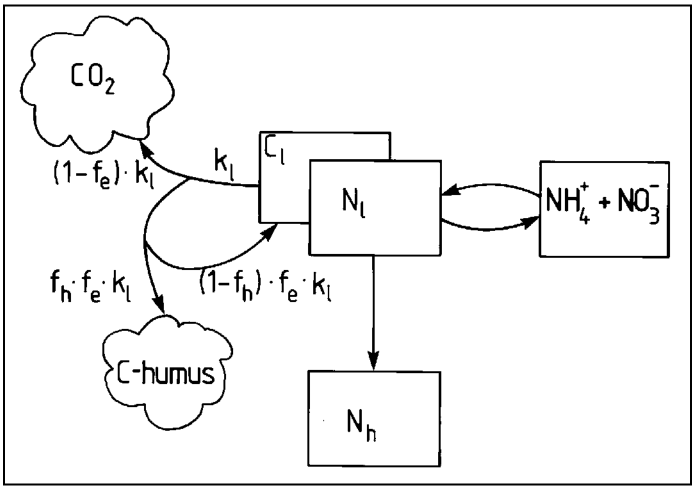


***Fig. 3.*** *Flow diagram illustrating the carbon and nitrogen balance associated with litter (or faeces) in SOILN. Explanations of parameter symbols are given in the text or in Johnsson et al., 1987.*

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.

Plant uptake of N is calculated with a time-dependent empirical function requiring crop specific parameter values. A logistic growth curve is used to define a potential uptake, $N_{\mathrm{totup}}$ (i.e. maximum uptake), during the growing season, which is distributed in the soil profile according to an assumed root distribution. Nitrogen uptake is reduced when the demand exceeds the available mineral N in the soil (given as a fraction of the total mineral N in soil). At harvest and ploughing the roots and harvest residues are incorporated into the soil litter pool.

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.

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, and cultivation management related data. Input data can be given either directly by the user or be supplied in database form.

### *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, $d_{\mathrm{lat}}$, used for calculating daylength 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.

*Table 1. Concentration of $NH_4$-N, $c_{ammN}$, organic N, $c_{orgN}$, and C-N ratios in bedding in manure, $CN_{fec}$, in the SOILNDB database (Steineck et al., 1999)*

| Type of manure | $c_{ammN}$ (kg N $ton^{-1}$) | $c_{orgN}$ (kg N $ton^{-1}$) | $CN_{fec}$ |
|---|---|---|---|
| Solid manure, cattle | 1.3 | 4.1 | 26 |
| Solid manure, pigs | 2.3 | 4.5 | 21 |
| Solid manure, hen | 6.2 | 15.2 | |
| Urine, cattle | 1.5 | 0.4 | |
| Urine, pigs | 1.4 | 0.3 | |
| Slurry, cattle | 1.9 | 1.5 | 22 |
| Slurry, pigs | 3.2 | 1.6 | 20 |

### *Cropping system*

Yearly input of crop and management information includes: crop type and sowing date, harvest date and yield, fertilisation amount and time, time and amount of manure applications, soil cultivation time and, if a catch crop is simulated, the expected N uptake of the catch crop. Currently, there is an option to chose between the following main crops: spring wheat, spring barley, oats, spring rape, winter wheat, rye, winter barley, winter rape, potatoes, sugar beet and grass ley.

*Table 2. Volatilisation loss of $NH_3$, $f_{sloss}$, for different types of manure and for various types of application techniques from the SOILNDB parameter database (after Claesson and Steineck, 1991)*

| | | | | | $f_{sloss}$ | | | |
|---|---|---|---|---|---|---|---|---|
| Application time | Application technique | Incorpo-ration | Time until incorporation (hours) | Ley | solid manure | urine | deep straw manure (%) | slurry |
| Winter | Broadcasting | No | 0 | No | 20 | 40 | 20 | 30 |
| | Band-spreading | No | 0 | No | 0 | 30 | 0 | 20 |
| Spring | Broadcasting | Yes | 1 | No | 15 | 8 | 15 | 10 |
| | | Yes | 12 | No | 50 | 20 | 50 | 20 |
| | | No | 0 | Yes | 70 | 35 | 70 | 40 |
| | Band-spreading | Yes | 1 | No | 0 | 7 | 0 | 5 |
| | | Yes | 12 | No | 0 | 20 | 0 | 10 |
| | | No | 0 | Yes | 0 | 25 | 0 | 30 |
| Summer | Broadcasting | No | 0 | Yes | 90 | 60 | 90 | 70 |
| | Band-spreading | No | 0 | Yes | 0 | 40 | 0 | 50 |
| | | No | 0 | No | 0 | 10 | 0 | 7 |
| Early autumn | Broadcasting | Yes | 1 | No | 20 | 15 | 20 | 5 |
| | | Yes | 12 | No | 50 | 30 | 50 | 30 |
| | | No | 0 | No | 70 | 45 | 70 | 70 |
| | Band-spreading | Yes | 1 | No | 0 | 10 | 0 | 3 |
| | | Yes | 12 | No | 0 | 25 | 0 | 15 |
| | | No | 0 | No | 0 | 30 | 0 | 40 |
| Late autumn | Broadcasting | Yes | 1 | No | 10 | 10 | 10 | 5 |
| | | Yes | 12 | No | 20 | 20 | 20 | 10 |
| | | No | 0 | No | 30 | 25 | 30 | 30 |
| | Band-spreading | Yes | 1 | No | 0 | 4 | 0 | 3 |
| | | Yes | 12 | No | 0 | 18 | 0 | 5 |
| | | No | 0 | No | 0 | 25 | 0 | 15 |

Crops can be combined without restraint in the crop rotation. The yield (kg $ha^{-1}$) must be given with a water content of 15% for cereals crops, 9% for rape seed crops, 79% for potatoes, 74% for sugar beets and 0% for leys, respectively. A choice can be made between a number of the most common types of manure (Table 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, $CN_{\mathrm{fec}}$). To account for different volatilisation losses of $NH_3$ at manure application, $f_{\mathrm{sloss}}$, various application techniques can be chosen from a database (Table 2), or alternatively, the user may specify the fraction of ammonia lost implicitly.

## 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, 'autopar.mdb' where most parameters 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) 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). 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.

*Soil and hydraulic properties*

The soil profile is divided into five layers, $n^o$, with a thickness, $\Delta z(l)$, of 0.25, 0.25, 0.25, 0.25 and 0.5 m, respectively, down to 1.5 m depth where free drainage is assumed. 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, $\lambda$, the residual water content, $\theta_{\mathrm{r}}$, saturated water content, $\theta_{\mathrm{s}}$, and the air entry tension, $\psi_{\mathrm{a}}$) and to the saturated hydraulic conductivity, $k_{\mathrm{s}}$, used in the Mualem model (see Table 3). The tortuosity factor, $n_{\mathrm{var}}$, 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 $n_{\mathrm{var}}$ was set to 5. The water content at wilting point, $\theta_{\mathrm{w}}$, and the upper limit for the use of the Brooks and Corey equation, $\psi_{\mathrm{x}}$, was set to 1000 for the 10 standard soil texture classes, but for the soils in the 'soils database', $\psi_{\mathrm{x}}$ was set to unique values for the different soils (Table 3). The saturated hydraulic conductivities including macropores, $k_{\mathrm{sm}}$, are rough esimates based on previous applications with the SOIL model (Table 3). The coefficients in the empirical function for the temperature dependence in the hydraulic conductivity $A_{0\mathrm{T}}$ and $A_{1\mathrm{T}}$, (set to 0.54 and 0.025, respectively), were set equal to default values given by the SOIL model for all soils.

*Table 3. Soil hydraulic parameters for the standard soil texure classes and for the specific soils in the database*

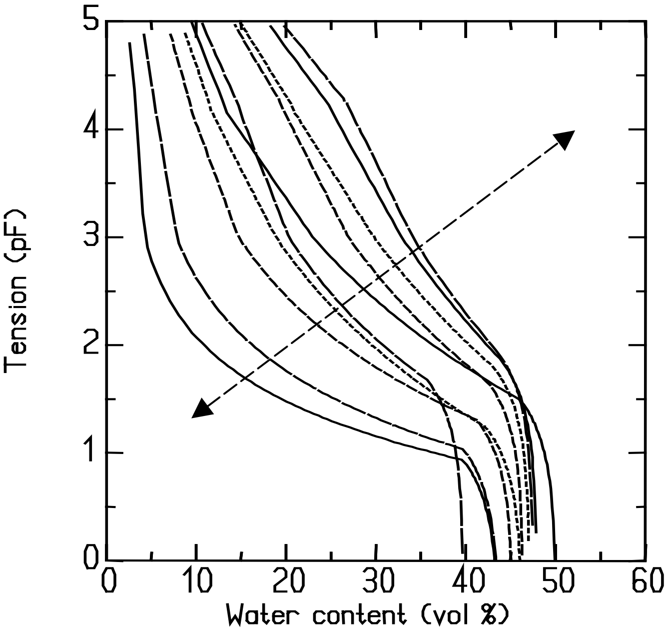
| Soil texture class for standard soils | Soil id. in database | $k_s$ (mm h$^{-1}$) | $k_{sm}$ (mm h$^{-1}$) | $\lambda$ (-) | $\theta_r$ (%) | $\theta_s$ (%) | $\psi_a$ (cm water) | $\theta_w$[a] (%) | $\psi_x$ (cm water) |
|---|---|---|---|---|---|---|---|---|---|
| Sand | | 210 | 210 | 0.59 | 2 | 43.7 | 7.26 | 3.3 | 1000 |
| Loamy sand | | 61.1 | 120 | 0.47 | 3.5 | 43.7 | 8.69 | 5.5 | 1000 |
| Sandy loam | | 25.9 | 120 | 0.32 | 4.1 | 45.3 | 14.66 | 9.5 | 1000 |
| Loam | | 13.2 | 120 | 0.22 | 2.7 | 46.3 | 11.15 | 11.7 | 1000 |
| Silt loam | | 6.8 | 120 | 0.21 | 1.5 | 50.1 | 20.76 | 13.3 | 1000 |
| Sandy clay loam | | 4.3 | 120 | 0.25 | 6.8 | 39.8 | 28.08 | 14.8 | 1000 |
| Clay loam | | 2.3 | 120 | 0.19 | 7.5 | 46.4 | 25.89 | 19.7 | 1000 |
| Silty clay loam | | 1.5 | 120 | 0.15 | 4 | 47.1 | 32.56 | 20.8 | 1000 |
| Silty clay | | 0.9 | 120 | 0.13 | 5.6 | 47.9 | 34.19 | 25 | 1000 |
| Clay | | 0.6 | 120 | 0.13 | 9 | 47.5 | 37.3 | 27.2 | 1000 |
| Soil texture class for soils in the database | | | | | | | | | |
| Loamy sand | a | 300 | 300 | 0.45 | 3 | 45 | 6 | 2.5 | 1000 |
| Loamy sand topsoil<br>sandy loam subsoil | b | 180 | 180 | 0.22 | 0.01 | 45 | 5 | 6.6 | 2000 |
| Silty loam | c | 90 | 180 | 0.09 | 0.1 | 42 | 8 | 6.6 | 100 |
| Loam | d | 90 | 180 | 0.11 | 3 | 41 | 36 | 11.9 | 1000 |
| Silty clay loam | e | 30 | 180 | 0.1 | 9 | 44 | 50 | 18.0 | 1600 |
| Silty clay | f | 12 | 240 | 0.08 | 0.01 | 50 | 33.5 | 31.0 | 30000 |
| Clay | g | 6 | 300 | 0.03 | 0.1 | 54 | 6 | 41.0 | 1000 |

[a] at pF 4.2.

The selection of the soils for the 'soils database' was done within a project for calculating nitrate leaching from the Nordic countries (Hoffmann and Johnsson, 1999b), and the selection was done to include a range of representative soils regarding texture composition in this area (Table 4), where soil denoted as *a* is Danish, soil *g* Finish, soils *b*, *c*, *d* and *e* Norwegian and soil *f* Swedish. Parameters used in the SOIL model connected to the Brooks and Corey equation were estimated from measured data on water retention characteristics using a least square fittings of equation 2. The saturated hydraulic conductivity, $k_s$, was measured, while the saturated hydraulic conductivity including macropores, $k_{sm}$, was estimated. Physical soil characteristics were assumed to be uniform for the whole soil profile. The water retention curves for the standard soils and for the specific soils in the database are shown in Figure 4.

*Table 4. Soil texture composition for the specific soils in the database*

| Swedish classification system | USDA class. system | Soil | Sand (0.2-0.02 mm) | Silt (0.02-0.002 mm) | Clay (< 0.002 mm) |
|---|---|---|---|---|---|
| Svagt lerig sand | loamy sand | a | 83 | 9 | 8 |
| Lerig sand | loamy sand (sandy loam) | b | 78 | 16 | 6 |
| Lerig mo | silty loam | c | 40 | 54 | 6 |
| Moig lättlera | loam | d | 43 | 38 | 19 |
| Mellanlera | silty clay loam | e | 17 | 50 | 33 |
| Styv lera | silty clay | f | 6 | 46 | 45 |
| Mycket styv lera | clay | g | 6 | 21 | 73 |



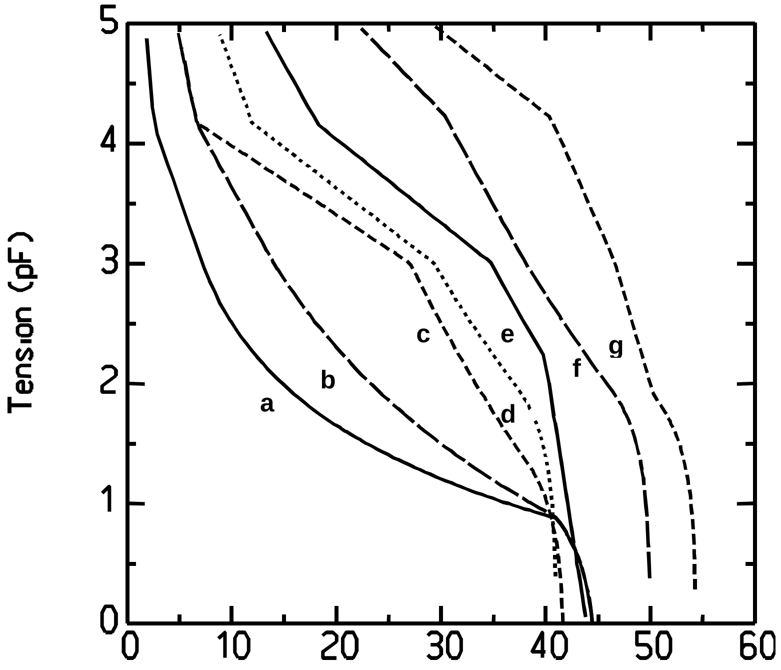


*Fig. 4. Water retention curves (a) for the 10 soil texture classes (USDA) included in SOILNDB with: sand, loamy sand, sandy loam, loam, sandy clay loam, silt loam, clay loam, silty clay loam, silty clay, and clay following the arrow from bottom left to top right, and (b) for the specific soils in the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

*Table 5. Parameters related to hydraulic properties in frozen soil ($f_{ci}$, $d_1$, $d_2$) and root water uptake ($\psi_c$) for the standard soil texure classes and for the specific soils in the database*

| Soil texture class for standard soils<br>-----------------------------------------------<br>Soil texture class for soils in database | Soil id. in database | $f_{\mathrm{ci}}$ (–) | $d_1$ (–) | $d_2$ (–) | $\psi_{\mathrm{c}}$ (cm water) |
|---|---|---|---|---|---|
| Sand | | 0 | 0.5 | 20 | 500 |
| Loamy sand | | 8 | 1 | 30 | 800 |
| Sandy loam | | 8 | 1 | 30 | 800 |
| Loam | | 8 | 1 | 30 | 800 |
| Silt loam | | 8 | 1 | 30 | 2000 |
| Sandy clay loam | | 8 | 1 | 30 | 2000 |
| Clay loam | | 8 | 1 | 30 | 3000 |
| Silty clay loam | | 8 | 1 | 30 | 3000 |
| Silty clay | | 8 | 1 | 30 | 4000 |
| Clay | | 8 | 1 | 30 | 4000 |
| Loamy sand | a | 0 | 0.5 | 20 | 500 |
| Loamy sand topsoil; sandy loam subsoil | b | 8 | 1 | 30 | 800 |
| Silty loam | c | 8 | 1 | 30 | 800 |
| Loam | d | 8 | 1 | 30 | 800 |
| Silty clay loam | e | 8 | 1 | 30 | 3000 |
| Silty clay | f | 8 | 1 | 30 | 4000 |
| Clay | g | 8 | 1 | 30 | 4000 |

### *Initial state of soil N and C content*

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

$$N_{lom}(l) = \frac{\Delta z(l) * \rho(l) * SOM(l)\, c_{Com}}{r_{CN}}\, r_{lh} \tag{12}$$

$$N_{\mathrm{hom}}(l) = \frac{\Delta z(l) * \rho(l) * SOM(l)\, c_{Com}}{r_{CN}} \left(1 - r_{lh}\right) \tag{13}$$

where $\rho(l)$ is the dry bulk density for the different soil layers, $l$, $r_o$ is the C/N ratio of soil organic matter, $r_{\mathrm{lh}}$ is the initial litter to humus ratio and $c_{\mathrm{Com}}$ 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, 'Organic matter (topsoil)', and the second layer (25 to 50 cm), 'Organic matter (subsoil)'. The C/N ratio of soil organic matter, $r_{\mathrm{CN}}$, is set to 10 and the initial litter to humus ratio, $r_{\mathrm{lh}}$, is set to 0.01 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, $C_{\mathrm{lom}}(l)$, is calculated from the soil organic matter content according to:

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

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.

*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 remaing 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 Table 5), the values were somewhat increased.

Most parameters related to snow properties were set to deafult values given by the SOIL model (see List of Symbols). However, the global radiation in the snow melt function, $m_{\mathrm{Rmin}}$ (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 Gustafsson (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 Gustafsson (1987).

*Water balance*

The parameters governing correction of precipitation due to errors in the measurement where for rain, $c_{\mathrm{rain}}$, set to 1.18 and for snow, $c_{\mathrm{snow}}$, set to 0.20. These values are somewhat higher than the default values given by the model ($c_{\mathrm{rain}}$ =1.07 and $c_{\mathrm{snow}}$ =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 resonable 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 are divided into five groups (i) spring cereals and spring oilseed crops, (ii) winter cereals and winter oilseed crops, (iii) potatoes, (iv) sugar beet, and (v) ley (Tables 6, 7, and 8). The surface resistance for transpiration when intercepted water occures, $r_{\mathrm{sint}}$, was set to 5 s $m^{-1}$ for all crops but ley, where it was assumed negligible. 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, the form factor, $c_{\mathrm{form}}(i)$, governing the interpolation between adjacent day numbers, $t_{\mathrm{day}}(i)$, set to unity, and the interception storage capacity per leaf area index (LAI), $i_{\mathrm{LAI}}$, set to 0.2 mm $LAI^{-1}$).

*Table 6. Dates for specification of parameters related to crop development and associated evapotransiration parameters*

| Crop | $t_{\mathrm{day}(1)}$ | $t_{\mathrm{day}(2)}$ | $t_{\mathrm{day}(3)}$ | $t_{\mathrm{day}(4)}$ | $t_{\mathrm{day}(5)}$ |
|---|---|---|---|---|---|
| Spring cerals and spring oilseed crops | $t_{\mathrm{s(i)}} + 12$ [a] | 29 June | $t_{\mathrm{sk(i)}} - 1$ [b] | $t_{\mathrm{sk(i)}}$ [b] | – |
| Winter crops (year of sowing) | – | – | – | – | $t_{\mathrm{s(i)}} + 12$ |
| Winter crops (year of harvest) | $u_{\mathrm{st(i)}} + 10$ | $\frac{t_{day(1)} + t_{day(3)}}{2}$ | $t_{\mathrm{sk(i)}} - 1$ [b] | $t_{\mathrm{sk(i)}}$ [b] | – |
| Undersown ley | – | – | – | – | $t_{\mathrm{s(i)}} + 14$ |
| Ley (not harvested) | $u_{\mathrm{st(i)}} + 10$ | $\frac{t_{day(1)} + t_{day(3)}}{2}$ | $u_{\mathrm{et(i)}}$ [c, d] | – | – |
| Ley with 1 harvest | $u_{\mathrm{st(i)}} + 10$ | $t_{\mathrm{sk1}} - 1$ [b] | $t_{\mathrm{sk1}}$ | $\frac{t_{day(3)} + t_{day(5)}}{2}$ | $u_{\mathrm{et(i)}}$ [c, d] |
| Ley with 2 harvests | $u_{\mathrm{st(i)}} + 10$ | $t_{\mathrm{sk1}} - 1$ [b] | $t_{\mathrm{day}(2)} + 1$ | $t_{\mathrm{sk2}} - 1$ [b] | $t_{\mathrm{day}(4)} + 1$ |

[a] $t_{\mathrm{s(i)}}$ represents the sowing timepoint
[b] $t_{\mathrm{sk(i)}}$ represents the harvest timepoint
[c] if soil cultication takes place, $t_{\mathrm{day(i)}}$ is set to $t_{\mathrm{sc}} - 1$, where $t_{\mathrm{sc}}$ is the time for soil cultivation
[d] if followed by a winter crop, $t_{\mathrm{day(i)}}$ is set to $t_{\mathrm{s(i+1)}} - 1$ where $t_{\mathrm{s(i+1)}}$ is the sowing date for the winter crop

*Table 7. Displacement height, $d_{h(i)}$, and leaf area index, $l_{ai(i)}$ for the different dates and crop groups. The numbers in parenthesis refers to the dates defined in Table 6*

| Crop | $d_{\mathrm{h}(1)}$ (m) | $d_{\mathrm{h}(2)}$ (m) | $d_{\mathrm{h}(3)}$ (m) | $d_{\mathrm{h}(4)}$ (m) | $d_{\mathrm{h}(5)}$ (m) | $l_{\mathrm{ai}(1)}$ (-) | $l_{\mathrm{ai}(2)}$ (-) | $l_{\mathrm{ai}(3)}$ (-) | $l_{\mathrm{ai}(4)}$ (-) | $l_{\mathrm{ai}(5)}$ (-) |
|---|---|---|---|---|---|---|---|---|---|---|
| Spring cerals and spring oilseed crops | 0 | 0.6 | 0.6 | 0 | 0 | 0 | 5 | 2 | 0 | 0 |
| Winter cerals and winter oilseed crops | 0.06 | 0.5 | 0.5 | 0 | 0.06 | 1 | 5 | 3 | 0 | 1 |
| Potatoes | 0 | 0.3 | 0.3 | 0 | 0 | 0 | 5 | 3 | 0 | 0 |
| Sugar beet | 0 | 0.25 | 0.3 | 0 | 0 | 0 | 4 | 4 | 0 | 0 |
| Ley | 0.1 | 0.5 | 0.07 | 0.35 | 0.1 | 1 | 5 | 1 | 4 | 1 |
| Undersown ley | – | – | – | – | $d_{\mathrm{h}(1)}$ [a] | – | – | – | – | $l_{\mathrm{ai}(1)}$ [a] |

[a] for undersown ley at $t_{\mathrm{day}(5)}$, the value corresponding to $t_{\mathrm{day}(1)}$ for ley is used

*Table 8. Reference height, $z_{0(i)}$, and surface resistance, $r_{s(i)}$, for the different dates and crop groups. The numbers in parenthesis refers to the dates defined in Table 6*

| Crop | $z_{0(1)}$ | $z_{0(2)}$ | $z_{0(3)}$ | $z_{0(4)}$ | $z_{0(5)}$ | $r_{\mathrm{s}(1)}$ | $r_{\mathrm{s}(2)}$ | $r_{\mathrm{s}(3)}$ | $r_{\mathrm{s}(4)}$ | $r_{\mathrm{s}(5)}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Spring cerals and oilseed | 0.005 | 0.08 | 0.08 | 0.005 | 0.005 | 150 | 40 | 100 | 150 | 150 |
| Winter cerals and oilseed | 0.01 | 0.07 | 0.07 | 0.005 | 0.01 | 120 | 40 | 100 | 150 | 120 |
| Potatoes | 0.005 | 0.015 | 0.045 | 0.05 | 0.005 | 150 | 100 | 30 | 60 | 150 |
| Sugar beet | 0.005 | 0.014 | 0.035 | 0.043 | 0.005 | 150 | 50 | 40 | 50 | 150 |
| Ley | 0.014 | 0.07 | 0.01 | 0.05 | 0.014 | 150 | 40 | 150 | 50 | 150 |
| Undersown ley | – | – | – | – | $z_{0(1)}$ [a] | – | – | – | – | $r_{\mathrm{s}(1)}$ [a] |

[a] for undersown ley at $t_{\mathrm{day}(5)}$, the value corresponding to $t_{\mathrm{day}(1)}$ for ley is used

The empirical coefficient regulating surface resistance, $r_{\psi}$, used to calculate soil evaporation was set to 200 s m$^{-1}$ for all soils but for sand, in the 10 standard soil texture classes, and for loamy sand, in the 'soils database', 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 areodynamic resistance from measurement height to the soil surface, $r_{\mathrm{alai}}$, was set to 50 s m$^{-1}$ for all crops, and the extinction coefficient, $k_{\mathrm{rn}}$, used for calculating net radiation at the soil surface from LAI, was set to 0.5 for all crops (Johnsson & Jansson, 1991).

The effect of catch crops on the water balance has shown to be negligible (Aronsson and Torstensson, 1998) and water uptake of catch crops is therefore not treated in SOILNDB.

*Root development and root water uptake*

Roots are assumed to develop stepwise from zero at sowing to a maximum at harvest, and the distribution between soil layers is assumed to depend on crop and soil type. Root development and root depths (Tables 9, 10 and 11) are rough estimates based on studies and reviews by Haak (1993), Lewan (1993), and Myrbeck (1998). 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, $r_{\mathrm{frac}}$, that is to be allocated within the maximum root depth given by, $z_{\mathrm{r}}$, was set to the default value given by the SOIL model (i.e. 0.05), while the corresponding parameter in SOILN, $r_{\mathrm{fracN}}$, was set to 0.001. The critical tension for reduction of water uptake during dry soil conditions, $\psi_{\mathrm{c}}$, was set to relatively high values (Table 5), allowing for water uptake during rather dry periods. The parameter for compensatory uptake, $f_{\mathrm{umov}}$, was to default in SOIL (i.e. 0.5).

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 respons function for transpiration, $p_1$ and $p_2$, were set to 0.2 and 0 respectively.

*Table 9. Maximum root depths for different crops, $z_{r(3)}$, for the 10 standard soil texure classes (and the soils in the soils database) used in both the SOIL and SOILN models. The maximum root depth for the specific soils in the database relates to the soils with corresponding texture. The index 3 in $z_{r(3)}$, refers to the dates, $t_{root(3)}$, defined in Table 11*

| | Maximum root depth, $z_{\mathrm{r(3)}}$, (m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Crop | clay | silty clay | silty clay loam | Clay loam | Sandy clay loam | silty loam | loam | sandy loam | loamy sand | sand |
| Spring wheat | -1 | -1 | -1 | -1.25 | -0.9 | -0.9 | -0.6 | -0.6 | -0.6 | -0.4 |
| Spring barley | -1 | -1 | -1 | -1.25 | -0.9 | -0.9 | -0.6 | -0.6 | -0.6 | -0.4 |
| Oats | -1 | -1 | -1 | -0.8 | -0.9 | -0.9 | -0.6 | -0.6 | -0.6 | -0.4 |
| Spring rape | -1 | -1 | -1 | -0.8 | -0.9 | -0.9 | -0.6 | -0.6 | -0.6 | -0.4 |
| Winter wheat | -1.2 | -1.2 | -1.2 | -1.2 | -1.1 | -1.1 | -0.8 | -0.8 | -0.8 | -0.7 |
| Winter rye | -1.2 | -1.2 | -1.2 | -1 | -1.1 | -1.1 | -0.8 | -0.8 | -0.8 | -0.7 |
| Winter barley | -1.2 | -1.2 | -1.2 | -1 | -1.1 | -1.1 | -0.8 | -0.8 | -0.8 | -0.7 |
| Winter rape | -1.3 | -1.3 | -1.3 | -1.1 | -1.1 | -1.1 | -0.9 | -0.9 | -0.9 | -0.8 |
| Potatoes | -1 | -1 | -1 | -0.8 | -0.9 | -0.9 | -0.6 | -0.6 | -0.6 | -0.4 |
| Sugar beets | -1.2 | -1.2 | -1.2 | -1 | -1.1 | -1.1 | -0.8 | -0.8 | -0.8 | -0.7 |
| Ley | -1.4 | -1.2 | -1.2 | -1.2 | -1.3 | -1.3 | -0.8 | -0.8 | -0.8 | -0.7 |

*Table 10. Maximum root depth in autumn for different crops, $z_{r(5)}$, for the 10 standard soil texure classes (and the soils in the soils database) used in the SOILN[a] model. The maximum root depth for the specific soils in the database relates to the soils with corresponding texture. The index 5 in $z_{r(5)}$, refers to the dates, $t_{root(5)}$, defined in Table 11*

| | Maximum root depth in autumn, $z_{r(5)}$, (m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Crop | clay | silty clay | silty clay loam | clay loam | sandy clay loam | silty loam | loam | sandy loam | loamy sand | sand |
| Winter wheat | -0.25 | -0.25 | -0.25 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 |
| Winter rye | -0.25 | -0.25 | -0.25 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 |
| Winter barley | -0.25 | -0.25 | -0.25 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 |
| Winter rape | -0.4 | -0.4 | -0.4 | -0.4 | -0.4 | -0.4 | -0.4 | -0.4 | -0.4 | -0.25 |
| Undersown ley [b] | -0.7 | -0.6 | -0.6 | -0.6 | -0.65 | -0.65 | -0.4 | -0.4 | -0.4 | -0.35 |
| Catch crops | -0.26 | -0.26 | -0.26 | -0.26 | -0.26 | -0.26 | -0.26 | -0.26 | -0.26 | -0.26 |

[a] the values for maximum root depth in autumn are not defined for the SOIL model. However, root water uptake still occur from the uppermost soil layer (0 to 25 cm depth) if a crop exists.

[b] this depth is estimated as half the maximum root depth for ley, $z_{r(3)}$, (Table 9)

*Table 11. Derivation of root development dates, $t_{root(i)}$*

| Crops | $t_{root(1)}$ | $t_{root(2)}$ | $t_{root(3)}$ | $t_{root(4)}$ | $t_{root(5)}$ |
|---|---|---|---|---|---|
| Spring sown crops | $t_{s(1)} + 14$ [c] | $(t_{root(1)} + t_{root(3)}) / 2$ | $t_{sk(1)}$ [b] | $t_{sk(1)} + 1$ [b] | — |
| Winter crops [f] | — | — | — | $t_{s(1)} + 14$ [c] | $t_{root(4)} + 30$ [e] |
| Winter crops [g] | $u_{st(1)}$ [a] | $(t_{root(1)} + t_{root(3)}) / 2$ | $t_{sk(1)}$ [b] | — | — |
| Ley | $u_{st(1)}$ [a] | 15 June | 15 July | 15 August | 15 September |
| Catch crops | — | — | — | $t_{sk(1)} + 1$ [b] | 31 Dec. or $t_{cu}$ [d] |

[a] where $u_{st(1)}$ is the start of the plant uptake period

[b] where $t_{sk(1)}$ is the harvest date

[c] where $t_{s(1)}$ is the sowing date

[d] where $t_{cu}$ is the date for soil cultivation (e.g. ploughing)

[e] if $t_{root(4)}$ +30 occures after the 31 December, $t_{root(5)}$ is set to 31 December

[f] for the calendar year of sowing

[g] for the calendar year of harvest

### *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 microorganisms 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 12. Parameters related to water response functions for mineralisation and denitrification used in the SOILN model for the standard soil texure classes and for the specific soils in the database*

| Soil texture class for standard soils<br>----------------------------------------------<br>Soil texture class for soils in database | Soil id. in database | $\Delta\theta 1$ (%) | $\Delta\theta 2$ (%) | $xm$ | $e_s$ |
|---|---|---|---|---|---|
| Sand | | 3 | 32 | 1 | 0.6 |
| Loamy sand | | 4 | 27 | 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 |
| Silty clay loam | | 12 | 6 | 1 | 0.6 |
| Silty clay | | 11 | 5 | 1 | 0.6 |
| Clay | | 10 | 4 | 1 | 0.6 |
| Loamy sand | a | 6 | 13 | 1 | 0.6 |
| Loamy sand topsoil; sandy loam subsoil | b | 17 | 9 | 1 | 0.6 |
| Silty loam | c | 10 | 22 | 1 | 0.6 |
| Loam | d | 20 | 4 | 1 | 0.6 |
| Silty clay loam | e | 19 | 4 | 1 | 0.6 |
| Silty clay | f | 10 | 4 | 1 | 0.6 |
| Clay | g | 7 | 3 | 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 12). The empirical constant, $xm$, in the soil moisture function, was set to unity for all soils, reflecting a linear respons, 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 the 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, $\theta_d$ 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, $N_{\mathrm{faeces}}$, in the soil at manure application is simply given by:

$$N_{faeces} = c_{orgN}(m) * M \tag{15}$$

where $c_{\mathrm{orgN}}$ 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, $N_{\mathrm{amm}}$, is calculated as:

$$N_{amm} = c_{ammN}(m) * M * \left(1 - f_{sloss}(m, a, t)\right) \tag{16}$$

where $c_{\mathrm{ammN}}$ is the concentration of $NH_4$-N in the applied manure, and $f_{\mathrm{sloss}}$ 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 $f_{\mathrm{sloss}}$ used in SOILNDB (Table 2) were taken from Claesson and Steineck (1991). Table 1 show all parameter values for $c_{\mathrm{ammN}}$, $c_{\mathrm{orgN}}$ and C-N ratios used in SOILNDB.

Information about deposition of N presented in Table 13, was taken from the Swedish Environmental Protection Agency (1997), and in SOILNDB the deposition is set according to the region selected.

*Table 13*
*Deposition of N used in SOILNDB*

| County | Wet deposition ($mg\ l^{-1}$) | Dry deposition ($kg\ ha^{-1}\ year^{-1}$) |
|---|---|---|
| Stockholms län | 0.83 | 0.5 |
| Södermanlands län | 0.73 | 1 |
| Östergötlands län | 0.74 | 1.5 |
| Jönköpings län | 0.92 | 2 |
| Kronobergs län | 0.98 | 2.5 |
| Kalmar län | 1.09 | 2 |
| Blekinge län | 1.18 | 2 |
| Skåne län | 1.33 | 3 |
| Hallands län | 1.35 | 3 |
| Göteborgs och Bohus län | 1.14 | 3 |
| Älvsborgs län | 0.98 | 2 |
| Skaraborgs län | 0.82 | 1.5 |
| Värmlands län | 0.59 | 1.5 |
| Örebro län | 0.69 | 1 |
| Västmanlands län | 0.74 | 0.5 |
| Kopparbergs län | 0.55 | 0.5 |
| Gävleborgs län | 0.64 | 0.5 |

*Table 14*
*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)*

| Crop | Grain N content $c_{N1}$, $c_{N3}$ (%) | Residues/grain ratio $f_a$ (-) | N content in residues[a] $c_{N2}$ (%) | Water content for residues $wc_2$ (%) | Straw/grain ratio $f_b$ (-) | Root N/plant N ratio $f_r$ (-) |
|---|---|---|---|---|---|---|
| Spring wheat | 2 | 1.2 | 0.85 | 15 | 0.4 | 0.2 |
| Spring barley | 1.7 | 1.2 | 0.85 | 15 | 0.39 | 0.2 |
| Oats | 1.7 | 1.2 | 0.85 | 15 | 0.39 | 0.2 |
| Spring rape | 3.5 | 2 | 0.9 | 16 | 0.67 | 0.2 |
| Winter wheat | 1.9 | 1.3 | 0.85 | 15 | 0.35 | 0.2 |
| Rye | 1.7 | 1.5 | 0.7 | 15 | 0.5 | 0.2 |
| Winter rape | 3.5 | 2.5 | 0.9 | 16 | 0.83 | 0.2 |
| Potatoes | 0.35 | 0.5 | 0.78 | 80 | 0.17 | 0.13 |
| Sugar beet | 0.2 | 0.5 | 0.45 | 80 | 0.17 | 0.17 |
| Ley (25 % clover) | 2.5 | 2 | 2.5 | 0 | 0 | 0.2 |

[a] Given at the specified water content for residues, $wc_2$

### *Plant N uptake and root related parameters*

Crop N uptake and N removed as grain and straw at harvest are calculated from values of ‘target’ harvest yields, which is 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.

For spring crops, the target N uptake, $N_{totup}$, as a function of year, $y$, and crop type, $c$, is calculated as:

$$N_{totup}(y,c) = \frac{S_1(y,c)*c_{N1}(c) + f_a(c)*S_1(y,c)*c_{N2}(c)}{1-f_r(c)} \tag{17}$$

where $S_1$ is the target harvest yield (i.e. grain, seed or tuber), $c_{N1}$ is the nitrogen concentration in the harvested product while $c_{N2}$ 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 biomass, and $f_r$ is the fraction of N in roots of total plant N. The target harvest yield, $S_1$, is the only parameter in equation *10* specified by the user, the remaining parameters are all included in the SOILNDB database (Table 14). For spring crops, the uptake parameter, $u_{a1}$, which is an input parameter to SOILN, is estimated as:

$$u_{a1} = N_{totup} * \frac{1-e^{-u_{c1}*t_{UP}}}{1-\frac{N_{totup}}{u_{b1}}*e^{-u_{c1}*t_{UP}}} + u_{b1} \tag{18}$$

where $u_{b1}$ and $u_{c1}$ are coefficients in the plant uptake function (see Table 15) and $t_{UP}$ is the length of the uptake period, calculated simply by subtracting the start of the uptake period $u_{st(i)}$ from the time of harvest, $t_{sk(i)}$, or if no harvest take place, the end of the uptake period, $u_{et(i)}$. For catch crops, $u_{a1}$, is calculated similarly to equation 12, substituting the coefficients in the plant uptake function for spring crops with those for catch crops (i.e. $u_{b2}$ and $u_{c2}$; see Table 16).

*Table 15*
*Parameters associated to plant N uptake and development for all crops but ley*

| Crop | $u_{a3}$, $u_{aiL}$ (gN m$^{-2}$) | $u_{b1}$ (gN m$^{-2}$ yr $^{-1}$) | $u_{b3}$ (gN m$^{-2}$ yr $^{-1}$) | $u_{c1}$ (d$^{-1}$) | $u_{c3}$ (d$^{-1}$) | $u_{et}$ |
|---|---|---|---|---|---|---|
| Spring wheat | — | 0.4 | — | 0.07 | — | $t_{sk}$ |
| Spring barley | — | 0.4 | — | 0.09 | — | $t_{sk}$ |
| Oats | — | 0.4 | — | 0.08 | — | $t_{sk}$ |
| Spring rape | — | 0.05 | — | 0.09 | — | $t_{sk}$ |
| Winter wheat | 1.4 | 0.4 | 0.4 | 0.06 | 0.11 | 30 Dec. and $t_{sk}$[a] |
| Winter rye | 1.9 | 0.4 | 0.4 | 0.1 | 0.12 | 30 Dec. and $t_{sk}$[a] |
| Winter rape | 4.1 | 0.4 | 0.07 | 0.07 | 0.13 | 30 Dec. and $t_{sk}$[a] |
| Winter barley | 1.4 | 0.4 | 0.4 | 0.06 | 0.11 | 30 Dec. and $t_{sk}$[a] |
| Potatoes | — | 0.7 | — | 0.06 | — | $t_{sk}$ |
| Sugar beets | — | 0.4 | — | 0.05 | — | $t_{sk}$ |

[a] 30 December for the calender year when the winter crop is sown and $t_{sk}$ for the year of harvest

For winter crops, the target N uptake for the spring/summer, $N_{totup}$, which is assumed to start, $u_{st}$, on the 10th of April, is approximated as:

$$N_{totup}(y,c) = \frac{S_1(y,c) * c_{N1}(c) + f_a(c) * S_1(y,c) * c_{N2}(c)}{1 - f_r(c)} - (u_{a3} - u_{b3}) * f_{lr} \tag{19}$$

where $u_{a3} - u_{b3}$ represents the potential N uptake for the autumn period and $f_{lr}$ is a parameter regulating plant death during winter, currently set to unity, which signify that no plant death will occur. As shown in Table 15, the potential N uptake for the autumn period ($u_{a3} - u_{b3}$), is set to 1.0, 1.0, 1.5 and 3.7 gN m$^{-2}$ for winter wheat, winter barley, rye and winter rape, respectively. These are somewhat low compared to mean values of measured uptake from field experiments in Sweden; 1.1, 2.7, and 7.1 gN m$^{-2}$ for winter wheat, rye and winter rape, respectively (Torstensson et al., 1996). However, the variation in uptake was considerable (e.g. the measured range for the 10 rye samples was from 0.4 to 5.4 g N m$^{-2}$). By using somewhat low values for the potential autumn N uptake, the risk for attaining large deviations between actual and potential N uptake during the autumn will also be minimized, and as a consequence, the risk for attaining large deviations between simulated and target N harvest yields will probably be reduced. Equally to spring crops, the empirical N uptake parameter, $u_{a1}$, for winter crops for the spring/summer period is described by equation *11*. Values for the coefficients in the uptake function for the autumn period, $u_{c3}$, and for the stop date for uptake, $u_{et}$, are shown in Table 15.

For grass ley, the target N uptake is calculated as:

$$N_{totup}(y) = S_{L1}(y) * \frac{c_{N3}}{f_{harvL}} + S_{L2}(y) * \frac{c_{N3}}{f_{harvL}} + N_{L3up} \tag{20}$$

where $S_{L1}$ and $S_{L2}$ are the target harvest yields for the first and second harvests, respectively, $c_{N3}$ is the nitrogen concentration in the harvested ley (Table 14), $f_{harvL}$ (set to 0.5) is the fraction of N in harvest corresponding to the total N amount in the plant at harvest, and $N_{L3up}$

*Table 16*
*Plant N uptake and developement parameters for ley and catch crops*

| Number of harvests | $N_{L3up}$ (g m$^{-2}$ yr$^{-1}$) | $u_{\mathrm{b(i)L}}$, $u_{\mathrm{b2}}$ (g m$^{-2}$ yr$^{-1}$) | $u_{\mathrm{c1L}}$, $u_{\mathrm{c2}}$ (d$^{-1}$) | $u_{\mathrm{c2L}}$ (d$^{-1}$) | $u_{\mathrm{c3L}}$ (d$^{-1}$) | $f_{\mathrm{sL}}$ (—) | $f_{\mathrm{sL}}$[c] (—) |
|---|---|---|---|---|---|---|---|
| 0 | 30 | 0.3 | 0.05 | — | — | 0.1 | 0.6 |
| 1 | 15 | 0.3 | 0.1 | 0.06 | — | 0.1, 0.1[a] | 0.6 |
| 2 | 7 | 0.3 | 0.1 | 0.09 | 0.08 | 0.1, 0.1, 0.1[b] | 0.6 |
| Undersown ley, year 1 | 7 | 0.3 | — | 0.08 | — | 1 | 0.6 |
| Catch crops | — | 0.5 | — | 0.07 | — | 0.1 | — |

[a] first value for first harvest second value for end of uptake period
[b] first value for first harvest second value for second harvest and third value for end of uptake period
[c] for the uptake period before ploughing of ley

is the potential N uptake after the last harvest each year or if no harvest is specified. The potential N uptake, $N_{\mathrm{L3up}}$, was set to small values to ensure that target N yields, $N_{\mathrm{harvL}}$, could be reached for normal harvest yields (Table 16). The uptake parameter, $u_{\mathrm{a(i)L}}(\mathrm{y})$, corresponding to the period before harvest one and between harvest one and two (if two harvests are specified), is calculated as:

$$u_{a(i)L}(y) = S_{L(i)}(y) * \frac{c_{N3}}{f_{harvL}} * \frac{1 - e^{-u_{c(i)L} * t_{UP}}}{1 - \frac{N_{totup}}{u_{b(i)L}} * e^{-u_{c(i)L} * t_{UP}}} + u_{b(i)L} \tag{21}$$

where $S_{\mathrm{L(i)}}$ is the target ley yield, $u_{\mathrm{b(i)L}}$ and $u_{\mathrm{c(i)L}}$ are coefficients in the uptake function, and *i*, set to *1* or *2*, denotes the first and second harvest, respectively (Table 16). Plant uptake in spring, $u_{\mathrm{st}}$, is for established ley set to start on 5th April, while for undersown lay and catch crops to the day after harvest of the main crop, and the plant uptake period is set to end, $u_{\mathrm{et}}$, at 30 November for ley and undersown ley, and at 31 December for catch crops.

The C/N ratio for roots, $C/N_{\mathrm{root}}$ was set to 20 for all crops, which is slightly lower than the default value of 25. The parameter for compensatory uptake of N, $f_{\mathrm{umov}}$, was set to unity in SOILN (i.e. total compensation) to minimize the risk for obtaining large discrepancies between target and simulated N uptake. The fraction of available mineral N for plant uptake and immobilization, $f_{\mathrm{ma}}$, was set to 0.08 d$^{-1}$, which is equal to the default value used in SOILN.

*Description of parameters and algorithms associated with harvest*
For all crops except ley, the target N yield, $N_{\mathrm{harv}}$, is calculated as:

$$N_{harv}(y,c) = S_1(y,c) * c_{N1}(c) \tag{22}$$

if only the grain or equivalent is harvested. If above ground residues (i.e. straw, tops, stalks, etc.) are also harvested, the target N yield, $N_{\mathrm{harv}}$ is calculated as:

$$N_{harv}(y,c) = S_1(y,c) * c_{N1}(c) + f_b(c) * S_1(y,c) * c_{N2}(c) \tag{23}$$

where $f_{\mathrm{b}}$ is the ratio of harvested straw to grain biomass (Table 14). The target N yield of ley is calculated as:

$$N_{harvL}(y) = S_{L1}(y) * c_{N3} + S_{L2}(y) * c_{N3} \tag{24}$$

For all crops except ley, the harvested N fraction, $f_{\mathrm{harv}}$, which is an input parameter to the SOILN model, is simply given by:

$$f_{harv}(y,c) = \frac{N_{harv}(y,c)}{N_{totup}(y,c)} \tag{25}$$

As described previously, the corresponding parameter for ley, $f_{\mathrm{harvL}}$ is not calculated but assumed to be 0.5. For catch crops $f_{\mathrm{harvL}}$ is logically set to zero. The above ground residue fraction of plant N at harvest, $f_{\mathrm{s}}$, also an input parameter to SOILN, is calculated for all crops but ley according to:

$$f_s = 1 - f_{harv} - f_r - f_{reslr} \tag{26}$$

where $f_{\mathrm{reslr}}$ is the fraction of living root N remaining after harvest, currently set to zero for all crops. For ley and catch crops, the above ground residue fraction of plant N at harvest, $f_{\mathrm{sL}}$, is set as shown in Table 16.

The C/N ratio of above ground residues, $C/N_{\mathrm{hres}}$, which is an input parameter for the SOILN model, is given by:

$$C/N_{hres}(y,c) = \frac{C_{C2}}{\left(c_{N2}(c)\left(1 - wc_2(c)\right)\right)} \tag{27}$$

where $C_{\mathrm{C2}}$ is the carbon concentration in plant biomass (set to 0.5) and $wc_2$ is the water content in above ground residues (Table 14).

## 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, an output in tabular form covering yearly averages and whole-simulation averages displays some selected variables (N deposition and fertilisation, manure input as organic-N or as $NH_4$-N, N leaching, denitrification, target N yield, actual N yield, potential (target) plant N uptake, actual plant N uptake, and drainage water discharge). 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.

# References

Addiscott, T.M., Mirza, N.A., 1998. Modelling contaminant transport at catchment or regional scale. Agriculture, Ecosystems and Environment 67, 211-221.

Aronsson, H., Torstensson G., 1998. Measured and simulated availability and leaching of nitrogen associated with frequent use of catch crops. Soil Use and Management 14, 6-13.

Bengtsson A., Larsson, S., Magnét, B., 1991. Stråsäd, trindsäd, oljeväxter: sortval 1992. Report, Speciella skrifter 48, SLU, P.O. Box 7075, SE-75007 Uppsala, Sweden. (In Swedish). 36 pp.

Bergström, L., Johnsson, H., 1988. Simulated nitrogen dynamics and nitrate leaching in a perennial grass ley. Plant and Soil 105, 273-281.

Bergström, L, Jarvis, N.J., 1991. Prediction of nitrate leaching losses from arable land under different fertilization intensities using the SOIL-SOILN models. Soil Use and Management 7, 79-85.

Borg, G.Ch., Jansson, P.-E., 1988. Simulation of moisture and temperature conditions in a clay arable soil. In: Königsson, L.-K. (Ed.), Computers and computer modelling within Nordic geosciences. Striae, 30:00-00, Uppsala ISBN 91-7388-062-0. ISSN 0345-0074.

Borg, G.C., Jansson, P.-E., Lindén, B., 1990. Simulated and measured nitrogen conditions in a manured and fertilised soil. Plant and Soil 121, 251-267.

Brady, N.C., 1990. The nature and properties of soils. Tenth edition. Macmillan Publishing Company, New York, USA, 621 pp.

Brooks, R.H. & Corey, A.T., 1964. Hydraulic properties of porous media. Hydrology Paper no.3, Colorado State University, Fort Collins, Colorado, 27 pp.

Claesson, S., & Steineck, S., 1991. Plant nutrient management and the environment. Special report 41. SLU, P.O. Box 7070, SE-750 07 Uppsala, Sweden. 69 pp.

Haak, E., 1993. Skiftesanpassad gödsling och växtproduktion. Field-related fertilization and crop production. Internal Report, Department of Soil Sciences, Division of Plant Nutrition, SLU, P.O. Box 7072, SE-75007 Uppsala, Sweden. (In Swedish). 43 pp.

Håkanson, L., 1995. Optimal size of predictive models. Ecological Modelling 78, 195-204.

Hansson, A.-C., Pettersson, R., Paustian, K., 1987. Shoot and root production and nitrogen uptake in barley with and without nitrogen fertilization. Journal of Agronomy & Crop Science. 158, 163-171.

Heathwaite, A.L., 1993. Nitrogen cycling in surface waters and lakes. In: Burt, T.P., Heathwaite, A.L., Trudgill, S.T. (Eds.), Nitrate: Processes, Patterns and Management. John Wiley & Sons Ltd, England, pp. 99-140.

Hessel Tjell, K., Aronsson, H., Torstensson, G., Gustafson, A., Lindén, B., Stenberg, M., Rydberg, T., 1999. Mineralkvävedynamik och växtnäringsutlakning i handels- och stallgödslade odlingssystem med och utan fånggröda. Resultat från en grovmo i södra Halland, perioden 1990-1998. Ekohydrologi 50. Division of Water Quality Management, Department of Soil Sciences, SLU, P.O. Box 7072, SE-75007, Uppsala, Sweden. (In Swedish). 42 pp.

Hoffmann, M. 1999. Assessment of leaching loss estimates and gross load of nitrogen from arable land in Sweden. Doctoral Thesis, Agraria 168, SLU, P.O. Box 7072, SE-75007 Uppsala, Sweden. 36 pp.

Hoffmann, M., Johnsson, H., 1999a. Test of a modelling system for estimating N leaching – a pilot study in a small agricultural catchment. In: Hoffmann, M., Assessment of leaching loss estimates and gross load of nitrogen from arable land in Sweden. Doctoral Thesis, Agraria 168, SLU, P.O. Box 7072, SE-75007 Uppsala, Sweden. Paper V, 19 pp.

Hoffmann, M., Johnsson, H., 1999b. A method for assessing generalised nitrogen leaching estimates for agricultural land. Environmental Modeling and Assessment, 4, 35-44.

Hoffmann, M., Johnsson, H., Gustafson, A., Grimvall, A., 2000. Leaching of nitrogen in Swedish agriculture – a historical perspective. Agriculture, Ecosystems and Environment 80, 277-290.

Jansson, P.-E., 1991. Simulation model for soil water and heat conditions. Description of the SOIL model. Report 165, Department of Soil Sciences, Division of Biogeophysics, SLU, P.O. Box 7014, SE-75007, Uppsala, Sweden. 72 pp.

Jansson, P.-E., Gustafson, G., 1987. Simulation of surface runoff and pipe discharge from an agricultural soil in nothern Sweden. In: Gustafson, G., Water Discharge and Leaching of Nitrate. Ecohydrologi 22., Division of Water Quality Management, Department of Soil Sciences, SLU, P.O. Box 7072, SE-75007, Uppsala, Sweden. 16 pp.

Jansson, P.-E., Halldin, S., 1979. Model for annual water and energy flow in a layered soil. In: Halldin, S. (Ed.), Comparison of Forest Water and Energy Exchange Models, International Society for Ecological Modelling, Copenhagen. pp. 145-163.

Jansson, P.-E., Halldin, S., 1980. Soil water and heat model. Technical description. Swedish Coniferous Forest Project. Technical report 26. Department of Soil Sciences, Division of Biogeophysics, SLU, P.O. Box 7014, SE-75007, Uppsala, Sweden. 81 pp.

Johnsson, H., Hoffmann, M., 1996. Nitrate leaching simulations. In Rekolainen, S., Leek, R. (Eds.), Regionalisation of Erosion and Nitrogen Losses from Agricultural Land in Nordic Countries. Tema Nord 1996:615, Copenhagen, Denmark, pp. 18-24.

Johnsson, H., Hoffmann, M., 1998. Nitrogen leaching from agricultural land in Sweden – Standard rates and gross loads in 1985 and 1994. Ambio 27, 481-488.

Johnsson, H., Jansson, P.-E., 1991. Water balance and soil moisture dynamics of field plots with barley and grass ley. Journal of Hydrology 129, 149-173.

Johnsson, H., Bergström, L., Jansson, P.-E., Paustian, K., 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. Agriculture Ecosystems and Environment 18, 333-356.

Johnsson, H., Klemedtsson, L., Nilsson, Å., Svensson, B.H., 1991. Simulation of field scale denitrification from soils with grass ley and barley. Plant and Soil 18, 287-302.

Johnsson, H., Larsson, M.H., Mårtensson, K., Hoffmann, M., 2002. SOILNDB: a decision support tool for assessing nitrogen leaching losses from arable land. Environmental Modelling & Software 17, 505-517.

Lewan, E., 1993. Evaporation and discharge from arable land with cropped or bare soils during winter. Measurements and simulations. Agricultural and Forest Meteorology 64, 131-159.

Lewan, E., 1994. Effects of a catch crop on leaching of nitrogen from a sandy soil: simulations and measurements. Plant and Soil 166, 137-152.

Lindén, B., Nouno, S., 1983. Det atmosfäriska nedfallets och kvävemineraliseringens bidrag till grödornas N-försörjning (Contribution of atmospheric deposition and nitrogen mineralization to crop nitrogen supply). In: Eriksson T. (Ed.) Kväveprognos – lägesbeskrivning och inriktning framöver. Rep. No. 3, Redovisning av seminarium, Kungliga Skogs och Lantbruksakademien, Stockholm, Sweden. (In Swedish) p. 41-59.

Mattson, L., 1991. Effects of annual straw application on soils and crops. Report 180, Department of Soil Sciences, Division of Soil Fertility, SLU, P.O. Box 7014, SE-75007, Uppsala, Sweden.  pp.

Mattson, L., 1994. Kärna/halm-kvot – en metodikstudie Internal Report 1994-05-03, Department of Soil Sciences, Division of Soil Fertility, SLU, P.O. Box 7014, SE-75007, Uppsala, Sweden. (In Swedish) 4 pp.

Miller, R.D., Johnson, D.D., 1964. The effect of soil moisture tension on carbon dioxide evolution, nitrification, and nitrogen mineralization. Soil Science Society of America Proceedings 28, 644-647.

Monteith, J.L., 1965. Evaporation and the atmosphere. In: Fogg, G.E., (Ed.), The state and movement of water in living organisms. 19th Symposium, Society of Experimental Biology, The company of biologists, Cambridge, pp. 205-234.

Mualem, Y., 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resoursec Research 12, 513-522.

Myrbeck, Å., 1998. Swedish agricultural and horticultural crops. Report, PM Nr 1/98 KEMI. Swedish Inspectorate for Chemicals (Kemikalieinspektionen), P.O. Box 1384, SE-17127, Solna, Sweden. 44 pp.

O'riordan, T., Bentham, G., 1993. The politics of nitrate in the UK. In: Burt, T.P., Heathwaite, A.L., Trudgill, S.T. (Eds.), Nitrate: Processes, Patterns and Management. John Wiley & Sons Ltd, England, pp. 404-429.

Owens, N.J.P., 1993. Nitrate cycling in marine waters. In: Burt, T.P., Heathwaite, A.L., Trudgill, S.T. (Eds.), Nitrate: Processes, Patterns and Management. John Wiley & Sons Ltd, England, pp. 169-209.

Penman, H.L., 1953. The physical basis of irrigation control. In: Synge, P.M. (Ed.), Report of the 13th International Horticultural Congress, 1952, The Royal Horticultural Society, London. Volume II, 913-924.

Rawls, W.J., Brakensiek, D.L., Saxton, K.E., 1982. Estimation of soil water properties. Transactions of the ASAE. 1316-1320.

Stanford, G., Epstein, E., 1974. Nitrogen mineralization-water relations in soil. Soil Science Society of America Proceedings 38, 103-107.

Steineck, S., Gustafson, G., Andersson, A., Tersmeden, M., Bergström, J., 1999. Animal manure – content of nutrients and trace elements. Rapport 4974. Naturvårdsverket, SE-106 48 Stockholm, Sweden. (In Swedish with English summary) 28 pp.

Swedish Environmental Protection Agency, 1997. Källor till kväveutsläpp: underlagsrapport. Rapport 4736. Naturvårdsverket, SE-106 48 Stockholm, Sweden. (In Swedish) 132 pp.

Torstensson, G., Johnsson., H., 1996. Simulation of water and nirogen dynamics in a five year leaching experiment with varying fertilisation and manure treatments. Report 29. Department of Soil Sciences, SLU, P.O. Box 7014, SE-75007, Uppsala, Sweden. 62 pp.

Torstensson, G., Aronsson, H., Lindén, B., 1996. Winter crops as green cover crops - nirogen uptake capacity and effects on nitrogen leaching. Technical Report 22., Division of Water Quality Management, Department of Soil Sciences, SLU, P.O. Box 7072, SE-75007, Uppsala, Sweden. 7 pp.

# APPENDIX I

*Table A1*
*Selections used in SOILNDB for the technical switches in the SOIL model*

| | | | | | |
|---|---|---|---|---|---|
| ADDSIM | OFF | AVERAGED | ON | AVERAGEG | ON |
| AVERAGET | ON | AVERAGEX | ON | CHAPAR | ON |
| DDAILY | ON | DRIVPG | 1 | INSTATE | OFF |
| LISALLV | ON | OUTFORN | OFF | OUTSTATE | OFF |
| VALIDPG | OFF | VISALLOUT | OFF | | |

*Table A2*
*Selections used in SOILNDB for the model specific switches in the SOIL model*

| | | | | | |
|---|---|---|---|---|---|
| ATIRRIG | OFF | CRACK | OFF | EVAPOTR | 3 |
| FRINTERA | ON | FRLIMINF | 1 | FRLIMUF | ON |
| FRLOADP | ON | FRPREFL | OFF | FRSWELL | OFF |
| GWFLOW | OFF | HEATEQ | ON | HEATPUMP | 0 |
| HEATWF | ON | INHEAT | OFF | INTERCEPT | ON |
| INWATER | 1 | PLANTDEV | OFF | ROOTDIST | 3 |
| ROUGHNESS | 0 | RSCALC | 0 | SALT | OFF |
| SNOW | ON | SUREBAL | 0 | UNITG | ON |
| WATEREQ | ON | WUPTAKE | 2 | | |

*Table A3*
*Selections used in SOILNDB for the technical switches in the SOILN model*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ADDSIM | OFF | AVERAGED | ON | AVERAGEG | ON | AVERAGET | ON |
| AVERAGEX | ON | CHAPAR | ON | DRIVPG | ON | INSTATE | ON |
| LISALLV | ON | OUTFORN | OFF | OUTSTATE | OFF | VALIDPG | OFF |

*Table A4*
*Selections used in SOILNDB for the model specific switches in the SOILN model*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DENDIST | 0 | DRIVCROP | 0 | DRIVEXT | 0 | DRIVMANA | 0 |
| GROWTH | OFF | GWFLOW | OFF | MANURE | ON | ROOTDIST | 3 |
| SPECIAL | OFF | TEMPR | ON | | | | |