Swedish University of Agricultural Sciences
Department of Soil and Environment

# Water balance and nitrate leaching from arable land in a changed climate
## – A model study

Therése Nanos

Degree project in Soil Science
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Institutionen för mark och miljö, SLU
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# Abstract

This thesis aims to present the essential background on how to perform climate change impact assessments, and to present the results from a climate impact assessment on water balance and nitrate leaching for an arable Swedish soil. The soil is a sandy soil in south-western Sweden, grown with spring cereals. This study is meant to be a benchmark example, and cannot be seen as a regional or national assessment for Sweden, rather as an approach to present and analyze the most important parts of these kinds of assessments.

A dynamical simulation model (COUP, Jansson and Karlberg, 2004) was used for this study. The model was parameterized and calibrated against data from an experimental site, located in Mellby in Hallands county, south western Sweden. Measurements were carried out between 1st of April 1988 and 1st of April 1991. The data set consists of daily standard weather data and discharge, data on soil water content, soil nitrogen and nitrogen contents in drainage water from to experimental fields grown with spring cereals. The model was calibrated against the 4-year data set based on a GLUE-procedure in which a number of "acceptable parameter sets" were identified. One of these parameter sets were randomly chosen for the climate impact model runs performed in this study. The driving data for the model are 30-year climate data, including data for precipitation, temperature, solar radiation, relative humidity and wind speed, which enables long-term simulations of water and nitrogen flows. Three different simulations were performed, one for present climate as a reference scenario with climate data from 1971-2000, and two different emission scenarios representing year 2071-2100. The driving data were constructed by the delta-change method, which is a common way of interfacing regional climate model output with impact models.

Results show that, for both scenarios, that nitrate leaching will increase with 41 % and 66 % respectively. This is mainly due to increased winter temperatures (increasing nitrogen mineralization with 22 % and 32 % respectively) and increased drainage (20 % and 33 % respectively) during the period when the soil is left bare.

It is important to remember that the study includes many generalizations, both in parameterization and in driving data. Despite that, the approach with a dynamical model driven with long-term climate data is a very robust and valuable way of making such assessments. Further studies need to consider crop growth characteristics and crop parameterization to be able to simulate growth of other varieties more suitable in a changed climate. Ensemble modeling can also be an approach to reduce biases in the modeling chain.


*Key words:* climate change, water balance, nitrate leaching, crop growth

# Sammanfattning

Syftet med den här studien är att presentera bakgrunden till hur klimatförändringarnas potentiella effekter på mark-växt-systemet kan uppskattas, samt resultat från en modellstudie av klimatförändringens effekter på vattenbalans och nitratutlakning från en svensk jordbruksmark odlad med vårkorn.. Denna studie syftar till att vara ett exempel, och det är inte inom studiens ramar att fungera som ett regionalt eller nationellt underlag för hur nitratutlakningen in Sverige påverkas av ett föränderligt klimat.

En dynamisk simuleringsmodell (COUP, Jansson och Karlberg, 2004), har använts i studien. Modellen är parameteriserad och kalibrerad mot data från ett fyra-årigt försök vid mätstationen i Mellby, Hallands län, sydvästra Sverige. Ett antal acceptabla parameter-set identifierades baserat på GLUE-metoden och ett av dessa valdes slumpmässigt ut för denna studie.

Drivdata till modellen är 30-åriga klimatdata, innehållande daglig information om nederbörd, temperatur, sol instrålning, relativ fuktighet och vindhastighet. Dessa data möjliggör långtids simuleringar av vatten och kväveflöden i marken med daglig utdata. Tre scenarier användes för att studera klimatförändringens effekter, ett referens scenario som motsvarar dagens klimat mellan 1971-2000, samt två olika klimatscenarier som motsvarar åren 2071-2100. Drivdata-seten konstruerades med hjälp av den så kallade ”delta-change” -metoden, vilket är en metod för att transformera utdata från regionala klimatmodeller (RCM) till drivdata för platsspecifika modeller.

Resultaten visar ökat läckage av nitratkväve för båda klimatscenarierna (41 % och 66 % från års medelvärde). Detta berodde huvudsakligen på ökad nederbörd samt ökat temperatur under vinterhalvåret, då marken är obevuxen. Netto mineraliseringen ökade med 22 % och 32 % respektive, och dräneringen genom markprofilen med 20 % och 33 % för respektive scenario. Tidigare skördetidpunkter bidrog också till ökat kväve-läckage på grund av att perioden av obevuxen mark förlängs.

Det är viktigt att komma ihåg att denna studie innehåller vissa generaliseringar, och att parameteriseringen representerar en av flera möjliga. Modellexemplet visar dock på ett möjligt tillvägagångsätt för att uppskatta potentiella effekter av klimatförändringen. Fortsatt forskning bör fokusera på växtspecifika egenskaper och parameterisering av grödan, för att undvika resultat som påverkas av för tidig mognad av grödan i ett varmare klimat. Det kan också vara lämpligt att göra så kallade ensemble-simuleringar, där utdata från flera RCM används för att driva en modell för vatten och kväveflöden i mark.

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# 1 Introduction and aim

Climate change, will affect the hydrological cycle, on both global and regional scale. Precipitation patterns will change and some areas will experience more rain, some areas will experience less. The Nordic regions will experience more rain, and generally higher increases than rest of the global mean (Andréassen, et al, 2004) Temperature increases will lead to more evaporative demand, and more transpiration affecting crop growth and soil moisture (IPCC Technical Paper, IV, 2008).

Predictions of climate change impacts on the hydrological cycle are uncertain. Different global scenarios have different outcomes, and different climate models, global and regional give different results (Andréassen et al., 2004). The study of hydrological impacts of climate change is most important, firstly when dealing with agriculture and food sustainability, but also when dealing with environmental issues, such as nitrogen leaching and eutrophication.

Nitrogen moves with the water in the soil, since it is a non-sorbing solute (Burt et al., 1993). The way climate change will alter the hydrology of an agricultural soil, will also affect the potential nitrogen leaching from that soil. Nitrogen leaching is one of the reasons for causing eutrophication of the Baltic Sea (Arheimer et al., 2005). Nitrate from agricultural soils contribute to the nitrate found in natural waters (Kirchmann et al., 2002), and the total leaching of nitrate nitrogen from agricultural soils to waters such as groundwater, watercourses and lakes, has been estimated to 43 000 tonnes N/ year, which correspond to approximately 15 kg N/ha/year (Kirchmann et al., 2002). However, leaching of nitrogen varies a lot both in time and space due to climatic factors, but also due to soil characteristics and agricultural measures (Johnsson and Mårtensson, 2002)

The aim with this thesis is to:

1. To present the essential background and components included in impact assessments of how climate change might affect water balance and nitrogen losses

from a Swedish arable soil. This will be presented in the part “Literature review”.

2. To perform a model study of the potential impacts of climate change on water balance and nitrogen leaching from a Swedish agricultural soil, grown with spring cereals.

A dynamical model for water, nitrogen and heat flows in soil-plant-systems (COUP, Jansson and Karlberg, 2004) was used for the climate impact assessment. The model was parameterized based on a 4-year field experiment. Long-term simulations of water and nitrogen flows was then performed with 30-year climate data series as input, both for present climate and two different climate scenarios. The scenario data was derived based on regional climate projections made at the Rossby Centre (Swedish Matereological and Hydrological Institute, SMHI).

It should be emphasized that this is not an attempt to make a regional or national assessment of climate change impacts on nitrogen leaching for Sweden. That was beyond the scope of this thesis. This thesis presents essential background perspectives for making assessments of climate change impacts on water balance and nitrogen leaching from arable systems. In addition it includes a bench-mark example on how such assessments could be performed with respect to a typical arable soil, where leaching is already potentially high, and finally, the results are interpreted and discussed.

Key questions to be answered and considered:

- What are the major impacts of the potential future changes in precipitation and temperature on the average annual water balance of a typical agricultural soil in southern Sweden?
- What are the climate change impacts on the average annual nitrogen balance?
- Will nitrogen leaching increase or decrease in the future climate scenarios, according to the results?
- How will crop growth and length of the growing season be affected?

# 2 Literature review

## 2.1 Nitrogen turnover in arable soils

Nitrogen is essential for all living organisms. For agriculture, nitrogen together with phosphorous and potassium, are the most common species to fertilize with to sustain good crop production. Nitrate is very mobile in soil due to the fact that it is an anion, not attracted to negatively charged clay particles, and the amount of ammonium leached from soil is more or less negligible (Eriksson et al., 2005). Nitrate leaching from agricultural soils can reach substantial levels in humid climates, where precipitations is high and evaporation low, especially if the soil is light textured (Aronsson, 2000).

If nitrate reaches the groundwater, it might impose a health threat to humans drinking the water, and there is legislation under both the Nitrate directive, but also the Drinking Water Directive, that the maximum permissible concentration of nitrate in drinking water is 50 mg $NO_3$/l. For surface waters and aquifers in agricultural areas, this concentration is often exceeded (Kirchmann, et al., 2002)

In most soils, nitrogen is present in organic forms, thereby inaccessible for plants. Organic forms of nitrogen are made up by several types of compounds and are derived from roots, microfauna, leaf litter and so on. The inorganic forms of nitrogen in soil are mostly present as ammonium, $NH_4^+$ or nitrate, $NO_3^-$ (Burth et al., 1993).

Nitrification is dependent on aerobic conditions, and under anaerobic conditions nitrate is reduced into nitrogen gas, $N_2$, or in worst cases $N_2O$ which is a strong greenhouse gas contributing to climate change, although most of the nitrogen leave the soil as $N_2$. Nitrogen can also leave the soil system as volatized ammonium gas, usually from recently applied slurry or manure (Burth et al., 1993).

### 2.1.1 Nitrate leaching from arable soils – factors influencing the losses

As mentioned earlier, nitrate is most mobile in soils due to its negative charge and it moves readily with water flow. When reaching the environment, nitrate can have ecosystems effects and health effects on humans. Foremost, losses of nitrogen from agricultural soils, are always negative in a nutrient cycling perspective.

Nitrogen leaching from arable land is said to be a diffuse source of nitrogen (in contrast to a point source, such as a sewage treatment plant) and might therefore be difficult to measure (Johnsson and Mårtensson, 2002). Other sources of nitrogen to natural waters are, as mentioned earlier, point source emissions, atmospheric deposition and biochemical removal processes (Arheimer et al., 2005). All the sources of nitrogen, except from point source emissions, are affected by the weather conditions, such as temperature and precipitation, and might therefore be affected by climate change (Arheimer et al., 2005). Nitrate have always been leaching out of soils, but in pristine conditions before agriculture was industrialized, there were many spots in the landscape acting as natural retention spots for nitrate, as lakes, wetlands and mires. These where effectively transformed into agricultural fields, and the excessive nitrate started to leach into the surrounding lakes and oceans instead, contributing to eutrophication, altering natural habitats (Miljömålsportalen, 2010).

The amount of nitrate that is leached out from an agricultural soil is dependent on abiotic factors such as soil type characteristics, soil water content and precipitation patterns. Nitrate movement in a field is a very complex system, but one can see that the rate of flow is higher in a sandy soil versus a clay soil. But the effect of soil structure is also important, and variations in pore size, pore size distribution and their spatial distribution all contribute to the irregular movement of water and therefore also nitrate. To be able to do model studies of nitrate movement in soil, one must be aware of both diffusion and dispersion processes in the particular soil type (Burth et al 1993).

As mentioned earlier most of the nitrogen in the soil is stored in organic forms, bound in organic matter or in microorganisms, and when mineralization occurs, this is only 1-2 % of the total organic nitrogen pool in the soil. This corresponds to 20-120 kg/ha which can be compared to the amount of inorganic fertilizer that is applied in Sweden, 80 kg N/ha (Kirchmann et al., 2002). During spring and summer, the mineralization of organic nitrogen is well coincided with crop growth, but the problem with nitrate leaching might occur during autumn or winter, when there is no crop to take up the mineralized nitrate ions, which are easily leached out of the soil profile (Kirchmann et al., 2002). Leaching also occurs mainly because of climatic conditions, especially in autumn and winter seasons when the climate is humid and precipitation exceeds evaporation and there is a downward movement in the soil profile (Stenberg, 1999). Management practices in agriculture have been very efficient in reducing the amount of nitrate that is leached from the soil profile. Amongst them, there are practices such as sowing catch crops during winter, which can be after sown or under sown into the main crop. This keeps the soil covered with growing vegetation which is an efficient way of reducing nitrate leaching (Lewan, 1993: Lewan 1994). Reduced tillage, no autumn tillage and right dose of fertilizer application are also good ways of reducing nitrate leaching from arable soils (Aronsson, 2000). Lysimeter experiments have shown that sandy soils leach more nitrate than clay soils, and that arable soils leach more nitrate than grasslands (Burth et al., 1993).

## 2.2 Climate change

### 2.2.1 Climate change – causes and trends

Emissions of greenhouse gases, such as $CO_2$ from burning of fossil fuels, has led to climate change. The total emissions of greenhouse gases from human activities have increased since preindustrial times. Between 1970 and 2004 the amount of $CO_2$ in the atmosphere increased with 70 %. $CO_2$ is the most important greenhouse gas, but also methane ($CH_4$) and nitrogen oxides ($N_2O$) are great contributors to the enhanced greenhouse effect (IPCC 2007). The relative importance of man´s contribution to climate change is still a matter of discussion. One argument against human induced climate change is that the change in temperature and rainfall patterns that we see today is just a result of natural variations. But according to the IPCC[1] the concentrations of $CO_2$ and $CH_4$ in the atmosphere during 2005 was much higher than the natural variation during the last 650 000 years (IPCC 2007.) The increased concentrations of $CO_2$ in the atmosphere are most certainly due to the burning of fossil fuels, whilst change in land use is of importance but not as relevant. For methane, it is most probable that the observed increase in concentration is due to agriculture, and the burning of fossil fuels. For $N_2O$ agriculture is said to be the biggest contributor (IPCC 2007).

[1] Intergovernmental Panel on Climate Change – intergovernmental body that reviews and assesses the recent scientific results about human induced climate change.

There are empirical results from all continents and most of the oceans that show that many natural systems are affected by regional climatic changes especially increase in temperature. Increased temperature might very likely affect many biological and physical systems, such that the patterns of wind, temperature and ocean levels are affected (IPCC 2007).

Even though the global humanity succeed in reducing the greenhouse gases from today, there are evidence of  that the impacts of climate change, such as rise of the sea level, will continue for over hundreds of years because of emissions already made(IPCC 2007).

### 2.2.2 Emission scenarios

When modeling the future climate under change, there are large uncertainties, and the future socio-economic development is hard to predict. Will there be even more increases in greenhouse gases, will they stabilize or decrease? Such questions very much depend on the socio-economic development in the world. Therefore, IPCC derived different emission scenarios in their report Special Report on Emission Scenarios in 2000 (Nakicenovic and Swart, 2000). Each scenario is based on a "storyline", which describes the way the world would look with different socio-economic developments. The storylines were grouped into four families, and each family can be divided into one or several so called marker scenarios (Arnell, 2004). The four families are according to Arnell 2004:

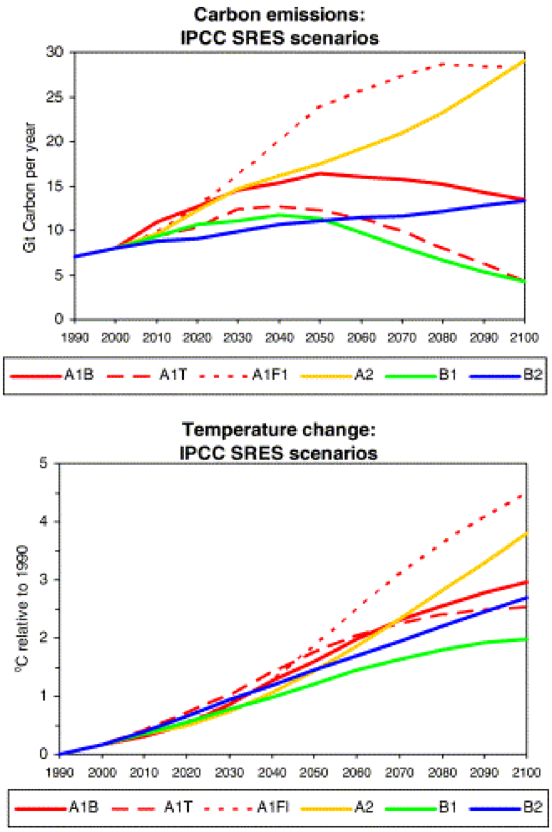
A1: In this scenario the world has a rapid economic and population growth and increased globalization. The world is market oriented, and the differences in income per capita over the world have smoothened out. There is a rapid technological growth. There are three different marker scenarios within this family: A1F1 is fossil intensive, A1T non fossil fuels and A1B where there is a balance across all sources.

B1: The B1 family has the same rapid population growth, but development is more sustainable and environmentally friendly. New clean and efficient technologies are introduced, and the emphasis is on global solutions, and the world strives against more sustainability.

A2: The world is heterogeneous, market-oriented, but with less rapid growth than A1. The population growth is though faster than A1. The underlying theme in the world is self-interest and to preserve local identities.

B2: Faster population growth than A1 and B1, but slower than A2. The development follows environmentally stable pathways, both economically and socially.

Figure 1 shows the carbon emissions and the respective temperature change within the different emission scenarios (Arnell, 2004). It is obvious that AIF1 has the highest carbon emissions and the highest temperature increase, whilst A1T and B1 seem to have decreasing carbon emissions over time, but still scenario B1 predicts the lowest temperature increases, due to its sustainable development.




Figur 1. Global carbon emissions and average annual temperatures for each of the scenarios. Used with permission from Elsevier. From Arnell, 2004.

## 2.3 Modeling the future climate: global, regional and local modeling

The climate is a complex system, and understanding it is of great scientific interest (Harvey et al., 1997). Climate modeling has evolved much the last decades due to the urgency of climate change, and the need for information about future hydrological impacts (Harvey et al., 1997). There is a great need for making hydrological impact studies on a relatively small spatial scale, such as local modeling predictions of, for example hydrology in a field, and there might be problems when taking model output from the General Circulation Models (GCM), into models representing smaller spatial scales (Räisänen 2003). The predictions of the climate are uncertain, which lies in their nature since they are dealing with the future. The global scenarios are providing several outcomes for the climate, and it has also been shown that the choice of for interfacing climate and hydrological models has an influence on the results (Andréasson et al, 2004). In this section, major types of models used for describing the future climate will be presented, as well as their use within the Swedish Regional Climate Modeling Programme (SWECLIM Rossby Centre), including the difficult, but most important task of interfacing global models and regional/local impact models.

### 2.3.1 Brief description of the model hierarchy and Swedish regional modeling

Global models for atmospheric and oceanic components of the climate system can be divided into three groups, one-, two and three dimensional models, where the three dimensional models are the most complex atmosphere and ocean models. They are generally called AGCM (Atmospheric general circulation model) and OGCM (Ocean general circulation model). These models divide the atmosphere and the ocean into a three dimensional horizontal grid, and the grid cell horizontal resolution is approximately 100-250 km (Harvey et al., 1997: Teutschbein and Seibert 2010). These models can directly do simulations on the characteristics of the atmosphere and the oceans, such as winds, ocean currents and many more variables. To get an even more complex model, AGCMs and OGCMs can be coupled into one model, AOGCM with information about the state of the atmosphere and ocean, and it can compute fluxes of heat, moisture and momentum between the atmosphere and the ocean (Harvey et al., 1997). An AOGCM simulates radation processesr in the atmosphere, snow and sea ice, transport of heat and water between the atmosphere and the ocean, as well as the uptake of heat by the ocean, which leads to the sea level rise by the swelling of water as it warms. An AOGCM also computes feedback processes in the climate system, which is of importance when dealing with the climatic systems sensitivity (Harvey et al., 1997). But, a lot of the processes are parameterized to some extent, and some parameterizations include some constants which are derived from the current climate. A GCM tries to describe the whole climate system, and to represent all the complex processes, which means that the processes themselves might be simplified and not very detailed. The simpler one- and two-dimensional models are describing processes more in detail (Harvey at al., 1997).

Due to the global models grid coarseness, there became a need for more detailed, high resolution models, that could describe the climate system on for instance, catchment scales, and the regional models came about. The principle behind an RCM is the concept of "downscaling". Downscaling means that you obtain regional or local details from numerical simulations with low resolution, such as a GCM (Rummukainen, 2010). There are different ways of downscaling, but the most common way is the so called dynamical downscaling where a RCM is driven with coarse-grid GCM output as initial and lateral[2] boundary conditions (Teutschbein and Seibert, 2010). The basic boundary conditions are temperature, moisture, winds as well as sea surface temperature and ice (Rummukainen 2010).

A regional climate model has a resolution of typically 20-50 km (Räisänen et al., 2004). There are different ways of creating a regional climate model (RCM). One way is to adapt a GCM into a so called Limited Area Model, LAM. Another way is to take one LAM, derived for another purpose, such as weather forecasting, and make it into a climate model simulating the future climate (Rummukainen et al., 2004).

The Swedish Regional Climate Modeling, SWECLIM, was a 6.5 year research effort carried out by the Swedish Meteorological and Hydrological Institute (SMHI), Stockholm University and Göteborg University. SWECLIM developed regional models, and chose to take an already existing Limited Area Model (LAM) and made it into the Rossby Centre[3] Regional Atmosphere Model (RCA) and the three-dimensional Rossby Centre Regional Ocean Model (RCO). These two models where in the end coupled into the Rossby Centre Atmosphere Ocean Model (RCAO) (Rummukainen et al., 2004). The resolution of these models are typically 50x50 km (for each grid cell), and they are run with historical time series (1961-1990), present time series, and future time series, such as 2011-2040 or 2071-2100 (SMHI, 2011, 1).

### 2.3.2 Regional climate model output for impact modeling

Traditionally, GCM model output have been used in local impact models, such as hydrological models or models which include some type of soil water flow. The downscaling method most commonly used was the statistical downscaling, where

[2] Lateral boundary condition: Information being computed needs input from the neighborhood. At the boundaries in the regional domain, data is needed from the domain outside (Rummukainen et al., 2004).

[3] The Rossby Centre is the research unit at SMHI that conducts research on climate change. The centre is also responsible for the regional climate models that are used for the purpose (SMHI, 2011)

statistical relationships between large-scale climate variables and regional information are the basis. The use of RCM data for impact modeling is quite new but becoming more and more common. There are many advantages of using RCM outputs, but also many challenges due to the considerable biases in the RCMs. (Teutschbein and Seibert, 2010). RCMs have as mentioned earlier, a resolution of 20-50km (Räisänen et al, 2004). They can include components such as surface and subsurface runoff, but on the catchment scale, their output is rarely applicable, and because of that, the hydrological variables from RCMs are not used directly in impact models. Rather, their information, like precipitation and temperature, are used to drive hydrological impact models to make simulations of, for instance, runoff (Teutschbein and Seibert, 2010).

As Teutschbein and Seibert (2010) notices, there is no "common practice" on how to use information from RCM outputs in impact modeling. They highlight the need for using both bias-correction methods as well as a multi-model approach, where several RCM:s are used to generate the information needed to run an impact model (Teutschbein and Seibert, 2010). This procedure, where output from 10-15 RCM:s are used to drive an impact model, are named ensemble modeling (SMHI, 2011, 2).

The two most common ways to use data from a RCM in a hydrological impact model is the Delta change approach and the bias correction method, where the delta-change approach has until recently been the most common way of interfacing RCM output with impact models (Graham et al., 2007)

*The Delta - Change approach*

In the delta-change approach, there is not a direct use of the RCM output. Instead the differences between the RCM control simulation and scenario simulation (the Δ) are added to an observed time series of climate variables. For example, a monthly average difference of +2°C in January between the control and the scenario runs are added to an observed time series of temperature at the site of interest (Graham et al., 2007). If the time series has daily output during a year, and the RCM gives monthly outputs, the "delta-change-values" can be interpolated between months, so that the change in temperature becomes more smooth. Temperature and solar radiation can be added as total numbers, whilst precipitation has to be added in percentage (Steffens, 2010). With the delta change approach, the scenario simulations will then have the same number of rainy days as the observed time series, so the temporal patterns of the climate variables will not change in the scenario simulations (Teutschbein and Seibert, 2010). The method does not account for any changes in extremes, which remain the same as in the present climate (Graham et al., 2007)'

*Bias correction method*

The most typical biases in outputs from a RCM are such as too many wet days with low-intensity rain, or incorrect estimations of temperature extremes (Teutschbein and Seibert, 2010). Biases in the RCM output may contribute to unrealistic results in impact modeling, and this is why different methods for bias correction are necessary. The term "bias correction" actually means a scaling of climate model output in order to account for the systematic errors in the climate model (Teutschbein and Seibert 2010). The main principle is that the biases between climate time series and observations of the climate are identified and then used to correct both scenario and control runs (Teutschbein and Seibert, 2011). There are different methods for correcting RCM output information to a hydrological model. For precipitation a threshold limit can be used, so that e.g. all days with precipitation less than 0,1 mm are defined as dry days (i.e. P=0). For more information about the different ways of applying bias correction, see Teutschbein and Seibert, 2010. Figure 2 illustrates the modeling scheme from GCM to impact models, and especially the delta-change method.

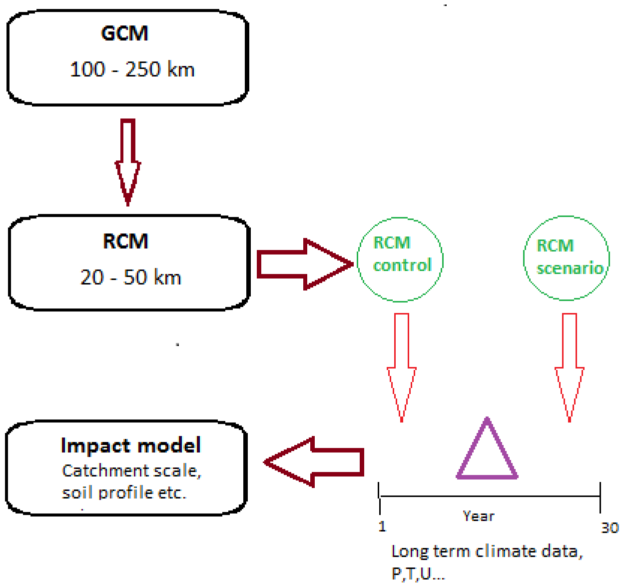



Figure 2. Illustration of the modeling scheme from GCM to Impact models. The figure illustrates the delta change method. Based on Teutschbein and Seibert, 2010.

## 2.4 Earlier studies on climate change and nitrogen leaching

*Eckersten et al., (2001)* studied possible consequences of climate change on carbon and nitrogen budgets of winter wheat, by the means of model predictions. Simulations of biomass, nitrogen and carbon, water and heat where carried out in long-term climatic conditions and on a sandy soil and a clay soil located in central Sweden (Uppsala), as well as a clay soil located in southern Sweden (Halmstad). The effects of elevated $CO_2$ concentrations and by that changed climatic conditions in 2050 where simulated with the coupled models SOIL/SOILN. The climate scenario was derived directly from a global climate model, HadCM2 global climate model. The results from applying the SOIL/SOILN models with the future climate scenarios for Uppsala showed that the winter wheat production was predicted to increase by 10-20 %, depending on soil type. Soil evaporation increased from both soil types, and evapotranspiration increase was predicted to be around 7-8 %. Drainage of water increased for the clay soil, but remained almost unchanged for the sandy soil. This was explained by the fact that the sandy soil experienced more surface runoff in the absence of a snow pack. The absence of a snow pack resulted in more frequent freezing of the soil. Nitrogen leaching was predicted to increase in both soil types with 17 % for the clay soil and 18 % for the sandy soil. The conclusions where that, on a ground surface basis, the load of N and C to the atmosphere and the surrounding ecosystems will increase during climate change. But, at the same time, the amount of harvested grain will increase, which will compensate for the increased load of nutrients. This means that, nitrogen leaching per unit harvested C will decrease on both of the clay soils, but for the sandy soil nitrogen leaching will increase, despite the increased harvest of grain (Eckersten et al., 2001).

*Ulén and Johansson (2009)* studied long-term nutrient leaching from a Swedish arable soil with intensified crop production against the background of climate change. This aim was to identify possible trends and impacts of the climate based on the long-term data series. The study period was present climate, 1973-2005, and analysis were made to see if the climate had changed significantly under this period, and which effect it might have had on nutrient losses. Both measurements and simulations were carried out. During the study period, temperature was estimated to have increased significantly with + 2˚C in the growing season (April-September). Both precipitation (+16 mm) and humidity (+ 11 %) had also increased significantly during the study period, and the greatest change was visible in the month of June. Simulations with the coupled N-database model, SOILN-

DB, showed that N-mineralization rates had increased with +2 kg/ha/year, and also N-leaching to drainage pipes had increased with 0.06 kg/ha/year due to climate changes. There where although results that showed that altered management practices, such as spring tillage instead of autumn tillage, might reduce the effects of climate change on nitrogen leaching (Ulén and Johansson, 2009).

*Patil et al.( 2010)* studied the effect of climate change, increased soil temperature and varying precipitation patterns on nitrogen cycling with the help of an open field lysimeter experiment. The experiment was carried out during one year for a loamy sand in Denmark. Three factors were studied; number of rainy days, rainfall amount and soil temperature. The reference treatment was based on climate data from 1961-1990. When studying the effect on nitrogen cycling with respect to the number of rainy days, the average number of rainy days from 1961 until 1990 was taken from the reference period, and for the future treatment this number was reduced with 50 %. This was done to mimic the effect of less rainfall events and longer drought seasons that are predicted to occur in that area during climate change. The reference treatment was given an average annual precipitation amount of 627 mm and the future treatment 658 mm of average annual precipitation (based on IPCC scenario A2). Soil warming was achieved by warming plots 5˚C more than reference plots. All plots were sown with winter wheat. The treatments showed that, when the soil was heated, the crop production was increased, with increased above-ground biomass and nitrogen uptake, but the growing season was shortened with 12 days. Rainfall amount treatment and rainy days treatment increased drainage with 46 % respective 10 %, but in contrast to that, the soil warming increased evapotranspiration with 18 % and therefore reduced drainage with 41 %. Future rainfall amount projections increased $NO_3$-N leaching with 289 %. The heated plots showed reduced $NO_3$-N leaching amounts, both with increased rainfall amounts and present rainfall amounts. Soil warming resulted in more available nitrate in the soil for crop growth, but also left more nitrate in the soil after harvest that might impose a risk for leaching during autumn/winter seasons (Patil et al., 2010).

*Thomsen et al. (2010)* studied the effect of increased temperatures on crop growth during winter and autumn seasons when the light intensity is low. The study tested if a catch crop of ryegrass or winter wheat could take up the extra mineralized nitrogen during autumn and winter, both in present climate and future climate. The study took place in growth chambers, where the crops where grown in pots with three different temperature treatments, current average temperature, and current average temperature +4 ˚C and +8 ˚C. The study showed that even though mineralization rates increases with higher temperatures, this was prevented by more intense crop growth and thereby crop uptake of mineral nitrogen, despite the low light intensities. However, it was important to sow the crops sufficiently early in autumn, for the crops to be able to take up the possible mineralized nitrogen, and this might be, according to the authors, contradictory to the projected need of sowing crops later in the season because of climate change (Thomsen et al., 2010).

*Arheimer et al., (2005)* studied nitrate leaching form agricultural soils, nitrogen retention and water discharge in Rönneå catchment based in Southern Sweden. 6 different climate change scenarios where created, four of them where with the Rossby Centre Regional Atmosphere Ocean Model (RCAO) coupled with a Baltic Sea Ocean model, with boundaries from two different GCMs. Here the climate change scenarios used was A2 and B2. The remaining two scenarios were created by an earlier version of regional model from the Rossby Centre, RCA1, with model boundaries from two different GCMs and an older climate change scenario, called Business as Usual (BaU), which assumes a 1 % increase in $CO_2$ concentration per year after 1990. For simulations of nitrogen leaching, the coupled N-database model, SOILNDB was used. The studied Rönneå catchment can be divided into three different agricultural regions, and for each region 120 different combinations of soil, crop and fertilization regime where simulated with a 20 year time series. The results point on that all crops show higher N-concentrations in the root zone, and leaching rates where increased as a result of the changed climate. N-leaching increased with 32-70 %, depending on which scenario and crop that was used for the simulations. Two reasons were said to be the explanation to the increase; firstly increased precipitation during winter months when the soil is bare, secondly increased mineralization rates during the winter months due to increased soil temperatures and higher soil moisture content (Arheimer et al., 2005).

# 3 Materials and methods

This section covers the materials and methods for the "bench-mark example". It includes a general description of the simulation model used (COUP), of the site and data based on which the model was parameterized and calibrated, the driving data and model set up.

## 3.1 COUP –model

COUP is an abbreviation for Coupled Heat and Mass Transfer Model for Soil-Plant-Atmosphere systems, and the model was initially developed to simulate conditions in forest soils, but have been further developed to be able to simulate conditions in any type of soil, independent of plant cover (Jansson and Karlberg, 2004). The structure of the model is a one-dimensional soil profile, where processes such as snow-melt, interception of precipitation and evapotranspiration are treated as a boundary between the soil and the atmosphere, transferring energy and momentum. The model is based on two coupled differential equations for water and heat flow, and they are solved in the model by numerical methods. The assumptions behind the equations are based on:

1. The law of conservation of mass and energy
2. Flow is a result of a gradient in water potential (Darcy´s law) or energy (Fourier´s law) (Jansson and Karlberg, 2004).

Nitrogen and carbon processes are included in the model, which enables a dynamic interaction between the plant, soil and the atmosphere and by that plant growth can be simulated. There are also options in the model to simulate several plants that are competing for water, nutrients and solar energy (Jansson and Karlberg, 2004).

Calculations of water and heat flows in the soil are based on soil physical properties, such as: the water retention curve, different functions for unsaturated and saturated hydraulic conductivity and heat capacity. Driving data for the model are meteorological data, and the driving variables represent the flows at the boundaries between the soil, plant and atmosphere. Precipitation and air temperature are of most importance, but also air humidity, wind speed and cloudiness are of interest (Jansson and Karlberg, 2004). Lower boundary conditions can be specified in several ways, such as saturated conditions or groundwater flow (Jansson and Karlberg, 2004).

The main advantages of the COUP-model in comparison of its forerunners (SOIL; SOIL-NDB) is that the model is dynamical; the soil water and heat fluxes are directly coupled with soil nitrogen and crop modeling, at every time step which can be a minute or a day. The growth of the plant is directly driven by climatic conditions, soil moisture and nitrogen conditions.

### 3.1.1 Soil heat processes and temperature

Heat flow in the soil is the sum of heat conduction and convection of water flow, combined with the law of energy conservation. The surface temperature is the upper boundary condition for the soil, and it can be described in different ways. When there is no information about the surface temperature, in snow free periods, the easiest way is to assume the surface temperature to be equal to the air temperature. If the aim is to analyze the interactions between plant cover, surface evaporation and aerodynamics, then another approach has to be used for the surface temperature, namely to solve the heat flow equation in the uppermost layer (Jansson and Karlberg, 2004). When the soil is covered with snow, the soil temperature under the snow pack is calculated assuming steady state flow between the soil and the snow (Jansson and Karlberg, 2004). There are also possibilities in the model to account for heat flow in the upper boundary when the soil is partially covered with snow and also when the humus layer is ununiform (Jansson and Karlberg, 2004).

Lower boundary conditions can be defined either as a temperature, or as a constant flow. The presence of a groundwater table affects the heat convection in the lower boundary. When the soil is unsaturated, the convection follows percolation from the lowest layer, but when a groundwater table is present; convection follows this movement and is neglected for all layers below the ground water table (Jansson and Karlberg, 2004).

### 3.1.2 Soil water processes

The water flow is assumed to be laminar, and therefore follows Darcy´s law. The general equation for unsaturated flow, Richard´s equation, combines Darcy´s law and the law of conservation of mass

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K_w\left(\frac{\partial \Psi}{\partial z}+1\right)\right] \qquad (1),$$

where Θ is the volumetric water content, z is the layer depth, Ψ the water tension, and $K_w$ the unsaturated hydraulic conductivity. To solve the equation, the soil hydraulic properties has to be known, such as the water retention curve and the unsaturated hydraulic conductivity function. Both the properties are functions of water content, and temperature effects are neglected for the water retention curve but included for the unsaturated hydraulic conductivity function (Jansson and Karlberg, 2004). It is natural that these properties are given to the model as parameters, either from databases or from measurements. For the water retention curve, there are two ways of describing it, either as Brooks & Corey (1964):

$$\bar{\theta} = \left(\frac{\Psi}{\Psi_a}\right)^{-\lambda} \qquad (2)$$

where $\bar{\theta}$ is the effective water content, $\Psi_a$ is the air entry pressure potential, and λ is the pore size distribution index. .Or as an alternative to Brooks & Corey expression, the water retention curve by van Genuchten (1980) is available as an option:

$$\bar{\theta} = (1 + |\alpha \times \Psi|^{N})^{\frac{1}{N}-1} \qquad (3)$$

where α is describing the average pore sizes and N is describing the distribution of pore sizes in the soil.

The unsaturated conductivity is, when the retention curve is described by equation number 2, following Mualem (1976), where

$$k_w = k_{mat} S_e{}^{\left(n+2+\frac{2}{\lambda}\right)} \qquad (4),$$

where $k_w$ is the unsaturated hydraulic conductivity, $k_{mat}$ is the saturated matrix conductivity, n is a parameter accounting for flow paths and tortuosity.

Upper boundary conditions are accounting for snowmelt and interception of precipitation. The infiltration capacity of the soil is calculated from the saturated hydraulic conductivity of the upper part of the soil, assuming gravity flow (Lewan

1993). Surface runoff can occur even when the infiltration rate is not exceeded, this happens because of the hydraulic conductivities in the underlying layers are too low (Lewan 1993).

### 3.1.3 Evaporation and transpiration

Evaporation is calculated by the Penman-Monteith (PM) equation (1965):

$$\lambda ET = \frac{\Delta(R_s - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \qquad (5)$$

where λ is the latent heat of vaporization, ET the evapotranspiration rate, Δ the net radiation, G is the soil heat flux, $\rho_a$ is the air density, $c_p$ the specific heat of air at constant temperature, $e_s$ the saturated vapour pressure, and $e_a$ actual vapour pressure, γ is the psychrometer constant and $r_s$ and $r_a$ are the surface and aerodynamic resistances.

Total evaporation can be divided into three components, evaporation from soil ($E_s$), transpiration ($E_t$) and evaporation from intercepted water by the canopy ($E_i$)

$$E = E_s + E_t + E_i \qquad (6)$$

The three components of total evaporation are calculated by the PM-equation, but with slight changes. When calculating soil evaporation, $R_n$ is substituted with $R_{ns,}$ which corresponds to the net radiation available at the soil surface, $r_a$ is substituted with $r_{as}$ which is the total aerodynamic resistance between the soil surface and a reference height, usually the canopy, $r_s$ is replaced by $r_{ss}$ which is the soil surface resistance. When using the PM-equation for calculating potential transpiration and evaporation of intercepted water, the energy fraction adsorbed by the canopy is used, and resistances above the canopy and crop surface resistances ($r_{sc}$) and resistance for evaporation of intercepted water, $r_{sint}$) (Lewan 1993).

### 3.1.4 Plant growth

In the model, there are three different ways to describe a plant. The simplest plant is the implicit big leaf plant, where transpiration and soil evaporation is treated as one flow. Plants can also be represented explicitly as one big leaf, and then transpiration is calculated separately from the soil evaporation. Both components are based on calculations of the potential evapotranspiration as obtained from the Pennman-Monteith equation. The third way to describe the plant is by an array of plants, where several canopies and root systems can be treated (Jansson and

Karlberg, 2004). The two options, multiple plants and explicit big leaf are in many ways similar, although the multiple plants option can for instance be useful when simulating different forest stands, and the competition between them. When choosing the multiple plants or explicit big leafs option, it is also possible to simulate dynamical development, where plant properties like LAI, root length, albedo, canopy height, varies with the season, climate and access to nutrients like nitrogen and carbon (Jansson and Karlberg, 2004). It is also possible to simulate dynamical crop growth, i.e. the start of crop growth as well as harvest dates are linked to temperature sums. This implies that the growing season varies from year to year depending on air temperature. Growth can be limited by water stress, nitrogen availability and temperatures, either too low or too high (Jansson and Karlberg, 2004), expressed in response function that varies between 0 and unity.

Plant water uptake can either be described in the model with the SPAC[4]- approach, where plant and soil properties are considered, or based on empirical functions for plant resistance and soil resistance used to calculate the water uptake rate. The more simplified approach is called the Pressure head response. Water uptake is then calculated as a fraction of the atmospheric demand for water. However, if the SPAC-approach is chosen, water uptake is calculated as a result of different water potentials in the plant and soil (Jansson and Karlberg, 2004).

The option Pressure head response is, as mentioned, a simple approach with response functions for water and temperature. Actual transpiration is calculated in two steps, this is to account for compensatory uptake of water from layers that experience no water stress. The response functions for soil water potential $f(\psi(z))$, soil temperature $f(t(z))$ and soil osmotic potential $f(\pi(z))$ are then calculated in the first step to estimate the actual transpiration (Jansson and Karlberg, 2004).

### 3.1.5 Nitrogen and carbon

Nitrogen and carbon enters the soil profile either as manure, fertilization or as litter fall from plants. After entering the soil, organic nitrogen and carbon end up in two soil organic pools called faeces or litter, and after decomposition they end up in the third organic pool, which is the humus pool, some carbon also leave as soil respiration (Jansson and Karlberg, 2004). Decomposition of carbon in the soil affects the C/N ratio in the organic part of the soil, which in turn affect the mineralization/immobilisation rate of organic nitrogen to or from the ammonium pool. Ni-

[4] SPAC (Soil-Plant-Atmosphere-Continuum)

trogen can further be transformed to nitrate and end up in the soil nitrate pool. Nitrogen is removed from the system by plant harvest, leaching of nitrogen and denitrification, whilst carbon leaves the system by soil respiration, plant harvest and leaching (Jansson and Karlberg, 2004).

As nitrate is easily transported with water, vertical movement of nitrate from one layer to another is calculated as:

$$q_{NO_3} = q_w \frac{N_{NO_3}}{\theta(z)\Delta z} \quad (7)$$

where $q_w$ is the soil water flow, $N_{NO3}$ is the amount of nitrate in the soil layer, $\Theta(z)$ is the water content in a specific layer, and $\Delta z$ is the layer depth (Jansson and Karlberg, 2004). Horizontal drainage of water from the profile means that nitrogen from the profile is leached. The horizontal drainage transport of nitrogen is calculated as follows:

$$q_{NO_3\,dr} = \frac{N_{NO_3}}{\theta(z)\Delta z} \times q_{dr} \quad (8)$$

where $q_{dr}$ is the total amount of drainage water.

Deep percolation of water also means losses of nitrate from the system, and the leaching of nitrate with deep percolation, $q_{NO3dp}$ is calculated as follows:

$$q_{NO_{3dp}} = q_{deep} \frac{N_{NO_3}}{\theta(z)\Delta z} \quad (9)$$

where $q_{deep}$ is the deep percolation of water flow (Jansson and Karlberg, 2004).

## 3.2 Site description and measurements

The model was parameterized and calibrated against data from an experimental site, located in Mellby in Hallands county, south western Sweden (lat 56˚29 N long. 13˚0 E, alt. 10 m). The data set on which the parameterization of the model was based are published in Lewan (1993) and Lewan (1994). Experiments were made to explore differences in water balance, discharge and nitrate leaching between winter bare and winter cropped soil (spring barley with and without under sown Italian rye grass).

Measurements were made during 1 April 1988 until 1 April 1991. Annual precipitation was 910 mm, 697 mm and 697 mm (Lewan 1993). The average annual precipitation in the area is 736 mm, and the mean annual temperature 7.5 ˚C (Lewan 1993), the climate is cold temperate.

The Mellby soil is made up of sand deposits with a thickness of 90-130 cm, and under there is glacifluvial clay. According to USDA, the topsoil is a sandy loam, with a clay content of 5-10 % and an organic matter content of 5 %. The subsoil consists of loamy sand with a clay and organic matter content of less than 1 % (Lewan 1993).

The experimental field is made up of four tile-drained plots, with the tiles placed at a depth of 0.9 m and 7 m apart. The plots are surrounded by discard drainage pipes, which prevent the lateral flow of water to the plots. To each plot, a lysimeter was installed, and drainage from the lysimeter was collected through a pipe at its bottom. Spring cereals where sown in all four plots, and in two of them, Italian ryegrass was sown together with the main crop as a catch crop that was ploughed down before spring sowing (Lewan 1993). The model set up used in this particular study, is the one without any catch crops.

Discharge was measured with a tipping bucket system, whereas nitrogen concentrations in the drainage water were measured by taking samples of the drainage water every two weeks. The samples were analyzed for $NH_4$ and $NO_3$ and total nitrogen content. Groundwater pressure was measured twice a month in piezometer pipes at depths of 170 cm and 340 cm at three different places just outside of the plots, and nitrate concentration in groundwater was measured every two months (Lewan 1994). Soil samples were taken to determine mineral nitrogen content, and samples were taken in spring, at harvest, in early autumn, late autumn and in early spring before ploughing the catch crop. Nitrogen content in biomass was also analyzed (Lewan 1994).

## 3.3 Model set up

### 3.3.1 Driving variables

The model is run with meteorological data as driving variables, temperature, solar radiation, wind speed, relative humidity and precipitation. Three scenarios where run, reference scenario, which corresponds to 1st of april 1971 - 1st of April 2000, and scenario B1 and A2, both which corresponds to year 1st of April 2071- 1st of April 2100. Climate data for the scenario runs was obtained from the Swedish Meteorological and Hydrological Institute (SMHI), based on a regional climate model, RCA3, driven by the global model results from ECHAM5 as boundary conditions. RCA3 covers Europe and has a grid cell resolution of 50 km.

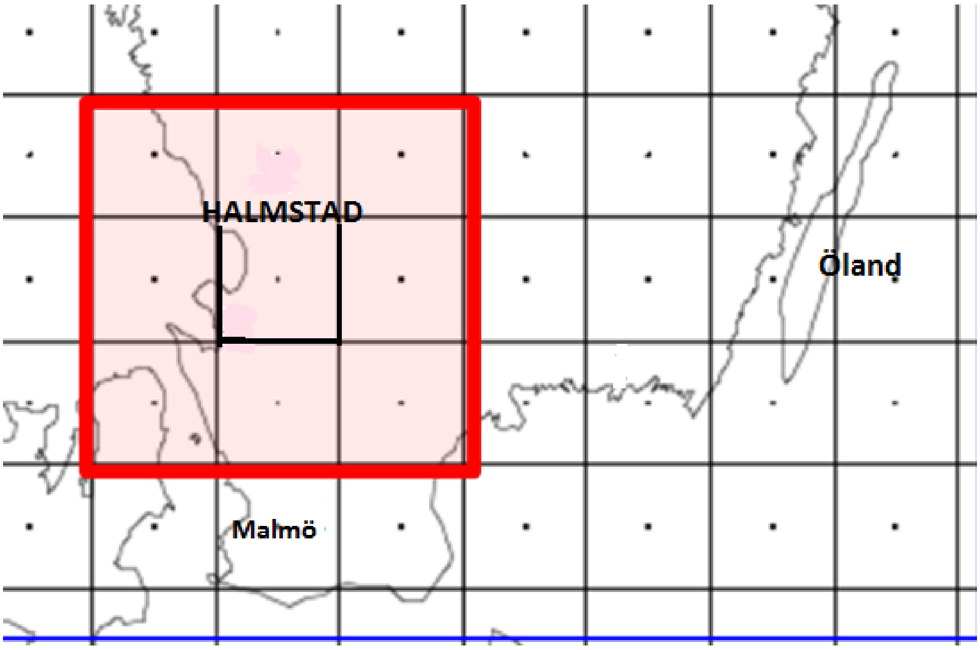



Figure 3. Grid cell resolution for RCA3. The middle cell in the red 9- grid cell area represents the area for which this study was performed. Coordinates lat 56.485° long 13.161° (Steffens 2011, SMHI, 2011, 3)

Scenario climate data was prepared according to the delta change method (Teutschbein and Seibert, 2010) based on Steffens (2011). Solar radiation, precipitation, wind speed and temperature were altered, whereas relative humidity was assumed to be constant in the future climate. The delta-factors, for temperature and solar radiation, were derived based on calculating differences in monthly averages over 30 years for both reference and scenario run results. The delta-factor values were then added to the observed time series. For precipitation, the procedure is the same, but the delta is expressed as a percentage change between the scenario and the reference results. The climate time series has a daily resolution and the monthly delta – values were smoothed over time by linear interpolation.

The long-term climate data set is mainly based on observations from the climate metereological station in Halmstad, covering 1$^{st}$ of January 1971 until 1$^{st}$ of January 2001. For details and gap-filling, see Johnsson et al., 2008. The figures 4-9 displays climate input data for temperature and precipitation, to demonstrate the input data and the delta change method. Observed precipitation data is corrected by 7 % to account for wind losses, and 8 % if the precipitation falls as snow.

*Temperature*

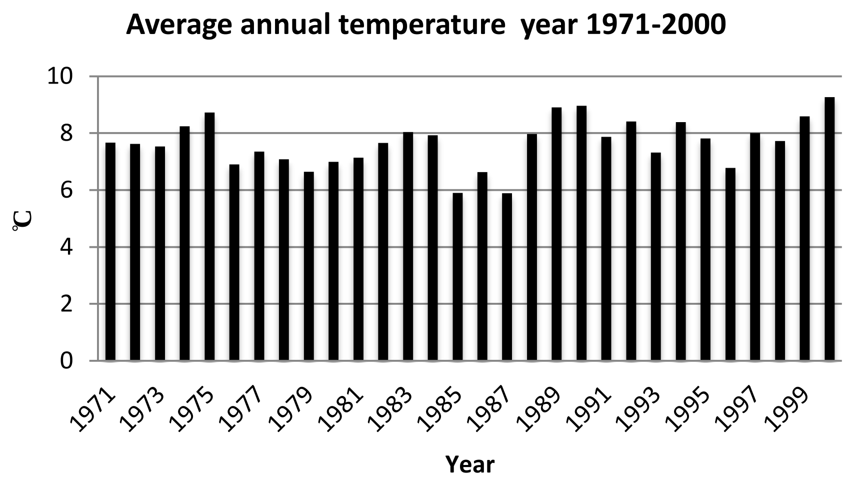



Figure 4. The figure shows the average annual temperature for the reference period for Halmstads county during the years 1971-2000.

For the reference climate the 30 year average annual temperature was estimated to 7.7˚C, for B1 9.7˚C and A2 10.5˚C, which represents a potential increase of average annual temperature for Halmstad of 1.9˚C for B1 and 2.8˚C for A2, depending on the future socioeconomic development. This represents the delta factor per year in the delta change method.

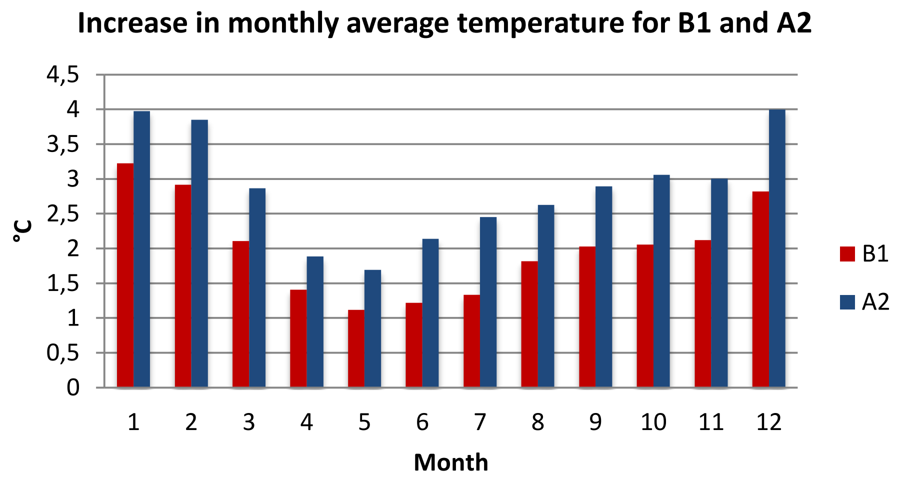



Figure 5. 30 – year monthly average temperature increase for B1 and A2 scenario.

Figure 5 demonstrates that the average annual temperature increase for both scenario B1 and A2 will be more pronounced during the winter months. Winters will be relatively warmer than summers.

Figure 6 shows that monthly average temperature will increase more in scenario A2 than B1, and that none of the future climate scenarios will experience a monthly average temperature below 0 ˚C.

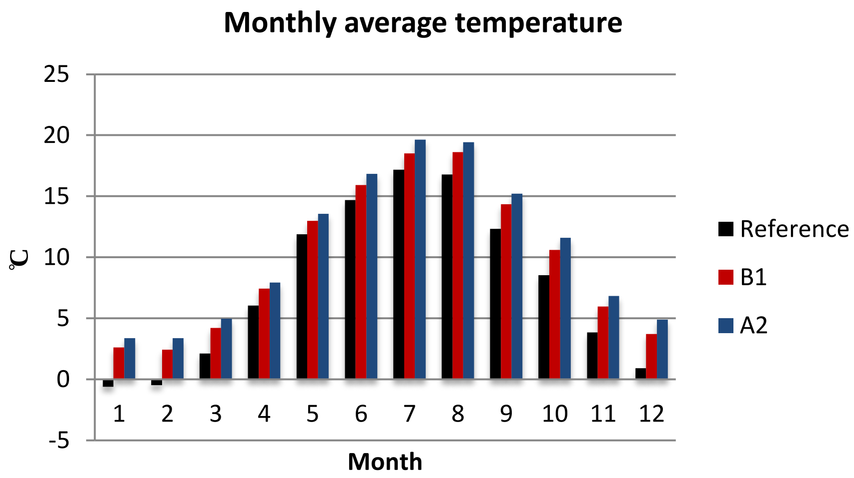



Figure 6. 30 year monthly average temperature for reference, B1 and A2 scenario.

*Precipitation*

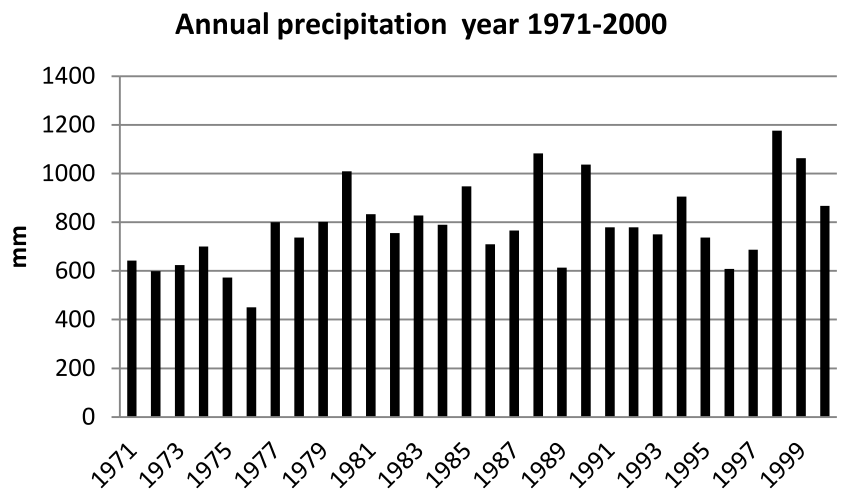



Figure 7. Annual precipitation for 1971-2000 based on data from Halmstad (southern Sweden).

Figure 7 illustrates the between year variations in observed precipitation. The between year variations will, be kept for scenario B1 and A2 as a result of the delta change method. Average annual precipitation for the reference scenario is estimated to 787 mm, with 872 mm and 916 mm for scenario B1 and A2 respectively.

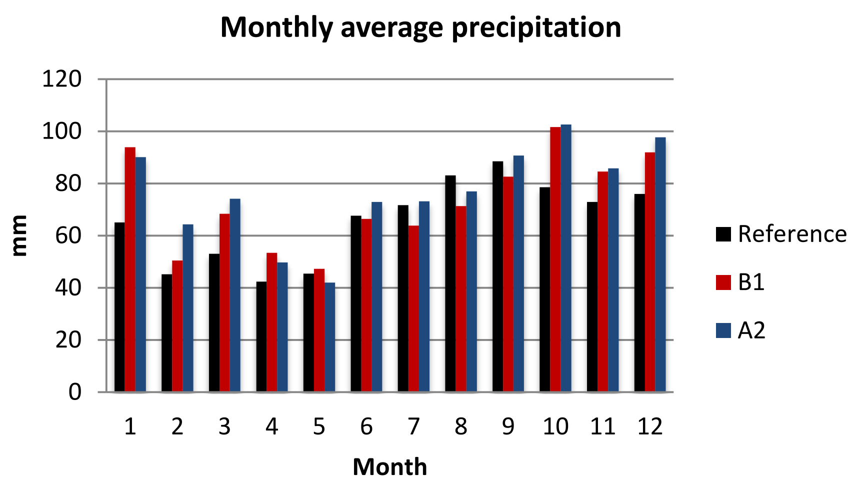



Figure 8. 30-year average monthly precipitation for reference , B1 and A2 scenario.

Figure 8 displays the 30 –year monthly average precipitation for the reference climate, and scenario B1 and A2. The different scenarios exhibit different within year precipitation patterns for the years 2070-2100. Scenario B1 shows the largest precipitation increase in January (+44 %), and during the summer months, from June to September, there is less precipitation in comparison with the reference climate. Scenario A2 is more heterogeneous, showing large precipitation increases of approximately 40 % in January to March but 7 % less precipitation in May to the reference climate. In June and July the precipitation increases slightly, whereas August obtains 7 % less rainfall. For both scenarios, precipitation increase is pronounced during October to December, see figure 9.

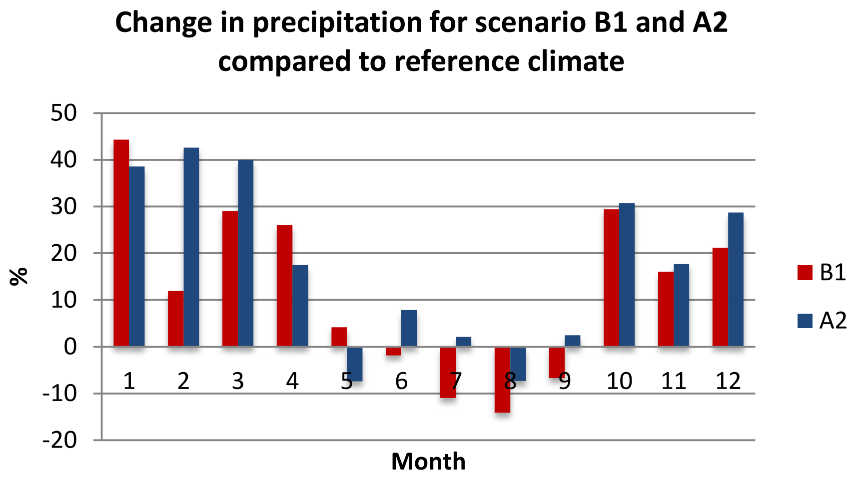



Figure 9. Change in precipitation for scenario B1 and A2 as compared to the reference climate.

The model runs were performed for a 30 year period from 1st of April 1971 – 1st of April 2000 .The data were set to correspond to an agricultural year for spring cereals. A pre-period year was run from 31st of March 1970, to adjust the model for initial conditions.

### 3.3.2 Model parameterization and calibration

The initial parameterization of the soil and the crop was parameterized according to measurements, observations and management practices at the Mellby site, published in Lewan 1993, 1994. This initial parameterization includes soil physical parameters, specific crop parameters for maximum root-depth, root distribution and maximum crop height, parameters covering fertilization amount, date and dry and wet deposition of nitrogen (Lewan et al., in prep).

The initial parameterization for the crop was based on a static crop, and to find the most appropriate parameterization for a dynamical crop growth, the model was further parameterized and calibrated according to the GLUE[5]-method based on a large number of Monte Carlo model runs in which key-parameter values were varied within predefined ranges. The GLUE-methodology was introduced in 1992 by *Beven and Binely* and is an uncertainty estimation method that is often used in environmental simulation modeling (Stedinger et al., 2008). The GLUE-method estimates the uncertainties between, for example, actual flows and predicted flows, and estimated parameters and true values (in the case that there exists any) (Stedinger et al., 2008). The method is a tool to identify parameter combinations that statistically agrees with the observed data, in this case the four years of field measurements between 1988 and 1992 in Mellby. When performing Monte Carlo simulations for calibration of the model, 15 parameters were stochastically varied within predefined intervals, generating 20000 simulations with different parameter sets. Each of the simulations where then compared with the measurement data from the field site. The “acceptable” simulations were chosen on the basis of calculating a mean error between simulated results and observed data. With the highest criterion for acceptance, only 35 simulations of 20000 were “accepted” (Lewan et al., in prep.**)**. One of these 35 acceptable parameter sets were randomly chosen for this study. For more detailed information about the model set up and parameterization, see Appendix 1.

### 3.3.3 Method limitations

The model was only calibrated based on four years of measurements, which might be too short period to get normalized parameter data. Within this study only one of the “acceptable parameter sets was applied. A more complete picture would be

[5] GLUE: Generalized likelihood uncertainty estimation

obtained if the model was applied with all the 35 identified parameter sets. However, this was beyond the scope and time frame of the masters' thesis. In the model parameterization, the fertilization rate is set to 90 kg/ha/year, which is based on current conditions and the rate of fertilization is not changed in the future scenarios, which might be unrealistic. The required amount of fertilizer in a changed climate might be different. For the climate data, the delta change method has inherent flaws, such as those mentioned earlier. The method does not account for changes in temporal patterns, for instance when the precipitation falls. The relative humidity remains unchanged between the reference simulations and the scenario simulations.

# 4 Results

## 4.1 Model output

In this section the changes between the reference model runs and the two climate-scenario runs will be presented – especially changes in soil temperature, water balance components and nitrogen balance and leaching.

### 4.1.1 Soil temperature

Figure 10 shows the 30-years monthly average soil temperature at 5-15 cm depth for all scenarios.

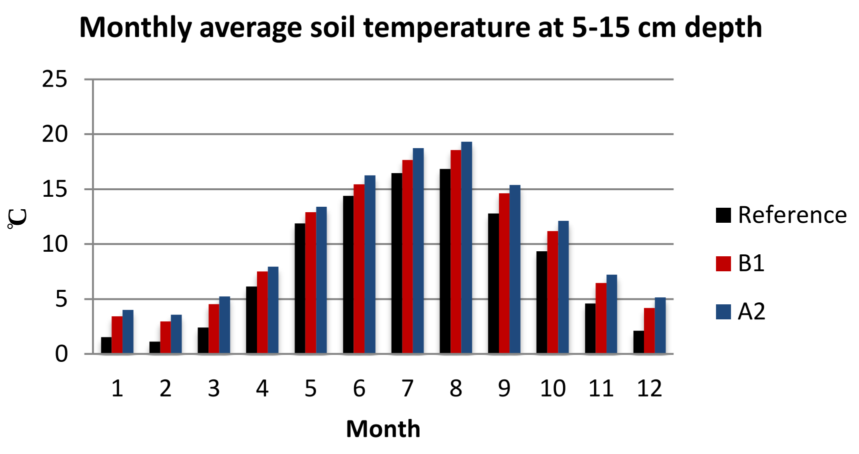



Figure 10. Soil temperature at 5-15 cm depth for reference, B1 and A2 scenarios. Monthly average values based on 30-year simulations.

The soil is located in southern Sweden, and very seldom experiences frozen soil, and the reference average monthly temperature in January, is 1.5℃. Figure 11 shows the increase in monthly average temperature for the two scenarios, and it is evident that the pattern for the soil is the same as for the atmosphere (figure 5), namely that the greatest temperature increase is occurring in the winter months, see figure 11.

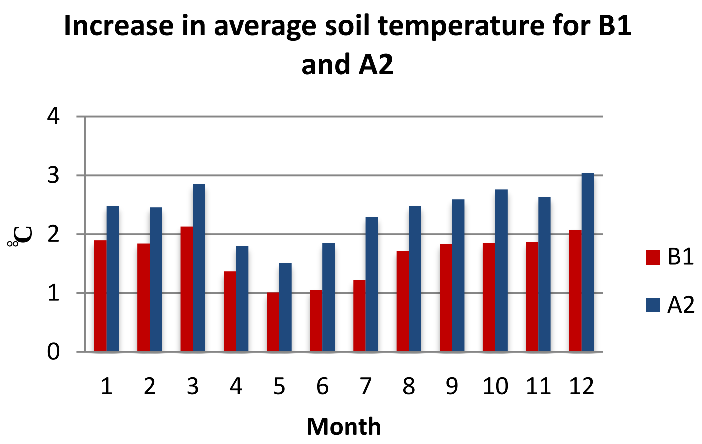



Figure 11. Increase in monthly average soil temperature at 5-15 cm depth for scenario B1 and A2 based on 30-year simulations.

### 4.1.2 Water and nitrogen balance

*Table 1.Simulated average annual water balance for the soil for the reference climate, and scenario B1 and A2. P is precipitation (mm), E is total evaporation (soil evaporation, transpiration and interception evaporation (mm)), R is surface runoff, D is drainage through the soil profile. .Notation (xx) means percentage increase from the mean in the reference climate.*

| (mm/year) | Reference | B1 | A2 |
|---|---|---|---|
| P | 822 | 907 *(10)* | 953 *(16)* |
| E | 380 | 390 *(2.6)* | 386 *(1.6)* |
| R | 31 | 22 *(-29)* | 18 *(-41)* |
| D | 412 | 495 *(20)* | 548 *(33)* |
| **Balance** | -0.01 | 0.1 | 0.1 |

In scenario B1, precipitation, evaporation and drainage increases, whereas surface runoff decreases with 29 % from 31 mm to 22 mm. In scenario A2 surface runoff decreases with 41 %, whereas drainage increases with 33 %. Evaporation increases more in scenario B1, with 2.6 % in comparison with A2 where the increase is 1.6 %, see Table 1. To analyze this further, Table 2 shows the differences in soil evaporation, interception evaporation and transpiration components between the three scenarios.

*Table 2. Simulated average annual soil evaporation, transpiration and interception evaporation for the reference climate, scenario B1 and A2.(xx) denotes percentage change from the reference mean.*

| (mm/year) | Reference | B1 | A2 |
|---|---|---|---|
| Soil evaporation | 218 | 239 *(9.6)* | 244 *(12)* |
| Transpiration | 145 | 136 *(-6.2)* | 128 *(-12)* |
| Interception evaporation | 17 | 15 *(-12)* | 14 *(-18)* |
| ∑ | 380 | 390 | 386 |

The results from the scenario simulations indicate less transpiration for both B1 and A2, although more pronounced in scenario A2, where transpiration decreases with 12 %, see Table 2. In line with this result, interception evaporation decreases with 12 % for B1 and 18 % for A2 respectively. Instead of leaving as transpiration or interception evaporation, the water directly evaporates from the soil surface, for scenario B1 soil evaporation increases with 9,6 % and with 12 % for scenario A2. These results point out that there might be earlier crop harvests in the future climate, which indeed affects more than just the water balance. Table 3 summarizes the average annual nitrogen balance for the three simulations.

*Table 3 Simulated average annual. nitrogen balance for reference climate, scenario B1 and A2. (xx) notes percentage difference from the reference mean.*

| | $gN/m^2/year$ | Reference | B1 | A2 |
|---|---|---|---|---|
| **Input** | Deposition | 1.5 | 1.6 *(12)* | 1.7 *(16)* |
| | Fertilization | 9 | 9 | 9 |
| ∑ | | **10.5** | **10.6** | **10.7** |
| | | | | |
| **Export** | Denitrification | 1.4 | 1.8 *(26)* | 2.1 *(49)* |
| | Harvest | 9.7 | 9.5 *(-2.6)* | 8.6 *(-11)* |
| | Net leaching | 4.3 | 6.0 *(41)* | 7.1 *(66)* |
| ∑ | | **15** | **17** | **17** |
| | | | | |
| **Storage** | Humus | -4.7 | -5.9 *(-22)* | -6.3 *(-31)* |
| | Litter | -0.09 | -0.08 *(22)* | -0.07 *(33)* |
| | Mineral N 0-90 cm depth | 0.05 | 0.06 *(20)* | 0.07 *(40)* |
| ∑ | | **-4.8** | **-6.0** | **-6.4** |

Table 3 show that for both scenario B1 and A2, the amount of nitrogen in the nitrogen cycle of the soil-plant-atmosphere system will increase when inputs such as deposition is increasing with 12 % for scenario B1 and 16 % for scenario A2. This is affecting processes such as denitrification, mineralization and thus leaching of nitrogen. Denitrification increases with 26 % for the B1 scenario, and with 49 % for scenario A2. Denitrification means losses of valuable nitrogen to the atmosphere. Leaching increases in for both climate scenarios, with 41 % for B1 and 66 % for A2, whereas harvests are slightly decreased in the future climate, -2.6 % for

B1 and -11 % for A2. There is also a decrease in the humus pool, which corresponds to an equally increased mineralization in the two climate change scenarios, with 22 % for B1 and 31 % for A2, bringing organic nitrogen into a mineral form, available for nitrification and plant uptake. Figures 12-15 will give additional perspectives on nitrate leaching.

Figure 12 shows the annual nitrate leaching from the soil in the reference climate. Minimum annual leaching is estimated to 1.4 gN/m$^2$, and maximum nitrate leaching 8.4 gN/m$^2$. Figure 12 demonstrates quite large between year variations for nitrate leaching, which is not only coupled to precipitation amounts, but also to temperature, plant growth and soil moisture. But, as figure 9 reveals, the importance of precipitation cannot be underestimated. For instance, in 1976 there was an annual precipitation of 450 mm, and as a result leaching that year was quite low, 1.4 gN/m$^2$, which corresponds to the minimum value. In 1980 there was a precipitation amount of 1001 mm, and the leaching that year reaches its maximum value of 8.4 gN/m$^2$. But when looking at year 1977, it is obvious that precipitation is not the only factor governing leaching, since precipitation that year reached a quite normal value of 800 mm and the leaching was still quite high, 7 gN/m$^2$.

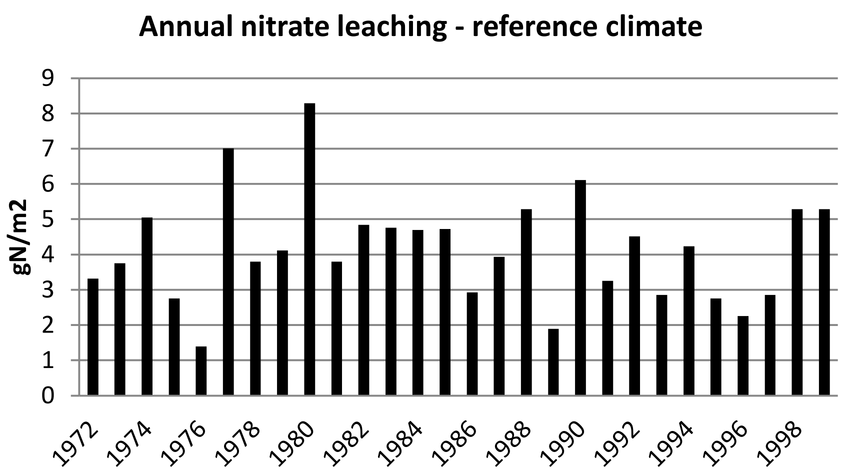



Figure 12. Simulated annual nitrate leaching for the reference climate. Note that neither 1971 nor 2000 are included in the figure, because of the model settings that start from 1st of April 1971 and ends 1st of April 2000.

Figure 13 shows the between year variations in annual leaching for scenario B1 and A2. The leaching pattern is similar in many ways with figure 12, which can partly be explained by the climatic conditions and the effects of the delta-change method which does not take into account any temporal variations in the future climate. Although, as mentioned earlier, nitrogen turnover in, as well as leaching from, the soil is controlled by other factors than only precipitation and temperature. Therefore Figure 14 illustrates the difference in nitrate leaching between the reference climate and scenario A2 and B1.

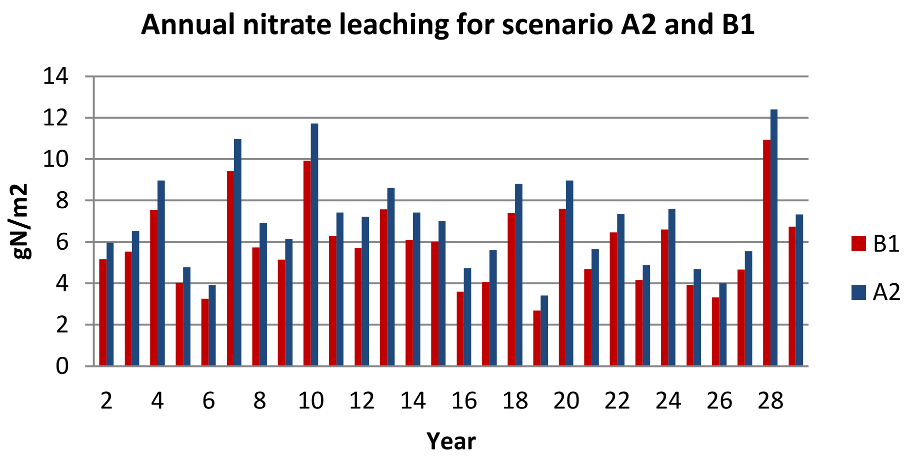



Figure 13.Simulated annual nitrate leaching for scenario B1 and A2 on the Mellby soil in Halland, southwestern Sweden. Year 2-28 corresponds to 2072-2099.

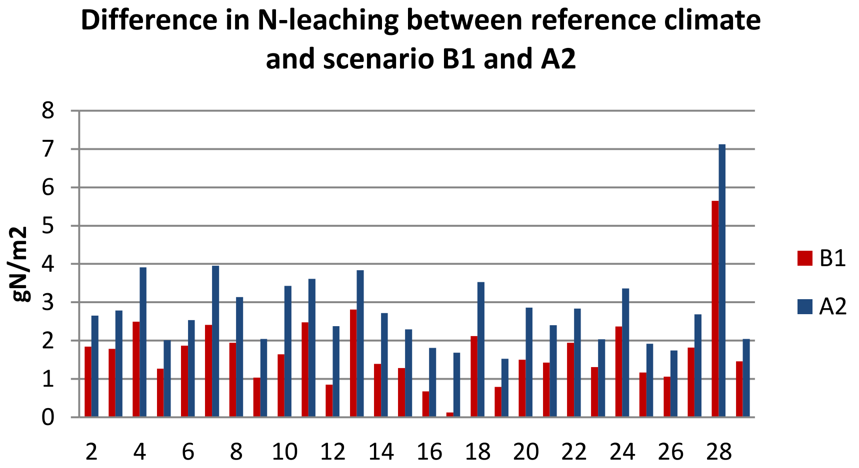



Figure 14. Difference in amount of nitrate leached from the soil between the reference scenario and scenario B1 and A2. Note that 2-29 corresponds to the future years of 2072 -2099.

Figure 14 demonstrates the differences in the amount of nitrate leached per year from the system, between the reference climate and scenario B1 and A2. For scenario B1, the minimum annual leaching is estimated to 2.6 gN/m$^2$ and maximum annual leaching 11 gN/m$^2$, and for scenario A2 minimum annual leaching is 3,4 gN/m$^2$ and maximum 12 gN/m$^2$ which indicates that leaching increases together with temperature and precipitation. Figure 14 also displays this pattern, leaching increases for both scenarios, but it seems like leaching will be higher in scenario A2. It is noticeable, that leaching increases for all years in the future climate. In 2087, there is a noticeable small increase in leaching for scenario B1, and that year is also a very dry year for scenario B1, especially during the winter months. Whereas, 2098 leaching increases quite much for both climate change scenarios, and that year is a particularly rainy year, especially during the winter months.

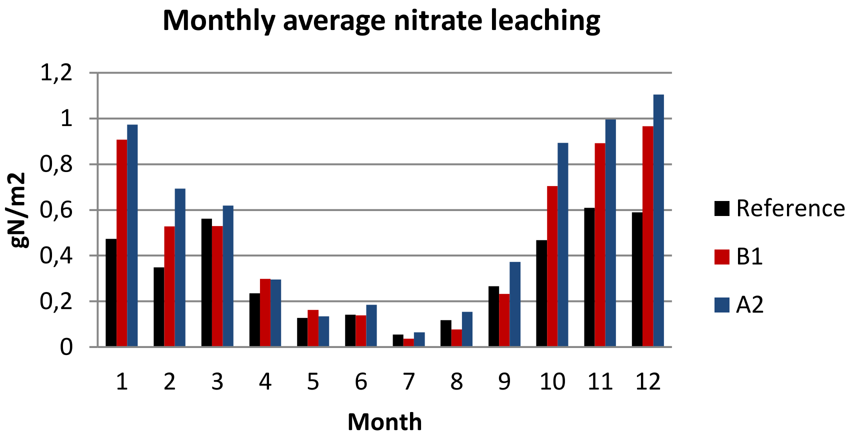



Figure 15. Simulated monthly average nitrate leaching for reference climate, scenario B1 and A2.

Figure 15 displays that leaching of nitrate is more pronounced during the winter months, when the soil is bare and precipitation amounts higher. This is most pronounced in the climate change scenario simulations, where also increased winter temperatures can play a role, by increasing mineralization and nitrification rates in the soil. Figure 15 corresponds well with input data, see figure 5 and figure 9, as well as figure 11 which displays average monthly soil temperature.

### 4.1.3 Harvest of nitrogen in above ground biomass

The main explanation to why transpiration is less and amount of nitrogen harvested in above ground biomass is lower in the future climate, can be seen in figure 16, which illustrates harvest dates. Harvests are, in the future climate, earlier in the growing season, which affects both transpiration rates and amount of nitrogen harvested, but also amount of nitrogen lost through leaching if the soil is left bare after harvest. Harvest dates for reference climate is usually in the middle of August, with a variation from the last of July, until the 24$^{th}$ of August. For scenario B1, harvest dates are one week to 10 days earlier, on average around the last of July with a variation between 6$^{th}$ of July until 9$^{th}$ of August. In scenario A2 harvest dates are on average three weeks earlier than the reference scenario, with a variation between 12$^{th}$ of July until 5$^{th}$ of August. Figure 16 displays how harvests dates are changed in the future climate based on the COUP-model predictions. Figure 16 shows that there seem to be more pronounced between year variations for the reference scenario, whereas both of the scenario simulations exhibit a more uniform pattern, with a few outliers, for instance in 1992 for scenario B1, where harvest of biomass is already 6th of July.

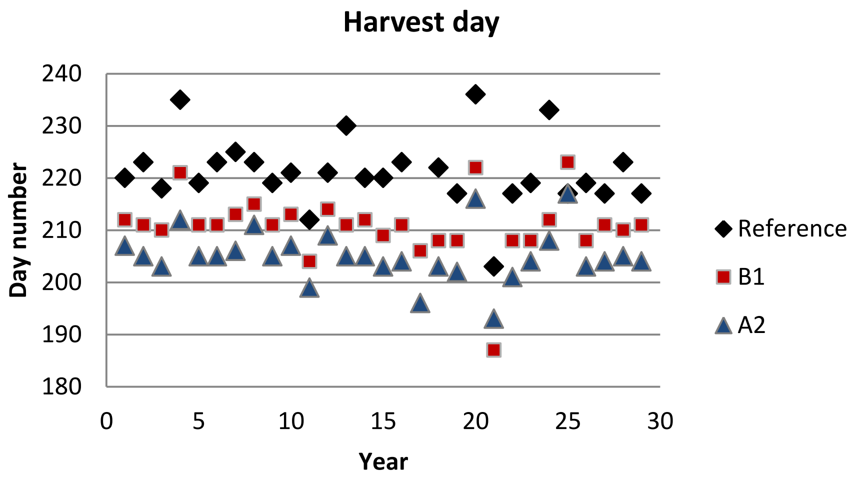



Figure 16.. Simulated harvest day of spring barley for reference climate, scenario B1 and A2. Day number: 1st of January corresponds to day 1. 1st of July correspond to day 182. Year 1-29 corresponds to year 1971-1999 for the reference climate and 2071-2999 for scenario B1 and A2. No harvest is simulated in years 2000 and 2100 since simulations end 1st of April.

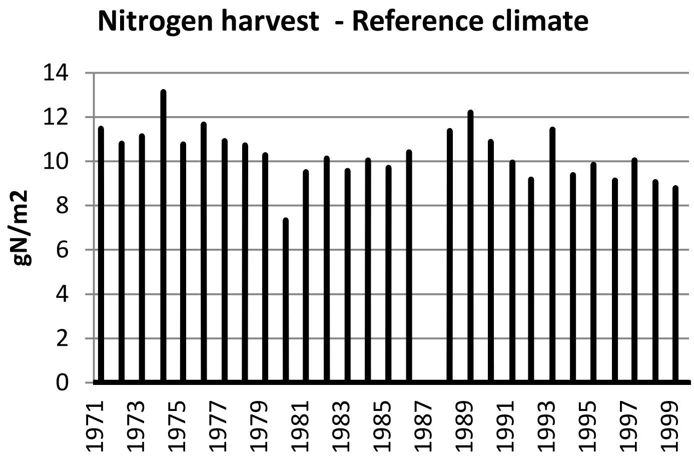



Figure 17.Nitrogen harvest in above ground biomass for the reference climate.

The changed climate promotes earlier harvests, which is one of the main reasons to why there is less biomass harvested. To illustrate this further, figure 17 and 18 illustrates amount nitrogen harvested each year for reference climate (figure 17) and scenario B1 and A2 (figure 18).

Figure 17 reveals that there is no harvest in 1987, which there is when looking at figure 18. This can be caused by the calculations parameter settings that control when the crop is mature and ready for harvest, which based on calculations of temperature sums. Both the scenario simulations show the same pattern, that harvests will be slightly reduced in a changed climate; this is especially pronounced when looking at scenario A2.

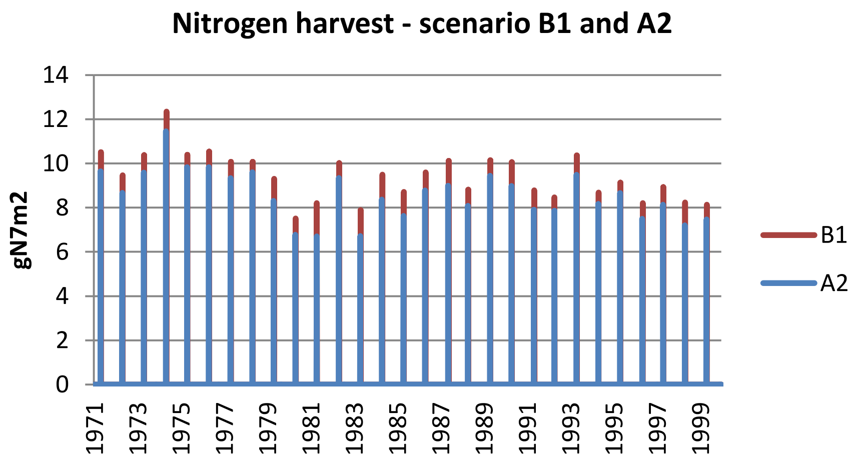



Figure 18. Nitrogen harvest in above ground biomass for scenario A2 and B1.

# 5 Discussion

In the first part of this thesis, a few key-questions were asked, regarding what impacts future climate scenarios will have on both water and nitrogen balance. Will changes of precipitation and temperature influence these balances, and how? Will there be any changes in the time for the growing season and how will that affect the crop and the harvest? What are the future perspectives of this, can further studies bring more robust results? Most of these questions can be answered, and supported by other studies, but still there are many generalizations made and the results might not be taken for granted.

## 5.1 Water balance

The results from the water balance simulation are mostly in accordance with *Eckersten et al., 2001*, where the pattern in a changed climate is assumed to show higher amounts of precipitation which increases drainage from the soil profile as well as soil evaporation. In contrast with *Eckersten et al., 2001*, the results from this study indicates less transpiration from both scenarios, as well as reduced surface runoff. The study by *Eckersten et al, 2001* was performed for a winter crop which means that transpiration might increase due to higher temperatures all the year around, whereas this study was made for a spring crop which left the soil bare during a large part of the year. It shall be noted that in *Eckersten et al., 2001*, simulations where carried out with the same soil settings, but with climate data from the middle of Sweden, Uppsala, where the climate is dryer.

The annual changes of water balance, with increased drainage from the soil profile as well as soil evaporation, can be attributed to increased precipitation as well as temperatures for both climate scenarios. However, the reduction in transpiration and interception evaporation in this study, are mainly attributed to the earlier harvests of the main crop. Reduced surface runoff can be explained by less freezing of the soil, which enables more water to infiltrate.

## 5.2 Nitrogen balance

Water balance, as well as soil temperature, have significant effects on the nitrogen balance of the soil. Increased soil temperatures, especially during winter time, results in higher mineralization rates, which is in accordance with *Arheimer et al, 2005*. This study also show, that when the soil is left bare during winter time, the risk for nitrate leaching is increased, and in accordance with both *Arheimer et al, 2005* and *Eckersten et al, 2001* average annual nitrate leaching increases in the future climate, irrespective of which climate change scenario or climate impact model that was used. *Eckersten et al, 2001* showed an annual leaching rate of 1.9 $gN/m^2$/ year on the Mellby soil with the Uppsala climate, which is much lower than the results presented in this study, where leaching was estimated to 5,99-7,06 $gN/ m^2$. This can be the result of lower precipitation rates in the Uppsala climate, as well as the choice of crop. *Arheimer et al, 2005* simulated nitrate leaching in a future climate from soils in southern Sweden covered with spring cereals of the magnitude of 6-7 $gN/ m^2$, which is in accordance with this study.

The most important factors governing leaching in this study is of course the increase in precipitation and temperature, especially during winter when the soil is left bare. Increased temperature leads to higher mineralization rates, higher precipitation rates leads to more drainage through the soil profile, and thus more leaching. One more factor can be important when discussing the nitrate balance of this particular study, and that is crop growth. The results indicate that harvests will be earlier in the future climate, which firstly leads to the soil being left bare during a longer period, but also to the fact that less nitrogen will be bound into biomass resulting in reduced harvests but also more nitrate that potentially leaves the soil profile. The most probable reason to why harvests are earlier and slightly reduced in the future climate is that the crop matures faster when temperature gets higher. This means that the time for grain-filling becomes shorter and more nitrogen is left in the soil, potentially leaching during the time when soils are without crop cover.

## 5.3 Future perspectives

It is most important to remember that this is just one of many possible parameter settings, and the study includes many generalizations. According to *Lewan et al. in prep.,* there is need for a more detailed sensitivity analysis on the parameters, and also a more developed strategy for the calibration, where the impact of different calibrations variables could be more examined in detail. One example on how the parameter settings affect the results is visible when looking at Figure 15, where harvest is missing one year, 1987. Is this really a result of disturbed crop growth that year or the result of the parameters governing the function of crop growth? Such questions are very important to answer when developing this kind of study further.

Development of bias correction methods for climate input data are also important questions for future development. The “delta change” approach is a quite useful way of interfacing RCM-model output with impact models, but still it does not account for the possible changes of frequencies of, for instance precipitation, both between years and within years

Some important variables where not accounted for in this study, for instance the need for different amounts of fertilizer in the changed climate, which is a very important factor when discussing leaching. Will there be a greater need of fertilizer, or less need? Increasing mineralization and deposition rates might reduce the need for fertilizer, but faster growing crops might enhance the need of fertilizer. This is a very important future task to deal with, especially when deciding on which crops to grow to reduce both needs of fertilizer, but also leaching.

The chosen crop, a spring cereal, might also affect the results. Would nitrate leaching be in the magnitude of *Eckersten et al, 2001* if, for instance, winter wheat was grown? The choice of variety within species might also be rather important for results obtained from model-simulations. In this case the parameterization of the barley crop was based on a species grown and fitted for the present climate. The sowing of varieties adapted for changed temperature conditions might increase the potential N-uptake and allow for slower crop development and thus also contribute to higher yields. This would require changes in the crop parameter settings, which were not accounted for in this study. A deeper understanding of how the model estimates harvest of the crop is necessary to determine which date of harvest that is reasonable to expect in the future climate. Since harvest of the crop is estimated by temperature sums, this might have to be corrected for warmer climates. Future studies might also deal with the fact that if varieties adapted for a warmer climate is chosen in the future climate, they might not be suited to the light climate in the northern region, which can affect both growth, harvest and thus nitrate leaching

Another future perspective could be to account for changed water use efficiency by the plant when $CO_2$ levels in the atmosphere gets higher. This approach would then require another set up of the simulation model, accounting for this process.

This thesis presents the background and basic procedures for how to perform a climate change impact assessment. It gives perspectives an all the possible factors that has to be accounted for – starting from the choice of GCM input, the climate downscaling procedure, the choice of impact model as well as description and parameterization of the crop, which all include biases. With this in mind, it is important not to forget to treat the results carefully, not taking them as truth but indications on how the possible changes might affect the water and nitrogen balance of this particular soil.

Nevertheless, these kinds of studies are of importance, especially when planning for the future, both with respect to agricultural production and environment. The dynamic type of model applied within this study, enables opportunities for performing similar studies with respect to different soils and/or crops (such as maize or for instance energy forest), or crop rotations e.g cereals  with an undersown catch crop in combination with different climate scenario projections.

# 6 Conclusions

Climate impact assessments include several generalizations and simplifications, and therefore the results should be treated carefully. Nevertheless, the results can be considered as valuable indications and possible outcomes of the future climate. This particular study indicates that nitrate leaching will increase in a future climate, mostly due to increased amounts of precipitation and higher temperatures, affecting both water balance and nitrogen balance. In addition, earlier harvests of spring cereals might contribute to higher leaching, since the soil will be left bare for a longer time period. This is unless another crop can be sown in the autumn or the spring crop can be combined with another type of catch crop. This study also demonstrated the need for careful parameterization of crop growth parameters as well as the importance of accounting for changes in crop varieties and therefore in crop growth characteristics. The uncertainty in both climate scenario input and the significance of using different “impact models” should preferably be explored by applying ensemble model runs both with respect to climate models and impact models.

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Karin Steffens, 2011-02-24

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# Appendix 1

All explanations are based on Jansson and Karlberg, 2004.

*Table 4. Overview of model set up which describes the most important equations and functions that are chosen for this particular study.*

| | FUNCTION | VALUE | EXPLANATION |
|---|---|---|---|
| **Common abiotic functions** | Temperature response | Ratowsky function | Temperature response function, which governs microbial activity, mineralization/immobilization and denitrification. |
| **Drainage and deep percolation** | Drive drain level | Parameter | Water level in the drainage system is set with a parameter. |
| | Physical Drainage equation | Hooghoudt model | When using this equation, drainage flow below the pipes are also considered. |
| **External N inputs** | N Deposition | On | Atmospheric deposition of mineral nitrogen. |
| | N fertilization | Parameters | 90 kg/ha/ year |
| **Interception** | Precipitation interception | On | Precipitation interception is accounted for. |
| | Snow interception | Off | |

| | | | |
|---|---|---|---|
| **Model structure** | Evaporation | Radiation input style | Physical based equation, which is accounting for net radiation as well as the transport of vapour in the boundary layer of the at-mosphere |
| | Ground water flow | On | Ground water is present in the soil if any layer reach-es saturation. |
| | Heat equation | On | Heat flows between the soil layers will be calculat-ed |
| | Nitrogen and Carbon | Dynamic interac-tion with abiotics | |
| | Plant type | Explicit big leafs | Transpiration from canopy and soil evaporation is treated as separate flows. Above ground plant char-acteristics can be described by various options. An array of leaves can be con-sidered by the model. |
| | Snow Pack | On | Snow is simulated by a sub-model which is ac-counting for snow accu-mulation, melting heat conduction and exchange of energy between snow and the atmosphere. |
| | Soil vapour | Only soil vapour flow | Calculations of water va-pour is determined by a gradient between adjacent soil layers. No flows be-tween snow and soil is ac-counted for. |

| | | | |
|---|---|---|---|
| | Water Equation | On with complete soil profile | Flow of water between adjacent soil layers are calculated. |
| **Plant** | Albedo Vegetation | Static | Specified by a parameter. |
| | Canopy-HeightInput | Simulated | The height of the canopy is simulated based on above ground biomass. |
| | LAI input | Simulated | The biomass of the leaves are simulated, and LAI is calculated. |
| | Plant development | Start=f(temperature sum) | Growing season starts and end with a temperature sum. Accumulation of temperature start when the day light is longer than 10 hours. |
| | Root distribution | Exponential | Exponential decrease of root density from the soil surface to the depth of the roots. |
| | RootInput | Simulated | Depth and length of the roots are calculated from the biomass. |
| **Plant growth** | Growth | Radiation use efficiency | Plant growth is proportional to the radiation absorbed by the canopy. And also is limited by unfavorable nitrogen, carbon, water and temperature conditions. |

| | | | |
|---|---|---|---|
| | Harvest day | Estimated GSI | GSI: Growth stage index.<br>-1 No plant exists (temperature sum)<br>0 Sowing (temperature sum)<br>1 Emergence of plant (day length and temperature sum)<br>2 Grain filling starts (temperature sum)<br>3 Maturing of grain (only time)<br>4 Harvest (temperature sum). |
| | Harvest range | All plants | |
| | Leaf Allocation Shoot | Linear function | Allocation from the leaf to the shoot is determined by a linear function, instead of, for instance an exponential. |
| | Litter fall dynamics | Static | Independent of air temperature. |
| | Plant respiration | Maintenance only | Plant respiration is only simulated as maintenance respiration, without growth respiration. |
| | Respiration Temp response | Q10 whole range | Plant growth response on a 10℃ soil temperature change. |
| **Soil hydraulic** | Conductivity function | Mualem | |
| | Hydraulic functions, pF-curve | Brooks & Corey | |

| | | | |
|---|---|---|---|
| | Matric conductivity | Independent | The actual matric conductivity is treated independently from the saturated matric conductivity. |
| **Soil Management** | Deep ploughing | On | |
| **Soil evaporation** | Evaporation method | PM-equation, Rs(3Par) | Soil evaporation is calculated with the PM-equation, but with an additional function which describes the resistance of the soil, governed by three parameters. |
| | Surface temperature | f(PM-equation) | |
| **Soil mineral N processes** | Default settings for all options | - | |
| **Soil Water flows** | Initial water conditions | Water content(z) | |
| **Validation mode** | Eight validation files | | |
| **Water uptake** | Basic equation | Pressure head response | Water uptake is calculated from a potential demand, and reductions are based on abiotic functions of soil water pressure head, osmotic potential and temperature. |
| | Demand redistribution | With flexible roots | Water uptake is flexible in the sense that if there is water deficiency in any soil layer, compensatory water uptake from another layer with roots will occur. |

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|---|---|---|---|
| | Temperautre response | Double exponential | Function used to determine temperature response on water uptake. |

*Table 5. Parameter settings of the model. Only parameters that differ from the default values within the model are presented.*

| TYPE | NAME | VALUE | UNIT | EXPLANATION |
|---|---|---|---|---|
| **Drainage and deep percolation** | $z_p$ | 0,9 | m | Depth of drainage pipes |
| | $d_p$ | 7 | m | Spacing between drainage pipes |
| **Interception** | $i_{LAI}$ | 0,2 | mm | Interception storage |
| | $r_{sint}$ | 5 | $sm^{-1}$ | Canopy resistance |
| **Albedo** | α | 0,25 | (-) | Leaf Albedo |
| **Soil evaporation** | $r_\psi$ | 100 | $sm^{-1}$ | Parameter in RS_3 that governs interactions between actual surface resistance and soil water tension in the top layer of the soil and also surface gradient of soil moisture. |
| | $r_{alai}$ | 34,455 | $sm^{-1}$ | LAIs contribution to the total aerodynamic resistance from a reference level to the soil surface. |
| | $z_{om}$ | 0,0003825 | | Roughness length for surface momentum above a bare soil surface. |
| **Radiation properties** | α | 0,23 | (-) | Albedo of a dry soil |
| | $l_{at}$ | 56,5 | (-) | |
| **Soil management** | $m_{p,day}$ | 254 | (-) | Ploughing day |
| | $m_{p,dep}$ | -0,25 | m | Ploughing depth |

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| **Soil Heat Flows** | $\Delta T_{pa}$ | 0 | ℃ | Difference between soil temperature and infiltrating precipitation |
| **Soil mineral N processes** | $d_{pot}$ | 0,1477 | $gN/m^2/day$ | Parameter which is dependent on cropping system and soil |
| | $\rho_{\theta dp}$ | 2 | (-) | Coefficient in the dentitrification response function |
| | $n_{Uptflex}$ | 1 | (-) | Parameter that governs the flexibility of N uptake from layers with excess of nitrogen. |
| **Soil organic processes** | $i_{h,d}$ | -0,5 | m | Initial depth for where humus is distributed |
| | $i_{h,n}$ | 725 | $gN/m^2$ | The initial amount of nitrogen contained in humus for the total soil profile. |
| | $i_{l1,CN}$ | 20 | (-) | Initial C/N ratio for the litter in pool 1 |
| | $i_{l2,CN}$ | 14,1137 | (-) | Initial C/N ratio for the litter in pool 2. |
| | $k_h$ | 0,0001877 | /day | Rate coefficient for decomposition of humus. |
| **Water Uptake** | $\psi_c$ | 800 | cm water | When the pressure head exceeds this critical pressure head, reduction of water uptake will occur. |
| | $f_{umov}$ | 0,5 | (-) | Water uptake can occur from different soil layers, if the tension is too high in some layers. Compensatory water uptake is controlled by this parameter. |

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|---|---|---|---|---|
| **External N inputs** | $p_{dry}$ | 0.0015 | $gN/m^2/day$ | Dry deposition of nitrogen on to the soil surface. A value of 0.001 corresponds to 3.65 kg N/ha |
| | $p_{cwet}$ | 1.2 | $gN/m^2/day$ | Concentration of mineral N in surface water and water that potentially infiltrates the soil. |
| **Common abiotic responses** | $p_{\theta, low}$ | 10 | vol % | An interval of water content which usually can range within 0-15, within the response function for mineralization, nitrification, denitrification and microbial activity. |
| **Numerical** | NC Iteration | 4 | # | Time step for calculations of nitrogen and carbon processes in the soil. |
| **Metereological data** | $T_{aamp}$ | 7 | ℃ | The analytical air temperature amplitude |
| | $T_{amean}$ | 11 | ℃ | A mean value in the air temperature function |
| | $T_{ph}$ | 22 | days | In the air temperature day number function, where a positive value will move the air temperature forward in time. |