User's Guide for the DNDC Model

(Version 9.1)

Institute for the Study of Earth, Oceans and Space
University of New Hampshire

April 15, 2007

ACKNOWLEDGEMENT

We would like to acknowledge the US Environmental Protection Agency (EPA), National Aeronautics, Space Administration (NASA), National Science Foundation (NSF), Department of Agriculture (USDA)/Forest Service, National Oceanic and Atmospheric Administration (NOAA), and National Center for Atmospheric Research (NCAR/UCAR), which provided grants to support development of the DNDC model during the past 18 years since 1989. Researchers who made contributions to the model by either providing data for validation or developing new features are Changsheng Li (USA), Steve Frolking (USA), Robert Harriss (USA), Richard Terry (USA), Michael Keller (USA), Patrick Crill (USA), Antje Weitz (Germany), Ted Peck (USA), Wayne Wendland (USA), David Jenkinson (UK), Yingping Wang (Australia), Yahui Zhuang (China), Zhaohua Dai (China), Roel Plant (The Netherlands), Ye Zhou (China), Yu Zhang (China), Qinghua Lin (China), Xiaoke Wang (China), Florian Stange (Germany), Klaus Butterbach-Bahl (Germany), Hans Papen (Germany), Sophie Zechmeister-Boltenstern (Austria), Xunhua Zheng (China), Jianzhong Sun (China), Xiaoguang Qin (China), Steve Jarvis (UK), Bronwyn Syed (UK), Lorna Brown (UK), Ray Desjardins (Canada), Ward Smith (Canada), Brian Grant (Canada), Ron Sass (USA), Yao Huang (China), Zucong Cai (China), Guoding Kang (China), Jariya Boonjawat (Thailand), Haruo Tsuruta (Japan), Takuji Sawamoto (Japan), Kazuhiko Kobayashi (Japan), Jianjun Qiu (China), Ralf Kiese (Germany), Carl Trettin (USA), Sun Ge (USA), Cheng-I Hsieh (Taiwan), R. Lemke (Canada), Surinder Saggar (New Zealand), Robbie Androw (New Zealand), Arvin Mosier (USA), Carlos Eduardo (Brazil), Genwei Cheng (China), Cari Minkkinen (Finland), Reiner Wassmann (Germany), Nui Smakgahn (Thailand), Xu Ri (China), Rhoda Lantin (Philippines), Robert Rees (UK), Yoko Nakagawa (Japan), Neda Farahbakhshazad (USA), William Salas (USA), Steve Boles (USA), Tamon Fumoto (Japan), Magda Kesik (Germany), Donna Giltrap (New Zealand), Himanshu Pathak (India), Jagadeesh Babu Yeluripati (India), Daan Baheydt (Belgium), Steven Sleutel (Belgium), Dan Jaynes (USA), Dana Dinnes (USA), Dennis McLaughlin (USA), and Christina Tonitto (USA).

TABLES OF CONTENTS

I. DNDC Overview

1. Introduction
2. DNDC Model Description

II. PC Windows Version of DNDC

1. Overview of a Modeling Session
2. Hardware Requirements
3. Installation
4. Site and Regional Modes

III Model Operation

1. Site Mode

1.1. Input Parameters

- Page 1: Site and climate
- Page 2: Soil
- Page 3: Farming management
- Page 4: Crop
- Page 5: Tillage
- Page 6: Fertilization
- Page 7: Manure amendment
- Page 8: Weeding
- Page 9: Flooding
- Page 10: Irrigation
- Page 11: Grazing and cutting

1.2. Save and Open Input File
1.3. Run DNDC at Site Scale
1.4. A Quick View of Modeled Results
1.5. Batch Run

2. Regional Mode

2.1. GIS Databases
2.2. Library Databases
2.3. Initiate Regional Simulation
2.4. Run DNDC at Regional Scale

IV Modeled Results

1. Results from Site Runs
2. Results from Regional Runs

V Uncertainty Analysis

VI Relevant Publications

I. DNDC OVERVIEW

1. Introduction

The DNDC model is a general model of carbon (C) and nitrogen (N) biogeochemistry in agricultural ecosystems. This document describes how to use the PC Windows versions of the DNDC model for predicting C sequestration, trace gas emissions, crop yield, and N leaching in the agroecosystems. Part I gives a brief description of the model structure and the scientific basis for the model. Part II tells how to install the software, run the model, and look at results. Part III demonstrates how to run the site version of DNDC step-by-step. Part IV explains how to run DNDC at regional scale. A list of relevant publications of DNDC is included in Part V. These publications describe the DNDC model and its applications in detail.

DNDC9.1 can run in two modes: site or regional. Based on the mode selected, a proper interface will be loaded to process the corresponding input data. This version has been calibrated and validated at site scale against numerous field data sets measured in temperate and tropical agro-ecosystems. This version may not produce proper results if applied to non-agricultural areas.

2. DNDC Model Description

The Denitrification-Decomposition (DNDC) model is a process-oriented computer simulation model of soil carbon and nitrogen biogeochemistry. The model consists of two components. The first component, consisting of the soil climate, crop growth and decomposition sub-models, predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles driven by ecological drivers (e.g., climate, soil, vegetation and anthropogenic activity). The second component, consisting of the nitrification, denitrification and fermentation sub-models, predicts NO, N_2O, N_2, CH_4 and NH_3 fluxes based on the modeled soil environmental factors. Classical laws of physics, chemistry and biology, as well as empirical equations generated from laboratory studies, have been employed in the model to parameterize each specific geochemical or biochemical reaction. The entire model forms a bridge between C and N biogeochemical cycles and the basic ecological drivers (Figure 1).

In DNDC, soil organic carbon (SOC) resides in four major pools: plant residue (i.e., litter), microbial biomass, humads (i.e., active humus), and passive humus. Each pool consists of two or three sub-pools with different specific decomposition rates. Daily decomposition rate for each sub-pool is regulated by the pool size, the specific decomposition rate, soil clay content, N availability, soil temperature, and soil moisture. When SOC in a pool decomposes, the decomposed carbon is partially allocated into other SOC pools, and partially lost as CO_2. Dissolved organic carbon (DOC) is produced as an intermediate during decomposition, and can be immediately consumed by the soil microbes. During the processes of SOC decomposition, the decomposed organic nitrogen partially transfers to next organic matter pool and is partially mineralized to

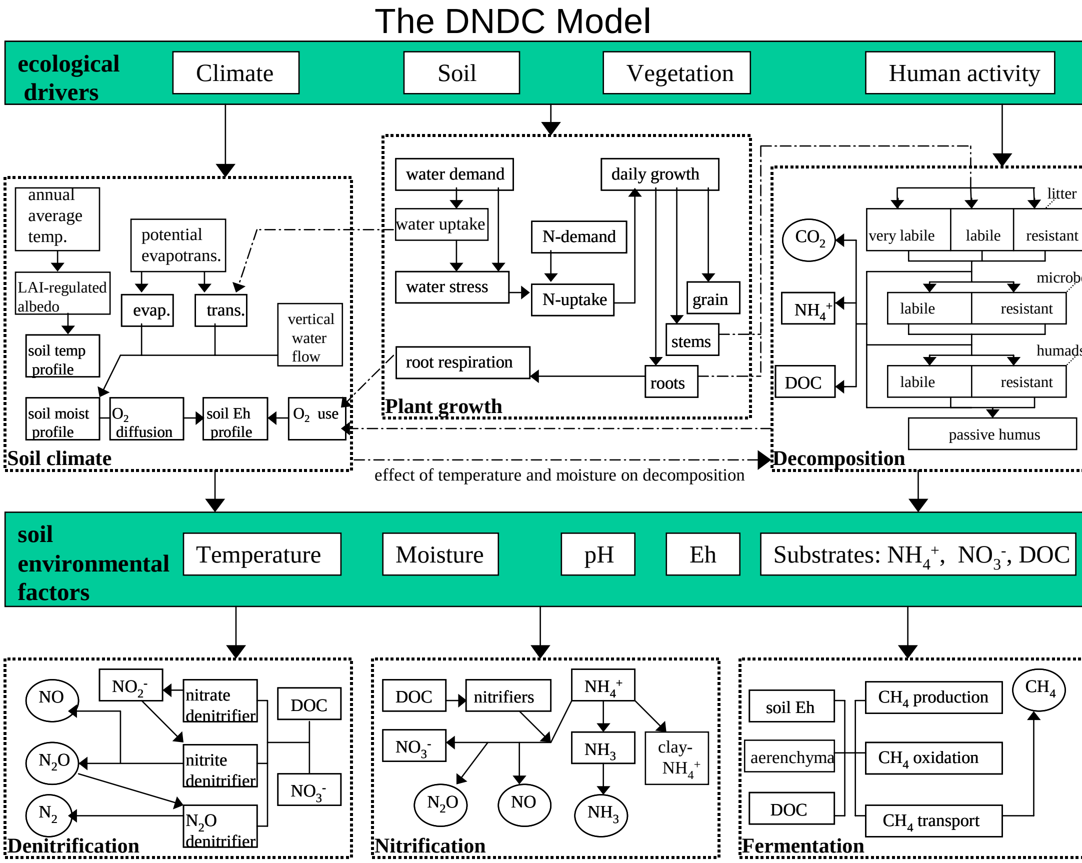


Figure 1. Structure of the DNDC model.

ammonium (NH_4^+), which is then subject to nitrification. The free ammonium concentration is in equilibrium with both clay-adsorbed NH_4^+ and dissolved ammonia (NH_3). Volatilization of NH_3 to the atmosphere is controlled by NH_3 concentration in the soil water phase and soil environmental factors (e.g., temperature, moisture, and pH). When a rainfall occurs, NO_3^- is leached into deeper layers with the soil water flow. A simple kinetic scheme "anaerobic balloon" in the model predicts soil aeration status by calculating oxygen diffusion and consumption in the soil profile. Based on the predicted redox potential, the soil at each layer is divided into aerobic and anaerobic parts where nitrification and denitrification occur, respectively. When the anaerobic balloon swells, more substrates (e.g., DOC, NH_4^+, and N oxides) will be allocated to the anaerobic microsites to stimulate denitrification. When the anaerobic balloon shrinks, nitrification will be enhanced. Gases NO and N_2O produced in either nitrification or denitrification are subject to further transformation during their diffusion between the aerobic and anaerobic microsites. Long-term (e.g., several days to months) submergence will activate fermentation, which produces hydrogen sulfide (H_2S) and methane (CH_4) driven by decreasing of the soil Eh.

There are two options for simulating crop growth. If the empirical approach is selected, crop growth will be calculated based on accumulative temperature, optimum crop biomass, N stress, and water stress at a daily time step. If the process-based approach is selected, crop development and growth will be tracked by photosynthesis, respiration, and C allocation based on not only the above listed environmental factors but also several physiological or phenology parameters such as initial efficiency of use of absorbed light, maximum rate of leaf photosynthesis, rate of crop development in vegetative stage, rate of crop development in reproductive phase, and initial biomass at emergency. The process-based modules adopted from the MACROS model (Penning et al., 1989). Crop demand for N is calculated based on the optimum daily crop growth and the plant C/N ratio. The actual N uptake by crop could be limited by N or water availability during the growing season. After harvest of the crop, all of the root biomass is left in the soil profile, and a user-defined fraction of the above-ground litter remain as stubble in the field until next tilling application, which will incorporate the stubble onto (for no-till) or into (for conventional tillage) the soil profile. The crop litter incorporated in the soil will be partitioned into different soil organic matter pools based on the C/N ratio of the litter. Please find detailed information about impacts of farming management on soil C and N dynamics in former publications (e.g., Li et al., 1992; Li et al., 1994; Li 2000; Li et al., 2004; Li et al., 2006).

The entire model is driven by four major ecological drivers, namely climate, soil physical properties, vegetation, and anthropogenic activities. Obtaining accurate input data will ensure the success of your simulations at either site or regional scale. The details for how to prepare the input parameters are discussed in the relevant chapters of this guide.

II. PC WINDOWS VERSION OF DNDC

1. Overview of a Modeling Session

The DNDC model predicts C and N biogeochemistry in agricultural ecosystems at site or regional scale. For site runs, users need to input all of the required driving parameters through the user's input interface. During regional runs, DNDC reads all of the driving parameters from a set of databases, which must be prepared in advance. DNDC simulates agricultural C and N dynamics through a year to centuries.

You start the modeling session by installing the model on your computer. The model is written in Visual C++ and must be executed in the Windows environment.

2. Hardware Requirements

The DNDC model requires an PC or compatible with Windows installed. A minimum memory of 64M is required. The computers with speed of 350MHz or higher are highly recommended. A graphics adapter of SVGA or higher is recommended. The output files from a 100-year simulation requires about 0.5 MB of disk space. A Windows screen with 1024 by 768 pixels resolution will ensure the best graphic output.

3. Installation

You can download a zipped package at our web site http://www.dndc.sr.unh.edu, which contains a folder named DNDC with an installation batch file. After unzipping the package, double click "Install". All of the directories and files of DNDC will be automatically created in the C drive of your computer.

The folder DNDC in your C drive contains the latest version of DNDC (e.g., DNDC89) and supporting data sets. At C:\DNDC\Database\, there is a subdirectory named Shangrila, which contains a complete set of regional input data for the illusive region. However, the Shangrila datasets provide an example for preparing input data sets. Following the formats of the files of Shangrila, users can easily create their own databases for their own regions.

Now, you are ready to run DNDC. Go to C:\DNDC, and click DNDC89 to start the model.

4. Site and Regional Modes

When the model starts, a main menu will be shown on the screen (Figure 2).

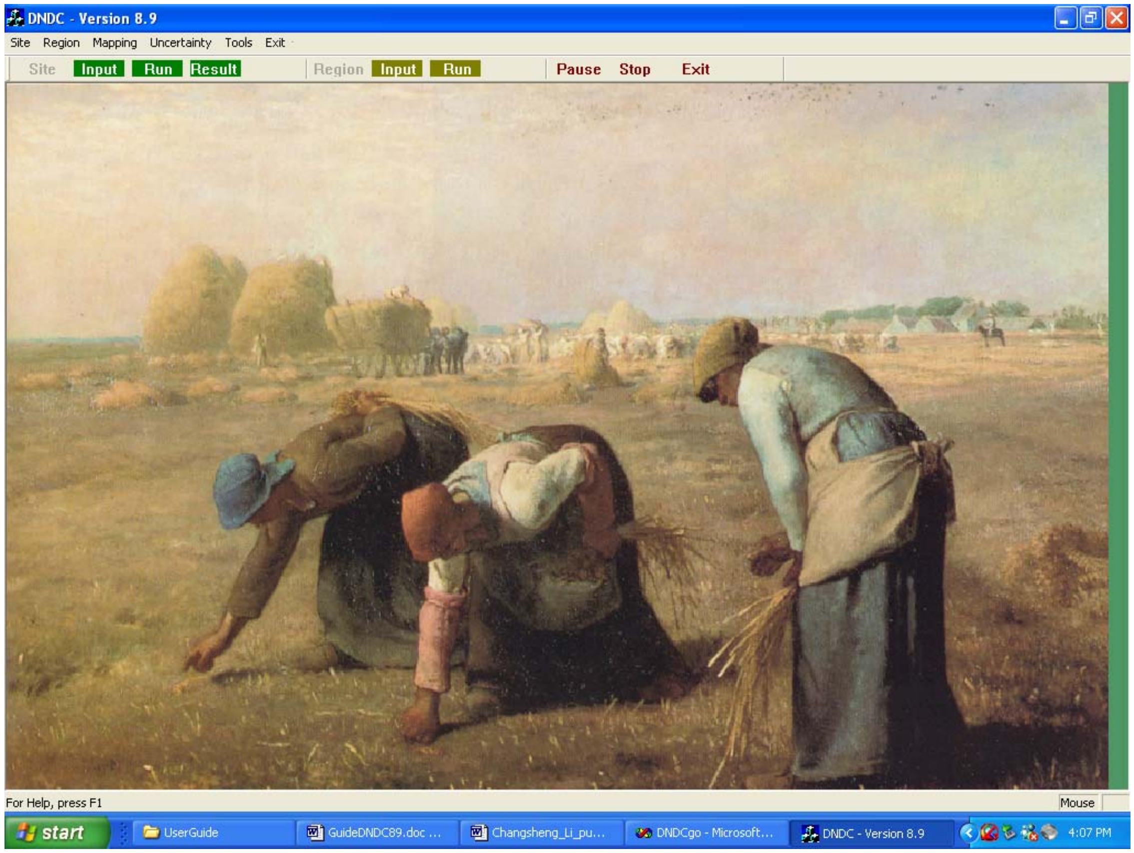


Figure 2. Main menu of DNDC

***The Site Mode*:**

Clicking the “Input” button by the sign “Site” on the main menu will initiate the input procedure in site mode. There are three major pages for inputting (1) climate information, (2) soil information, and (3) farming management information, respectively. The farming management page contains eight sub-pages to allow you to define the most popular management approaches, such as crop type and rotation, tillage, fertilization, manure amendment, irrigation, flooding, weeding, grazing and grass cutting. During the input process, you can come back to any specific page to make modifications. The only thing needed to keep in your mind is to click the “Accept” button when you finish the input or modification for each page. Your input data or modifications will be lost if you leave the page without clicking “Accept”. When all the inputs have been typed in for all the pages, click the OK button at the bottom of the climate page to end the input procedure. At this moment, you are ready to start the site simulation by clicking button “Run”.

At the beginning of each simulated year, DNDC first reads in all the input information for the specific year, and then executes the sub-models in the order “soil climate – plant growth – decomposition – nitrification – denitrification – fermentation”. Soil climate profiles are first calculated based on the daily climate data and soil properties at an hourly time step. Then DNDC simulates plant growth as well as exchange of water, C and N at the atmosphere/plant/soil interfaces based on climatic conditions, farming practices, and soil water and N availabilities at a daily time step. Decomposition is calculated based on soil climate profile and N availability at a daily time step. Nitrification and denitrification are predicted at an hourly time step driven by the dynamics of the “anaerobic balloon” and relevant substrates. If a flooding event occurs, DNDC will track soil Eh decrease driven by the sequential reductions of nitrate, nitrite, Mn^{4+}, Fe^{3+} and sulfate. At certain low Eh conditions, the fermentation sub-model will be activated to calculate methane (CH_4) production at a daily time step. If you require during the input procedure, DNDC will record the modeled daily results of soil C pools/fluxes, N pools/fluxes, soil temperature and moisture profile, and plant biomass at the end of each of the simulated days. Following this simulating sequence, DNDC continuously runs day-by-day. When the simulation reaches the December 30th of a year, DNDC will shift to the January 1st of next year. The simulation will continue year-by-year until reaching the end of the last year. At the end of each simulation year several files are created to record the annual C and N pools and fluxes, crop yield, and water balance for the simulated site. The files are stored in subdirectory "C:\DNDC\Result\Record\Site\".

The Regional Mode:

To run DNDC in regional mode, you will need to have all the input data compiled in a database in advance. The database consists of two categories of data files: Geographic Information System (GIS) files and library files. The GIS files hold all of the spatially differentiated information including name/location, climate data file ID, soil properties, and crop acreage for each of the grid cells within the simulated domain. Map data for region is optional. The library files store the data of general information, such as crop physiological/phenology parameters, soil thermal/hydraulic parameters, farming practices for crops, or daily climate data. We highly recommend users review the data files provided with the DNDC package for the example region “Shangrila” to become familiar with the structure, content and format of the database before they start composing their own databases.

As soon as your regional database is set up, you will be ready to conduct the regional runs. The detailed information about the database construction, simulation procedure and results is described in section “III. Model Operation: 2. Regional Mode”.

III. MODEL OPERATION

By clicking DNDC89.exe at C:\DNDC, you will start the model. At first, you will see a main menu (Figure 2). On this menu, you can choose to run DNDC in site or regional mode.

1. Site Mode

In the site mode, most of the input parameters will be typed in manually through the input pages. Let's start. Click the "Input" button by "Site" in the main menu. See, a new page is opened. This is the "Climate" page (Figure 3).

1.1. Input Parameters

Page 1. Climate

This is the first page to initiate the input procedure for site simulations. This page allows you to input site location and climate information. You need to type in the site name and other required information. DNDC provides default values for atmospheric background concentrations of ammonia (NH_3) and carbon dioxide (CO_2). You can keep or modify the default values. The required daily climate data file(s) can be selected by clicking button "Select Climate File". When you finish all the input items for this page, just click button "Accept" to move all of the input information into the computer's memory.

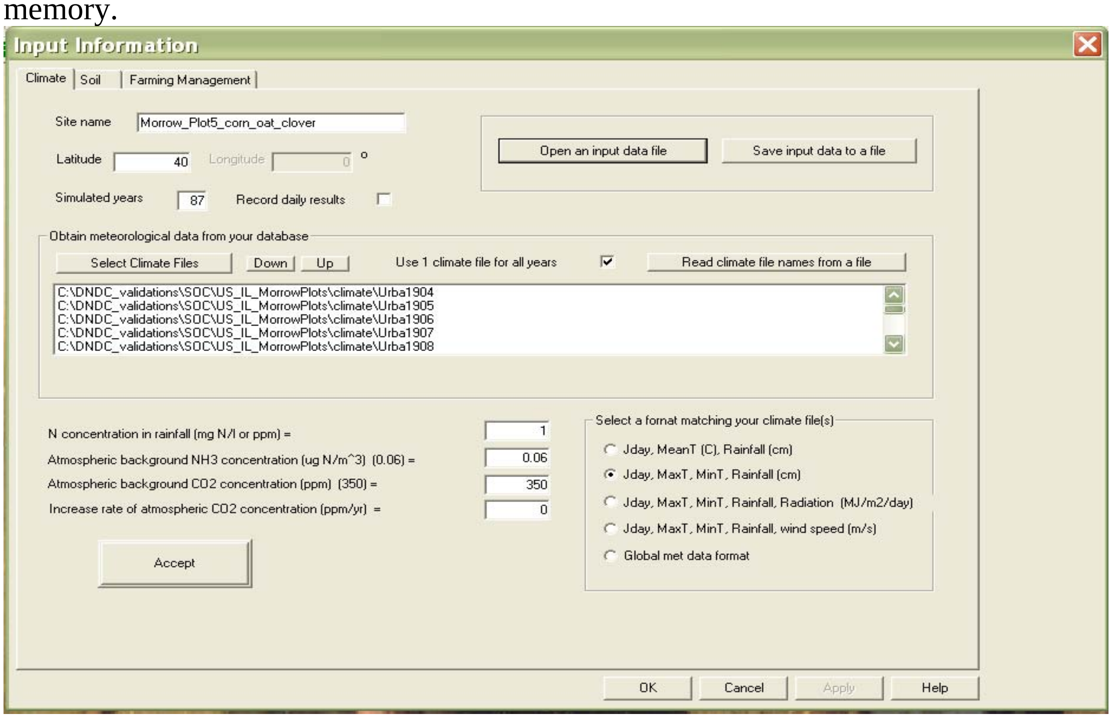


Figure 3. Input information for location and climate

[***Site name***]: A string for site name (no space is allowed in the string);

[***Latitude***]: The latitude (decimal unit) of site location;
[***Simulated years***]: An integer number for total simulated years.
[***Record daily results***]: Checking this box will have the simulated daily results recorded.
[***Climate File Format***]: Select the format consistent with your climate data file(s);
[***Select Climate File***]: Click this button to browse and select the required climate file(s). Use Down and Up to adjust the order of the climate files. Double-clicking a file name will delete it from the list.
[***Use 1 climate file for all years***]: Checking this box will enable you to use one selected climate file for all the simulated years.
[***Read climate file names from a file***]: Puss this button will enable you to read all the required climate files names from a file prepared in advance. The format of the list file is as follows:

```
5
C:\DNDC\datafiles\urbana1990
C:\DNDC\datafiles\urbana1991
C:\DNDC\datafiles\urbana1992
C:\DNDC\datafiles\urbana1993
C:\DNDC\datafiles\urbana1994
```

[***N concentration in rainfall (mg N/l or ppm)***]: Annual average N (dissolved nitrate and ammonium) concentration in rainfall in unit mg N/l or ppm.
[***Atmospheric background*** $\boldsymbol{NH_3}$ ***concentration (ug N/m^3) (0.06)***]: Atmospheric background concentration of NH_3 (the default value is 0.06 ug N/m^3).
[***Atmospheric background CO2 concentration (ppm) (350)***]: Atmospheric background CO_2 concentration with a default value 350 ppm.
[***Increase rate of atmospheric CO2 concentration (ppm/yr)***]: For multi-year simulations, the atmospheric CO_2 concentration can be changed by setting this annual change rate.

Daily meteorological data file(s) must be prepared in advance. The file(s) should have a plain text (i.e., ASCII) format. Each year has an individual file. The climate data file can be constructed with five different formats based on the availability of the original data sources or the purpose of the simulation.

Format 1:

```
IA1987
1       -2.5        0.0
2       -1.0        1.2
3       -0.5        0.5
4        1.7        0.0
.
.
365      5.6        0.0
```

The first line is a file name. The first column contains dates in Julian day, the second column contains mean daily air temperatures in ºC, and the third column contains daily precipitation in cm.

Format 2:

IA1987			
1	-0.5	-4.5	0.0
2	0.0	-1.2	1.2
3	3.5	0.8	0.5
4	5.7	2.0	0.0
.			
.			
365	5.6	-0.2	0.0

The first line is a file name. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, and the forth column daily precipitation in cm.

Format 3:

IA1987				
1	-0.5	-4.5	0.0	1.23
2	0.0	-1.2	1.2	1.59
3	3.5	0.8	0.5	3.20
4	5.7	2.0	0.0	2.25
.				
.				
365	5.6	-0.2	0.0	1.11

The first line is a file name, which must be a string. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, the forth column daily precipitation in cm, and the fifth column solar radiation in million J/m^2/day.

Format 4:

IA1987				
1	-0.5	-4.5	0.0	0.25
2	0.0	-1.2	1.2	1.10
3	3.5	0.8	0.5	0.80
4	5.7	2.0	0.0	0.02
.				
.				
365	5.6	-0.2	0.0	0.00

The first line is a file name, which must be a string. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, the forth column daily precipitation in cm, and the fifth column daily average wind speed in m/second.

Page 2: Soil

Click the "***Soil***" button at the top of the current sheet (i.e., Figure 3) to open the soil page (Figure 4). All of the main soil parameters, including the defaults or the user-defined, will be defined on this page. When the input process is done, don't forget clicking the  button to move the input data into the computer's memory. Leaving the page without clicking "Accept" will lose the newly input or modified data.

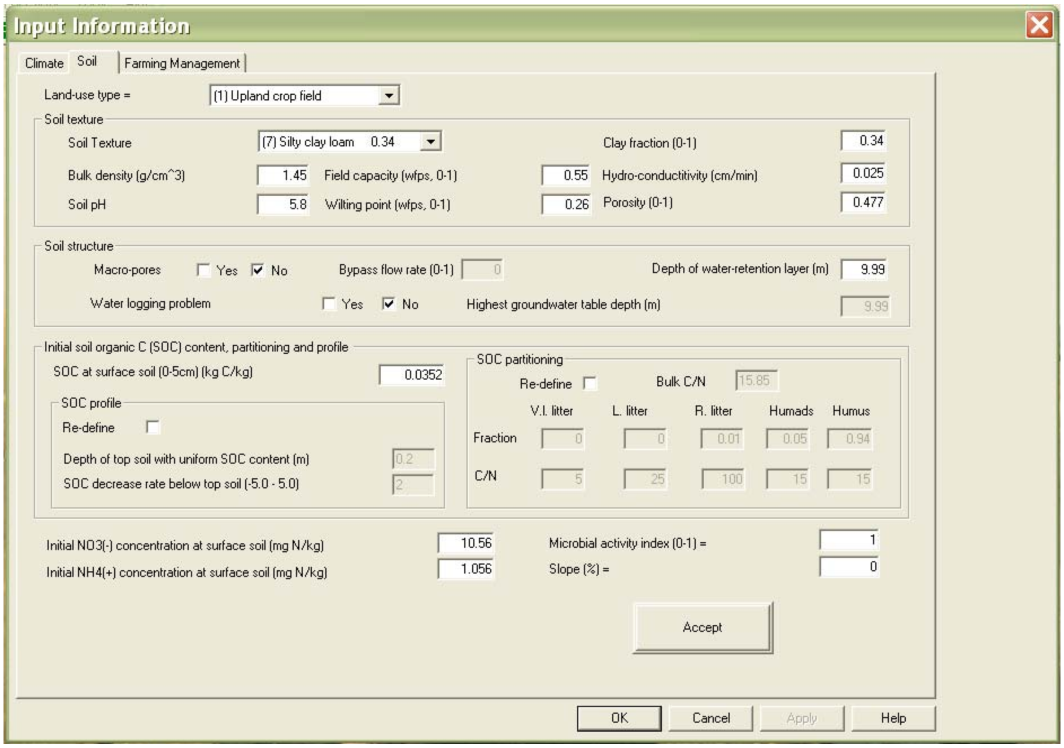


Figure 4. Input information for soil properties

[***Land-use***]: Current land use. Options are u*pland crop field, rice paddy field, moist grassland/pasture, and dry grassland/Pasture.*

[***Soil Texture***]: Select soil type based on either its texture or clay fraction. There are 12 soil types including s*and, loamy sand, sandy loam, silt loam, loam, sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay, clay, and organic soil.*

[***Bulk density (g/cm^3)***]: Bulk density (g/cubic cm) of top soil (0-10 cm).

[***Soil pH***]: pH of top soil.

[***Clay content (0-1)*]:** Clay fraction of soil by weight. When soil texture is selected, default clay content will be given although it can be modified by users.

[***Field Capacity (0-1)***]: Water-filled porosity (WFPS) at soil field capacity. When soil texture is selected, default field capacity value will be given although it can be modified by users.

[***Wilting Point (0-1)***]: Water-filled porosity (WFPS) at soil wilting point. When soil texture is selected, default wilting point value will be given although it can be modified by users.

[***Macro-pores and bypass flow***]: Select "Yes" if there are macro-pores and bypass flow applicable to this soil (usually for tropical soils).

[***Depth of water retention layer (cm)***]: Depth of water retention layer, which could be formed by soil compaction (common for intensively grazed pasture) or clay pan.

[***SOC at surface soil (0-5cm) (kg C/kg)***]: Content of total soil organic carbon (SOC), including litter residue, microbes, humads, and passive humus at surface layer (0-5 cm). After defining the total SOC content, you can obtain the default SOC profile as well partitioning values for SOC sub-pools (i.e., litter, humads or passive humus).
[***SOC profile: Re-define***]: Checking this box will activate the process to re-define the SOC profile.
[***Depth of top soil with uniform SOC content (m)***]: A depth, above which the SOC content is uniform.
[***SOC decrease rate below top soil (-5.0 – 5.0)***]: A rate, which determines how fast the SOC content decreases below the top soil. The higher the rate, the faster the SOC content decreases. Negative rates mean SOC content increases along with increase in the soil depth.
[***Soil partitioning: Re-define***]: Checking this box will activate the process to re-define the SOC partitioning.
[***V.l. litter***]: Fraction of very labile litter pool.
[***L. litter***]: Fraction of labile litter pool.
[***R. litter***]: Fraction of resistant litter pool.
[***Humads***]: Fraction of humads (active humus) pool.
[***Humus***]: Fraction of passive humus pool.
[***Initial NO3(-) concentration at surface soil (mg N/kg)***]: DNDC calculates default initial nitrate content at surface layer based on soil organic carbon content. You can replace the default with your observed data.
[***Initial NH4(+)concentration at surface soil (mg N/kg)***]: DNDC calculates default initial ammonium content at surface layer based on soil organic carbon content. You can replace the default with your observed data.
[***Microbial activity index (0-1)***]: An index raging from 0.0 to 1.0 for indicating impact of soil toxic materials on soil microbial activity. The default value 1.0 is for normal soils.
[***Depth of water-retention layer (cm)***]: If there is a water-retention layer existing withing the simulated soil profile (i.e., 0-100 cm), define the depth of the layer.
[***Slope (0-90)***]: Slope of the soil surface in degree. The slope for a level soil is 0.
[***High groundwater table***]: Select "Yes" if the groundwater table is seasonally or the year around above the bottom of the simulated soil profile (0-50 cm).

Page 3. Farming management

Clicking the Farming button at the top line will open a new page for inputting farming management information. On this page, you can construct your cropping system by defining the number of rotations during the entire simulated years, the time span (years) of each rotation, and the number of years of a cycle in a rotation.

[***Total years***]: Number of total years of this simulation. This number is automatically set based on the total years input on page "Climate".
[***Number of cropping systems applied during the entire simulated years***]: Number of

different cropping systems consecutively applied during the entire simulated time span.
[***Cropping system #***]: Cropping system sequential number.
[***Duration***]: Number of the years this cropping system lasts for.
[***Years of a cycle***]: Number of the years a cycle of this cropping system has.
[***Year in a cycle***]: Sequential number of the year in a cycle for current input process.

Farming management practices (e.g., crop planting/harvest, tillage, fertilization, manure amendment, irrigation, flooding, grazing, and grass cutting) will need to be defined for each year in a cycle of the cropping system. You can define or review the management practices for each specific year in each specific cropping system by select the right numbers at [***Cropping system #***] and [***Year in a cycle***].

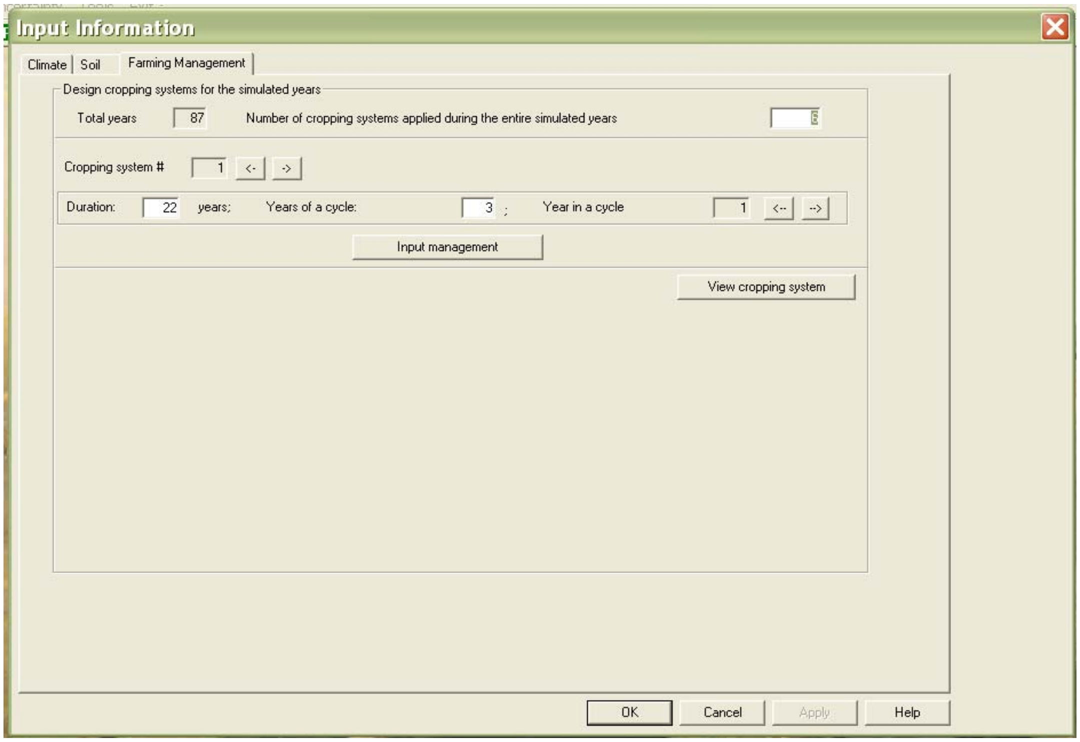


Figure 5. Rotation information: Cropping systems and Cycles

Below-listed is an example to illustrate how to define the cropping systems for a long-term simulation.

(1) How many years I am going to simulate totally:
- 100 years;
(2) How many cropping systems are involved in the simulation:
- 2 cropping systems (corn-soybean rotation system, and then winter wheat-fallow-alfalfa rotation system);
(3) How many years each cropping system lasts for:
- The corn-soybean system lasts for 40 years, and the winter wheat-fallow-alfalfa system lasts for 60 years;
(4) How many years a cycle takes in each system:
- A cycle of the corn-soybean system takes 2 years, and a cycle of the winter wheat-fallow-alfalfa

system takes 3 years;

(5) What farming practices take place in each year of each cycle:

- For year 1 of the corn-soybean cycle, plant corn with two applications of conventional tillage and an application of 120 kg urea-N/ha. For year 2 of the cycle, plant soybean with two applications of conventional tillage with no fertilizer used.
- For year 1 of the winter wheat-fallow-alfalfa cycle, plant winter wheal with two applications of tillage and an application of 100 kg urea-N/ha. For year 2 of the cycle, fallow the land after harvest of the winter wheat with no tillage and no fertilizer used. For year 3 of the cycle, plant alfalfa with an application of tillage and no fertilizer used.

A scheme can be plotted based on the above-described 100-year cropping systems as follows:

Total years (100):
Total cropping systems (2):
Years of system 1 (40)
Years of a cycle of system 1 (2)
Management for year 1 of the cycle: corn
Management for year 2 of the cycle: soybean
.
.
.

Years of system 2 (60)
Years of a cycle of system 2 (3)
Management for year 1 of the cycle: winter wheat
Management for year 2 of the cycle: fallow
Management for year 3 of the cycle: alfalfa

.

A 100-year scenario will be automatically constructed by DNDC with the user-defined farming practices for the five specific years with corn, soybean, winter wheat, fallow and alfalfa is planted, respectively. The following several paragraphs explain how to define the farming practices.

The “Review” button on this page can provide a graphic view of the cropping systems you have input to DNDC.

Page 4. Crop

Click “Input Management” on page “Farming Management” to start the procedure for inputting farming practices for the selected year. The first page “Crop” (Figure 6) allows you to define (1) crop physiological and phenology parameters, (2) types of the crops consecutively planted in this year, (3) planting and harvest dates, (4) maximum biomass production (DNDC will give you default values, but you can modify them), and (5) fraction of above-ground crop residue left in the field after harvest (Figure 6).

[***Number of new crops consecutively planted in this year****:*]: Number of crops consecutively planted in this year. Only the new crops planted within this year are counted.

[***Crop #***]: Crop sequential number.

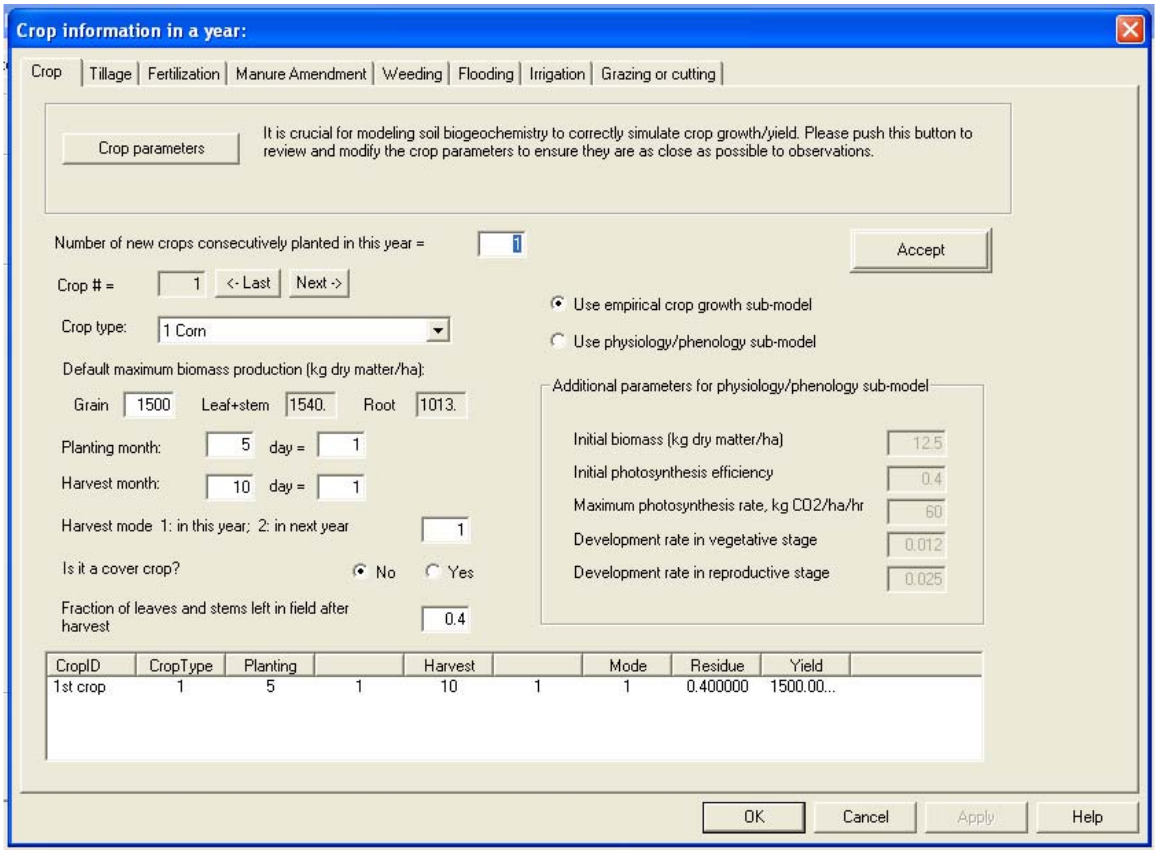


Figure 6. Input information for crop type, planting/harvest dates and residue management

[***Crop type***]: Select one of the crop types parameterized in DNDC. The options are

0 Fallow
1 Corn
2 Winter wheat
3 Soybean
4 Legume hay
5 Non-legume hay
6 Spring wheat
7 Sugarcane
8 Barley
9 Oats
10 Alfalfa
11 Grassland
12 Perennial grass
13 Sorghum
14 Cotton
15 Rye
16 Vegetables

17 Undefined
18 Potato
19 Beet
20 Paddy_rice
21 Banana
22 Celery
23 Peanut
24 Upland_rice
25 Rapeseed
26 Tobacco
27 Millet
28 Sunflower
29 Beans
30 Deep water rice
31 Onion
32 Undefined
33 Strawberry
34 Lettuce
35 Artichoke
36 Nursery flowers
37 Brussels sprout
38 Berries
39 Truck crops
40 Fruit trees
41 Citrus
42 Grapes
43 Silage corn
44 Hops
45 Tomato
46 Rainfed rice
47 Mixed cover crop
48 Safflower
49 Flax

[***Default maximum biomass production (kg dry matter/ha): Grain/Leaf+Stem/Root***]: Default values for production of grain, leaf+stem and root for the selected crop based on its physiological parameters defined in the crop library files (see details in III. 3.3. Crop Files). The default values can be modified by users by altering the grain yield.

[***Planting month***]: A number from 1 to 12.
[***Planting day***]: A number from 1 to 31.
[***Harvest month***]: A number from 1 to 12.
[***Harvest day***]: A number from 1 to 31.
[***Harvest mode***]: A integer number indicating if the crop is harvested in this year as it is planted (1), or harvested in the next year (2).

[***Is it a cover crop?***]: Selecting "Yes" will define the selected crop as a cover crop, whose total biomass will be left in the field without any fraction harvested by the end of the crop season.

[***Fraction of leaves and stems left in field after harvest***]: Specify a fraction of total above-ground crop residue (leaves and stems) left as stubble or litter in the field after harvest.

[***Use empirical crop growth sub-model***]: Click this radio button will select using an empirical model to simulate crop growth based on the crop physiological/phenology parameters, accumulative temperature, and soil water and N availability.

[***Use physiology/phenology sub-model***]: Click this radio button will select using a physiological model to simulate crop development and growth.

[***Initial biomass (kg dry matter/ha)***]: Crop biomass at germination.

[***Initial photosynthesis efficiency***]: Initial efficiency of use of absorbed light (kg CO_2/ha/hr)/(J/m^2/s).

[***Maximum photosynthesis rate***]: Maximum rate of leaf photosynthesis, kg CO_2/ha/h.

[***Development rate in vegetative stage***]: Rate constant of crop development in vegetative stage (1/day).

[***Development rate in reproductive stage***]: Rate constant of crop development in reproductive phase (1/day).

If you have a second crop planted in the year, click button "Next->" to define the parameters for the second crop.

It is crucial for modeling soil biogeochemistry to correctly simulate crop growth and production. By clicking button "Crop parameters" in Figure 6, you can review and modify the physiological and phenology parameters defined by DNDC as defaults of the concerned crops. The parameters listed in the left column in Figure 7 can be modified by users. The alterable parameters include:

[***Crop name***]: Name of the crop.

[***Maximum grain production, kg dry matter/ha***]: Grain production of the crop.

[***Grain (or harvested) fraction of total biomass***]: A fraction (0-1) of total biomass (i.e., grain + leaves + stems + roots), which is taken from the field at harvest.

[***Leaf+stem (or above-ground residue) fraction of total biomass***]: A fraction (0-1) of total biomass (i.e., grain + leaves + stems + roots), which is left in the field after harvest.

[***Root fraction of total biomass***]: Root fraction (0-1) of total biomass (i.e., grain + leaves + stems + roots).

[***C/N ratio for grain***]: Ratio of C vs. N contents in the grain of the crop.

[***C/N ratio for leaf+stem***]: Ratio of C vs. N contents in the leaves and stems of the crop.

[***N fixation index***]: For legume crops, the N fixation index equals ratio of total N content in the plant/the plant N taken from soil.

[***Water requirement***]: Potential water demand of the crop, which is defined as the water required to produce a unit of crop biomass (kg water/kg dry matter of crop).

[***Maximum LAI***]: Maximum leaf area index of the crop.

[***Maximum height, m***]: Maximum height of the crop in meter.
[***Accumulative degree days for maturity (TDD), °C***]: The accumulative daily average air temperature (>0°C) from seeding to maturity for the crop.
[***Initial biomass (kg dry matter/ha)***]: Crop biomass at germination.
[***Initial photosynthesis efficiency***]: Initial efficiency of use of absorbed light (kg CO_2/ha/hr)/(J/m^2/s).
[***Maximum photosynthesis rate***]: Maximum rate of leaf photosynthesis, kg CO_2/ha/h.
[***Development rate in vegetative stage***]: Rate constant of crop development in vegetative stage (1/day).
[***Development rate in reproductive stage***]: Rate constant of crop development in reproductive phase (1/day).

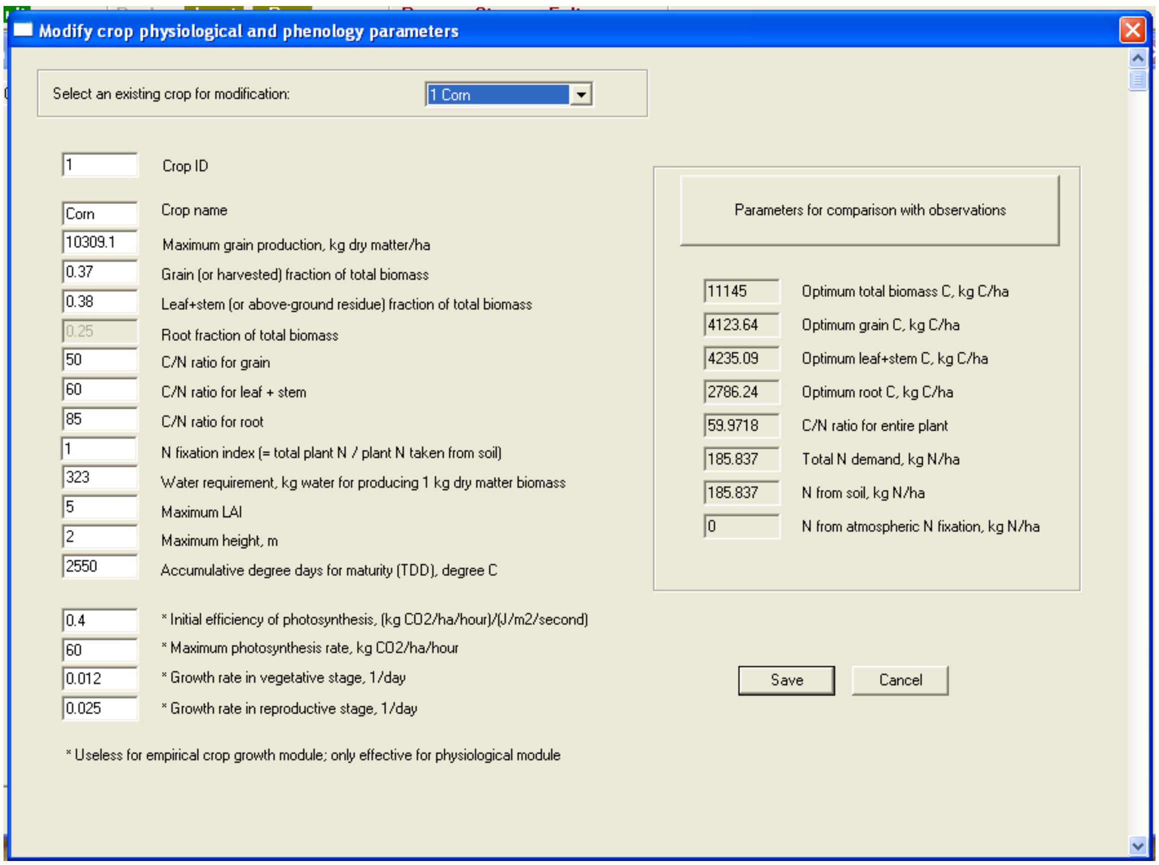


Figure 7. Review and modify crop physiological and phenology parameters

After modifying the above-listed parameters, you can click button “Parameters for comparison with observation” to calculate the crop biomass, C pools, crop C/N ratio, total N demand and other parameters which are routinely measured by the farmers or agronomists. By repeatedly adjust the parameters listed in the left column, you are able to bring the physiological or phenology factors to close to the observations. When you feel satisfied with the new parameters, you can click button “Save” to save the new parameters in a permanent file stored at \DNDC\Library\Lib_crop. This procedure is important for correctly simulating the soil C and N dynamics including C sequestration, trace gas emissions and N leaching.

Page 5. Tillage

Fill up the tillage page (Figure 8) to define number, timing and method of tillage applications.

[***How many applications in this year***]: Number of applications in the year.
[***Till #***]: Sequential number of each application.
[***Month/Day***]: Date of tillage application.
[***Till method***]: Define tilling depth by selecting methods as (1) no-till (i.e., only mulching) (0 cm), (2) tilling slightly (5 cm), (3) tilling with disk or chisel (10 cm), (4) tilling with moldboard (20 cm), or (5) tilling deeply (45 cm).

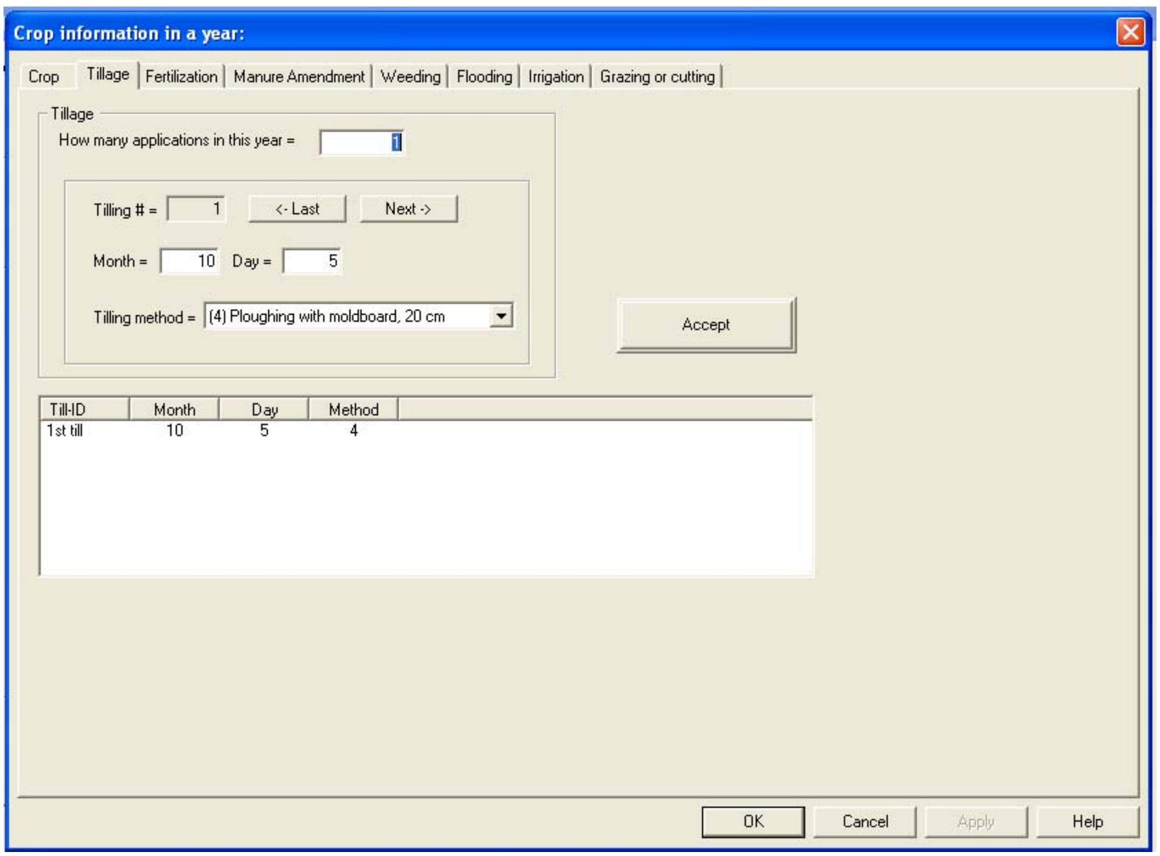


Figure 8. Iput information for tillage

Page 6. Fertilization

Fertilization is defined by specifying times, timing, method, fertilizer type and amount and special treatment for each application (Figure 9).

[***How many applications in this year***]: Number of applications in the year.

[***Fertilization #***]: Sequential number of each application.
[***Month/Day***]: Date of each application.

[***Applying method***]: Select surface application or injection in certain depth (usually for anhydrous ammonia).
[***Depth (cm)***]: Depth the fertilizer is applied to in unit cm.
[***Applied amount of fertilizers (kg N/ha)***]: Seven types of fertilizers can be singly or collectively selected by specifying the amount (kg N/ha) for each.
[***They are release-controlled fertilizer***]: If this button is checked, the total days during which the fertilizer-N will be uniformly released must be specified.
[***Nitrification inhibitor is applied***]: If this button is checked, the efficiency and effective duration (days) of the nitrification inhibitor must be specified.

In case if fertigation is applied, the button "Use daily fertigation file" can be checked and a file recording daily water and fertilizer-N amounts must be created in advance.

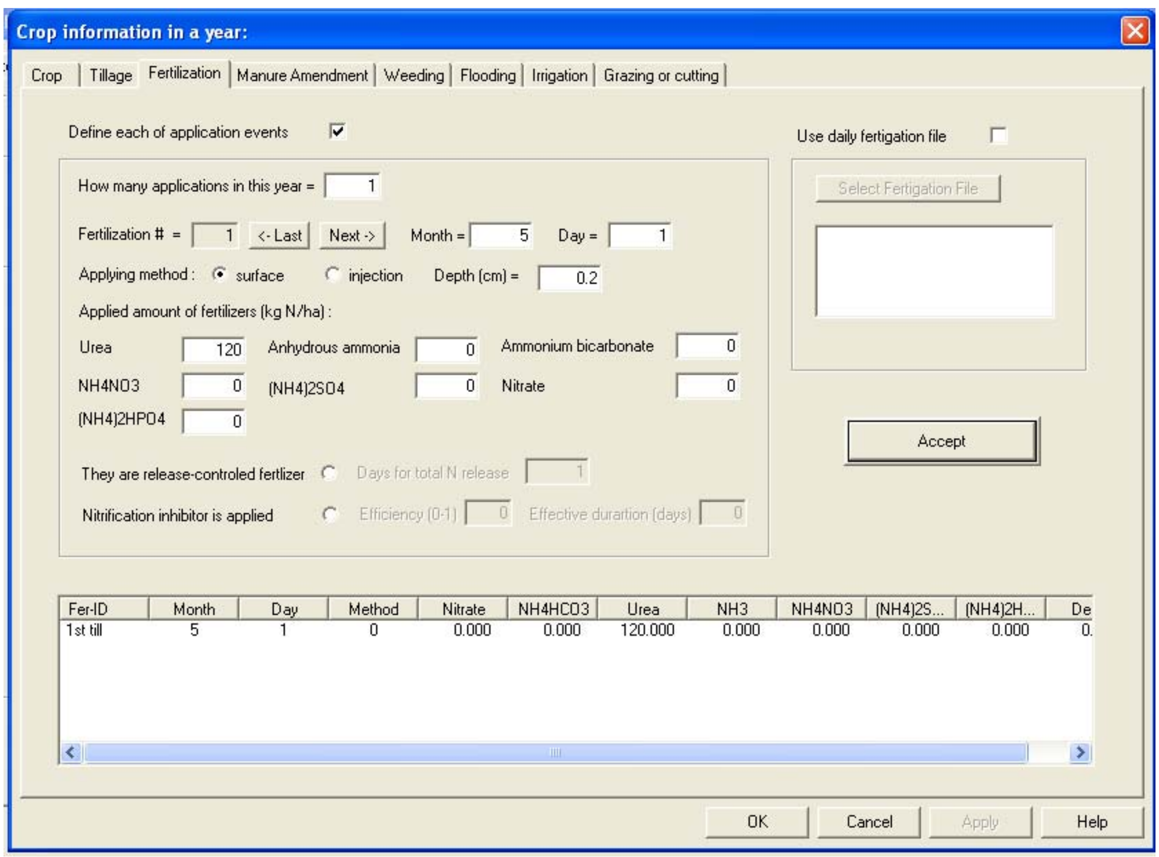


Figure 9. Input information for fertilization

Page 7. Manure amendment

Manure application is defined by its timing, type and amount (Figure 10).

[***How many applications in this year***]: Number of applications in the year.
[***Application #***]: Sequential number of each application.
[***Month/Day***]: Date of each application.
[***Manure type***]: Select a type of manure. Five types of manure (e.g., farmyard manure, green manure, straw, liquid animal waste, and compost) are parameterized in DNDC. Each of the types is characterized with its C/N ratio.
[***Amount (kg C/ha)***]: Specify amount of manure as kg C per ha per application.
[***C/N ratio***]: Ratio of C/N in the manure. The default value is provided by DNDC but can be modified by users.

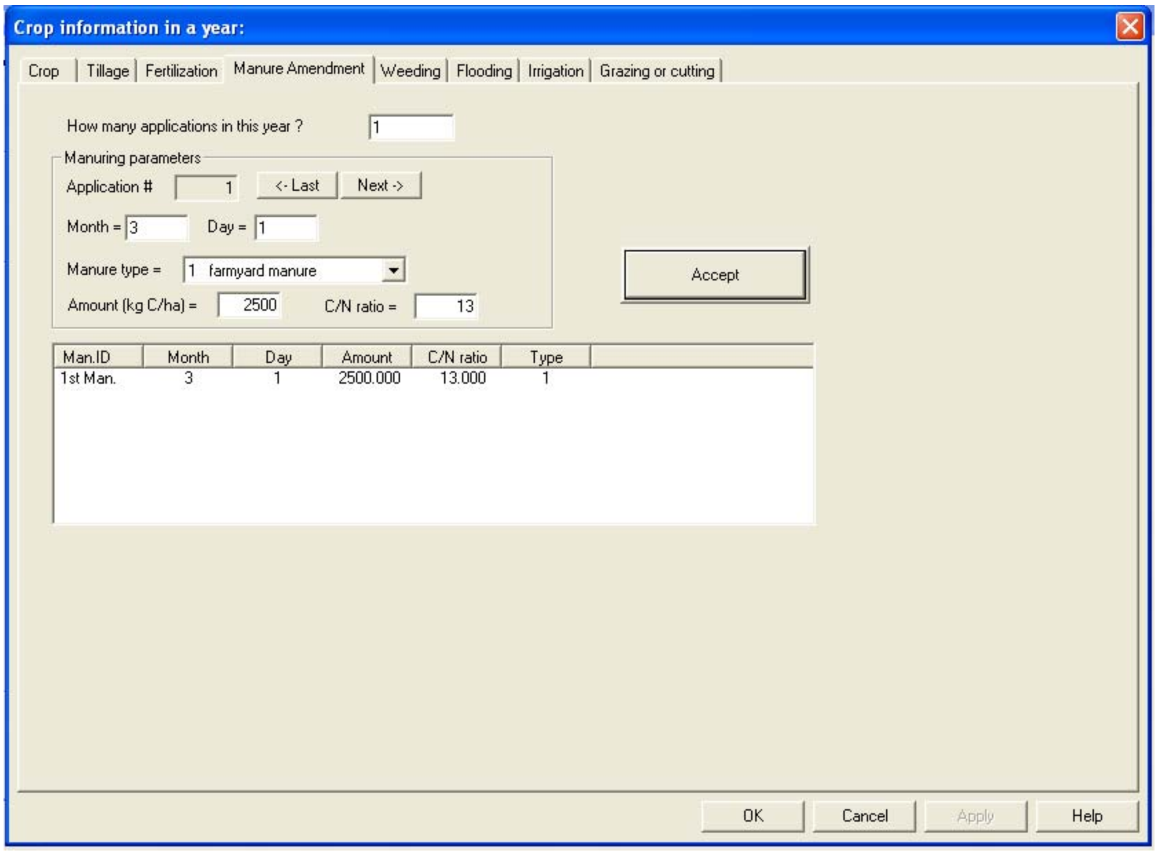


Figure 10. Input information for manure amendment

Page 8. Weeding

Weeding is defined as termination of weeds with mechanical or chemical approaches, and the terminated weeds will be incorporated in the soil by tillage.

[***Weeds problem***]: Select one of the options to define the weeds problem.
[***Weeding applications***]: Number of weeding applications.
[***Weeding #***]: Sequential number of each weeding application.
[***Month/Day***]: Date of each application.

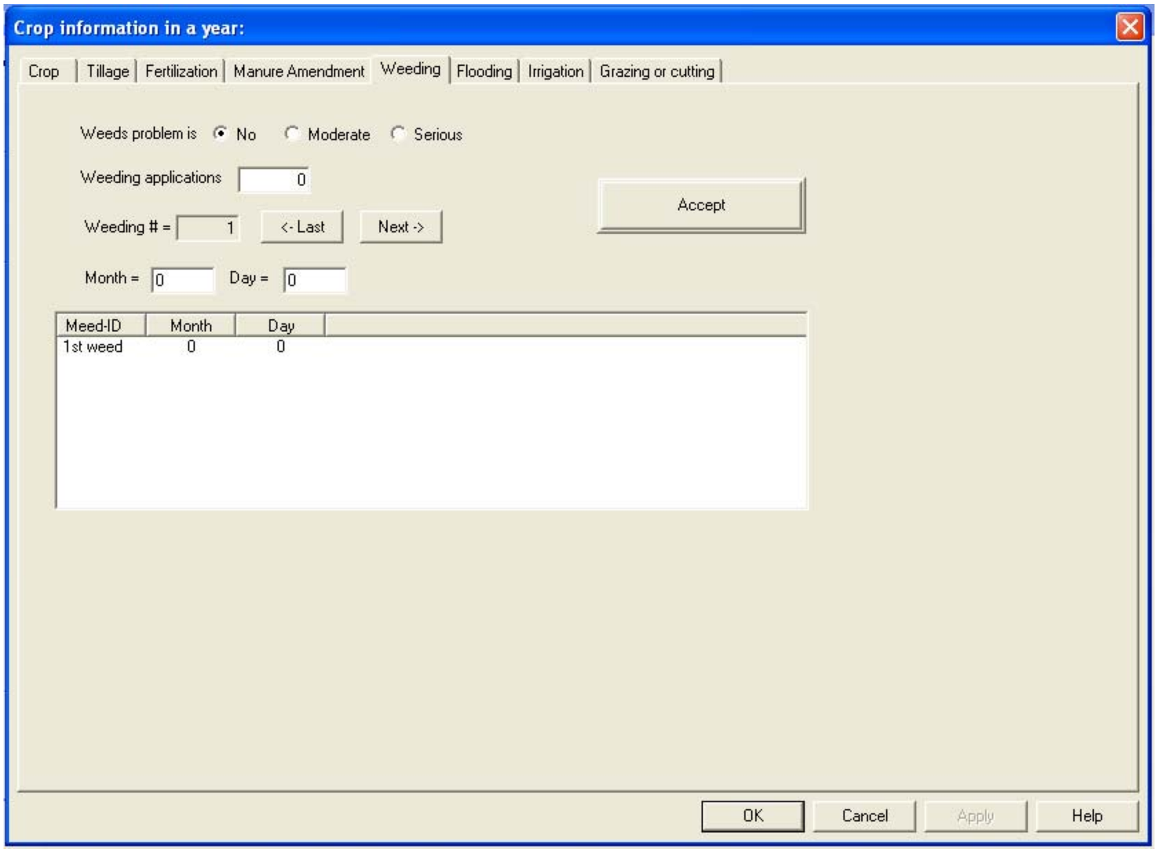


Figure 11. Input information for weeding

Page 9. Flooding

Flooding practice is usually applied for paddy rice or other wetland crops. There are three options to define flooding duration: (1) irrigation (Control 1), (2) rainfed (Control 2), and (3) observed water table fluctuation (Control 3).

For Control 1 (i.e., scheduled irrigation), the required input parameters include

[***How many times the field is flooded in this year***]: Number of flooding applications in the year.
[***Flooding #***]: Sequential number of each application.
[***From month/day***]: Starting date of each flooding application.
[***To month/day***]: End date of each flooding application.
[***Conventional flooding (5-10 cm)***]: Conventional flooding with surface water thickness 5-10 cm.
[***Marginal flooding (-5-5 cm)***]: Marginal flooding with surface water thickness –5 - 5 cm.

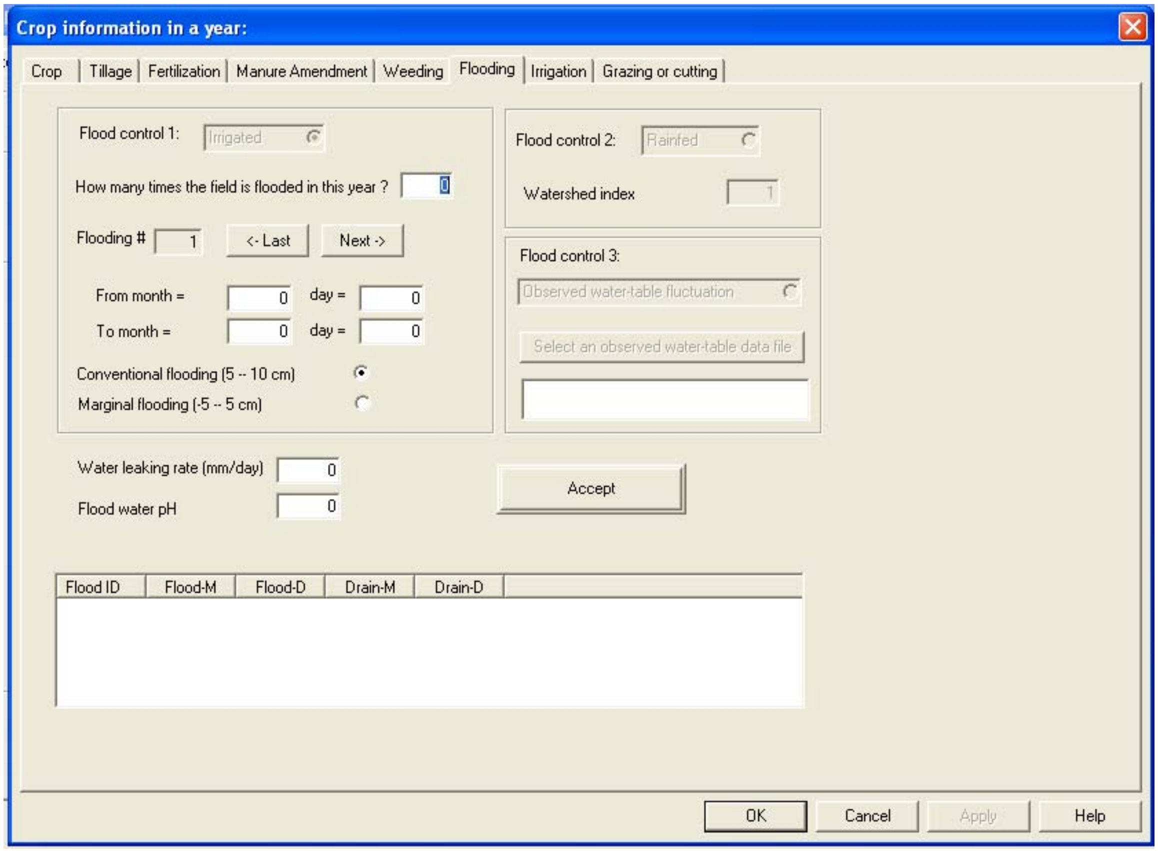


Figure 12. Input information for flooding

For Control 2 (i.e., rainfed), the required input parameter is

[***Watershed index***]: An index indicating the area from which the rain water is collected to supply a unit of crop land (ha/ha).

For Control 3 (i.e., observed water table fluctuation), a file recording daily water table depth should be prepared in advance.

For the above-listed three options, water leaking rate (mm/day) and flood water pH are required.

Page 10. Irrigation

Irrigation is define as supplement of water to the field without causing long-term (> 24 hours) ponding water on the soil surface.

[***Irrigation input mode***]: In DNDC, there are two ways to define irrigation. The first option is to define irrigation events by specifying the date, water amount and pH of each application. The second way is to define an irrigation index. The index specifies a fraction (0-1) of the water deficit, whenever water stress occurs, which will be met with the irrigation water.

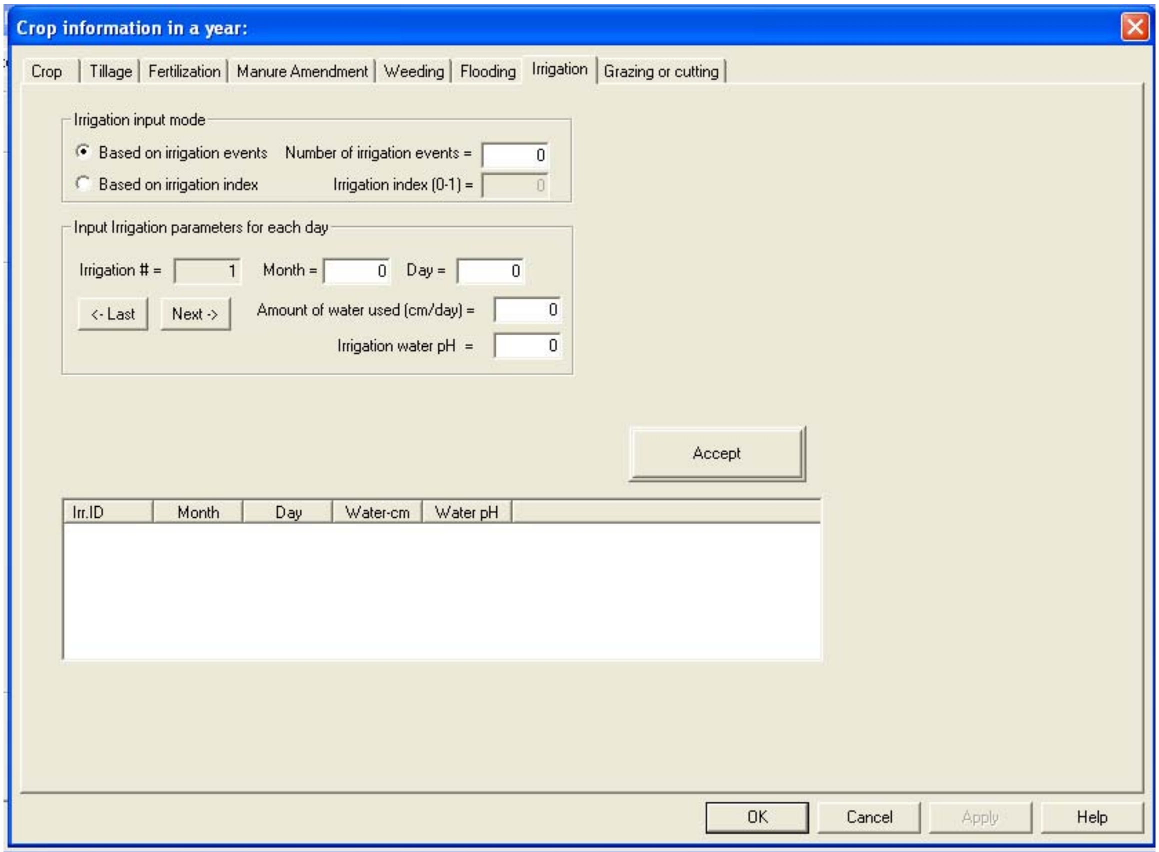


Figure 13. Input information for irrigation

Page 11. Grazing and Grass Cutting

Grazing is usually applied to grassland or pasture. Grazing practice is defined in DNDC by specifying the livestock type and the grazing duration, which will be used to quantify feeding intensity and waste deposition of the livestock when they stay in the field.

[***Number of grazing time periods***]: Number of grazing periods in the year.
[***Start month/day***]: Starting date of each grazing period.
[***End month/day***]: End date of each grazing period.
[***Grazing hours per day***]: Hours per day the livestock stay in the field during the grazing period.
[***Grazing intensity (heads/ha)***]: Number of cattle, horse, or sheep grazing in the field for each grazing period.

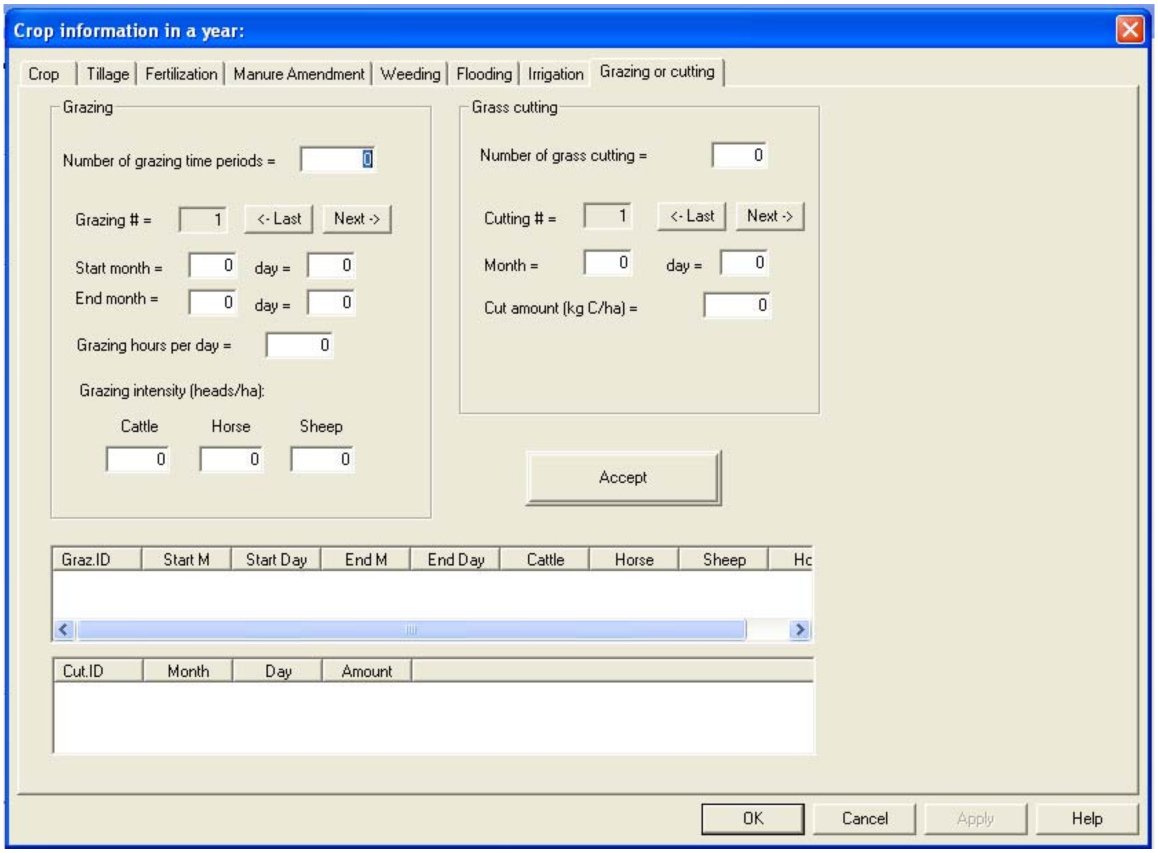


Figure 14. Input information for grazing and grass cutting

For grass cutting, the required input parameters include

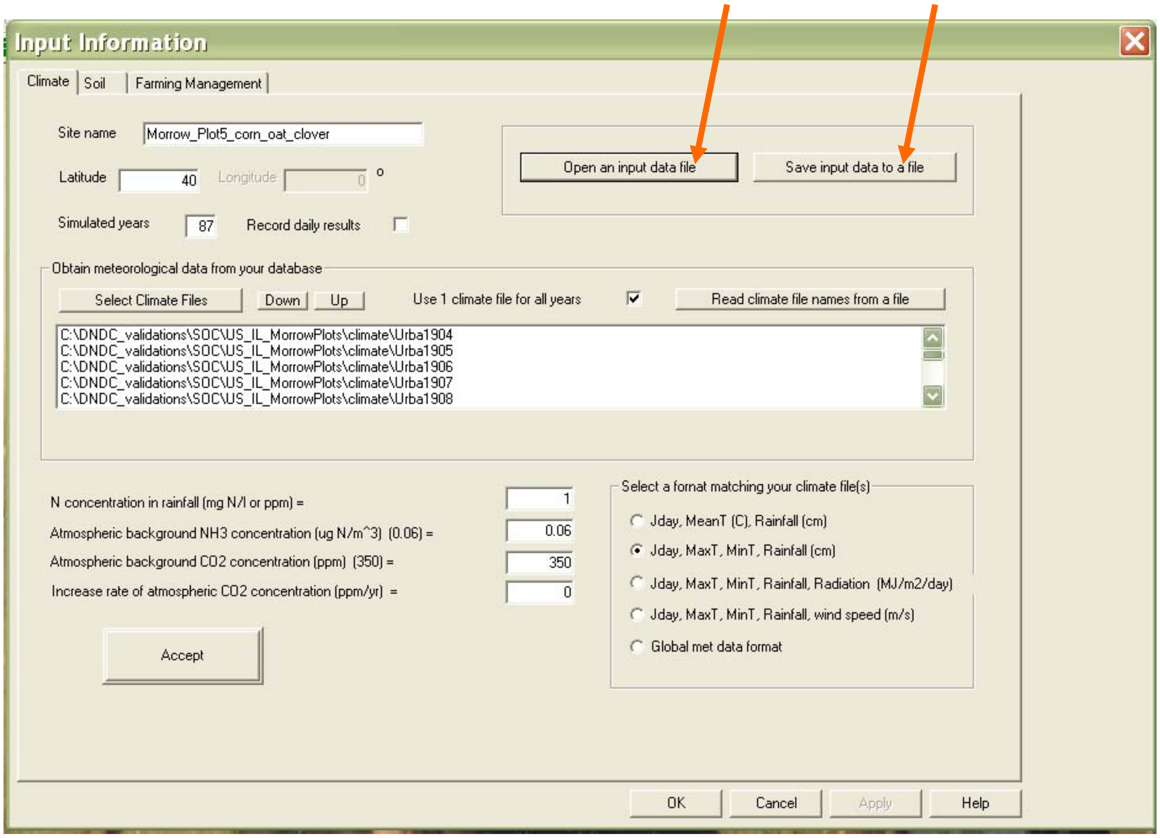
[***Number of grass cutting***]: Number of cutting applications in the year.
[***Cutting #***]: Sequential number of each cutting.
[***Month/Day***]: Date of each cutting.
[***Cut amount (kg C/ha)***]: Amount of grass cut by this cutting.

Finally, we accomplished the input processes. When we are leaving the last page, it may be worth reminding ourselves again: Don't forget clicking the "Accept" button every time when we finish a page.

When you have finished all of the pages, please click "OK" at the bottom of the first page (Climate) that will automatically organize all of the input information into a group of DNDC-required input files. After this click, you will be ready to execute the simulations.

1.2. Save and Open an Input File

After going through the input procedure, you may like to save all the input information for future use. To do so, please go back to the first page by clicking page "Climate". Clicking button "Save input data to a file" will allow you to create a file to save all the input information you have provided. In future, if you want to retrieve the input data, just click button "Open an input data file" on the same page to find the right file. After opening the file, you can go to any pages to modify the data, and resave the new data set as a new file if you want.



Below-listed is an example input file, which is in plain text format so that can be composed with any word processor or programming software.

```
Input_Parameters:
----------------------------------------
Site_data:                Beitem
Simulated_Year:             1
Latitude:                50.900
Daily_Record:                 1
----------------------------------------
Climate_data:
Climate_Data_Type:          1
NO3NH4_in_Rainfall            1.3300
NO3_of_Atmosphere              0.0600
BaseCO2_of_Atmosphere        350.0000
Climate_file_count=          1
   1   C:\Belgium_Esen\Climate\Beitem_1999.txt
----------------------------------------
Soil_data:
  Soil_Texture            4
  Landuse_Type              1
  Density              1.35000
  Soil_pH               6.00000
  SOC_at_Surface           0.02000
```

```
   Clay_fraction           0.14000
   BypassFlow              0
   Litter_SOC              0.02500
   Humads_SOC              0.02500
   Humus_SOC               0.95000
   Soil_NO3(-)(mgN/kg)     0.33300
   Soil_NH4(+)(mgN/kg)     0.80000
   Moisture                0.30000
   Temperature             8.25000
----------------------------------------
Crop_data:
Rotation_Number=          1
  Rotation_ID=            1
  Totalyear=              1
  Years_Of_A_Cycle=       1
    YearID_of_a_cycle=    1
    Crop_total_Number=    1
      Crop_ID=            1
        Crop_Type=        1
        Plant_time=       5 10
        Harvest_time=     10 20
        Year_of_harvest=  1
        Ground_Residue=   0.000000
        Yield=            10309.099609
        Rate_reproductive=  0.025000
        Rate_vegetative=  0.012000
        Psn_efficiency=   0.400000
        Psn_maximum=      60.000000
        Initial_biomass=  12.500000
        Cover_crop=       0
    Tillage_number=       2
      Tillage_ID=         1
        Month/Day/method=  5 7 4
      Tillage_ID=         2
        Month/Day/method=  5 10 2
    Fertil_number=        0
    Manure_number=        1
      Manure_ID=          1
        Month/Day=        5 7
        Amount/C|N_ratio=  948.662109 3.162200
        Type=             4
    Weed_number=          0
    Weed_Problem=         0
    Flood_number=         0
    Leak_type=            1
    Water_control=        0
    Leak_rate=            10.000000
    Irrigation_number=    0
    Irrigation_type=      0
    Irrigation_Index=     0.000000
    Grazing_number=       0
    Cut_number=           0
Climate_file_mode         0
Soil_microbial_index      1.000000
Crop_model_approach       0
Depth_WRL_cm              100.000000
Slope                     0.000000
Field_capacity            0.400000
Wilting_point             0.200000
CO2_increase_rate         0.000000
SOC_profile_A             0.200000
SOC_profile_B             2.000000
```

High_WT 0

1.3. Run DNDC at Site Mode

When the input procedure is accomplished, you can click the button "Run" to start the simulation for the site. During the site runs, there are seven windows appearing on the screen to demonstrate the daily dynamics of simulated meteorological conditions, soil climate and chemistry, crop growth, and gas emissions (Figure 15).

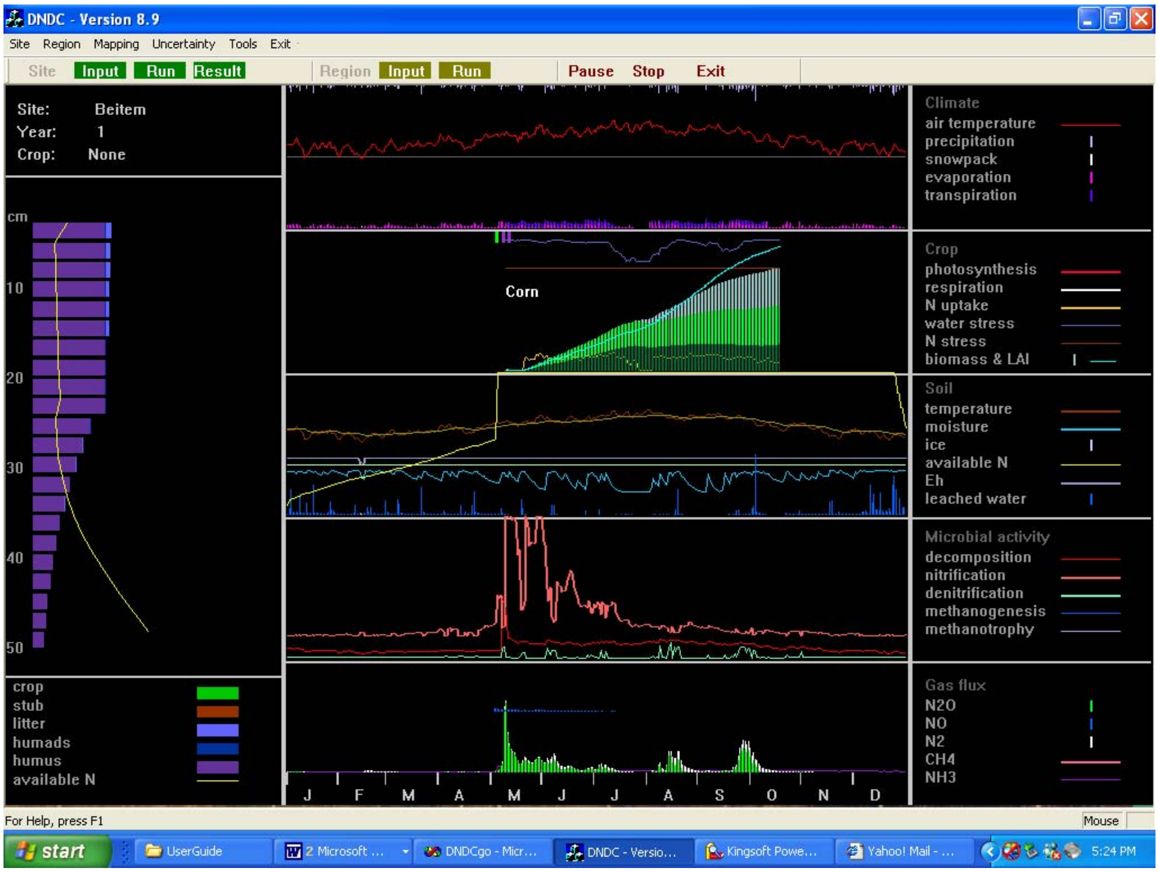


Figure 15. The seven windows allow users to monitor daily dynamics of several major simulated factors during the model run.

Window 1 (up-left corner) shows site name, simulated year, and crop type.

Window 2 (middle-left) shows soil carbon and nitrogen profiles for 0-50 cm.

Window 3 (top in the middle) shows daily air temperature, precipitation, snow pack, evaporation, and transpiration.

Window 4 (second in the middle) shows crop biomass, LAI, N uptake, water stress and n stress.

Window 5 (third in the middle) shows soil temperature, moisture, Eh, ice content, available N, and water leaching flux.

Window 6 (forth in the middle) shows daily rates of decomposition, nitrification, denitrification, methanogenesis, and methanotrophy.

Window 7 (bottom-middle) shows daily fluxes of NH_3, CH_4, N_2O, NO, and N_2.

These windows allow users to observe the general dynamics of several key factors during the model runs.

1.4. A Quick View of Modeled Results

The simulated results including daily and annual crop biomass, C and N pools/fluxes, and water budget, are recorded in a series files stored at \DNDC\Result\Record\Site\. All the files are in a plain text format so that they can be retrieved reprocessed with any spreadsheet or word-processor tools (e.g., Excel etc.). The contents of the result files are described in detail in "IV. Modeled Results". However, DNDC provides a handy tool to allow the users to have a quick view on results from the just finished simulation. By clicking button "Result" on the main menu (Figure 2), you will open a new page, on which you can select the year and the item you are going to observe (Figure 16).

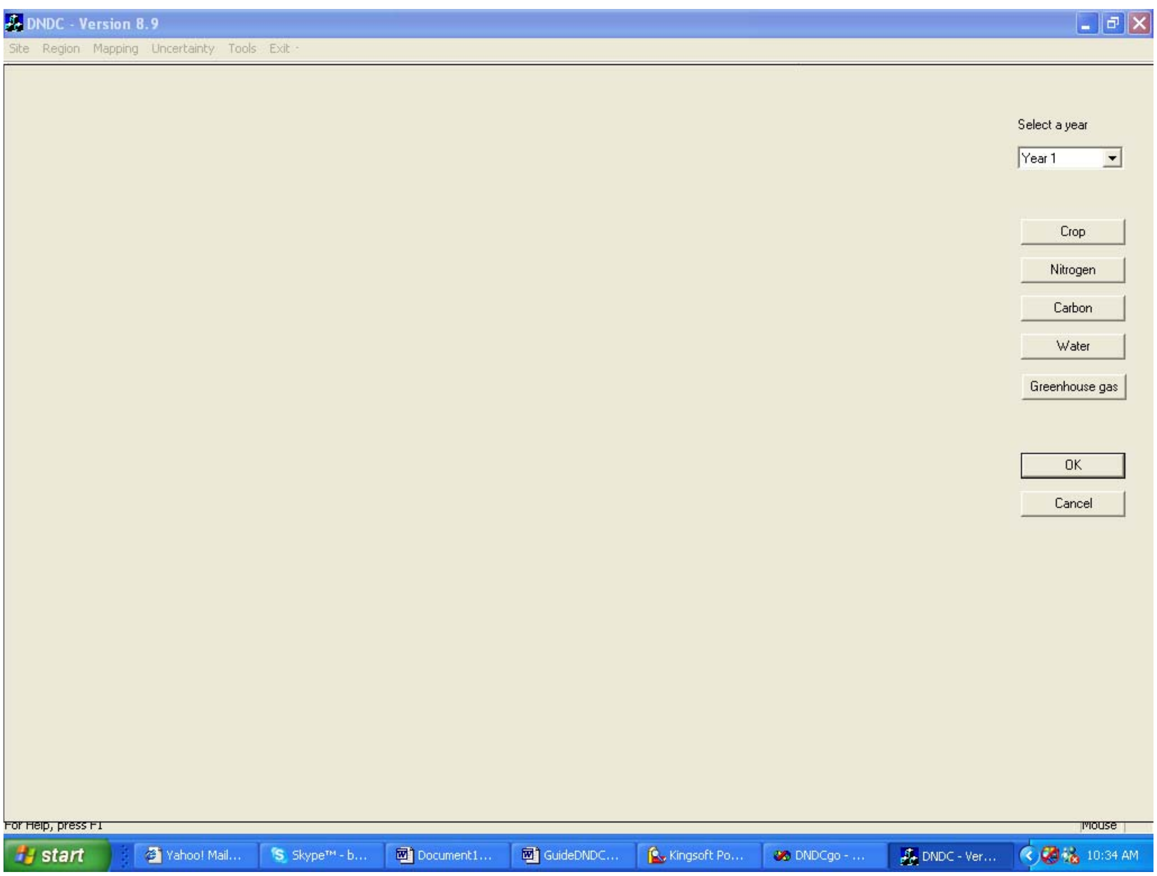


Figure 16. Main menu for quick view of modeled results

Clicking button “Crop” will draw a chart of crop production as shown in Figure 17. In this chart, the yellow bars represent the maximum production for grain, leaf + stem, or root; and the green bars for the actual production simulated by DNDC. If the actual production is lower than the maximum values, the stresses of temperature, water and/or N should be identified by comparison between the demand and the uptake bars for temperature, water or N. This quick look would provide you an opportunity to understand why the simulated crop yield could be lower than the maximum yield if it was a case. This information could be essential for you to modify your crop physiological/phenology parameters or adjust the farming management practices to obtain an optimum yield.

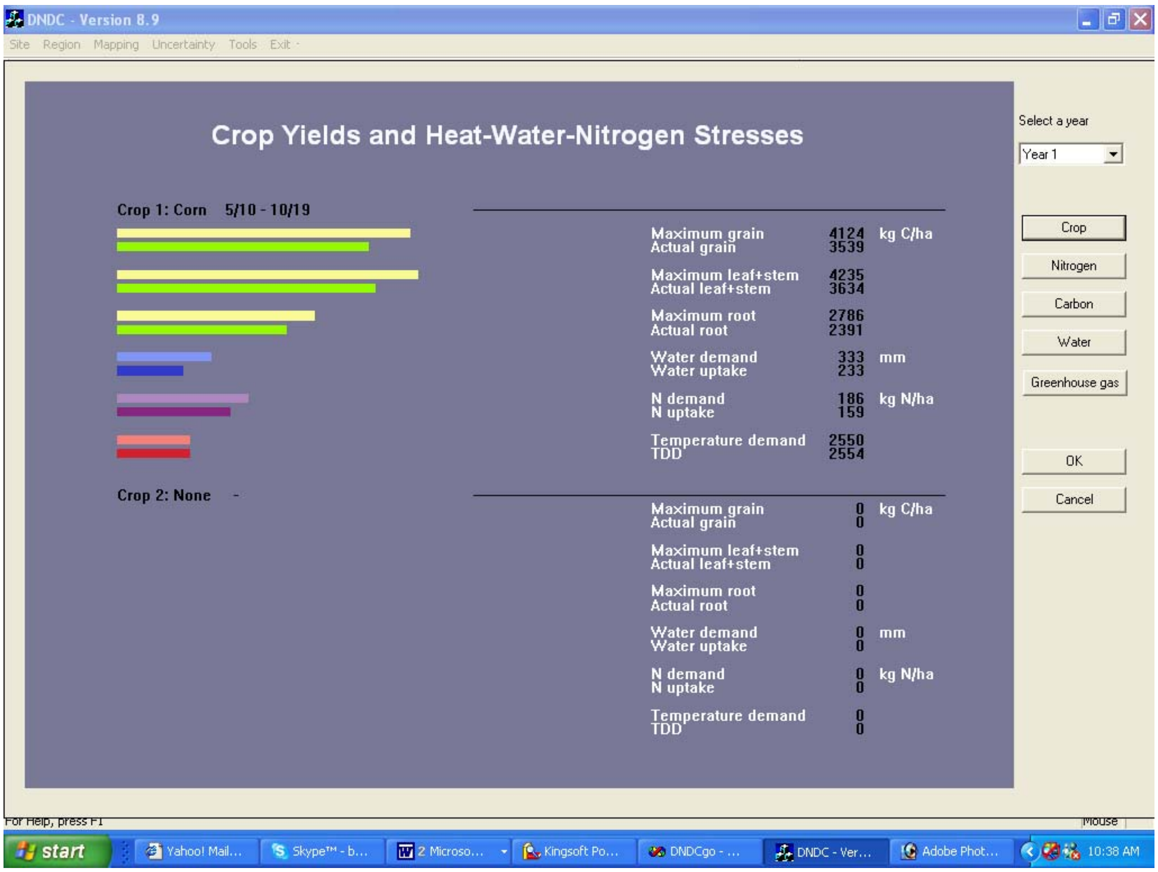


Figure 17. Modeled result 1: Crop biomass production and stresses of temperature, water or nitrogen. (TDD – accumulative thermal degree days of crop growth season)

Clicking button “Nitrogen” will draw a chart of annual N budget for the plant-soil system as shown in Figure 18. The N gained by the system includes the input fluxes from manure amendment, crop residue (stub and roots) and weeds incorporation, atmospheric deposition, synthetic fertilizer application, and biotic N fixation. The N lost from the system includes the output fluxes due to leaching, runoff, crop uptake, weeds uptake, ammonia volatilization, and emissions of nitrous oxide, nitrite oxide and dinitrogen.

Clicking button “Carbon” will draw a chart of annual C budget for the plant-soil system as shown in Figure 19. The C gained by the system includes the input fluxes from manure amendment, crop residue (stub and roots) and weeds incorporation. The C lost from the system includes the output fluxes due to soil heterotrophic respiration, DOC leaching, and methane emission.

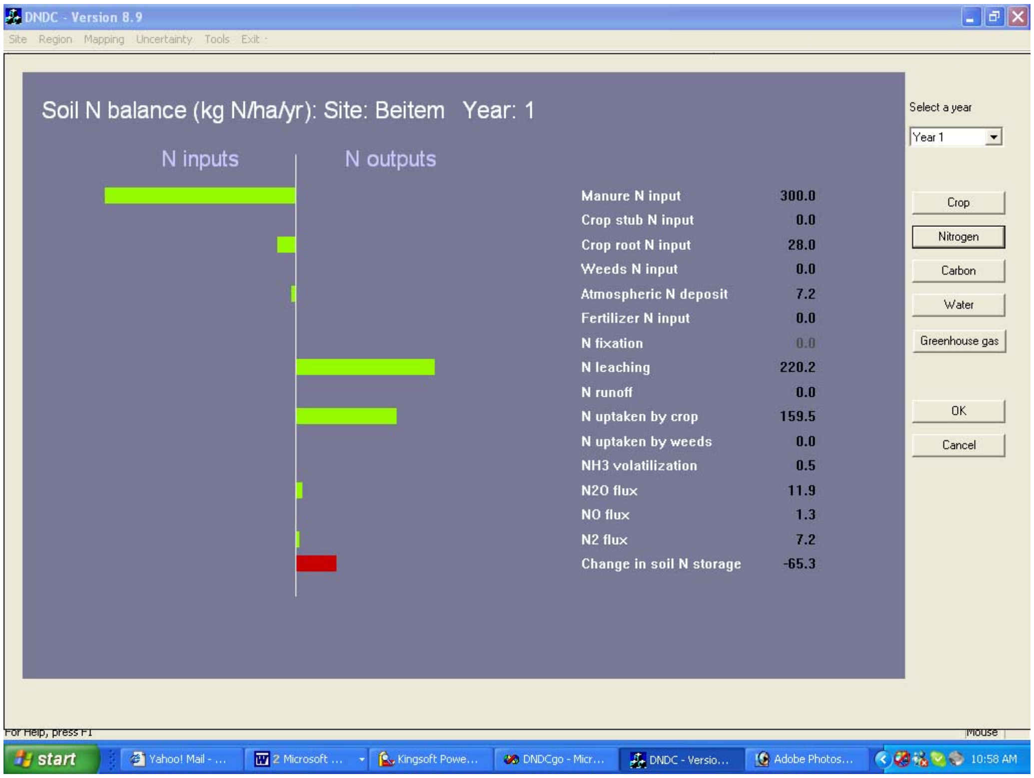


Figure 18. Modeled result 2: Soil N budget.

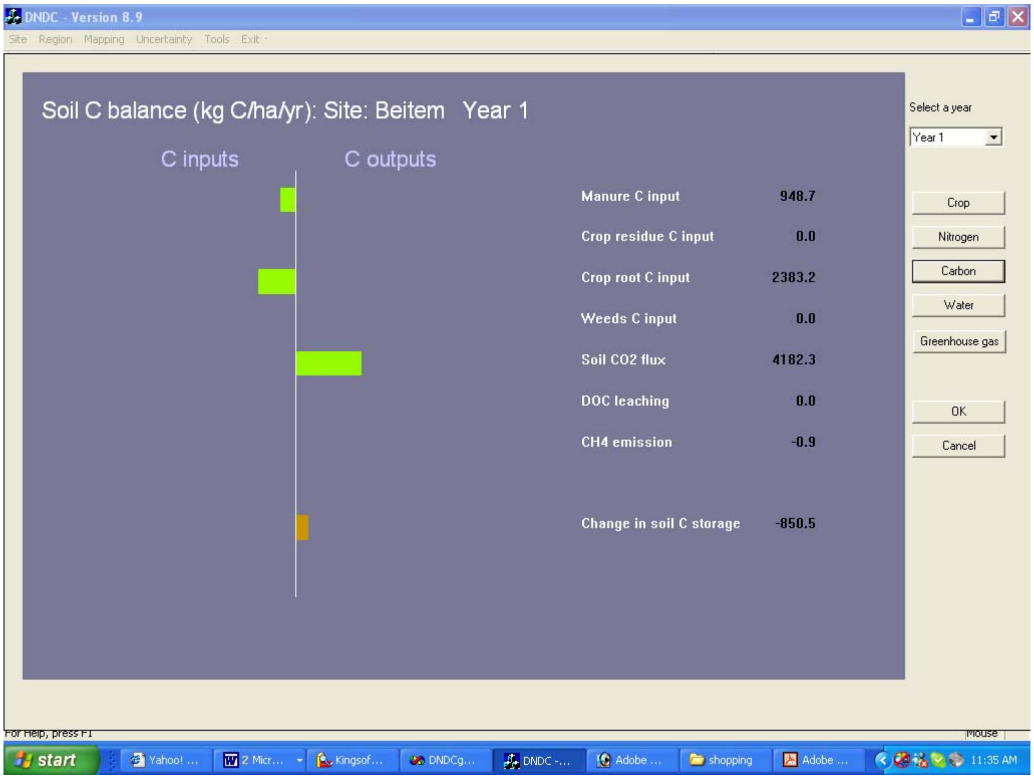


Figure 19. Modeled result 3: Soil C budget.

Clicking button "Water" will draw a chart of annual water budget for the plant-soil system as shown in Figure 20. The water received by the system includes the input fluxes from precipitation, irrigation and groundwater supply. The water lost from the system includes the output fluxes due to transpiration, soil evaporation, surface water evaporation (for flooded soil), leaching and runoff.

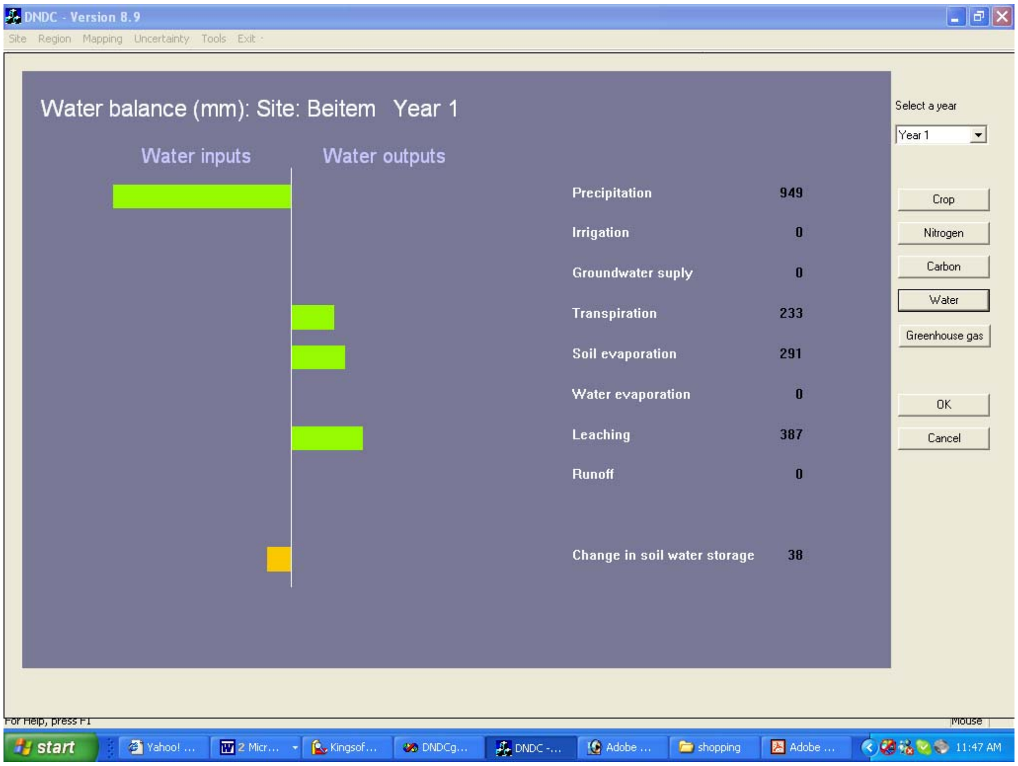


Figure 20. Modeled result 4: Water budget

Clicking button "Greenhouse gas" will demonstrate the net greenhouse gas emissions from the agroecosystem (Figure 21). Annual emission fluxes of three major greenhouse gases, i.e., carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), are listed in the table. The fluxes are also converted into 100-year Global Warming Potentials (GWPs) based on the worming forces of the gases, which is expressed as CO2-equevalent. The annual contribution of the modeled agroecosystem to global warming is the net GWP of the three gases emitted from the system.

The quick view function could provide essential information for the users to understand the basic trends of the modeled system without dealing with the detailed datasets recorded in the result files. That could be a time-saver, especially during the model test periods.

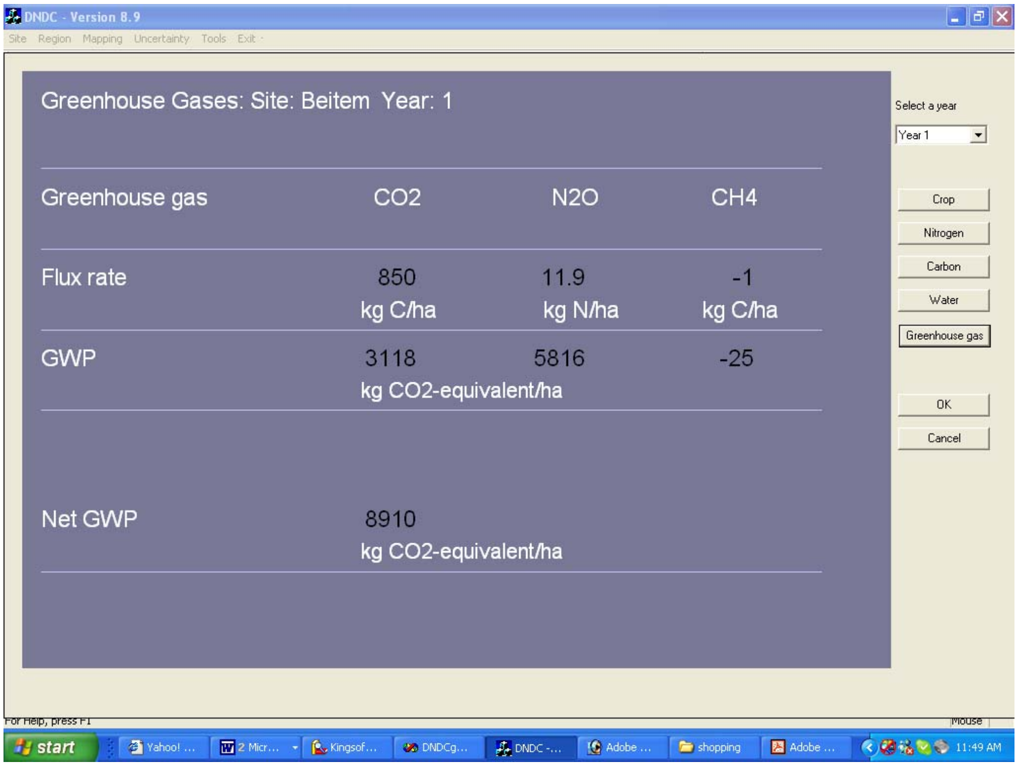


Figure 21. Modeled result 5: Net greenhouse gas emission

1.5. Batch run

Since the input files required by DNDC site runs are in a plain text format, they can be created with a variety of word processors or programming software. Users can make a series of input files, and run them in batch. This could be an efficient approach for sensitivity test or uncertainty analysis, which requires repeatedly model runs with only a single or a few parameters varied. DNDC provides an interface to allow the users to do so. When the input files have been prepared, the user can make a file to contain the number and the names of the files as shown in the example file as follows:

```
5
C:\Databse\Scenario_1.dnd
C:\Databse\Scenario_2.dnd
C:\Databse\Scenario_3.dnd
C:\Databse\Scenario_4.dnd
C:\Databse\Scenario_5.dnd
```

Number of input files

Paths and names of input files

Clicking “Tools” and then “Run batch” on the main menu of DNDC, a dialog box will appear to allow you to select the file containing the names of the candidate input files (Figure 22). After the selection, click OK to start the simulations.

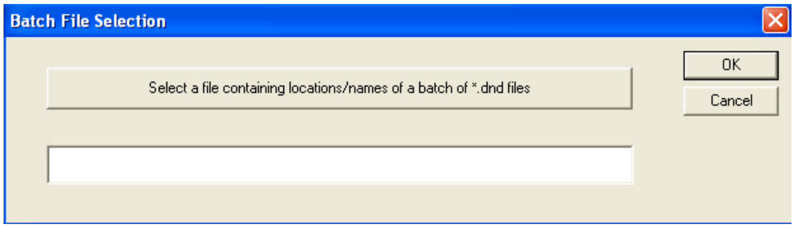


Figure 22. The dialog box allows user to select a file containing the paths and names of a batch of input files prepared in advance.

2. Regional Mode

At regional runs, DNDC receives all of the input information from a series of databases prepared in advance. Preparing the databases with the required formats is the key to successfully conduct regional simulations with DNDC. All of the input data required for the regional runs are organized into two categories of database, namely the Geographic Information System (GIS) database and the library database. The DNDC package you received includes a complete set of example databases for an illusive region named “Shangrila”. All the spatially differentiated information specifically required for regional simulations for Shangrila is contained in the files stored in folders “GIS”, “Lib_clim”, “Lib_farm” and “Lib_map” under directory “\DNDC\Database\Shangrila”. In addition, two folders named “Lib_crop” and “Lib_soil” containing general information are located under directory “\DNDC\Library” (Figure 23).

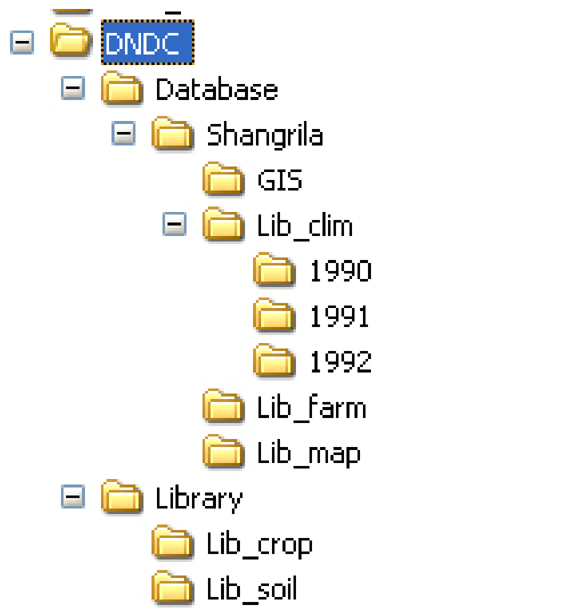


Figure 23. Structure of directories containing input information for regional simulations.

For applying DNDC for regional simulations with a target domain, the region is usually divided into a number of basic geographic units (e.g., polygons or grid cells) based on the administrative boundaries or other measures (e.g., 0.5°X0.5° gridding system), depending on the nature of the source data. Each unit is assumed to be uniform on all of the concerned properties (e.g., climate, soil etc.). Like most process-based models, DNDC accomplishes regional simulation by conducting the simulation for each unit across the target domain. During the regional runs, DNDC reads all the input data from the various files stored in the databases, and then reorganizes the information into the several specific files with the formats required by DNDC.

2.1. GIS Database

These are four files stored under directory "\DNDC\Database\Shangrila\GIS. The file names and contents are shown as follows:

File name: Shangrila_1.txt

ID	Region_name	Polygon_name	Longitude	Latitude
1	Shangrila	1	-82.513	41.384
2	Shangrila	2	-82.514	41.384
3	Shangrila	3	-82.514	41.383
4	Shangrila	4	-82.514	41.384
5	Shangrila	5	-82.513	41.383
6	Shangrila	6	-82.515	41.383
7	Shangrila	7	-82.512	41.383
……				

Shangrila_1.txt contains polygon ID, region name, polygon name, longitude and latitude.

File name: Shangrila_2.txt

ID	Climate_file_name	N_in_rain_ppm
1	72650	10.1
2	72659	10.1
3	72659	10.1
4	73888	12.5
5	73888	12.5
6	73888	12.5
7	77654	10.1
……		

Shangrila_2.txt contains polygon ID, name of daily climate file, and atmospheric N deposition rate in mg N/l or ppm.

File name: Shangrila_3.txt

ID	SOC		Clay		pH		Bulk density	
	max	min	max	min	max	min	max	min
1	0.04	0.02	0.23	0.22	6.7	6.5	1.38	1.25
2	0.04	0.02	0.23	0.22	6.7	6.5	1.38	1.25
3	0.04	0.02	0.23	0.22	6.7	6.5	1.38	1.25
4	0.03	0.02	0.23	0.22	6.7	6.5	1.38	1.25
5	0.03	0.02	0.23	0.22	6.7	6.5	1.38	1.25
6	0.03	0.02	0.23	0.22	6.7	6.5	1.38	1.25
7	0.03	0.02	0.23	0.22	6.7	6.5	1.38	1.25
……								

Shangrila_3.txt contains polygon ID and soil information including maximum and minimum SOC contents in kg C/kg soil, maximum and minimum clay fractions, maximum and minimum pH values, and maximum and minimum bulk density in mg/cm^3.

Cropping system ID

File name: Shangrila_4.txt

Number of cropping systems

Crop area in hectares

ID	soybean	corn	wheat	alfalfa	hay	vege	barley	grape	pasture	fallow
10	3	1	2	10	5	16	8	42	12	0
1	0	12.5	0	0	3.4	0	0	0	0	0
2	65.0	0	0	0	0	5.2	0	0	0	0
3	0	120.0	0	0	0	0	0	0	0	0
4	0	0	5.4	0	0	0	0	0	0	23.2
5	0	0	0	1.0	0	0	0	0	0	0
6	0	0	0	0	0	0	11.1	0	0	0
7	0	0	0	0	0	0	0	50.7	99.9	0
……										

Shangrila_4.txt contains polygon ID and crop information including crop name, crop ID and acreage in ha. The crop IDs should be consistent with that in Lib_crop.

2.2. Library Databases

The data stored in the library files are not polygon-specified, so that they can be utilized by multiple polygons. An example file is shown below for each kind of the library files.

Lib_clim: Daily meteorological data

Example file name: 72650

File name

Max, min temperature (°C), precipitation (cm)

```
 72650
    1   -1.10  -14.40    0.00
    2    5.60   -5.00    0.80
    3    3.90   -5.60    2.10
    4    1.70  -10.60    0.00
    5    3.30   -9.40    0.00
    6    6.10  -10.60    0.00
    7   10.60   -6.70    0.00
    ..........................................
    ..........................................
  365    9.40   -8.90    0.00
```

Lib_farm: Farming practices

Example file name: Farm0001.txt

```
1       number_of_crops

1       corn
10309   optimum_yield
4       planting_month
1       planting_day
10      harvest_month
1       harvest_day
0.9     percent_residue_left
999     season_flag

2       till_applications
4       month
1       day
3       method
10      month
15      day
2       method

1       number_of_fert
4       fert_month1
1       fert_day1
140     fert_rate1

0       manure_applications

1       irrigation_index
0       flooding
0       Cutting
0       Grazing
```

Number of crops planted in the year

999 indicates the crop as the last crop planted in the year

Lib_map: Polygon boundary data (optional)

The SHAPE files created with ArcView family are used for DNDC's mapping functions. For this example case, the map files are Shangrila.dbf, Shangrila.sbn, Shangrila.sbx, Shangrila.shp, and Shangrila.shx.

Lib_soil: Soil hydraulic data for each type of soil

Example file name: Soil_5 (for loam soil)

```
Loam    texture
0.19    clay_fraction
0.451   porosity
0.0417  satu_conductivity
0.49    field_capasity
0.22    wilting_point
```

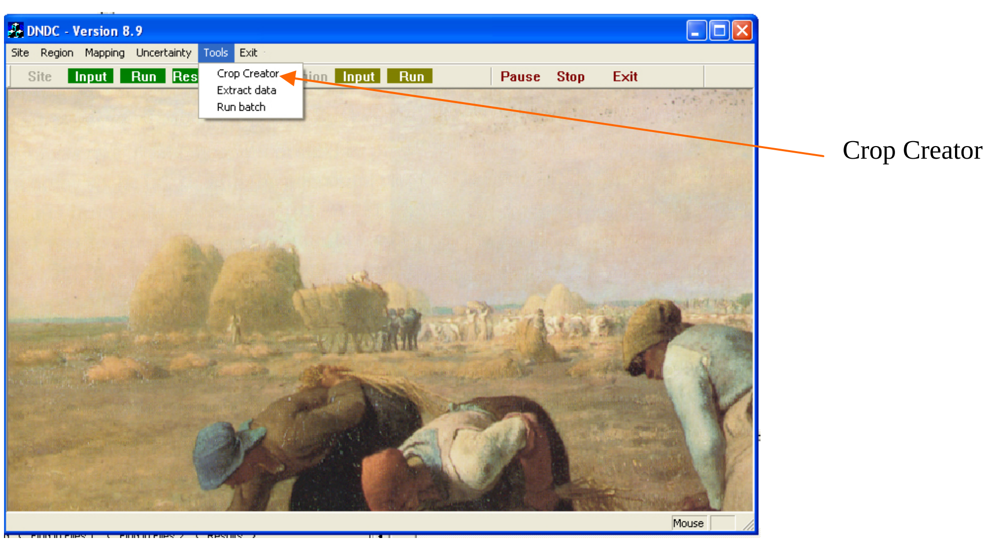
Lib_crop: Crop physiological and phonological data for each type of crop

Example file name: Crop_1 (for corn)

```
1               crop_code
CO              crop_name_1
Corn            crop_name_2
11145           total_biomass_C
0.370000        portion_of_grain
0.380000        portion_of_shoot
0.250000        portion_of_root
59.971802       plant_CN
50.000000       grain_CN_ratio
85.000000       root_CN_ratio
60.000000       shoot_CN_ratio
323.000000      water_requirement
5.000000        max_LAI
2.000000        max_height
2550.000000     TDD
1.000000        N_fixation

0.400000 initial efficiency of use of absorbed light (kg CO2/ha/h)/(J/m2/s)
60.000000 maximum rate of leaf photosytensis, kg CO2/ha/h
0.012000 rate constant of crop development in vegetative stage (1/d)
0.025000 rate constant of crop development in reproductive phase 1/d
0.700000 economic copmponent/storage organc by weight
450.000000 specific leaf weight constant, kg dm/ha
2775.000000 specific stem weight, kg dm/ha
0.500000 ratio of internal/external CO2 concentrations
1.000000 maximum root depth for crop, m
0.060000 increase rate of root depth, m/day
```

The crop file can be created or modified with the tool "Crop Creator" available at DNDC's user's input interface.



The above-described library files for soil and crop are provided as defaults in DNDC. The data in the soil and crop files are used for both site and regional simulations.

2.3. Initiation of Regional Simulation

When the GIS and library files have been prepared and located at the right directories, you should be ready to conduct the regional simulations. To initiate a regional run, you need to click the "Input" button by the "Region" sign to select the target region and set relevant input information.

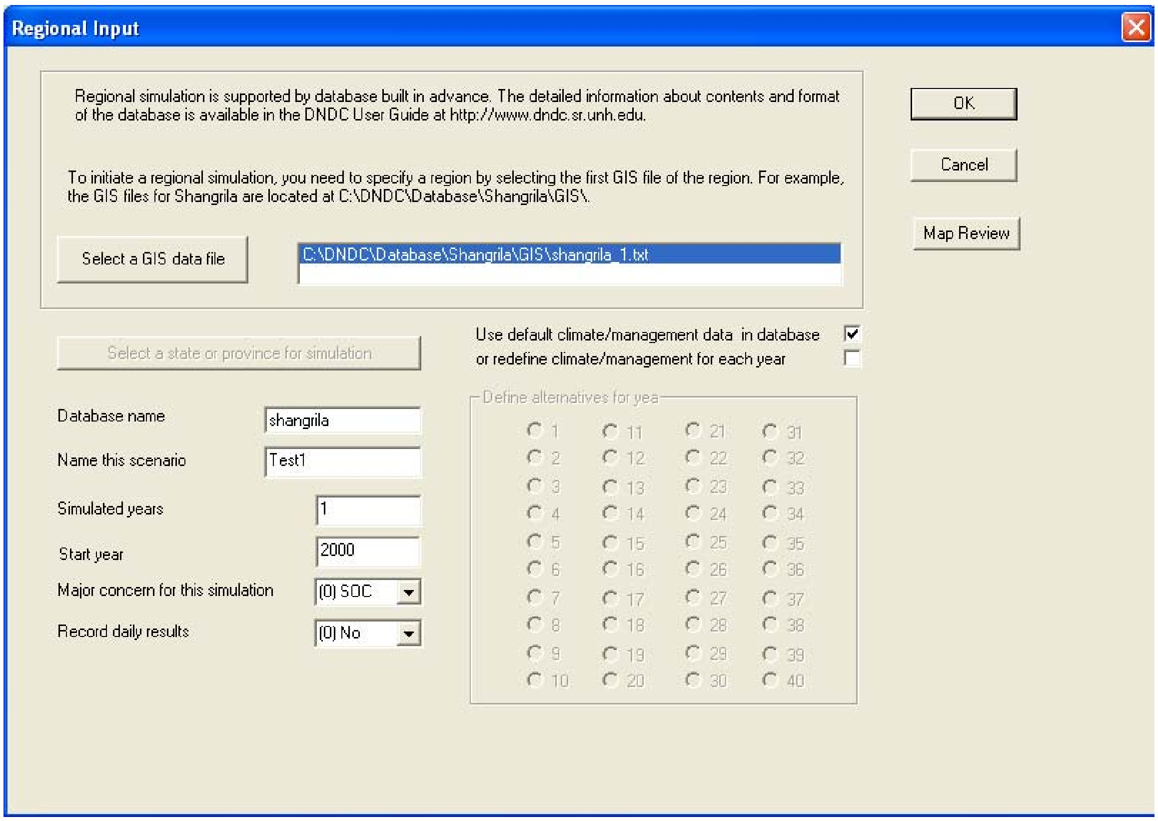


Figure 24. Page for region selection and scenario setting

Let's use "Shangrila" as an example to practice how to select the region. By clicking button "Select a GIS data file", you are asked to select a file. Let's go to C:\DNDC\Database\Shangrila\GIS, and select any of the four GIS files.

When you click the "Database name" box, "Shangrila" is automatically showing up. That means DNDC has learnt your target region is Shangrila, and will read out the necessary input information from the Shangrila-relevant directories for use during the model runs. Several input parameters are required to specify the regional run.

[***Name this scenario***]: Give a string (no space is allowed) to name this simulation. The name will be used to construct the result file names.

[***Simulated years***]: Number of years for the regional simulation.

[***Start year***]: An integer (e.g., 2000) for the first simulated year.

[***Major concern for this simulation***]: Select one from five options: SOC, CO2, N2O, CH4, NH3 and N leaching.

[***Record daily results***]: Selecting "Yes" will allow the model to record the simulated daily results for each polygon.

[***Use default climate/management data in database***]: Checking this box will conduct the regional simulations with the climate data stored in the Lib_clim files and farming management data stored in the Lib_farm files.

[***or redefine climate/management for each year***]: Checking this box will conduct the regional simulations with the climate and/or management conditions modified for each specific year.

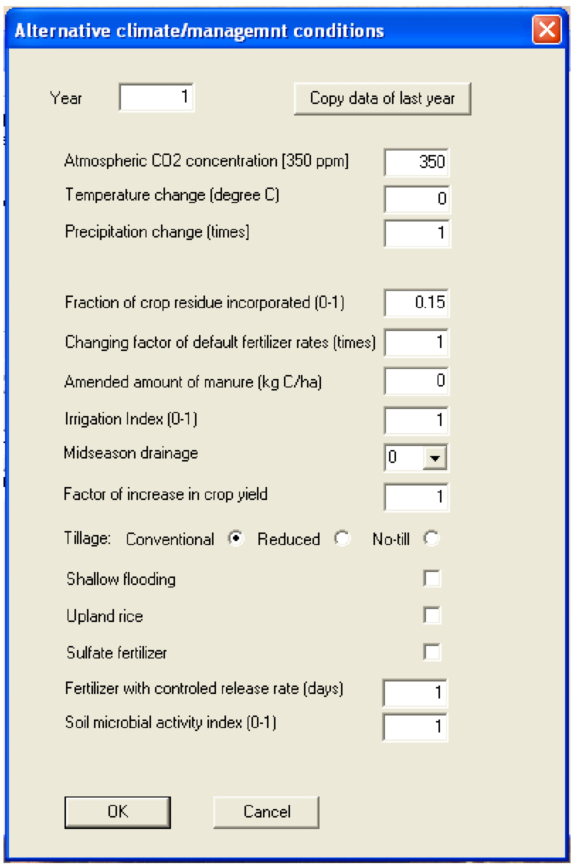


Figure 25. Systematically modifying climate and/or management conditions for regional simulation

[***Atmospheric CO2 concentration (350ppm)***]: The default value is 350 ppm. You can change it to any number to estimate the impacts of CO2 elevation on crop yield, C sequestration, trace gas emissions etc. at the regional scale.

[***Temperature change (degree C)***]: The default value is 0. You can change it to a positive number (e.g., 2, 4 etc.) or a negative number (e.g., -2, -4 etc.) to systematically alter the daily temperatures recorded in the original climate files. That will enable you to estimate the impacts of increase or decrease in temperature on crop yield, C sequestration, trace gas emissions etc. at the regional scale.

[***Precipitation change (times)***]: The default value is 1. You can change it to a number, with which the new precipitation will be calculated by multiplying the original daily precipitation for the entire region.
[***Fraction of crop residue incorporated (0-1)***]: The default value is 0.15. It means 15% of above-ground crop residue will be incorporated into the fields after harvest. You can set a new number between 0 and 1 to redefine the incorporated fraction for the entire region.
[***Changing factor of default fertilizer rates (times)***]: The default value is 1. You can change it to a new number, which will be used to multiply the original fertilizer rates recorded in the Lib_farm files for the entire region.
[***Amount of amended manure (kg C/ha)***]: The default value is 0. You can change it to add a certain amount of farmyard manure in unit kg C/ha per year into the fields across the region.
[***Irrigation index (0-1)***]: The default value is 0. That means no irrigation applied. You can change it to a number between 0 and 1. The number indicates the fraction of water stress that can be met with irrigation water if water stress occurs.
[***Midseason drainage***]: The default value is 0. You can change it to 1, 2 or 3 to apply midseason drainage for 1, 2 or 3 times each season for rice paddy fields across the region.
[***Fraction of increase in crop yield (0-1)***]: The default value is 1. You can set a new number lower or higher than 1 for systematically decrease or increase the default maximum yields for all the crops across the region.
[***Tillage***]: By selecting “Conventional”, “Reduced” and “No-till” you will be able to redefine the tillage method for the entire region.
[***Shallow flooding***]: Checking this box will convert the water management for all rice paddies to the shallow flooding, a new practice for elevating rice yield and reducing water use.
[***Upland rice***]: Checking this box will convert all the paddy rice field into upland rice field.
[***Sulfate fertilizer***]: Checking this box will convert all the N-fertilizer into ammonium sulfate.
[***Fertilizer with controlled release rate (days)***]: The default value is 1. If you apply fertilizer with controlled release rate, the effective days of the fertilizer will need to be specified in this box.
[***Soil microbial activity index (0-1)***]: The default value is 1. If there is any regional factor depressing the soil microbial activity, the number can be correspondingly reduced.

You can set the above-listed parameters for each specific year by selecting the specific year number. Clicking “Copy data of last year” will enable you to copy the entire set of the defined parameter values for a new year.

When you finish the regional input procedure, please click “OK” to transfer all the input information into computer’s memory. At this moment, you are ready to execute the regional simulation.

2.4. Run DNDC for Regional Scale

After completing the input procedure, click the "Run" button to start the regional simulation. During the regional simulations, DNDC runs for each cropping system in each polygon for the defined years twice with the maximum and minimum values of a specific soil factor depending on the user-defined “major concern” for this simulation. DNDC will continuously run polygon by polygon until reaching the end of the database. The simulated results will be recorded in a group of files stored at \DNDC\Result\Record\Region\(Region name)\. All the result files are in a plain text format, so they can be reprocessed with any word processor or spreadsheet software (e.g., Excel etc.).

IV. MODELED RESULTS

1. Results from Site Runs

In site mode, at the end of each simulated year, an annual report is recorded \DNDC\Result\Record\Site to summarize the dynamics of C and N pools and fluxes in the agro-ecosystem for the year. This file provides the key information for assessing annual C, N and water budgets as well crop production. Below-listed is an example file for the annual report:

File name: Year_1.txt

ANNUAL REPORT: Site Beitem Year 1 Thu Jul 06 10:34:36 2006

Site name and recording time

SOM pool	-----Litter-----		-----Humads---		-----Humus---		-----Total-----	
kg C (N)/ha	C	N	C	N	C	N	C	N
Day 1	2126	64	2126	213	80786	6732	85038	7008
Day 365	2254	38	1406	141	80528	6711	84188	6889

Organic C and N pools

Inorg. N pool							
kg N/ha	NO3-	NH4+	NH3(w)	Urea	NO(w)	Clay-N	Total
Day 1	1.42	2.38	0.00	0.00	0.00	20.43	24.23
Day 365	40.34	31.12	0.83	0.00	0.00	12.52	84.81

Inorganic N pools

Flux	C (kg C/ha/yr)	N (kg N/ha/yr)
Input		
Manure	949	300.00
Shoot litter	0	0.00
Root litter	2383	28.04
Weeds litter	0	0.00
Rain-N deposit		7.18
Fertilizer-N		0.00
N-fixation		0.00
Output		
Soil-CO2 emission	4182	
Root-CO2 emission	1778	
CH4 emission	-1	
DOC leached	0	0.00
Crop N uptake from soil		159.47
Weed N uptake from soil		0.00
NO3- leaching		220.17
NH3 volatilization		0.47
N2O		11.94
NO		1.32
N2		7.17
NO2		0.00

Fluxes of C and N into the agroecosystem

Fluxes of C and N from the agroecosystem

Mineralization: 4182.3 kg C/ha; 320.9 kg N/ha; Soil C/N ratio: 12.2

Mineralization rate

Crop number	1	2	3
Crop name	Corn	None	None
Planting date	130	0	0
Growing days	163	0	0
Total crop N (kg N/ha)	159	0	0
Total crop C (kg C/ha)	9564	0	0
-- Grain C	3539	0	0
-- Leaf+stem C	3634	0	0
-- Root C	2391	0	0
-- Water stress	0.75	0.00	0.00
-- Nitrogen stress	1.00	0.00	0.00
Stubble (kg C/ha)	0		
Grass cut (kg C/ha)	0		
Grazed biomass (kg C/ha)	0		
Growing season TDD:	2554	0	0

Crop biomass

Depth (cm)	kg C/kg	kg C/ha
0 - 10	0.0203	23294
10 - 20	0.0200	22521
20 - 30	0.0189	19183
30 - 40	0.0165	10626
40 - 50	0.0142	5918

Soil C profile

Water balance (mm)	
Precipitation	949
Irrigation	0
Transpiration	233
Soil evaporation	291
Surface water evaporation	0
Run off	0
Leaching	387

Water budget

Daily results from site runs will be recorded in a series of files located at \DNDC\Result\Record\Site. The daily files and their contents are listed as follows:

Day_C_(year #):

- Daily pools of very labile litter, labile litter, resistant litter, microbes, humads, humus, and DOC (dissolve organic C) in kg C/ha;
- Daily fluxes of soil-CO2 (heterotrophic respiration), root-CO2 (autotrophic respiration), CH4-production, CH4-oxidation, CH4-net emission, and DOC-leaching in kg C/ha/day.

Day_N_(year #):

- Daily pools of crop-N, weeds-N, urea, NH4+ at 0-10,10-20 and 20-30cm, NO3- at 0-10,10-20 and 20-30cm, NH3, ice-trapped N2O, and clay-adsorbed N in kg N/ha;
- Daily fluxes of N2O, NO, N2, soil-emitted NH3, and plant-emitted NH3 in g N/ha/day;
- Daily fluxes of leached N, mineralized N, and assimilated N in kg N/ha/day.

Day_Crop_(year #):

- Daily growth rates of total biomass, grain, shoot, and root in kg C/ha/day;
- Leaf area index (LAI);
- Daily pools of crop-N, shoot-C, root-C, and grain-C in kg C/ha;
- Daily N demand, N uptake, and N fixation in kg N/ha/day;
- Daily N stress, and water stress (fraction from 0-1. 1-no stress).

Day_Soil_(year #):

- Daily air temperature in °C and precipitation in mm;
- Daily redox potential (Eh) in mV;
- Daily soil temperature at 5, 15, 30, 40, 50 cm;
- Daily soil moisture (wfps) at 5, 15, 30, 40, 50 cm;
- Daily soil ice content (wfps and mm);
- Daily snow-pack (mm water).

Day_Water_(year #):

- Daily initial and end soil water pools in mm;
- Daily available water pool in mm;
- Daily soil ice content in mm;
- Daily water influx, evaporation, transpiration, surface water evaporation, runoff, and water leaching in mm/day;
- Daily ponding water pool, snow-pack, and deep water pool in mm;
- Daily water table depth in m.

Day_Manage_(year #):

- Daily irrigated water in mm;
- Daily applied fertilizer in kg N/ha;
- Daily applied manure in kg N/ha.

Day_Graze_(year #):

- Daily above-ground grass biomass in kg C/ha;
- Daily grazing intensity: heads of cattle, horse, and sheep/ha;
- Grazing hours per day;
- Daily grazed grass-C and grazed grass-N in kg C and N/ha;
- Daily production of dung-C, dung-N, and urine-N in kg C or N/ha;
- Daily food deficit;
- Daily NH3 volatilization from animal waste in kg N/ha.

All the result files are in a plain text format so that they can be reprocesses with any word processor or spreadsheet software.

2. **Results from Regional Runs**

The simulated results from regional runs are recorded in a series of files stored at C:\DNDC\Result\Record\Region\(scenario name). The files contain simulated annual pools or fluxes for each cropping system in each polygon. The files with names beginning with "rate" contain flux rates (e.g., kg C or N/ha/yr); and the files with names beginning with "sum" report total fluxes of C or N emission for the polygon (e.g., kg C or N/polygon/yr). The "max" and "min" files record the simulated maximum and minimum values, respectively, for the concerned fluxes or pools.

The fluxes and pools recorded in the regional files include annual atmospheric N deposition (DepositN), crop yield (GrainC), crop leaf and stem production (ShootC), crop root production (RootC), crop litter production (ResidueC), N uptake by crop (UptakeN), biotic N fixation (FixedN), fertilizer-N applied (FertilizerN), manure-C applied (ManureC), manure-N applied (ManureN), SOC storage in unit kg C (SOC), SOC storage in unit kg C/kg soil (pSOC), change in SOC storage (dSOC), soil mineralized N (MineralizedN), leached SOC (LeachedC), leached SON (LeachedN), CO_2 flux (CO2), CH_4 flux (CH4), ammonia volatilization (NH3), nitrous oxide flux (N2O), nitric oxide flux (NO), dinitrogen flux (N2), soil evaporation (WaterEvap), irrigated water (WaterIrri), leached water (WaterLeach), and transpiration (WaterTrans).

All the result files are in a plain text format so that they can be reprocesses with any word processor or spreadsheet software.

V. UNCERTAINTY ANALYSIS

For regional runs, uncertainty will be produced due to the inherent heterogeneity of soil properties and other input parameters at each simulated unit or grid. To bring the uncertainty under control, we allow DNDC to run twice for each cropping system in each grid with two extreme values of the most sensitive driving factors for the concerned C or N fluxes or pools. For example, DNDC runs twice with maximum and minimum SOC contents for a county, and produces a range of N2O emissions for the county. Since SOC is the most sensitive factor for N2O emission in soils, the predicted range should be wide enough to include the "real" N2O flux with a high probability. We called this approach as Most Sensitive Factor (MSF) method. To verify the reliability of the method, we have developed a Monte Carlo routine in DNDC. Users can utilize the GIS databases to test any cropping system in any county or grid (Figure 17). The Monte Carlo routine will randomly combine different soil properties to simulate the C and N fluxes (Figure 18). The default sample size is 2,000. Increasing the sample size will produce more smooth curves for frequency of distribution of the simulated fluxes. Preliminary tests have demonstrated that the results from the Monte Carlo approach and MSF method are comparable.

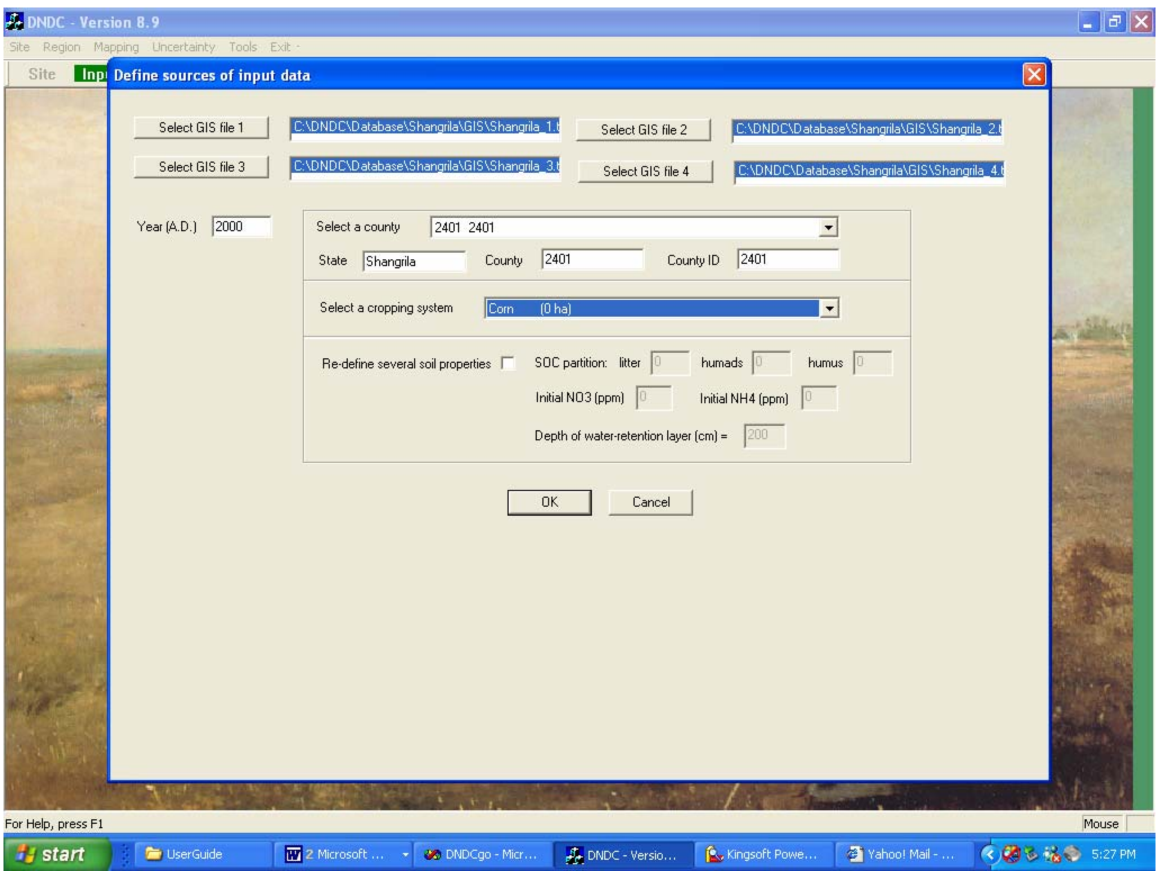


Figure 17. Users can utilize the Monte Carlo routine built in DNDC to conduct uncertainty analysis.

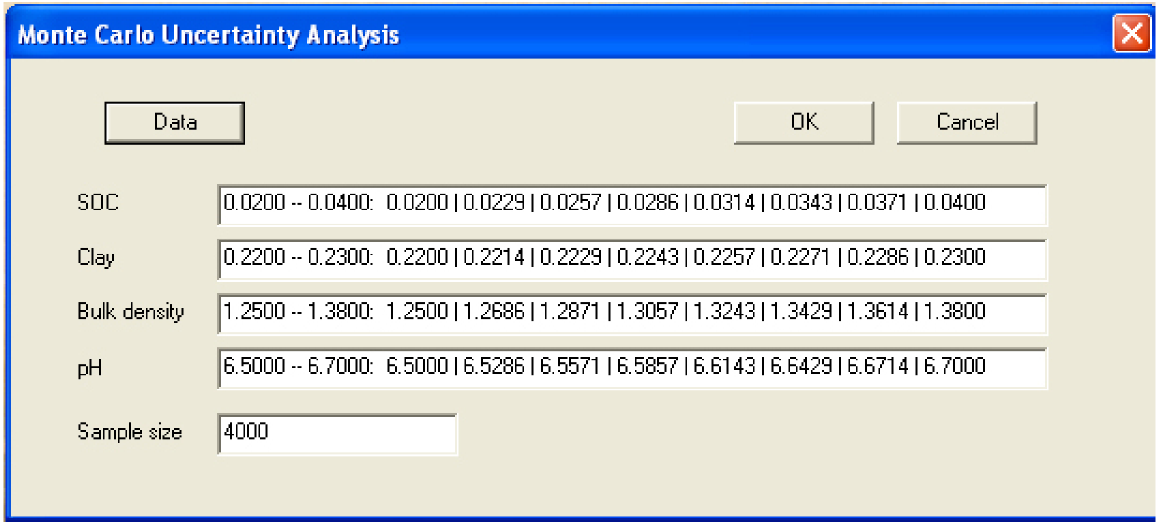


Figure 18. The default sample size for Monte Carlo analysis is 4,000.

VI. RELEVANT PUBLICATIONS

Tonitto C., M.B. David, L.E. Drinkwater, C. Li, 2007a, Application of the DNDC model to tile-drained Illinois agroecosystems: model calibration, validation, and uncertainty analysis, Nutrient Cycling in Agroecosystems DOI 10.1007/s10705-006-9076-0

Tonitto C., M.B. David, C. Li. L.E. Drinkwater, 2007b, Application of the DNDC model to tile-drained Illinois agroecosystems: model comparison of conventional and diversified rotations, Nutrient Cycling in Agroecosystems DOI 10.1007/s10705-006-9074-2.

Tang, H., J. Qiu, E. Van Ranst, and C. Li, 2006. Estimations of soil organic carbon storage in cropland of China based on DNDC model. Geoderma, 134:200-206.

Zhang, F., C. Li, Z. Wang, and H. Wu. 2006. Modeling impacts of management alternatives on soil carbon storage of farmland in Northwest China. Biogeosciences 3:451-466.

Kesik, M., N. Brüggemann, R. Forkel, R. Kiese, R. Knoche, C. Li, G. Seufert, D. Simpson, K. Butterbach-Bahl, Future Scenarios of N2O and NO emissions from European forest soils, Journal of Geophysical Research – Biogeosciences Volume 111, G02018, 2006

Miehle et al., 2006, Quantifying uncertainty from large-scale model predictions of forest carbon dynamics (2006)12:1421-1434. doi:10.1111/j.1365-2486.01176.x.

Li, C., W. Salas, B. DeAngelo, and S. Rose, 2006, Assessing alternatives for mitigating net greenhouse gas emissions and increasing yields from rice production in China over the next twenty years Journal of Environmental Quality 35:1554-1565. doi:10.2134/jeq2005.0208.

Jagadeesh Babu, Y., C. Li, S. Frolking, D.R. Nayak, and T.K. Adhya, 2006. Field validation of DNDC model for methane and nitrous oxide emissions from rice-based production systems of India. Nutrient Cycling in Agroecosystems, DOI 10.1007/s10705-005-6111-5.

Pathak H., C. Li, R. Wassmann R. and J.K. Ladha, 2006. Simulation of Nitrogen Balance in the Rice-Wheat Systems of the Indo-Gangetic Plains: Upscaling Using the DNDC Model. Soil Science Society of America Journal (in press).

Li, C., N. Farahbakhshazad, D.B. Jaynes, D.L. Dinnes, W. Salas, D. McLaughlin, 2006. Modeling nitrate leaching with a biogeochemical model modified based on observations in a row-crop field in Iowa. Ecological Modelling 196(2006):116-130.

Miehle et al., 2006. Assessing productivity and carbon sequestration capacity of Eucalyptus globulus plantations using the process model Fores-DNDC: Calibration and validation, Ecological Modelling 192(2006):83-94.

Neufeldt et al., 2006. Disaggregated greenhouse gas emission inventories from agriculture via a coupled economic-ecosystem model, Agriculture, Ecosystems and Environment 112 (2006) 233-240.

Kesik, M., P. Ambus, R. Baritz, N. Brüggemann, K. Butterbach-Bahl, M. Damm, J. Duyzer, L. Horváth, R. Kiese, B. Kitzler, A. Leip C. Li, M. Pihlatie, K. Pilegaard, G. Seufert, D. Simpson, U. Skiba, G. Smiatek, T. Vesala, S. Zechmeister-Boltenstern, 2005. Inventories of N_2O and NO emissions from European forest soils. Biogeosciences 2:353-375 SRef-ID:1726-4189/bg/2005-2-353.

Sun, G., C. Li, C. Trettin, J. Lu, and S. McNulty, 2005, Simulating the biogeochemical cycles in cypress wetland-pine upland ecosystems at a landscape scale with the Wetland-DNDC model (submitted to International Conference on Hydrology and Management of Forested Wetland, New Bern, NC, April 2006).

Jagadeesh Babu, J., C. Li, S. Frolking, D.R. Nayak, A. Datta, and T.K. Adhya, 2005, Modeling of methane emissions from rice-based production systems in India with the denitrification and decomposition model: Field validation and sensitivity analysis. Current Science, Vol 89, No. 11, 1-6.

Qiu et al., 2005, Studies on the situation of soil organic carbon storage in croplands in northest of China. Agricultural Sciences in China (2005) 4(1):101-105.

Kiese et al., 2005, Regional application of PnET-N-DNDC for estimating the N2O source strength of tropical rainforests in the Wet Tropics of Australia. Global Change Biology (2005) 11:128-144. DOI: 10.1111/j.1365-2486.2004.00873.x.

Cui et al., 2005, Linkage of MIKE SHE to Wetland-DNDC for carbon budgeting and anaerobic biogeochemistry simulation. Biogeochemistry (2005) 72:147-167. DOI: 10.1007/s10533-004-0367-8.

Cui, J., C. Li, and C. Trettin. 2005. Analyzing the ecosystem carbon and hydrologic characteristics of forested wetland using a biogeochemical procees model, Global Change Biology, 11:278-289, doi: 10.1111/j.1365-2486.2005.00900.x.

Li., C., S. Frolking, and K. Butterbach-Bahl, 2005. Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing. Climatic Change (2005) 72:321-338, DOI: 10.1007/s10584-005-6791-5.

Li, C., S. Frolking, X. Xiao, B. Moore III, S. Boles, J. Qiu, Y. Huang, W. Salas, and R. Sass. 2005. Modeling impacts of farming management alternatives on CO2, CH4, and N2O emissions: A case study for water management of rice agriculture of China. Global Biogeochemical Cycles, Vol. 19, doi:10.1029/2004GB002341.

Hsieh et al., 2005, The effect of future climate perturbations on N2O emissions from a fertilized humid grassland. Nutrient Cycling in Agroecosystems 73:15-23. DOI 10.1007/s10705-005-7129-4.

Pathak H., C. Li, and Wassmann R., 2005. Greenhouse gas emissions from India rice fields: calibration and upscaling using the DNDC model, Biogeosciences, 2, 113-123.

Zhuang et al., 2004, Emission inventory of carbon-containing greenhouse gases in China and technological measures for their abatement. Chinese Journal of Population, Resources and Environment Vol. 2 No. 3, 7-13.

Frolking, S., C. Li, R. Braswell, and J. Fuglestvedt, 2004, Short- and long-term greenhouse gas and radiative forcing impacts of changing water management in Asian rice paddies. Global Change Biology 10, 1180-1196, doi: 10.1111/j.1365-2486.00798.x.

Saggar, S., R.M. Andrew, K.R. Tate, N.J. Rodda, C.B. Hedley and J.A. Townsend 2004. Modelling nitrous oxide emissions from New Zealand dairy grazed pastures. *Nutr Cycling Agroecosyst 68:243-255.*

Grant, B., Smith, W.N., Desjardins, R., Lemkc, R., C. Li. 2004. Estimated N2O and CO2 emissions as influenced by agricultural practices in Canada, Climate Change 65 (3): 315-332.

Smith, W.N. , B. Grant, R.L. Desjardins, R. Lemke, B. Grant, C. Li, 2004. Estimates of the interannual variations of N2O emissions from agricultural soils in Canada, Nutrient Cycling in Agroecosystems, 68:37–45.

Li, C., A. Mosier, R. Wassmann, Z. Cai, X. Zheng, Y. Huang, H. Tsuruta, J. Boonjawat, and R. Lantin. 2004. Modeling Greenhouse Gas Emissions from Rice-Based Production Systems: Sensitivity and Upscaling. *Global Biogeochemical Cycles* 18: GB1043, doi:10.1019/2003GB002045.

Li, C. 2004. Modeling terrestrial ecosystems. Complex Systems and Complexity Science 1:49-57 (in Chinese).

Li, C., J. Cui, G. Sun, and C. Trettin. 2004. Modeling impacts of management on carbon sequestration and trace gas emissions in forested wetland ecosystems. Environmental Management DOI: 10.1007/s00267-003-9128-z.

Kiese, R., C. Li, D. Hilbert, H. Papen and K. Butterbach-Bahl, 2004. Regional application of PnET-N-DNDC for estimating the N_2O source strength of tropical rainforests in the Wet Tropics of Australia, *Global Change Biololgy 11:128-144, doi: 10.1111/j.1365-2486.2004.00873x.*

Butterbach-Bahl, K., M. Kesik, P. Miehle, H. Papen, and C. Li. 2004. Quantifying the regional source strength of N-trace gases across agricultural and forest ecosystems with process based models. Plant and Soil 260:311-329.

Ganzeveld, L., C. Li, L. Cardenas, J. Hawkins, and G. Kirkman. Nitrogen emissions from soils. In: C. Granier et al. (eds.), Emissions of Atmospheric Trace Components, 171-238. 2004 Kluwer Academic Publishers. Printed in the Netherlands.

Li, C., X. Xiao, S. Frolking, B. Moore III, J. Qiu, Y. Zhang, Y. Zhuang, X. Wang, Z. Dai, J. Liu, X. Qin, B. Liao, R. Sass. 2003. Greenhouse gas emission from cropland of China. Quaternary Sciences, 5:493~503.

Qiu JJ, Tang HJ, Frolking S, Boles S, Li C, Xiao X, Liu JY, Zhuang YH, Qin XG. 2003. Mapping single-, double-, and triple-crop agriculture in China at 0.5°x0.5° by combining county-scale census data with a remote sensing-derived land cover map. Geocarto International, 18(2):3-13.

Farahbakhshazad N., McLaughlin D., Dinnes D. L., Jaynes D. B., and Li C. A site-specific evaluation of a crop-Denitrification/Decomposition model based upon a U.S. Midwestern row-crop field. 2002 ASA-CSSA-SSSA, 677 South Segoe Road, Madison, WI 53711, USA. *Proceedings of the Sixth International Conference on Precision Agricultur*e.

Xu-Ri, M Wang, and Y. Wang. 2003. Using a modified DNDC model to estimate N2O fluxes from semi-arid grassland in China. Soil Biology and Biochemistry 35:615-620.

Qiu JJ, Tang HJ, Frolking S, Boles S, Li C, Xiao X, Liu JY, Zhuang YH, Qin XG. 2003. Mapping single-, double-, and triple-crop agriculture in China at 0.5°x0.5° by combining county-scale census data with a remote sensing-derived land cover map. Geocarto International, 18(2):3-13.

Cai, Z., T. Sawamoto, C. Li, G. Kang, J. Boonjawat, A. Mosier, R. Wassmann, and H. Tsuruta, 2003. Field validation of the DNDC model for greenhouse gas emissions in East Asian cropping systems, *Global Biogeochem. Cycles*, *17*(4), 1107, doi:10.1029/2003GB002046.

Saggar, S., R.M. Andrew, K.R. Tate, C.B. Hedley and J.A. Townsend 2003. Simulation of nitrous oxide emissions from New Zealand dairy-grazed pastures and its mitigation strategies. In Proceedings of the 3rd International Methane and Nitrous Oxide Mitigation Conference, 17-21 November, 2003 Beijing, China. pp. 461-468.

Li, C., Y. Zhuang, S. Frolking, J. Galloway, R. Harriss, B. Moore III, D. Schimel, and X. Wang, 2003. Modeling soil organic carbon change in croplands of China. *Ecological Applications* 13(2)327-336.

Li, C., J Qiu, S. Frolking, X. Xiao, W. Salas, B. Moore III, S. Boles, Y. Huang, and R. Sass, 2002. Reduced methane emissions from large-scale changes in water management in China's rice paddies during 1980-2000, *Geophysical Research Letters*, 29(20), doi:10.1029/2002GL015370, 2002.

Frolking, S., J. Qiu, S. Boles, X. Xiao, J. Liu, Y. Zhuang, C. Li, and X. Qin, 2002. Combining remote sensing and ground census data to develop new maps of the distribution of rice agriculture in China, *Global Biogeochem. Cycles*, 16(4), 1091, doi:10.1029/2001GB001425.

Farahbakhshazad N., McLaughlin D., Dinnes D. L., Jaynes D. B., and Li C. A site-specific evaluation of a crop-Denitrification/Decomposition model based upon a U.S. Midwestern row-crop field. 2002 ASA-CSSA-SSSA, 677 South Segoe Road, Madison, WI 53711, USA. *Proceedings of the Sixth International Conference on Precision Agricultur*e.

Li, C., W. Salas, S. Frolking, S. Boles, X. Xiao, B. Moore, and R. Sass, 2002. Quantifying the atmospheric impacts of paddy rice agriculture in China. In: National Institute of Agro-Environmental Sciences, Science and Technology Agency of Japan, The Japan International Science and Technology Exchange Center. Proceedings of NIAES-STA International Workshop 2001: Crop Monitoring and Prediction at Regional Scales. 19-21 Debruary 2001, Tsukuba, Japan. Pp. 29-36.

Smith, W.N., R.L. Desjardins, B. Grant, C. Li, R. Lemke, P. Rochette, M.D., and Corre, D. Pennock, 2002, Testing the DNDC model using N2O emissions at two experimental sites in Canada. *Canada Journal of Soil Science* 82:365-374.

Saggar, S., R.M. Andrew, K.R. Tate, N.J. Rodda, C.B. Hedley and J.A. Townsend 2002. Measurements and modelling of nitrous oxide emissions from dairy pastures. In proceedings of the workshop on *Dairy Farm Soil Management* (Eds L.D. Currie and P. Loganathan), *Occasional Report No.15*, Massey University, Palmerston North. Pp. 201–214.

Zhang, Y., C. Li, C. C. Trettin, H. Li, G. Sun, 2002. An integrated model of soil, hydrology and vegetation for carbon dynamics in wetland ecosystems, *Global Biogeochemical Cyc*les 10.1029/2001GB001838.

Zhang, Y., C. Li, X. Zhou, and B. Moore III, 2002. A simulation model linking crop growth and soil biogeochemistry for sustainable agriculture. *Ecological Modeling* 151:75-108.

Brown, L., Syed, B., Jarvis, S.C., Sneath, R.W., Phillips, V.R., Goulding, K.W.T., and C. Li, 2002. Development and application of a mechanistic model to estimate emission of nitrous oxide from UK agriculture. *Atmospheric Environment*, 36: 917-928.

Xiao, X., S. Boles, S. Frolking, W. Salas, B. Moore III, C. Li, L. He, and R. Zhao, 2002. Landscale-scale characterization of cropland in China using Vegetation and Landsat TM images. *Int. J. Remote Sensing* 23:3579-3594.

Xiao, X., L. He, W. Salas, C. Li, B. Moore III, R. Zhao, S. Frolking, and S. Boles, 2002. Quantitative relationships between field-measured leaf area index and vegetation index derived from VEGETATION images for paddy rice fields. *Int. J. Remote Sensing* 23:3595-3604.

Li, C. 2001. Biogeochemical concepts and methodologies: Development of the DNDC model. *Quaternary Sciences* 21:89-99 (in Chinese).

Butterbach-Bahl, K., F. Stange, H. Papen, G. Grell, and C. Li, 2001. Impact of changes in temperature and precipitation on N2O and NO emissions from forest soils, J. van Ham et al. (eds.) Non-CO2 Greenhouse Gases: Specific Understanding, Control and Implementation, 165-171. Kluwer Academic Pnblishers, the Netherlands.

Li C, Zhuang YH, Cao MQ, Crill1 PM, Dai ZH, Frolking S, Moore B, Salas W, Song WZ, Wang XK, 2001, Comparing a national inventory of N2O emissions from arable lands in China developed with a process-based agro-ecosystem model to the IPCC methodology. *Nutr. Cycl. Agroecosystems 60:159-175.*

Butterbach-Bahl, K., F. Stange, H. Papen, and C. Li, 2001, Regional inventory of nitric oxide and nitrous oxide emissions for forest soils of Southeast Germany using the biogeochemical model PnET-N-DNDC, *J Geophy Res* 106:34155-34165.

Li, C., W. Salas, S. Frolking, S. Boles, X. Xiao, B. Moore, and R. Sass, 2002. Quantifying the atmospheric impacts of paddy rice agriculture in China. In: National Institute of Agro-Environmental Sciences, Science and Technology Agency of Japan, The Japan International Science and Technology Exchange Center. Proceedings of NIAES-STA International Workshop 2001: Crop Monitoring and Prediction at Regional Scales. 19-21 Debruary 2001, Tsukuba, Japan. Pp. 29-36.

Smith, W.N., R.L. Desjardins, B. Grant, C. Li, R. Lemke, P. Rochette, M.D., and Corre, D. Pennock, 2002, Testing the DNDC model using N2O emissions at two experimental sites in Canada. *Canada Journal of Soil Science* 82:365-374.

Zhang, Y., C. Li, X. Zhou, and B. Moore III, 2002. A simulation model linking crop growth and soil biogeochemistry for sustainable agriculture. *Ecological Modelling* 151:75-108.

Li, C., Y. Zhuang, S. Frolking, Z. Dai, X. Wang, P. Crill, W. Song, B. Moore, W. salas, 2002, Scaling up nitrous oxide emissions from agricultural lands in China and the U.S., *Global and Planetary Change* (in press).

Li, C, Zhuang YH, Cao MQ, Crill1 PM, Dai ZH, Frolking S, Moore B, Salas W, Song WZ, Wang XK, 2001, Comparing a national inventory of N2O emissions from arable lands in China developed with a process-based agro-ecosystem model to the IPCC methodology. *Nutr. Cycl. Agroecosystems 60:159-175.*

Butterbach-Bahl, K., F. Stange, H. Papen, and C. Li, 2001, Regional inventory of nitric oxide and nitrous oxide emissions for forest soils of Southeast Germany using the biogeochemical model PnET-N-DNDC, *Journal of Geophysical Research* 106:34155-34165.

Butterbach-Bahl K., F. Stange, H. Papen, G. Grell, and C. Li, 2001, Impact of changes in temperature and precipitation on N2O and NO emissions from forest soils, J. van Ham et al. (eds.) *Non-CO2 Greenhouse Gases: Specific Understanding, Control and Implementation*, 165-171. Kluwer Academic Pnblishers, the Netherlands.

Li, C., Aber, J., Stange, F., Butterbach-Bahl, K., Papen, H., 2000, A process-oriented model of N2O and NO emissions from forest soils: 1, Model development, *J. Geophys. Res*. Vol. 105 , No. 4 , p. 4369-4384.

Li, C., 2000, Modeling trace gas emissions from agricultural ecosystems, *Nutrient Cycling in Agroecosystems* 58:259-276.

Stange, F., Butterbach-Bahl, K., Papen, H., Zechmeister-Boltenstern, S., Li, C., Aber, J., 2000, A process-oriented model of N2O and NO emission from forest soils 2, Sensitivity analysis and validation, *J. Geophys. Res*. Vol. 105 , No. 4 , p. 4385-4398.

Plant R.A.J., 2000, Regional analysis of soil-atmosphere nitrous oxide emissions in the Northern Atlantic Zone of Costa Rica. *Global Change Biology*, 6:639-653.

Li, C., 1999, The challenges of modeling nitrous oxide emissions, In: *Reducing nitrous oxide emissions from agroecosystems* (Eds. Raymond Desjardins, John Keng and Karen Haugen-Kozyra, P.Ag.), International N2O Workshop, held at Banff, Alberta, Canada, March 3-5, 1999.

Xiu WB, Hong YT, Chen XH, Li C, 1999, Agricultural N2O emissions at regional scale: A case study in Guizhou, China. *Science in China* 29:5. (in Chinese with English abstract)

Smith, W.N., R.L. Desjardins, and E. Pattey, 1999. Testing of N2O models and scaling up emission estimates for crop production systems in Canada. Eastern Cereal and Oilseeds Research Centre. In: *Reducing nitrous oxide emissions from agroecosystems* (Eds. Raymond Desjardins, John Keng and Karen Haugen-Kozyra, P.Ag.), International N2O Workshop, held at Banff, Alberta, Canada, March 3-5, 1999, pp. 99-106.

Li, C., Y. Zhuang, X. Wang, J. Sun, and X. Sheng, Scaling up soil carbon prediction: A case study for agricultural land in China, In: *Proceedings of Second LUTEA Workshop at Beijing*, March 2-5, 1998, pp. 87-102.

Frolking S.E., A.R. Mosier, D.S. Ojima et al., 1998, Comparison of N2O emissions from soils at three temperate agricultural sites: simulations of year-round measurements by four models. *Nutrient Cycling in Agroecosystems* 52:77-105.

Plant R.A.J., E. Veldkamp, C. Li, 1998, Modeling nitrous oxide emissions from a Costa Rican banana plantation, in: *Effects of Land Use on Regional Nitrous Oxide Emissions in the Humid Tropics of Costa Rica* (ed. R.A.J. Plant), Universal Press, Veenendaal, pp. 41-

50.

Li, C., S. Frolking, G.J. Croker, P.R. Grace, J. Klir, M. Korchens, and P.R. Poulton, 1997, Simulating trends in soil organic carbon in long-term experiments using the DNDC model, *Geoderma* 81:45-60.

Smith P., J.U. Smith, D.S. Powlson et al., 1997, A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments. *Geoderma* 81:153-225.

Wang, Y.P., C.P. Meyer, and I.E. Galbally, 1997. Comparisons of field measurements of carbon dioxide and nitrous oxide fluxes with model simulations for a legume pasture in southeast Australia. *Journal of Geophysical Research*, 102:28013-28024.

Li, C., V. Narayanan, and R. Harriss, 1996, Model estimates of nitrous oxide emissions from agricultural lands in the United States, *Global Biogeochemical Cycles* 10:297-306.

Li, C., 1995, Impact of agricultural practices on soil C storage and N2O emissions in 6 states in the US. In: *Advances in Soil Science (eds. R. Lai et al.), Soil Management and Greenhouse Effect*, pp.101-112.

Li, C., S. Frolking, and R. Harriss, 1994, Modeling nitrous oxide emissions from agriculture: A Florida case study, *Chemosphere* 28:1401-1415.

Li, C., S. Frolking, and R.C. Harriss, 1994, Modeling carbon biogeochemistry in agricultural soils. *Global Biogeochemical Cycles* 8:237-254.

Li, C., S. Frolking, and T.A. Frolking, 1992a, A model of nitrous oxide evolution from soil driven by rainfall events: 1. Model structure and sensitivity, *Journal of Geophysical Research*, 97:9759-9776.

Li, C., S. Frolking, and T.A. Frolking, 1992b, A model of nitrous oxide evolution from soil driven by rainfall events: 2. Applications, *Journal of Geophysical Research*, 97:9777-9783.