Introduction to DNDC model

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DNDC

- **DNDC: DeNitrification DeComposition Model**

- **DNDC is a comprehensive biogeochemistry model**
  that simulates crop growth and soil C and dynamics based on input data on soil properties, climate, and farming practices (e.g. Li et al., 1992, 1994).

- **The model was expanded to simulate the emission of trace gases such as NO, N_2O, NH_4 , and CH_4 from agricultural ecosystems and natural wetlands (Zhang et al., 2002; Li et al ., 2004).**

De-Nitrification De-Composition model

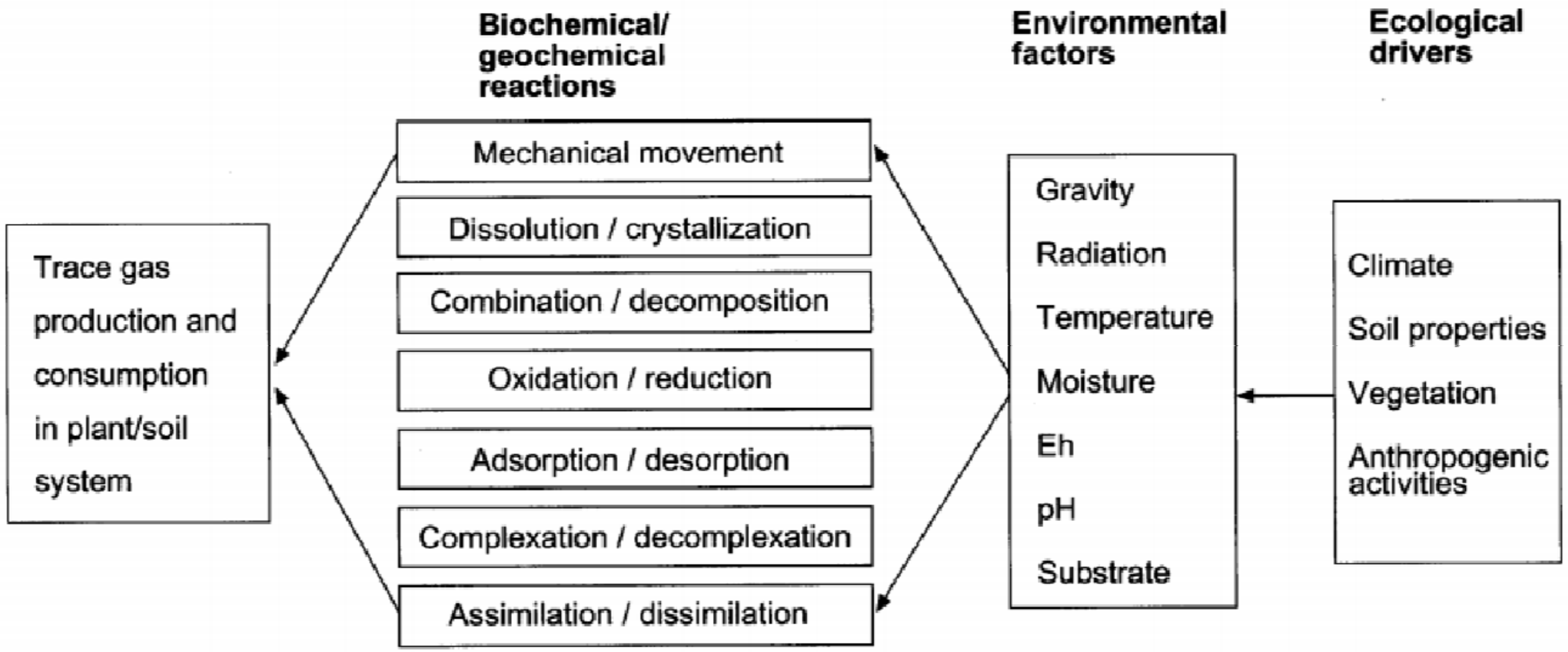


Figure 1. A biogeochemical model is a mathematical expression of biogeochemical field which consists of spatially and temporally differentiated environmental forces driving a series of biogeochemical reactions in ecosystems. Fluxes of NO, N_2O, CH_4, and NH_3 are regulated by directions and rates of the relevant biogeochemical reactions

C.S. Li 2000

DNDC

- **The DNDC model predicts C and N biogeochemistry in agricultural ecosystems at site and regional scales.**

- **The accuracy of prediction depends on the input data on four drivers.**

- **Four major ecological drivers, namely climate, soil physical properties, vegetation, and anthropogenic activities, drive the entire model.**

DNDC

All the impacts in the system can be categorized into 2 groups.

- **The first group includes impacts of ecological drivers on soil environmental variables,**
- **The second groups includes the impacts of the soil environmental variables on trace gas-related geochemical or biochemical reactions.**

DNDC components

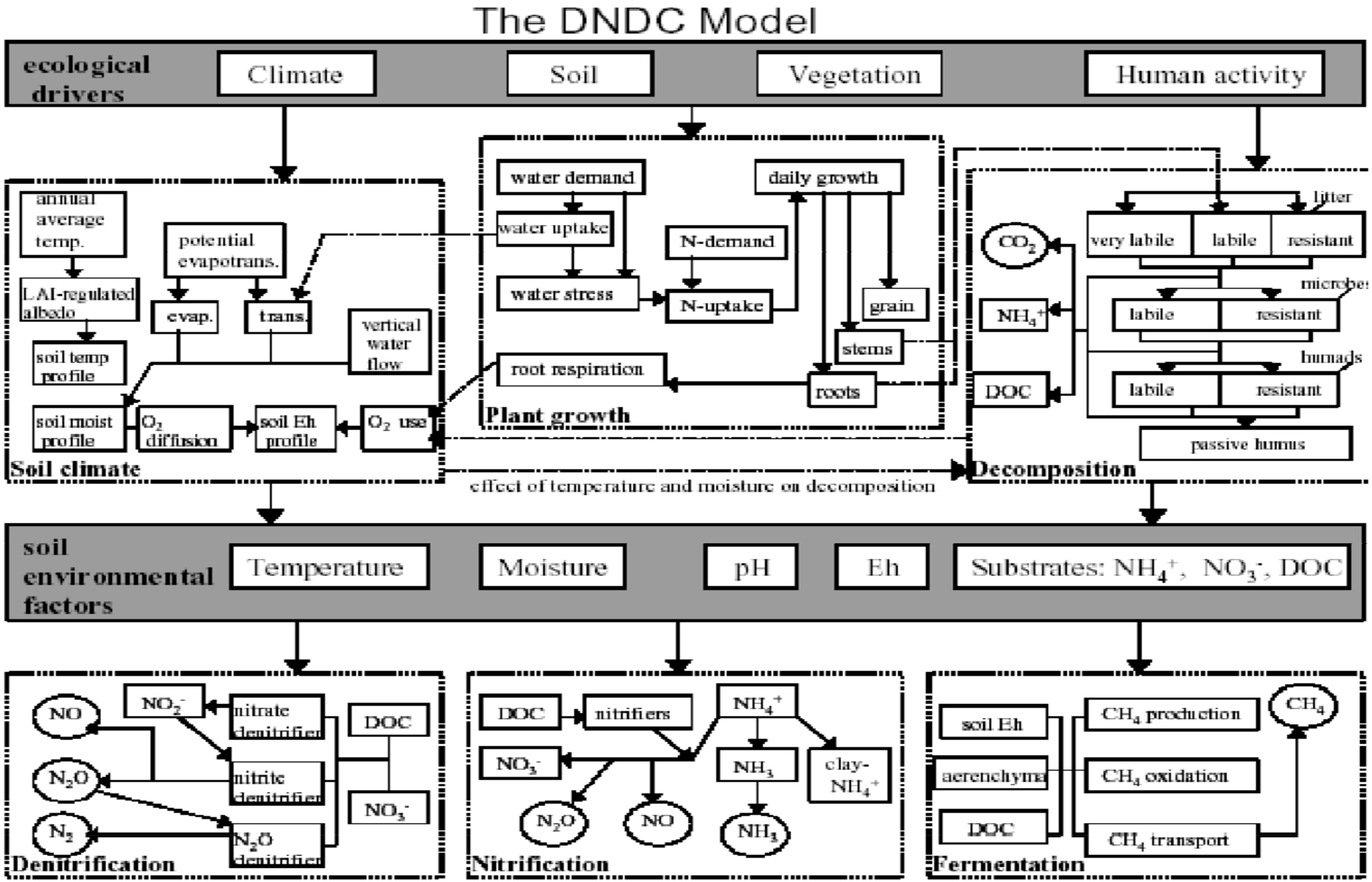
DNDC consisted of 2 components

- The first component consisting of the

Soil climate submodel, crop growth, and decomposition submodes, predicts soil temperature, moisture, pH, Eh, and substrates component,

- The second component consisting of nitrification, denitrification, and fermentation submodels, predicts NH_3, NO, N_2O, CH_4 fluxes

De-Nitrification De-Composition model



Source: University of New Hampshire, 2003

Linking ecological drivers to soil environmental variables

- **DNDC needs site-specific input data of climate, soil, vegetation, and farming practices for the simulated agricultureal land.**
- **DNDC integrates the ecological drivers in the three submodels to generate their collective effects on soil temperature, moisture, pH, Eh, and substrate concentrations.**

Linking ecological drivers to soil environmental variables

- **The soil climate submodel calculates soil temperatureม moisture, pH, Eh profiles by integrating air temperature, precipitation, soil thermal and hydraulic properites, and oxygen status.**
- **By integrating crop characters, climate, soil properties, and farming practices, the plant growth submodel simulates plant growth and its effects on soil temperature, moisture, pH, Eh, dissolved DOC, and available N concentration.**

Linking ecological drivers to soil environmental variables

- **The decomposition submodel simulates concentrations of substrates (e.g., DOC, NH_4^+, and NO_3^-) by integrating climate, soil properties, plant effect, and farming practices.**

- **The three submodels interact with each other to finally determine soil temperature, moisture, pH, Eh, and substrate concentrations in the soil profiles at a daily time step.**

Linking ecological drivers to trace gases

- **The links were set up based on either the basic physical, chemical, or biological laws, or equations obtained from the experiments under controlled conditions so that effect of each soil variable could be distinguished.**

Linking ecological drivers to trace gases

- **Biological oxidation/reduction dominates NO and N_2O evolution in soils.**
- **Nitrification (i.e., microbial oxidation of ammonium) has been observed to be the main source of NO and N_2O under aerobic conditions.**

$$\text{Nitrification: } NH_4^+ \rightarrow H_2NOH \rightarrow NOH \rightarrow NO_2^- \rightarrow NO_3^-$$

$$H_2NOH \downarrow NO \qquad H_2NOH \downarrow N_2O \qquad (1)$$

- **The factors controlling nitrification have been determined to be soil temperature, moisture, pH, and NH_4^+ concentration.**

Linking ecological drivers to trace gases

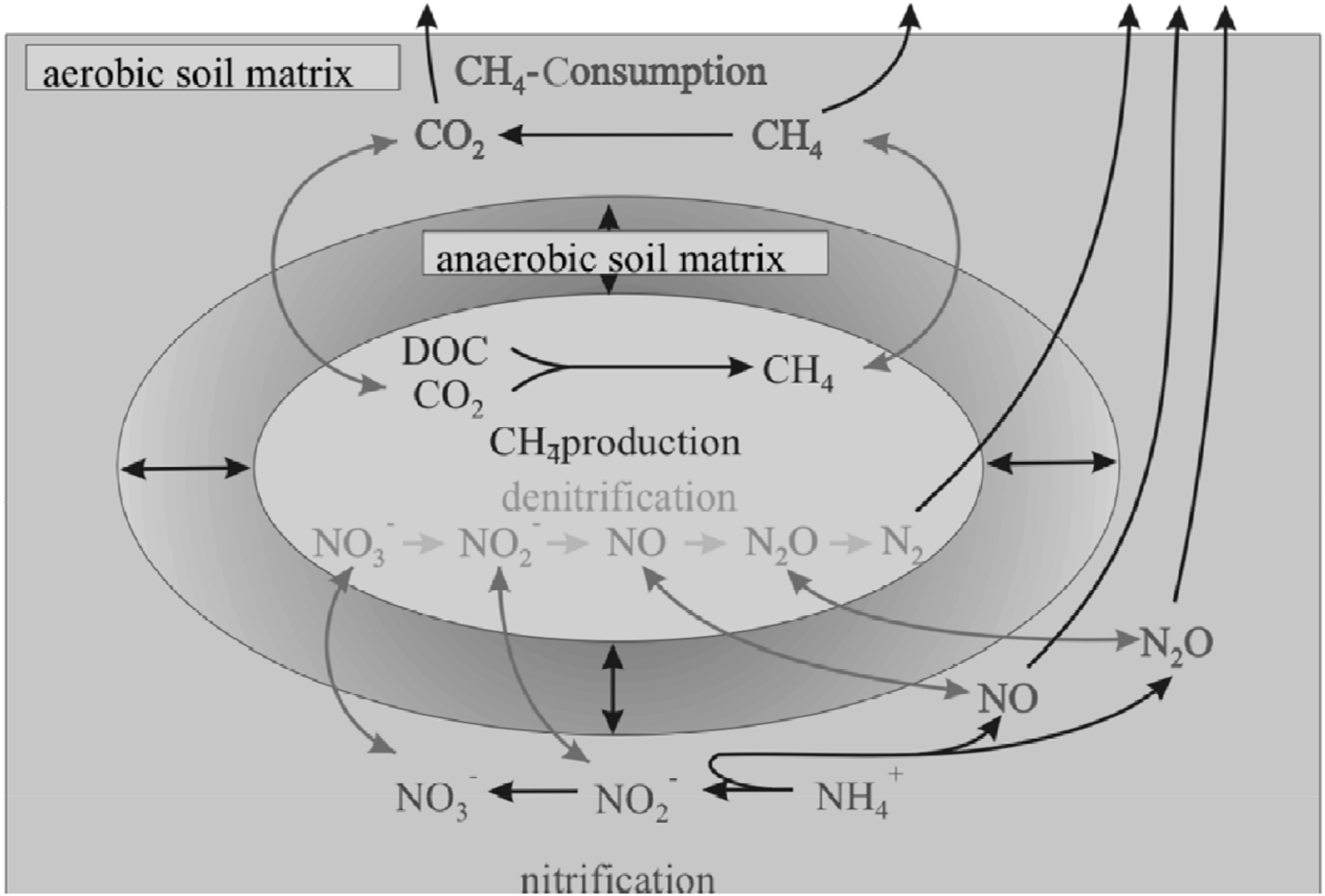
- **Denitrification is another main source of N_2O and NO from soil.**
- **Denitrification includes a sequential reduction of nitrate to dinitrogen (N_2) driven by denitrifying bacteria under anaerobic conditions.**

$$\text{Denitrification: } NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (2)$$

- **Denitrification controlled by soil moisture and Eh.**

Linking ecological drivers to trace gases

- **The DNDC model simulates relative growth rates of nitrate, nitrite, NO, and N_2O denitrifiers based on soi Eh, concentrations of DOC, and nitrogen oxides.**
- **A simple scheme of anaerobic balloon was developed in the model to divide the soil matrix in to aerobic and anaerobic parts.**
- **DNDC simulated swelling and shrinking of the anaerobic balloon.**
- **Only the substrates allocated in the anaerobic part are involved in denitrification.**



http://imk-ifu.fzk.de/823.php

Linking ecological drivers to trace gases

- **Methane is an end product of the biological reduction of CO_2 or organic carbon under anaerobic conditions.**

$$\text{Methane production: } CO_2 + 8\,H^+ \rightarrow CH_4 + 2\,H_2O \qquad (3)$$

or

$$\text{Organic C} + 4\,H^+ \rightarrow CH_4$$

- **Methane fluxes were strongly controlled by soil available carbon (i.e., DOC) content, and soil temperature.**
- **The reduction of available carbon to methane is mediated by anaerobic microbes (e.g., methanogens) that are only active when the soil Eh is low enough.**

Linking ecological drivers to trace gases

- **DNDC calculates methane production rate as a function of DOC content and temperature as soon as the predited soil Eh reaches -150 mV or lower.**
- **Methane is oxidized by aerobic methanotrophs in the soil. A highly simplified scheme was employed in DNDC to model methane diffusion between soil layers based on methane concentration gradients, tempeture, and porosity in the soil.**

Function 3.5. CH_4 diffusion rate (kg C/ha/d)

$$Rd = 0.01 * (CH_4[l] - CH_4[l+1]) * T[l] * PORO;$$

AC – Available C concentration, kg C/ha;
T – soil temperature, °C;
l – soil layer number;
AERE – plant aerenchyma;
FloodDay – flooding days;
PORO – soil porosity;
$CH_4[l]$ – CH_4 concentration at layer l, kg C/ha.

Linking ecological drivers to trace gases

- **DNDC predicts plant-transported methane flux as a function of methane concentration and plant aerenchyma.**

Equation 3.3. CH_4 flux through plant aerenchyma (kg C/ha/d)

$$CH_{4(aere)} = 0.5 * CH_4[l] * AERE;$$

$$AERE = -0.0009*PGI^5+0.0047*PGI^4-0.883*PGI^3+1.9863*PGI^2-0.3795*PGI+0.0251;$$

PGI = (days since planting) / (season days); (plant growth index)

- **DNDC assume that ebullition only occurs at the surface layer, and ebullition rate is regulated by soil methane concentration, temperature, porosity, and plant aerenchyma.**

Function 3.4. CH_4 flux through ebullition (kg C/ha/d)

$$CH_{4(ebullition)} = 0.025 * CH_4[l] * PORO * Ft * (1 - AERE);$$

$$Ft = -0.1687*(0.1*T[l])^3 +1.167*(0.1*T[l])^2 -2.0303*(0.1*T[l])+1.042;$$

Linking ecological drivers to trace gases

- Soil NH_3 concentration is directly regulated by a chemical reaction occurring in the soil liquid phase:

$$[NH_4^+] + [OH^-] = [NH_{3\,(liquid)}] + H_2O \qquad (4)$$

where $[NH_4^+]$ is ammonium concentration, $[OH^-]$ is hydroxide ion concentration, and $[NH_{3\,(liquid)}]$ is ammonia concentration in soil water.

- DNDC calculate $NH_{3(liq)}$ concentration base on NH_4^+ and OH^- concentration, and NH_4^+ concentration in the soil profile is calculated by the decomposition submodel.

Linking ecological drivers to trace gases

- **The equations describing the effects of soil environmental factors on NO, N_2O, CH_4, and NH_3 were organized into three submodels.**
- **1. The fermentation submodel contains all the methane related equation. This submodel calculates production, oxidation, and transport of methane under submerged conditions.**
- **2. The denitrification submodel contains all the denitrification equations. This submodel calculates production, consumption, and diffusion of N_2O and NO during rainfall, irrigation, or flooding events.**

Linking ecological drivers to trace gases

- **3. Nitrification related equations are included in the nitrification submodel. As a logical extension of the NH_4^+ / $NH_{3(liq)}$ /$NH_{3(gas)}$ equilibrium, functions for NH_3 production and volatilization are also included in the nitrification submodel.**

- **The three submodels compose the second component of the DNDC model.**

Input and output

- **Daily temperature**
- **Precipitation**
- **Soil bulk density**
- **Texture**
- **Soil organic carbon content**
- **pH**
- **Farming (e.g., crop type and rotation, flooding, grazing, and weeding)**

Input and output

When the DNC is used for regional estimates of trace gases emissions, the model needs the spatially and temporally differentiated input data stored in geographical information system type database in advance.

Base on the input parameters of the ecological drivers,

DNDC first predicts daily soil temperature, moisture, Eh, pH, and substrate concentration, and then uses the environmental parameters to drive nitrification, denitrification, methane production/oxidations.

Daily emissions of trace gases are finally calculated as their daily net fluxes.

Input and output

Most parts of the model run at a daily time step except the soil climate and denitrification submodels which run at an hourly time step.

Output paratmeters from the model runs are daily soil profiles of temperature, moisture, Eh, pH, and concentrations of total soil orgainic carbon, nitrate, nitrite, ammonium, urea, ammonia, as well as daily fluxed of trace gases emission.

For the regional version of DNDC, the simulated results are recorded as geographically explicit data in a GIS database.

DNDC Site mode

Figure 2. Main menu of DNDC

DNDC Site mode

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

DNDC Site mode

Figure 2. Main menu of DNDC

Climate/Soil/Cropping

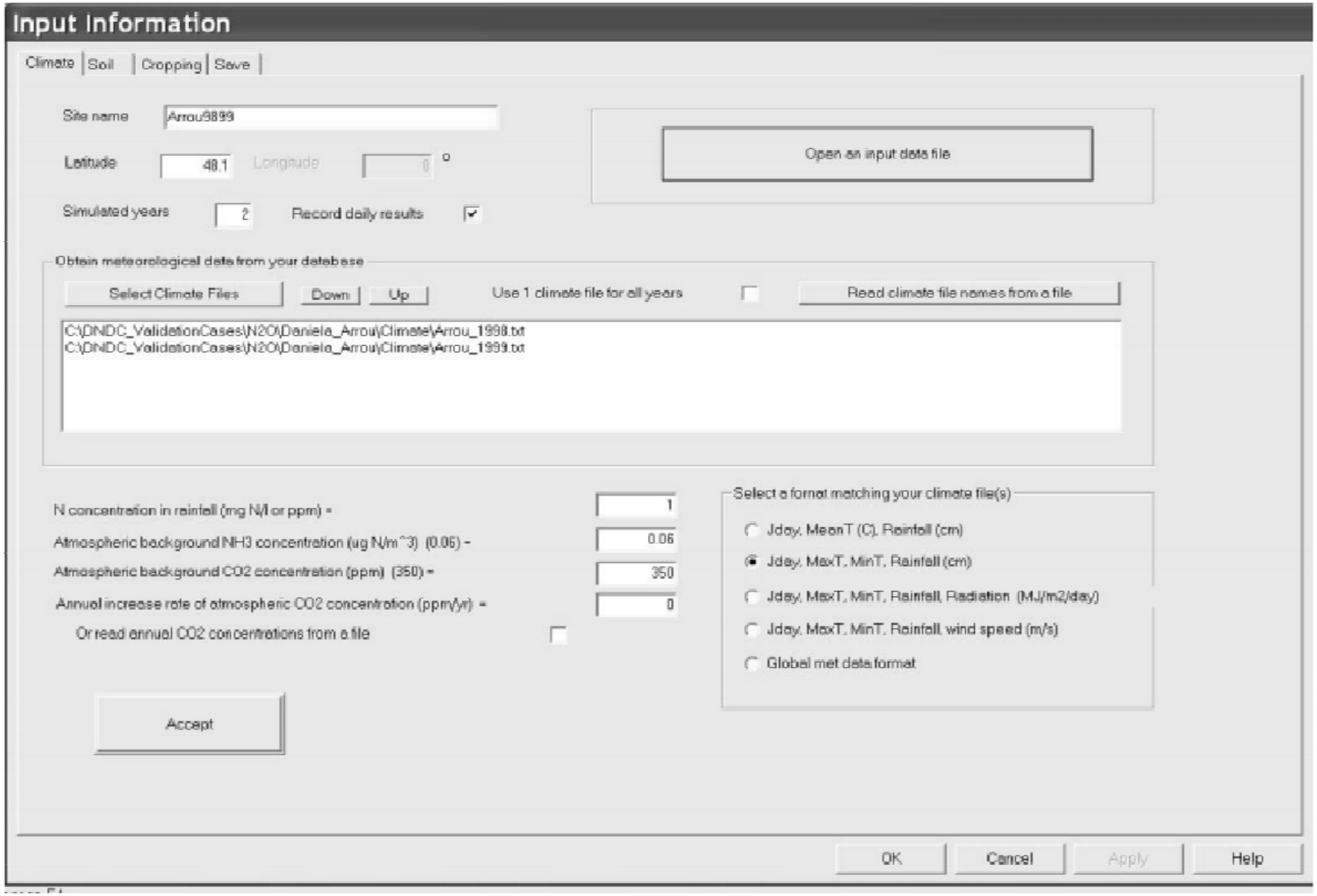


Figure 3. Input information for location and climate

Climate/Soil/Cropping

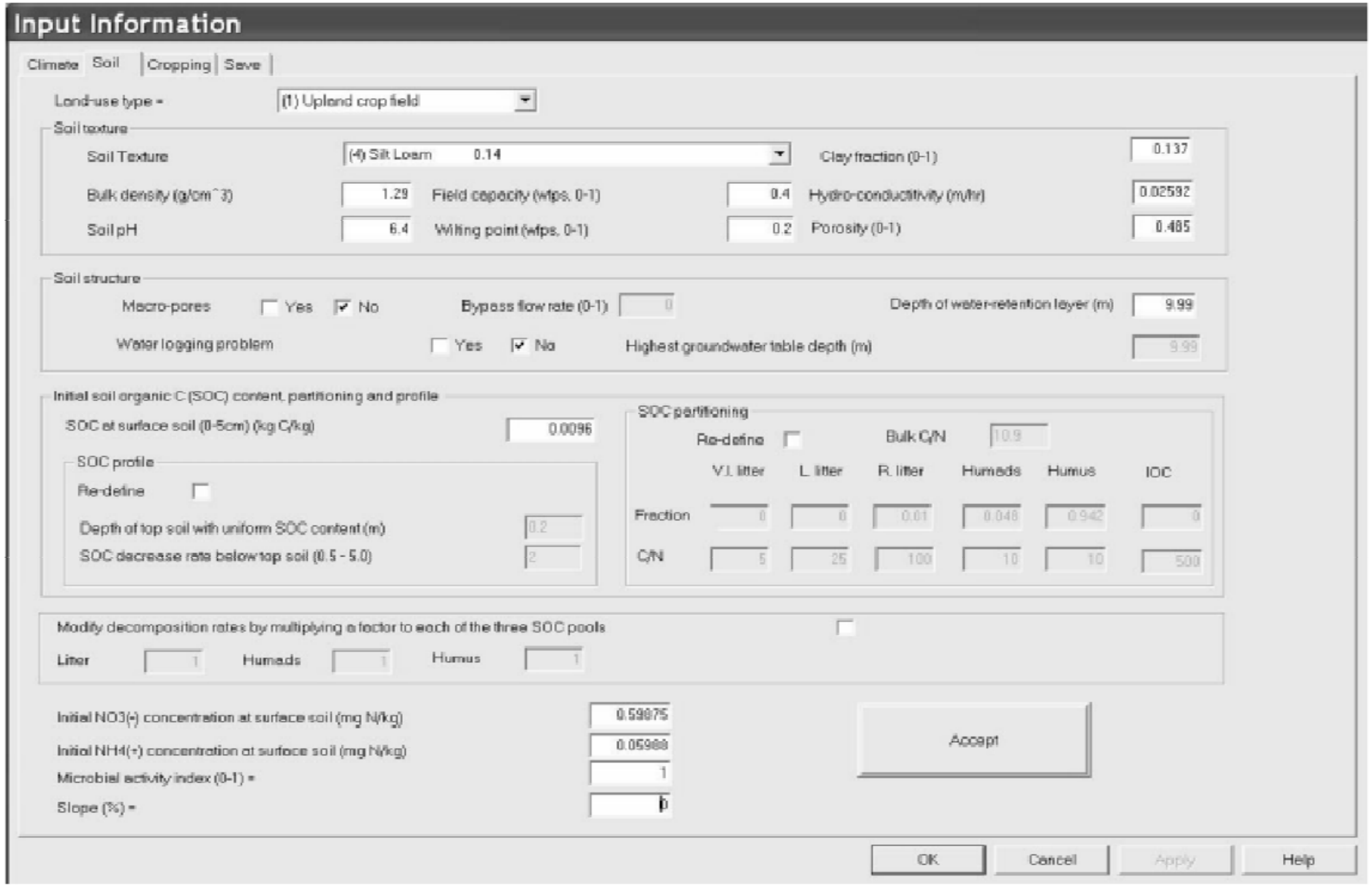


Figure 4. Input information for soil properties

Climate/Soil/Cropping

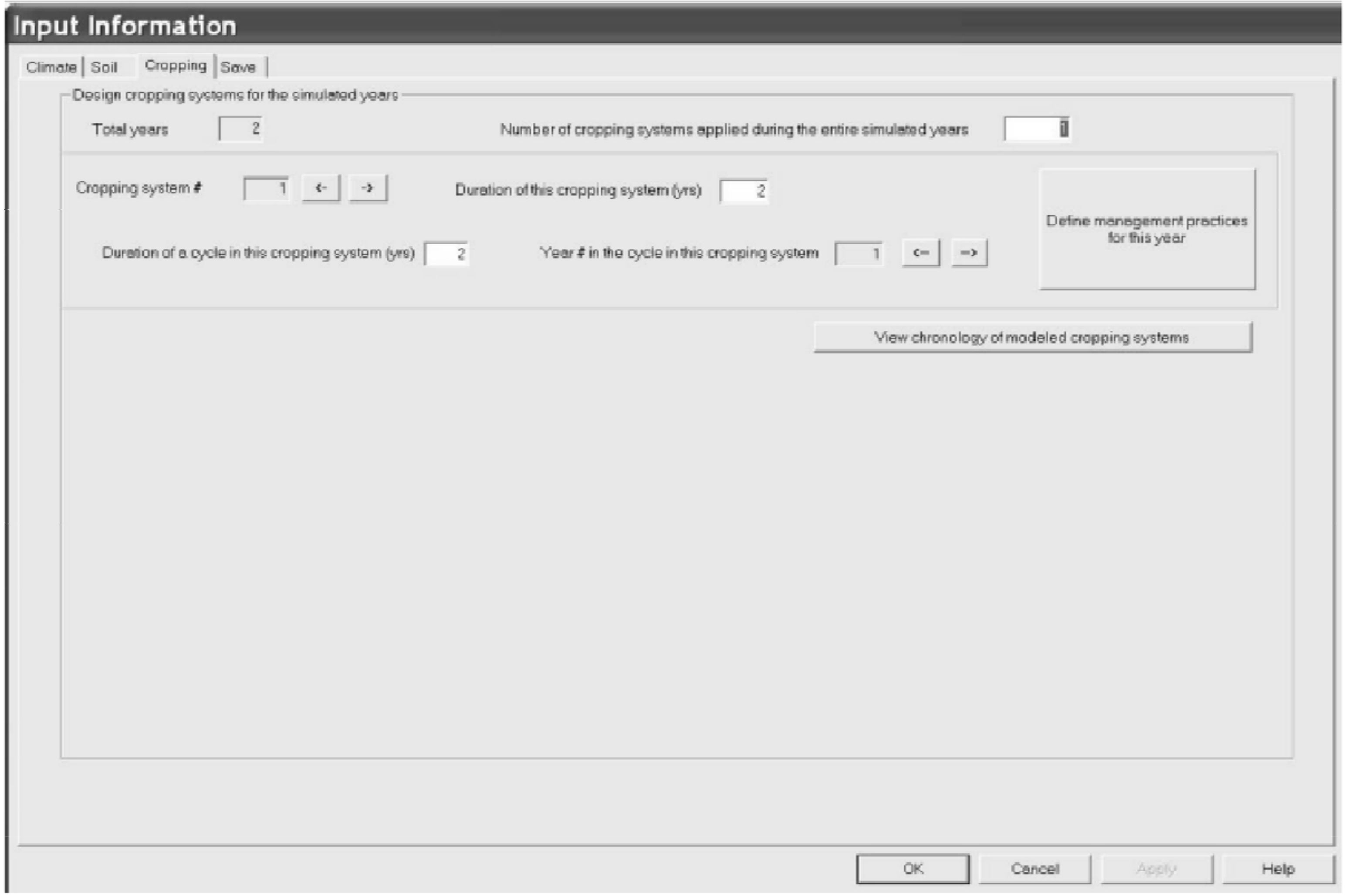


Figure 5. Rotation information: Cropping systems and Cycles

Farming management practices

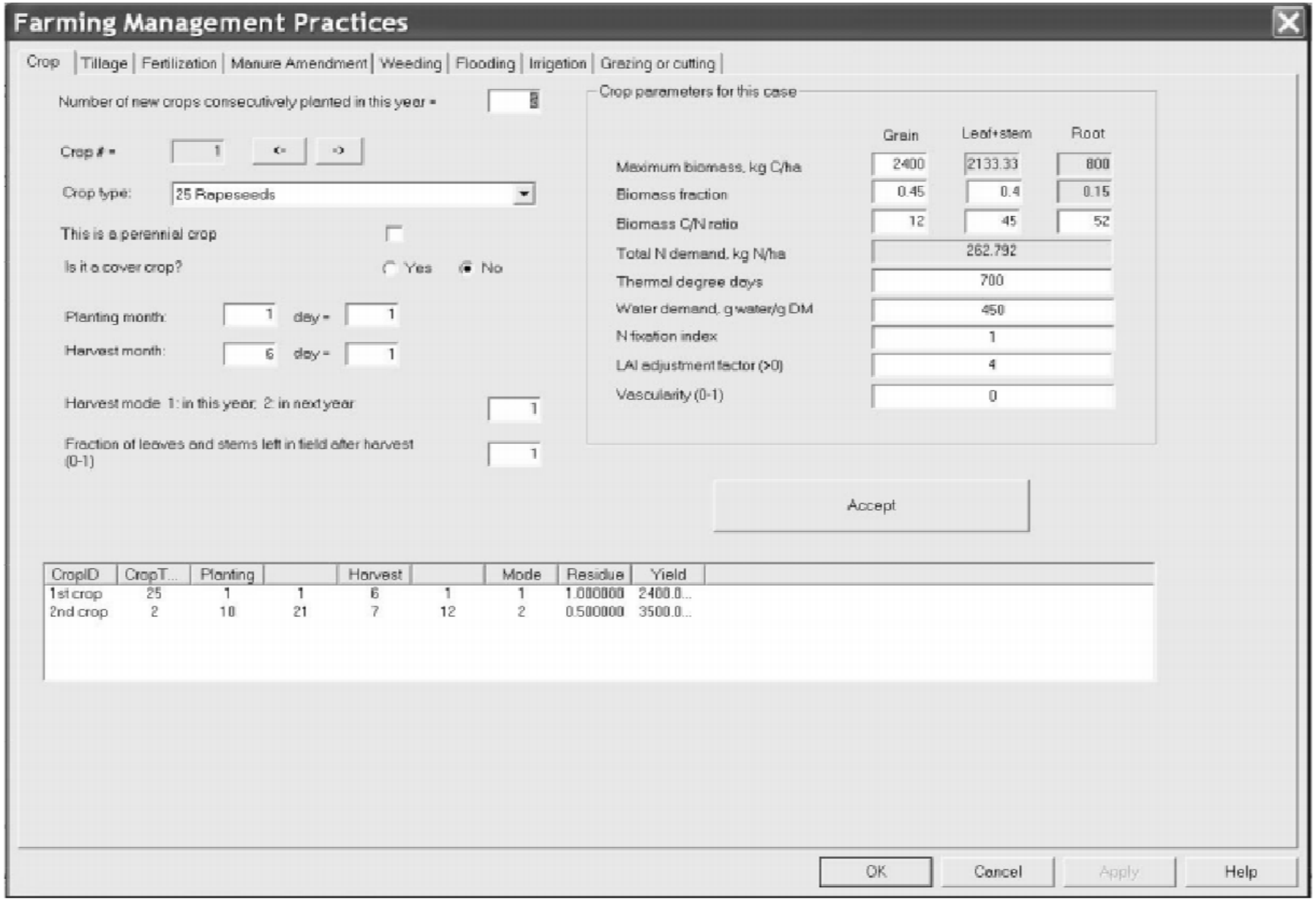


Figure 6. Input information for crop type, planting/harvest dates, residue management and crop physiological/phenology parameters

Farming management practices

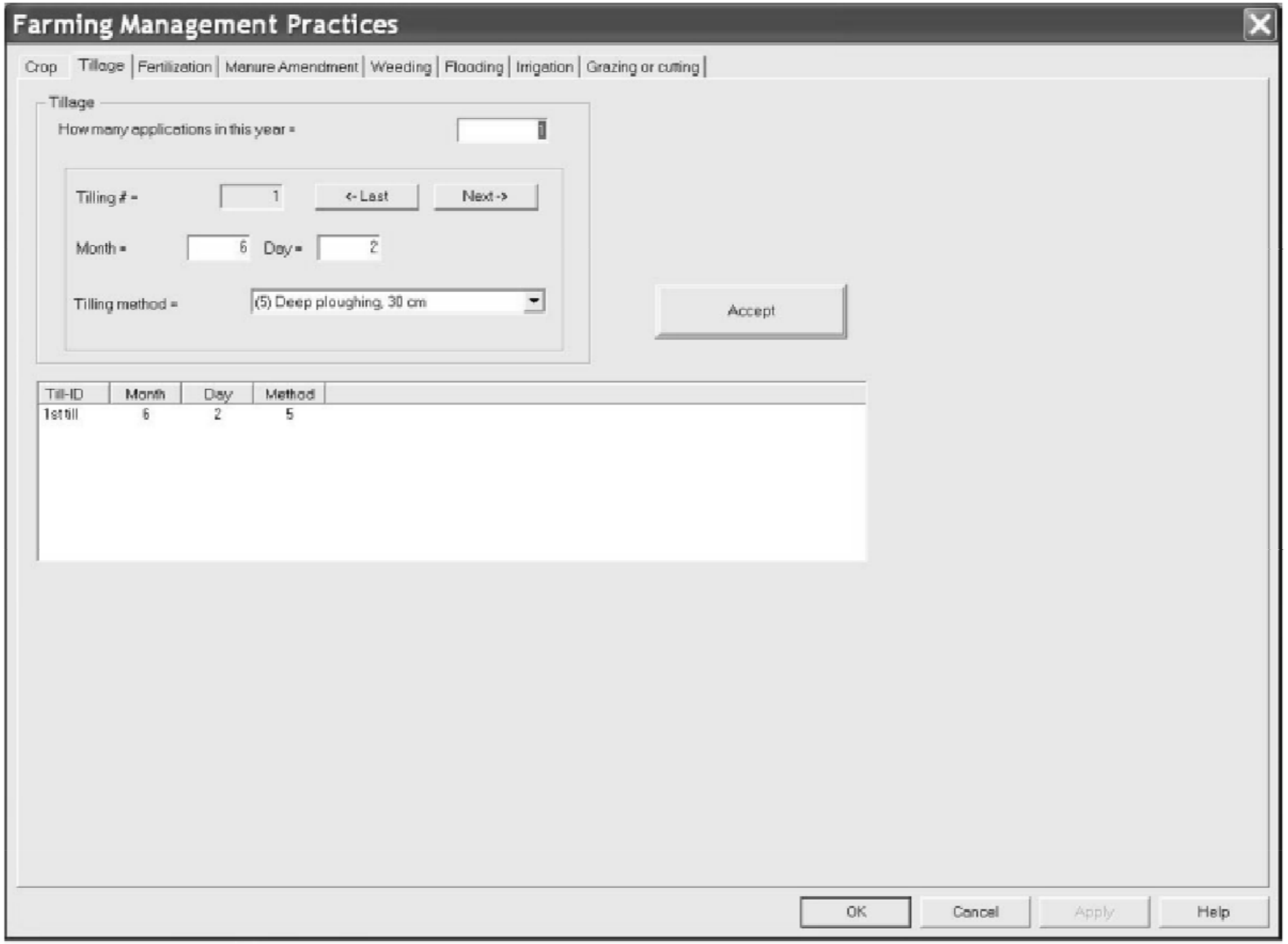


Figure 8. Iput information for tillage

Farming management practices

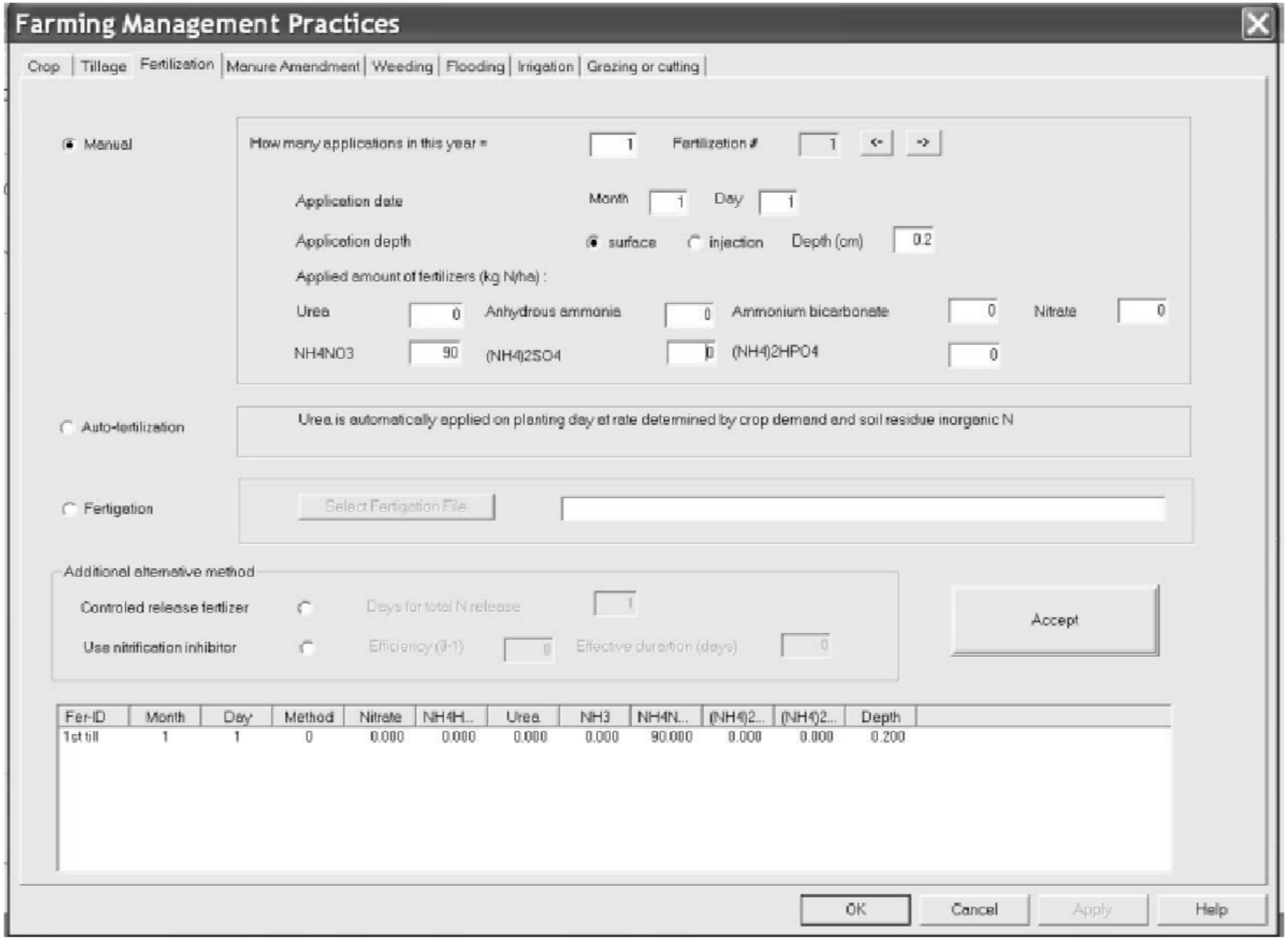


Figure 9. Input information for fertilization

Farming management practices

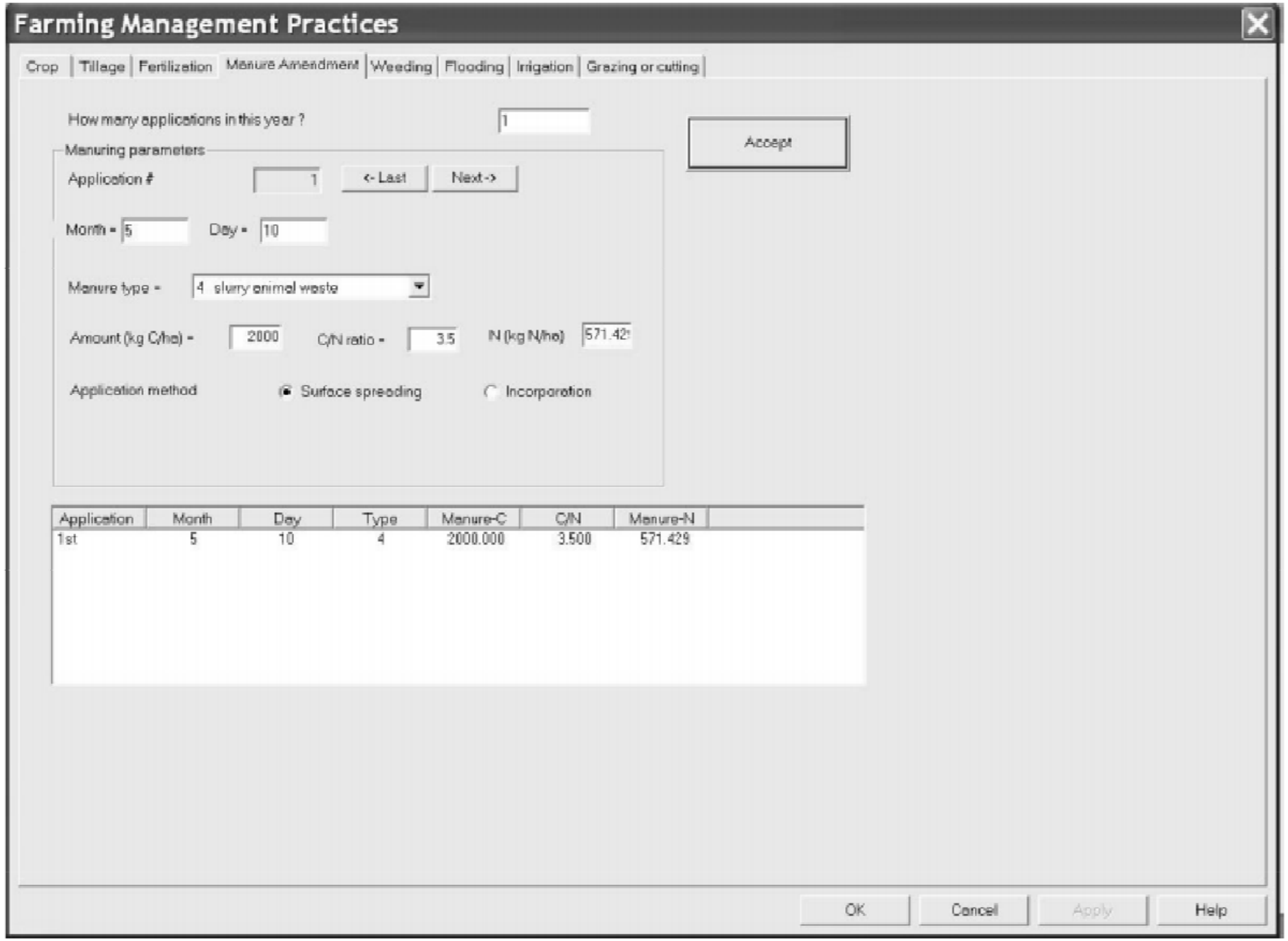


Figure 10. Input information for manure amendment

Farming management practices

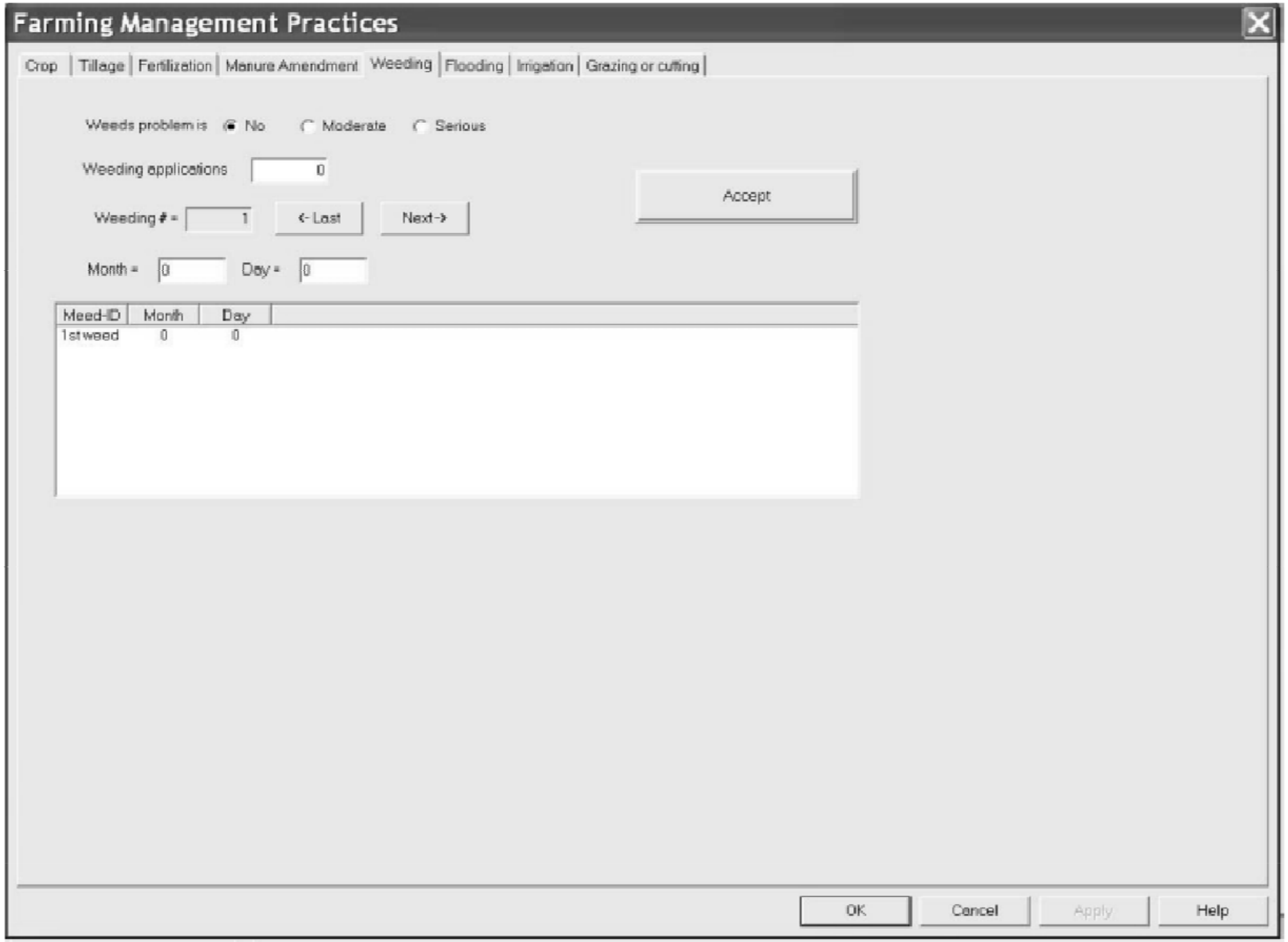


Figure 11. Input information for weeding

Farming management practices

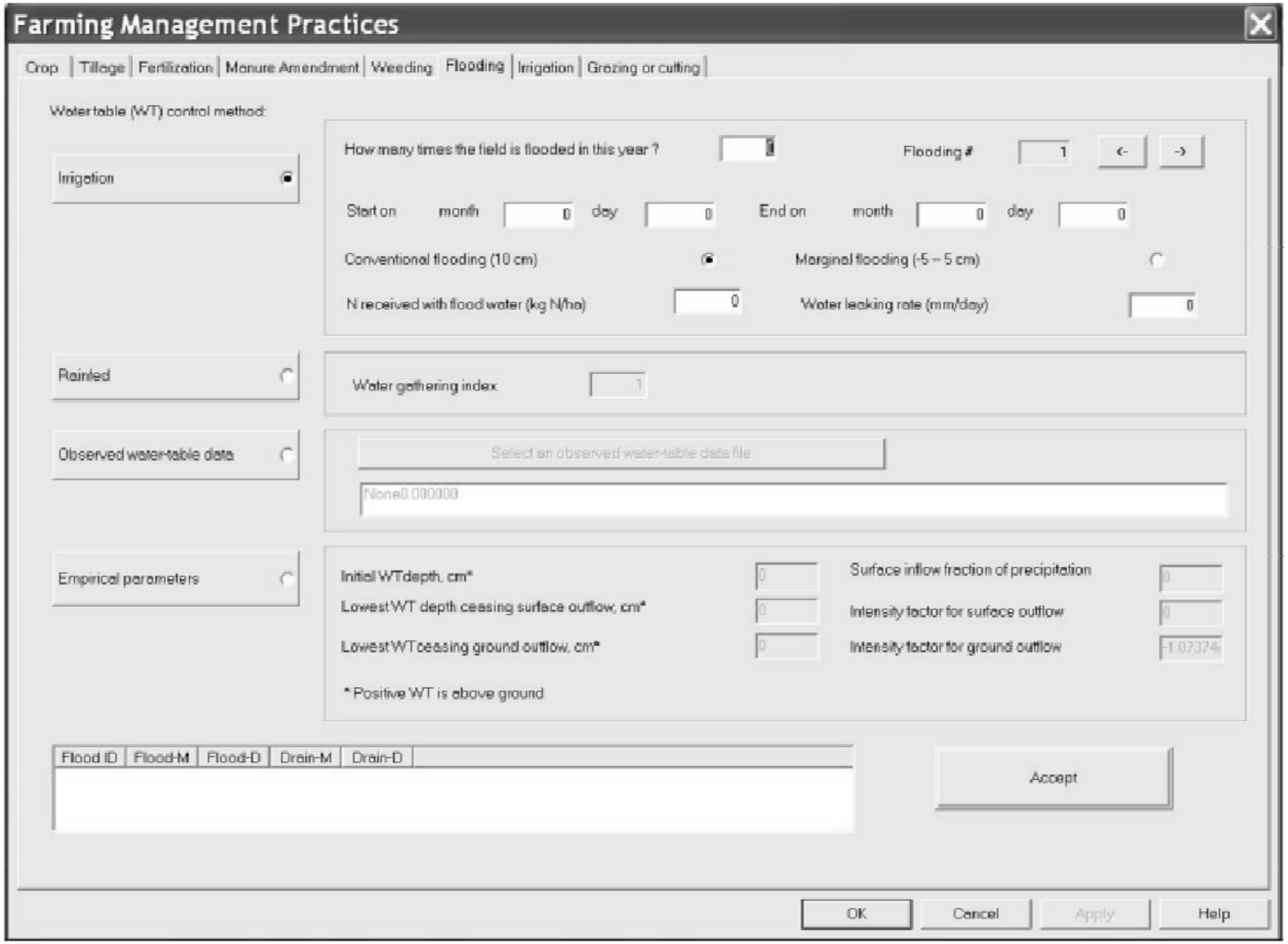
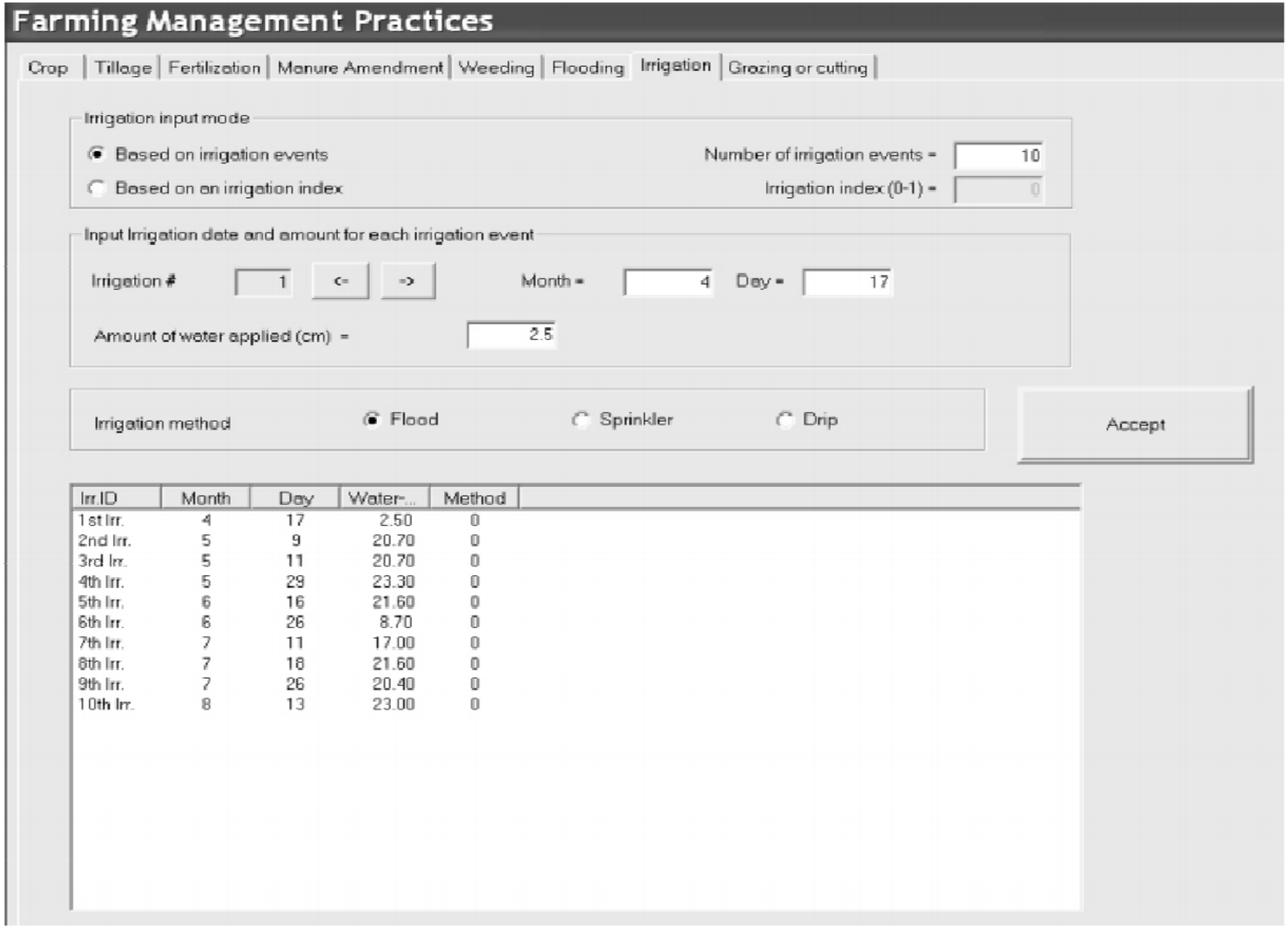


Figure 12. Input information for flooding

Farming management practices



Irr.ID	Month	Day	Water-...	Method
1st Irr.	4	17	2.50	0
2nd Irr.	5	9	20.70	0
3rd Irr.	5	11	20.70	0
4th Irr.	5	29	23.30	0
5th Irr.	6	16	21.60	0
6th Irr.	6	26	8.70	0
7th Irr.	7	11	17.00	0
8th Irr.	7	18	21.60	0
9th Irr.	7	26	20.40	0
10th Irr.	8	13	23.00	0

Figure 13. Input information for irrigation

Farming management practices

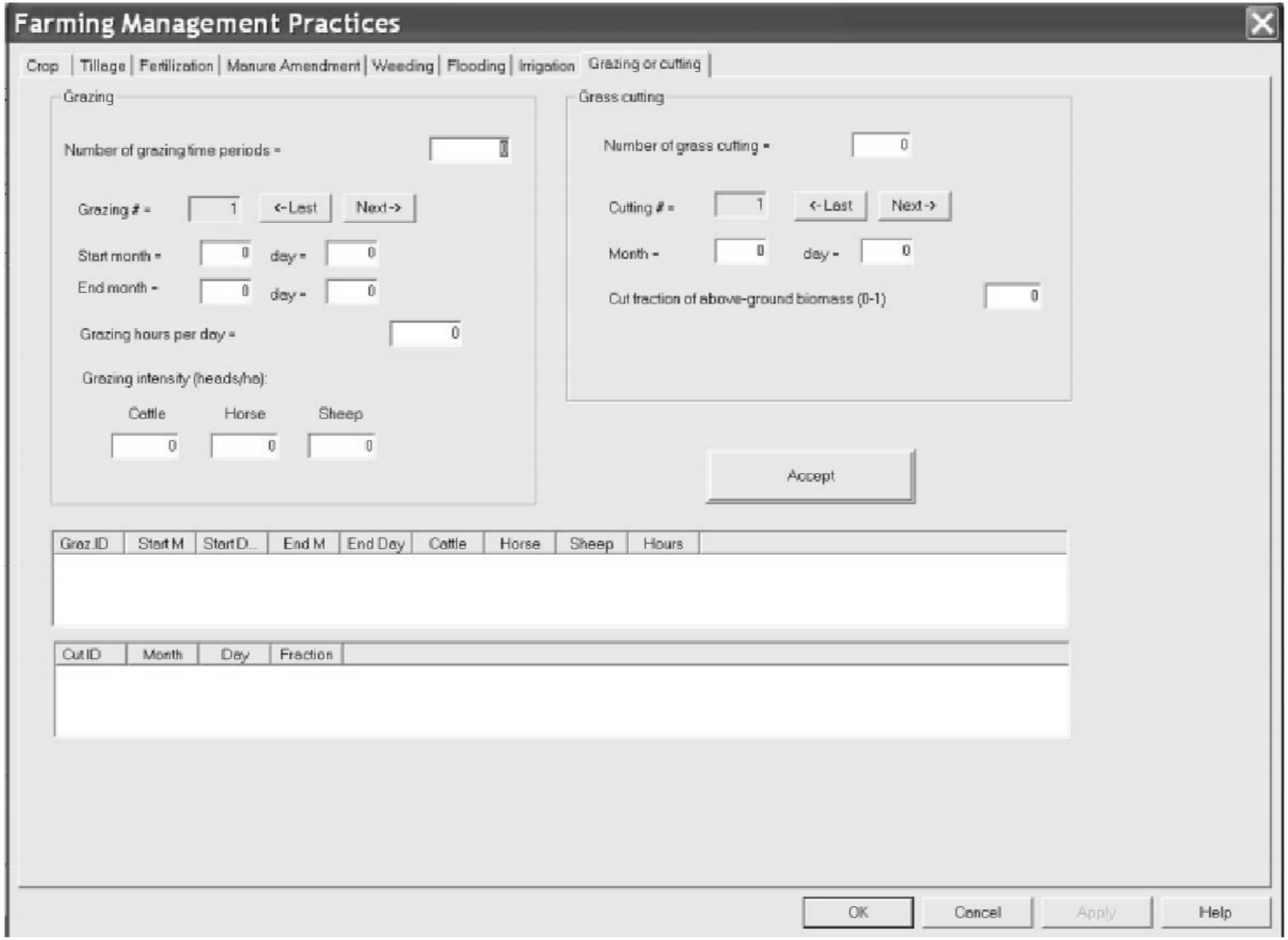
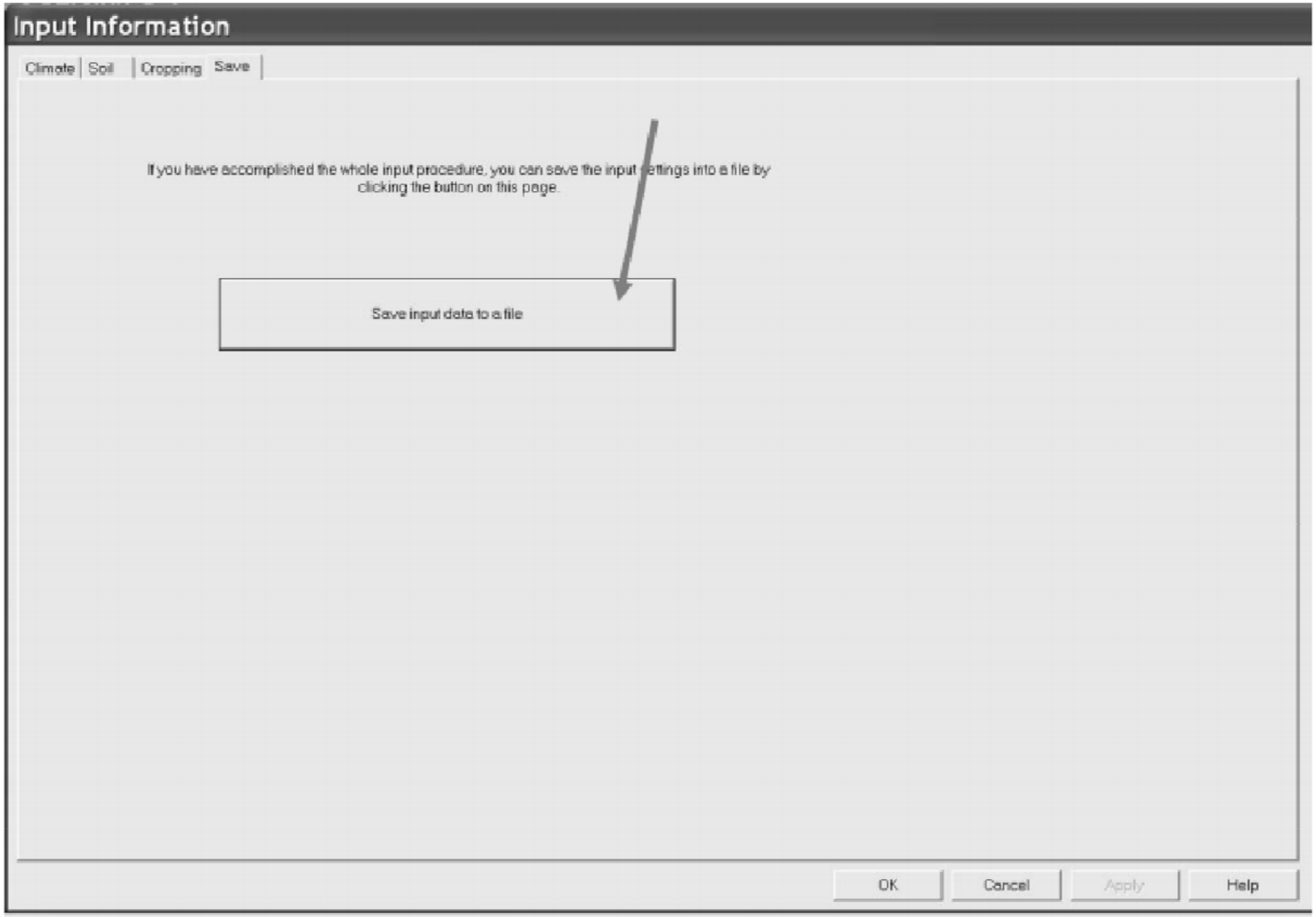


Figure 14. Input information for grazing and grass cutting

Save and open an input file



Input file

```
Input_Parameters:
----------------------------------------
Site_data:                    Arrou9899
Simulated_Year:               2
Latitude:                     48.100
Daily_Record:                      1
----------------------------------------
Climate_data:
Climate_Data_Type:            1
NO3NH4_in_Rainfall              1.0000
NO3_of_Atmosphere               0.0600
BaseCO2_of_Atmosphere         350.0000
Climate_file_count=           2
    1   C:\DNDC\N2O\Arrou\Climate\Arrou_1998.txt
    2   C:\DNDC\N2O\Arrou\Climate\Arrou_1999.txt
Climate_file_mode                  0
```

Input file

```
CO2_increase_rate              0.000000
----------------------------------------
Soil_data:
   Soil_Texture                 4
   Landuse_Type                 1
   Density                      1.29000
   Soil_pH                      6.40000
   SOC_at_Surface               0.00960
   Clay_fraction                0.13700
   BypassFlow                   0.00000
   Litter_SOC                   0.01000
   Humads_SOC                   0.04800
   Humus_SOC                    0.94200
   Soil_NO3(-)(mgN/kg)          0.59875
   Soil_NH4(+)(mgN/kg)          0.05988
   Moisture                     0.30000
   Temperature                  7.45000
Field_capacity                 0.400000
Wilting_point                  0.200000
Hydro_conductivity             0.025920
Soil_porosity                  0.485000
SOC_profile_A                  0.200000
SOC_profile_B                  2.000000
DC_litter_factor               1.000000
DC_humads_factor               1.000000
DC_humus_factor                1.000000
Humad_CN                       10.000000
Humus_CN                       10.000000
Soil_PassiveC                  0.000000
Soil_microbial_index           1.000000
Highest_WT_depth                  9.990000
Depth_WRL_m                    9.990000
Slope                          0.000000
Use_ION_file                   0
----------------------------------------
```

Input file

```
Crop_data:
Rotation_Number=              1
  Rotation_ID=                1
  Totalyear=                  2
  Years_Of_A_Cycle=           2
    YearID_of_a_cycle=        1
    Crop_total_Number=        2
      Crop_ID=                1
        Crop_Type=            25
        Plant_time=           1 1
        Harvest_time=         6 1
        Year_of_harvest=      1
       Ground_Residue=      1.000000
       Yield=               2400.000000
       Rate_reproductive=   0.020000
       Rate_vegetative=     0.040000
       Psn_efficiency=      0.480000
       Psn_maximum=         35.000000
       Initial_biomass=     12.500000
       Cover_crop=          0
       Perennial_crop=      0
       Grain_fraction=   0.450000
       Shoot_fraction=   0.400000
       Root_fraction=  0.150000
       Grain_CN=  12.000000
       Shoot_CN=  45.000000
       Root_CN=  52.000000
       TDD=  700.000000
       Water_requirement=  450.000000
       Max_LAI=  4.000000
       N_fixation=  1.000000
       Vascularity=  0.000000
     Crop_ID=               2
       Crop_Type=           2
       Plant_time=          10 21
       Harvest_time=        7 12
       Year_of_harvest=     2
```

Input file

```
Tillage_number=          1
  Tillage_ID=            1
    Month/Day/method=  6 2 5
Fertil_number=         1
  fertilization_ID=    1
    Month/Day/method=  1 1 0
    Depth=             0.200000
    Nitrate=           0.000000
    AmmBic=            0.000000
    Urea=              0.000000
    Anh=               0.000000
    NH4NO3=            90.000000
    NH42SO4=           0.000000
    NH4HPO4=           0.000000
  Release_rate=        1.000000
  Inhibitor_efficiency= 0.000000
  Inhibitor_duration=  0.000000
  FertilizationOption= 0
Manure_number=         0
Weed_number=           0
Weed_Problem=          0
Flood_number=          0
Leak_type=             1
Water_control=         0
Leak_rate=             0.000000
```

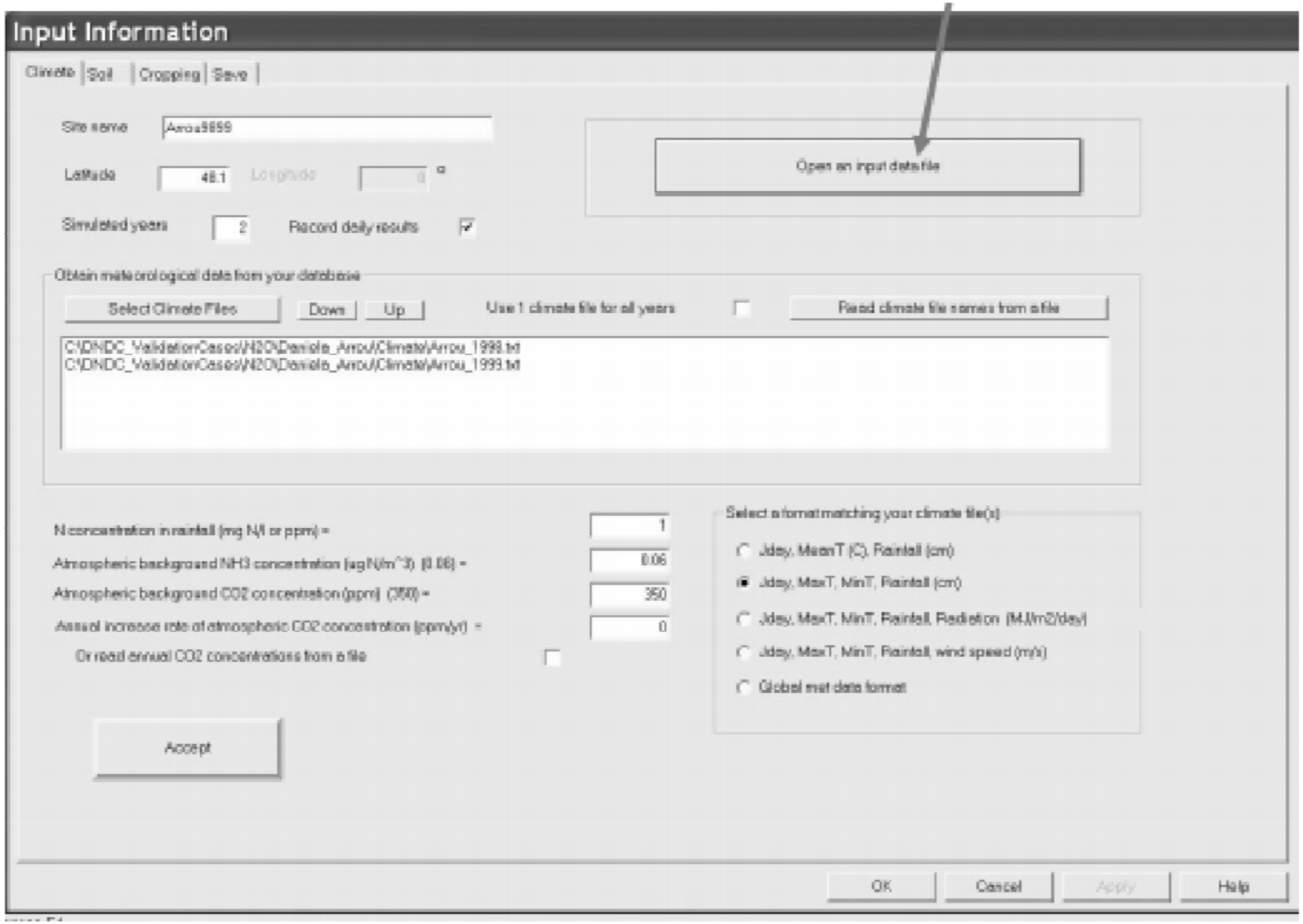
Input file

```
    Water_gather=   1.000000
    WT_file=        None0.000000
    Empirical_parameters= 0.0 0.0 0.0 0.0 0.0 0.0
Irrigation_number=      0
Irrigation_type=        0
Irrigation_Index=       0.000000
Grazing_number=           0
Cut_number=           0
YearID_of_a_cycle=      2
Crop_total_Number=      0
Tillage_number=         1
  Tillage_ID=           1
    Month/Day/method=   7 13 5
Fertil_number=          3
  fertilization_ID=     1
    Month/Day/method=   2 6 0
    Depth=              0.200000
    Nitrate=            0.000000
    AmmBic=             0.000000
    Urea=               0.000000
    Anh=                0.000000
    NH4NO3=             58.000000
    NH42SO4=            0.000000
    NH4HPO4=            0.000000
   Release_rate=          1.000000
   Inhibitor_efficiency= 0.000000
   Inhibitor_duration=   0.000000
   fertilization_ID=     2
     Month/Day/method=   3 12 0
     Depth=              0.200000
     Nitrate=            0.000000
     AmmBic=             0.000000
     Urea=               42.000000
     Anh=                0.000000
     NH4NO3=             41.000000
     NH42SO4=            0.000000
     NH4HPO4=            0.000000
   Release_rate=         1.000000
   Inhibitor_efficiency= 0.000000
   Inhibitor_duration=   0.000000
   fertilization_ID=     3
     Month/Day/method=   3 27 0
     Depth=              0.200000
```

Input file

```
      fertilization_ID=     3
        Month/Day/method=   3 27 0
        Depth=              0.200000
        Nitrate=            0.000000
        AmmBic=             0.000000
        Urea=               20.000000
        Anh=                0.000000
        NH4NO3=             20.000000
        NH42SO4=            0.000000
        NH4HPO4=            0.000000
      Release_rate=         1.000000
      Inhibitor_efficiency= 0.000000
      Inhibitor_duration=   0.000000
      FertilizationOption=  0
    Manure_number=          0
    Weed_number=            0
    Weed_Problem=           0
    Flood_number=           0
    Leak_type=              1
    Water_control=          0
    Leak_rate=              0.000000
        Water_gather=   1.000000
        WT_file=        None0.000000
        Empirical_parameters= 0.0 0.0 0.0 0.0 0.0 0.0
    Irrigation_number=      0
    Irrigation_type=        0
    Irrigation_Index=       0.000000
    Grazing_number=           0
    Cut_number=           0
Crop_model_approach         0
```

Open an input data file



Run model at site mode

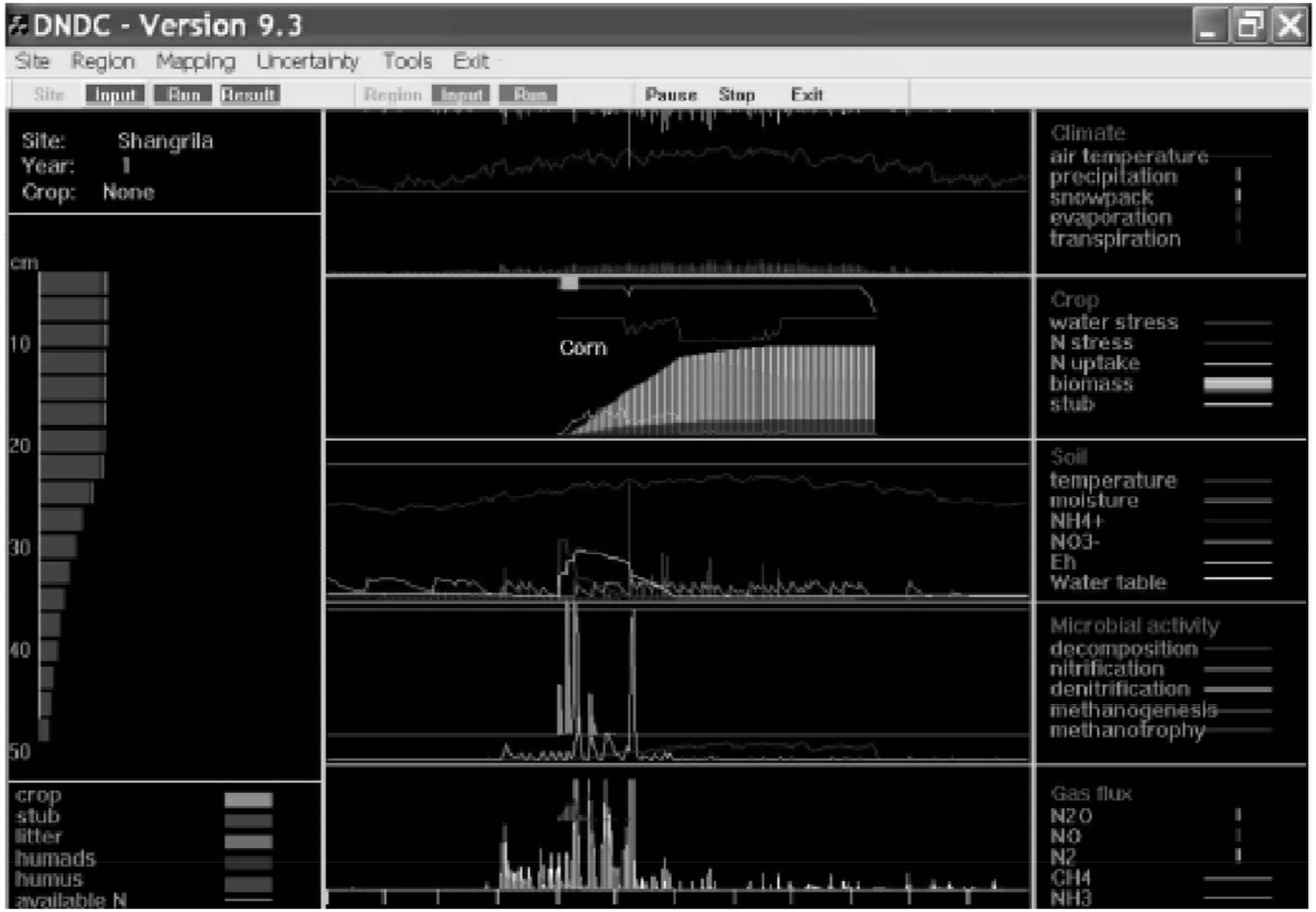


Figure 15. The seven windows allow users to monitor daily dynamics of several major simulated factors during the model run.

Quick view of modeled results

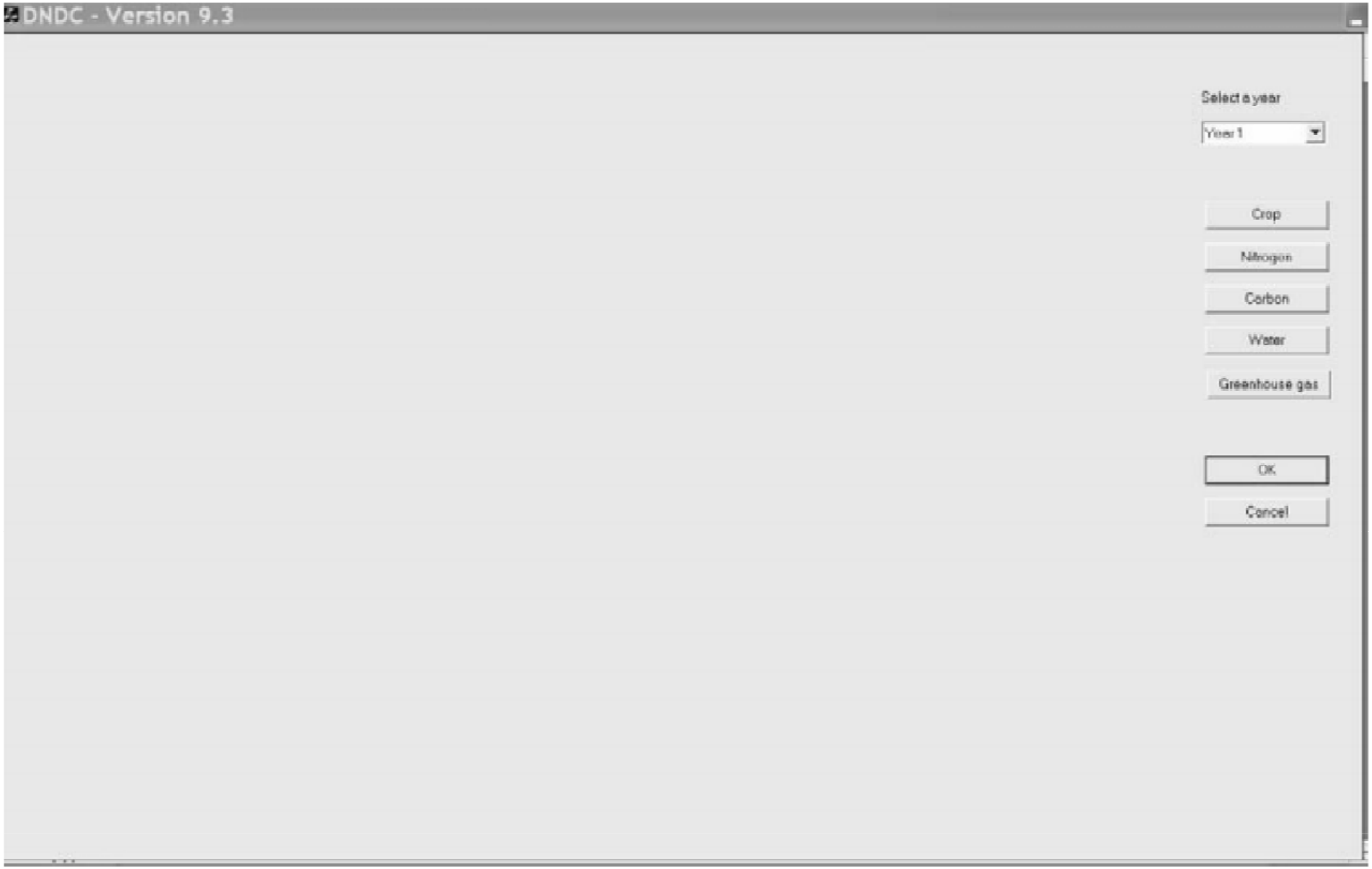


Figure 16. Main menu for quick view of modeled results

Modeled results

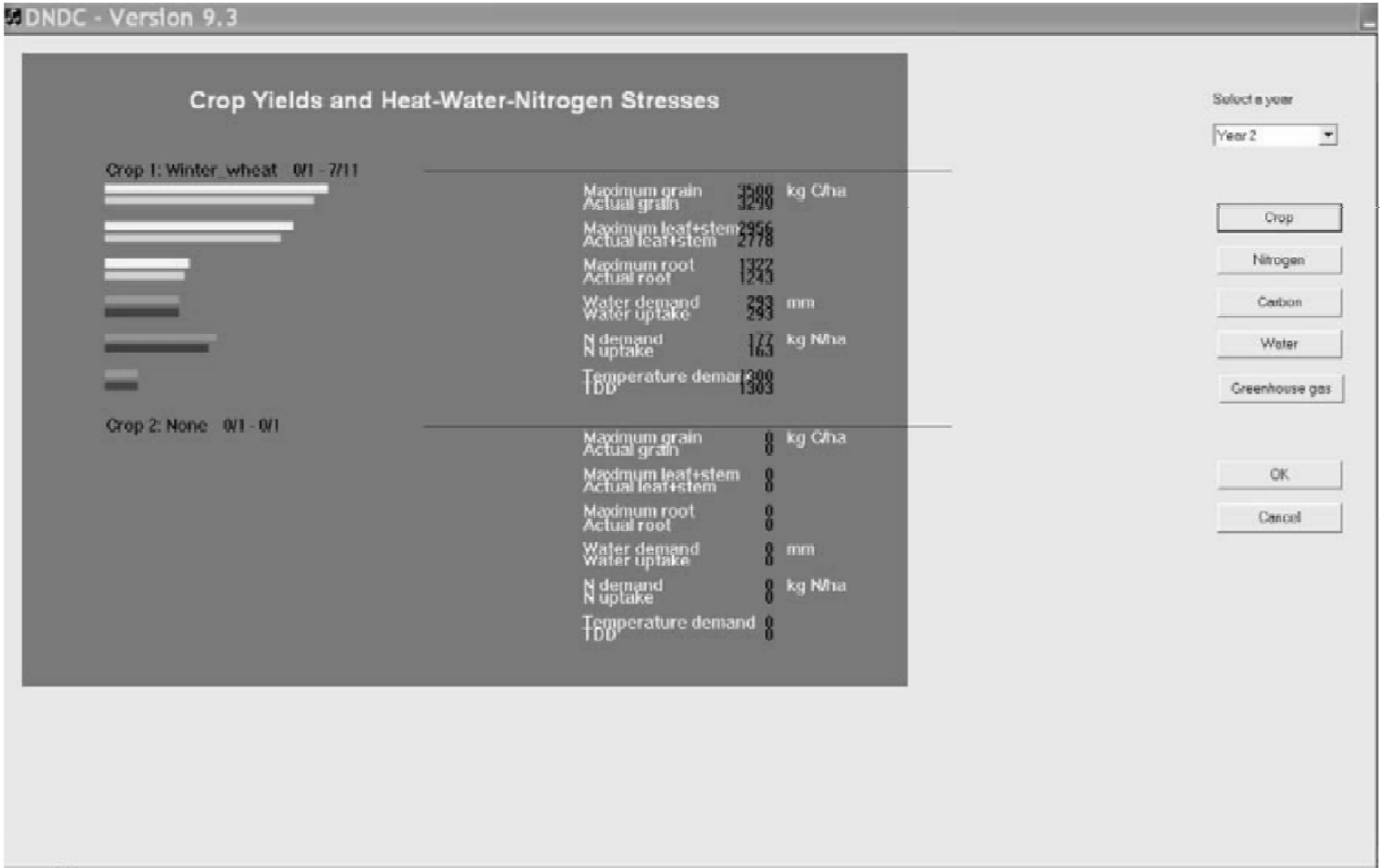


Figure 17. Modeled result 1: Crop biomass production and stresses of temperature, water or nitrogen. (TDD – accumulative thermal degree days of crop growth season)

Modeled results

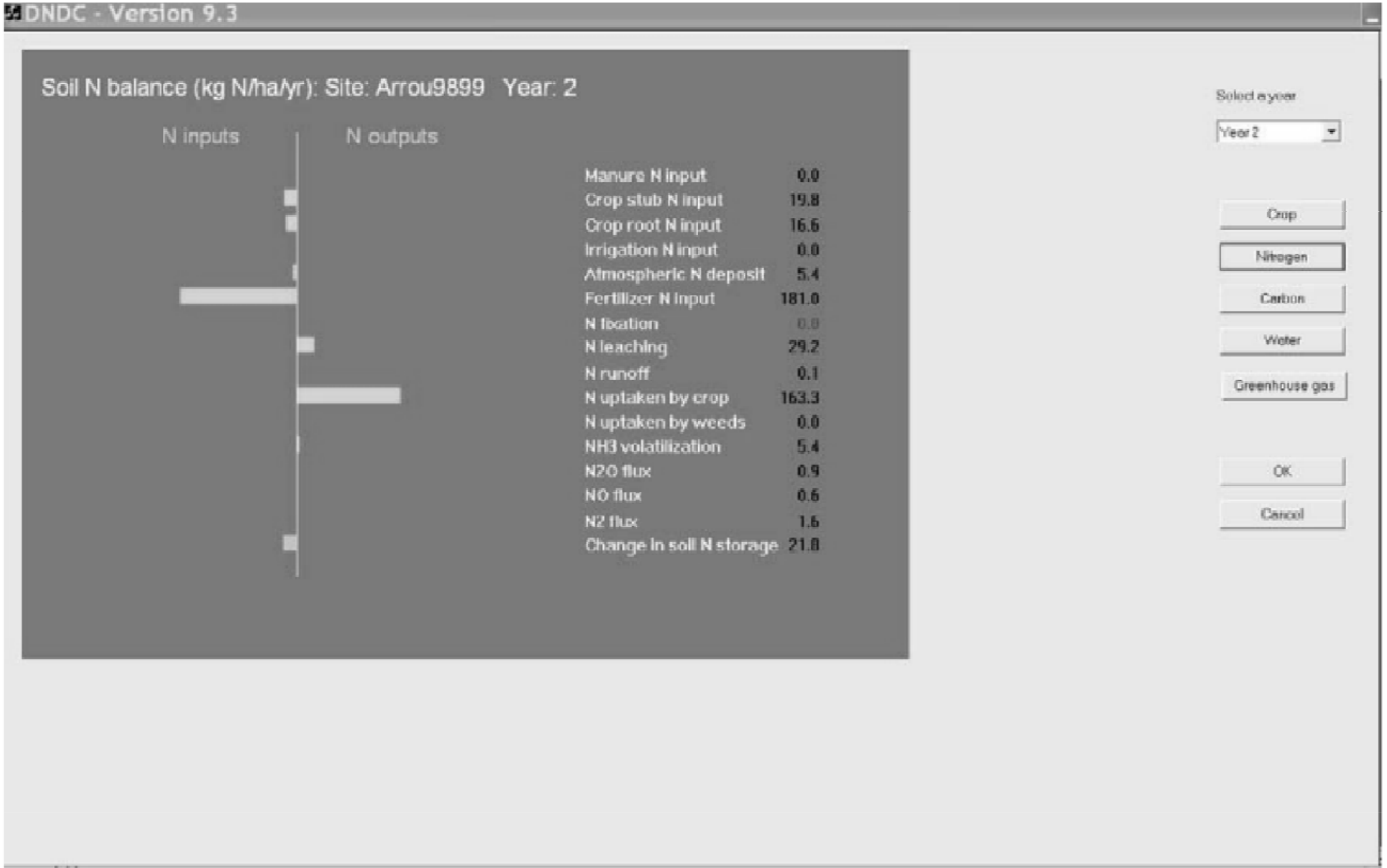


Figure 18. Modeled result 2: Soil N budget.

Modeled results

Figure 19. Modeled result 3: Soil C budget.

Modeled results

Figure 20. Modeled result 4: Water budget

Modeled results

Figure 21. Modeled result 5: Net greenhouse gas emission


Thank you