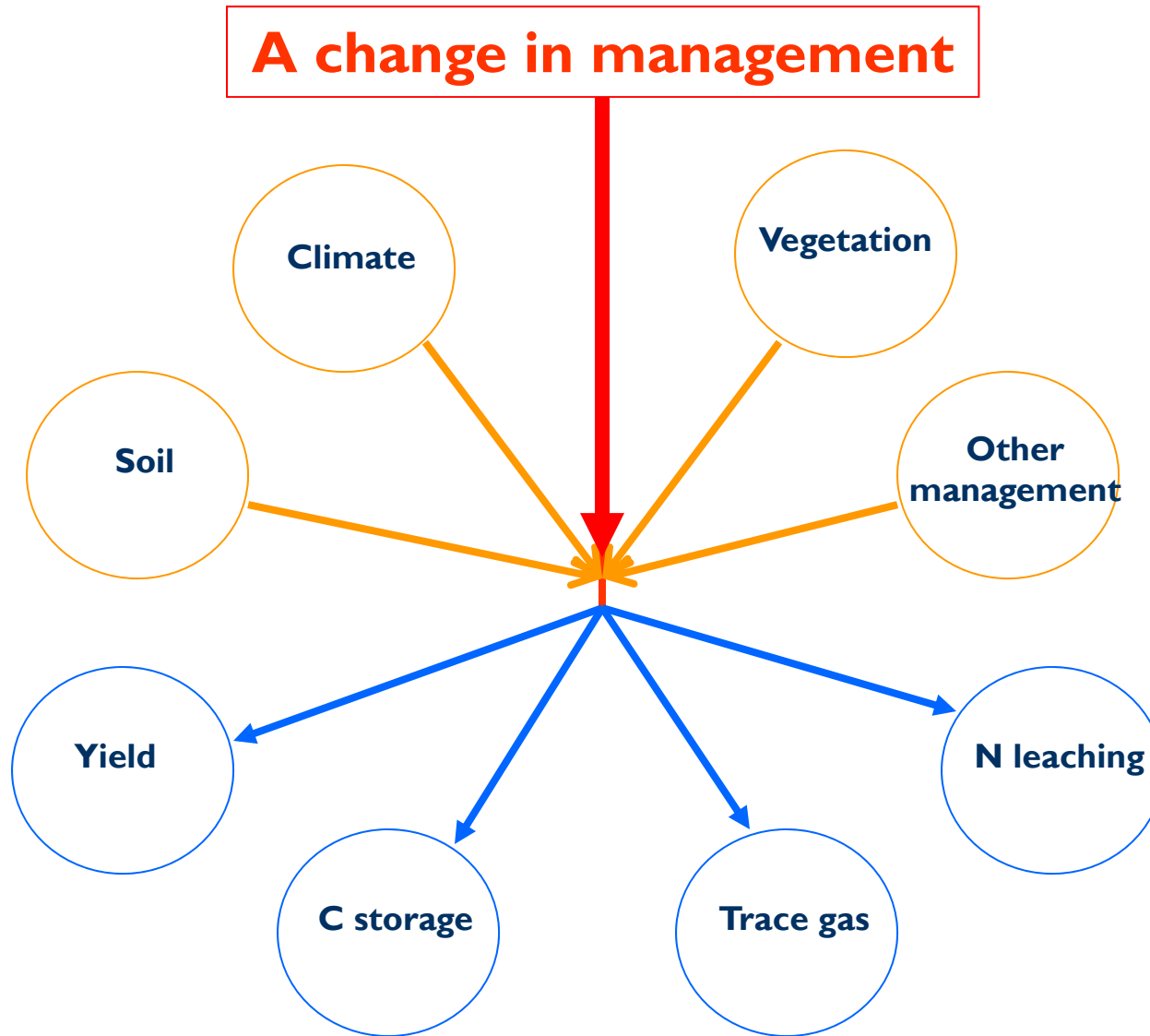# DNDC, a Tool for Quantifying Impacts of Farming Management Alternatives on Ecosystem Services

Changsheng Li
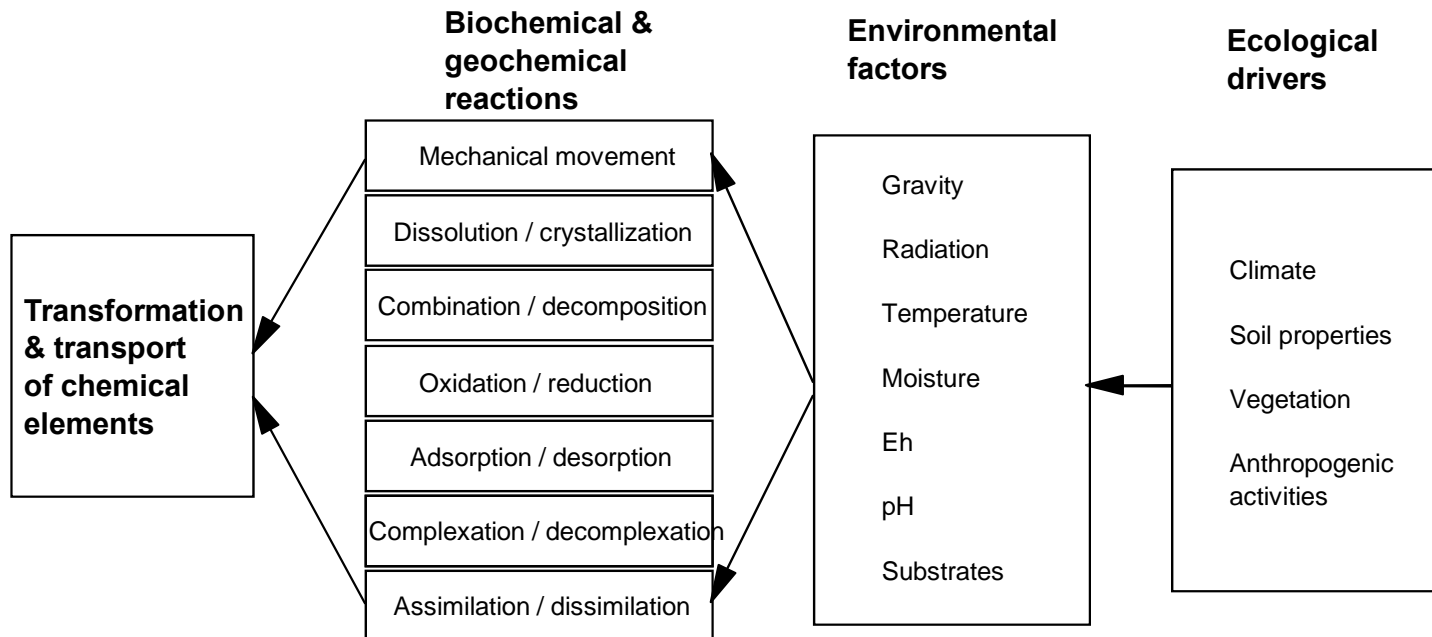
University of New Hampshire

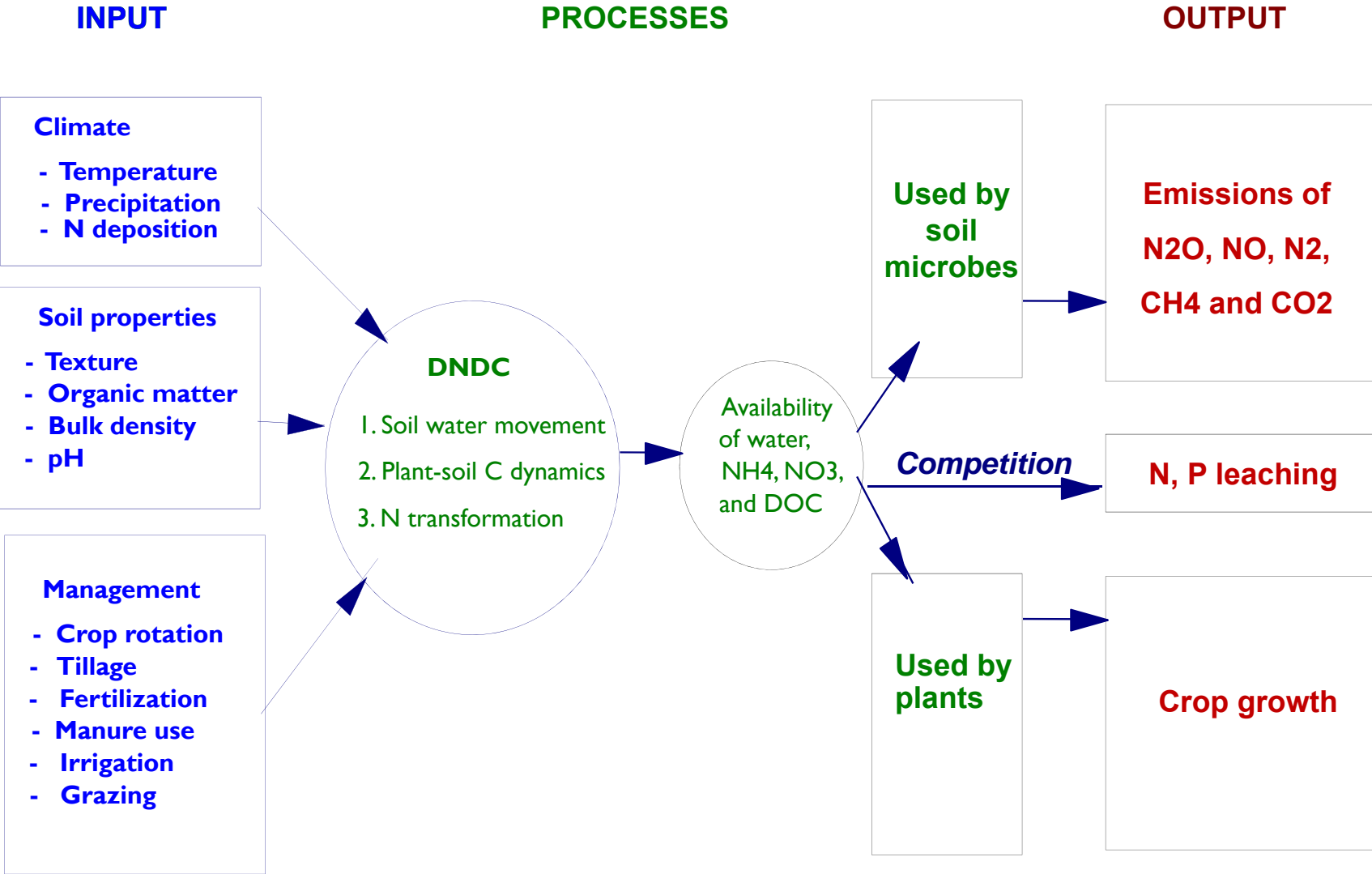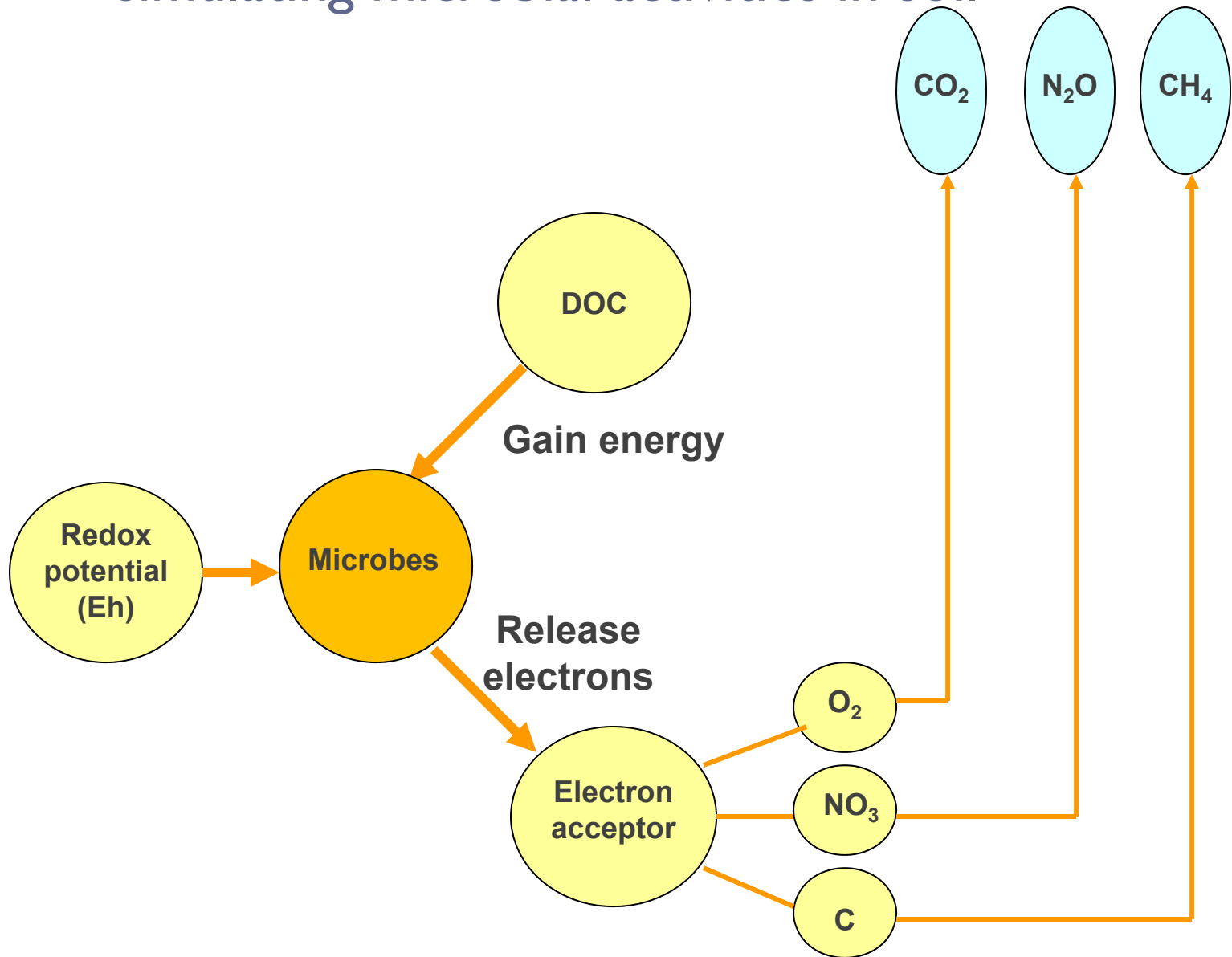April 17-18, 2012, Washington D.C.

A Complex System

A change in management

Climate

Vegetation

Soil

Other management

Yield

C storage

Trace gas

N leaching

Process-Based Model is an Answer for Complex Systems

Biochemical & geochemical reactions

Environmental factors

Ecological drivers

Transformation & transport of chemical elements

Mechanical movement
Dissolution / crystallization
Combination / decomposition
Oxidation / reduction
Adsorption / desorption
Complexation / decomplexation
Assimilation / dissimilation

Gravity

Radiation

Temperature

Moisture

Eh

pH

Substrates

Climate

Soil properties

Vegetation

Anthropogenic activities

DNDC was developed in light of biogeochemical principles

INPUT **PROCESSES** **OUTPUT**

Climate

- **Temperature**
- **Precipitation**
- **N deposition**

Soil properties

- **Texture**
- **Organic matter**
- **Bulk density**
- **pH**

Management

- **Crop rotation**
- **Tillage**
- **Fertilization**
- **Manure use**
- **Irrigation**
- **Grazing**

DNDC

1. Soil water movement
2. Plant-soil C dynamics
3. N transformation

Availability of water, NH4, NO3, and DOC

Used by soil microbes

Used by plants

Competition

Emissions of N2O, NO, N2, CH4 and CO2

N, P leaching

Crop growth

For example, DNDC quantifies GHG emissions by simulating microbial activities in soil

Management practices are overlapped on natural processes in DNDC
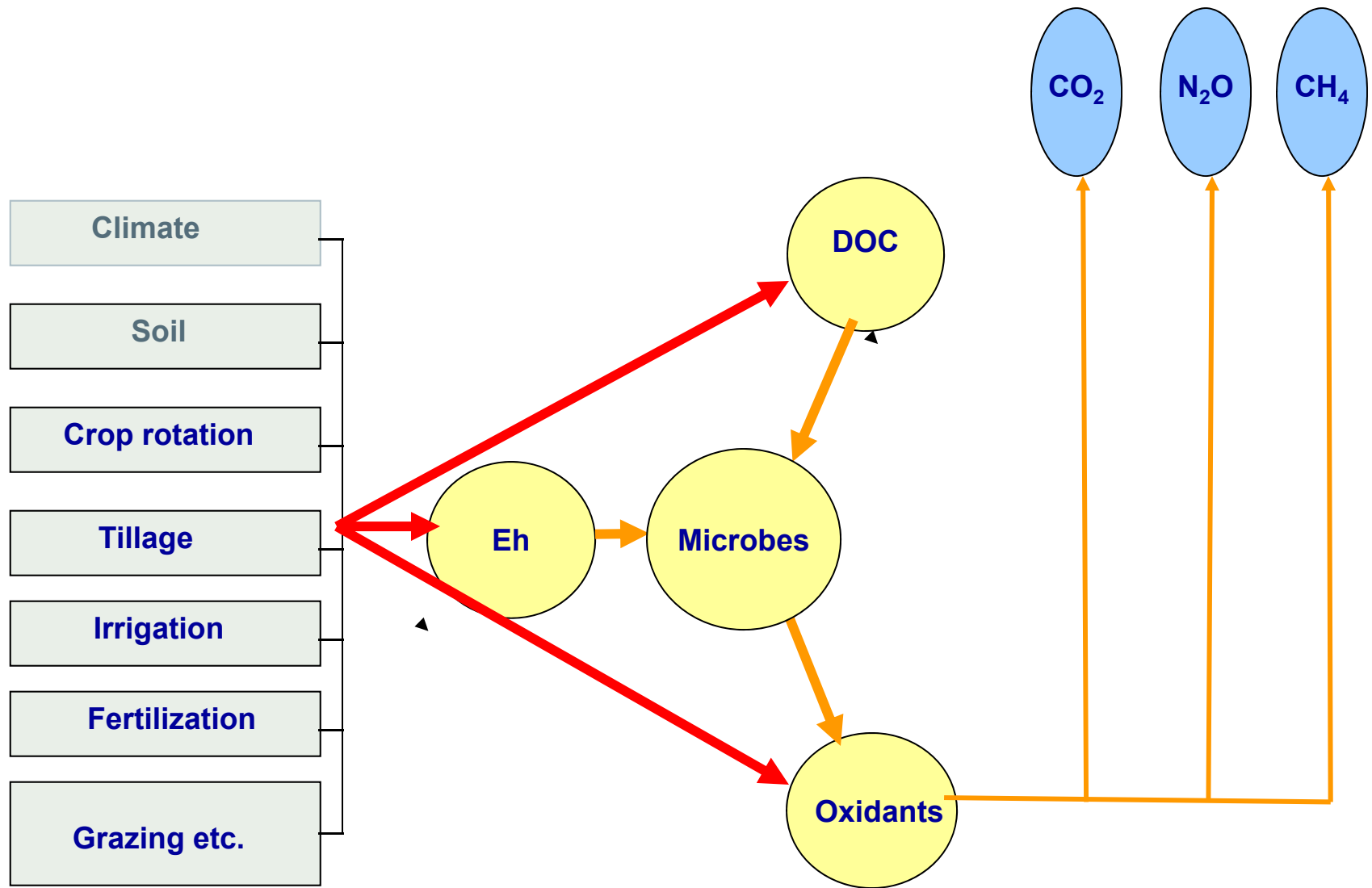
Input Parameters Required for DNDC

1. Climate:
   - Daily max and min air temperature;
   - Precipitation;

2. Soil:
   - Bulk density;
   - Texture (clay fraction);
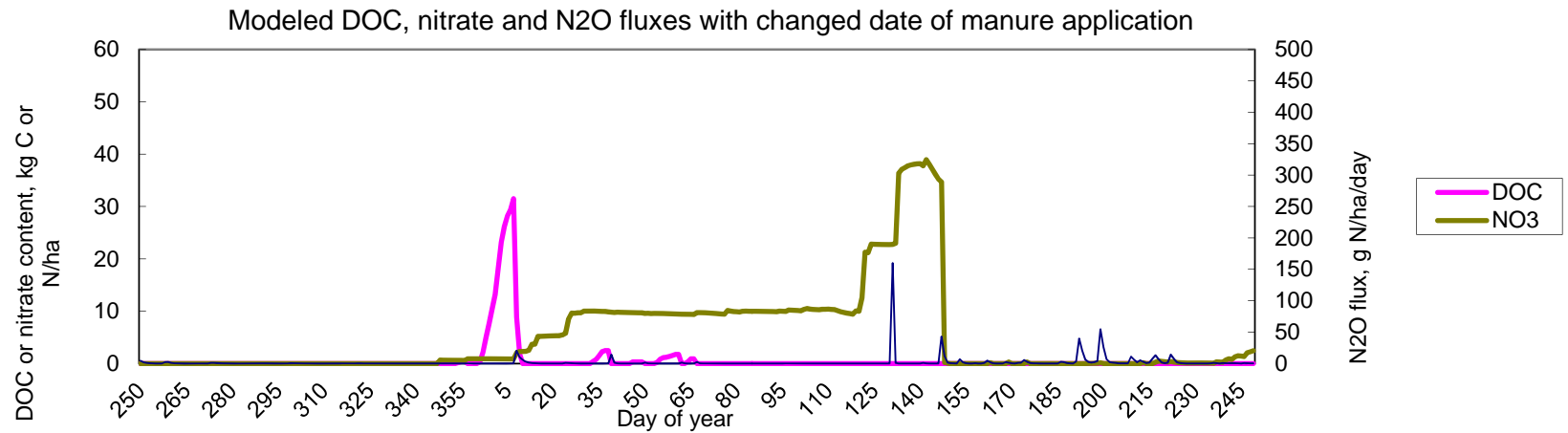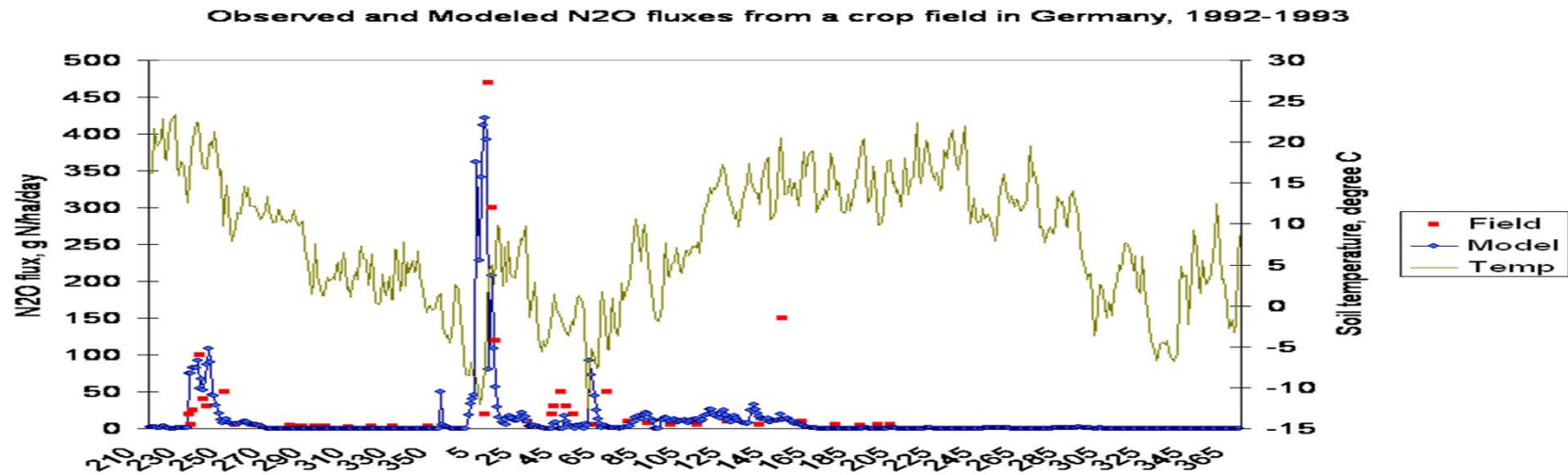   - Total organic C content;
   - pH;

3. Management:
   - Crop type and rotation;
   - Tillage;
   - Irrigation;
   - Fertilization;
   - Manure amendment;
   - Grazing.

Output Parameters produced by DNDC

1. Crop:
   - Photosynthesis;
   - Respiration;
   - Water and N demands/uptake;
   - C allocation;
   - Yield and litter production;

2. Soil:
   - Temperature, moisture, pH and Eh profiles;
   - SOC dynamics;
   - N and P leaching loads;
   - Emissions of N_2O, NO, N_2, NH_3, CH_4 and CO_2

DNDC provided clew to mitigate N2O emissions from a German crop field

Observed and Modeled N2O fluxes from a crop field in Germany, 1992-1993

Modeled DOC, nitrate and N2O fluxes with changed date of manure application

Measured and modeled 150-year yields and SOC dynamics in a winter wheat field with three treatments at Rothamsted Station in the U.K. (field data from D.S. Jenkinson)

Observed and modeled grain yields for a winter wheat field in Rothamsted, UK
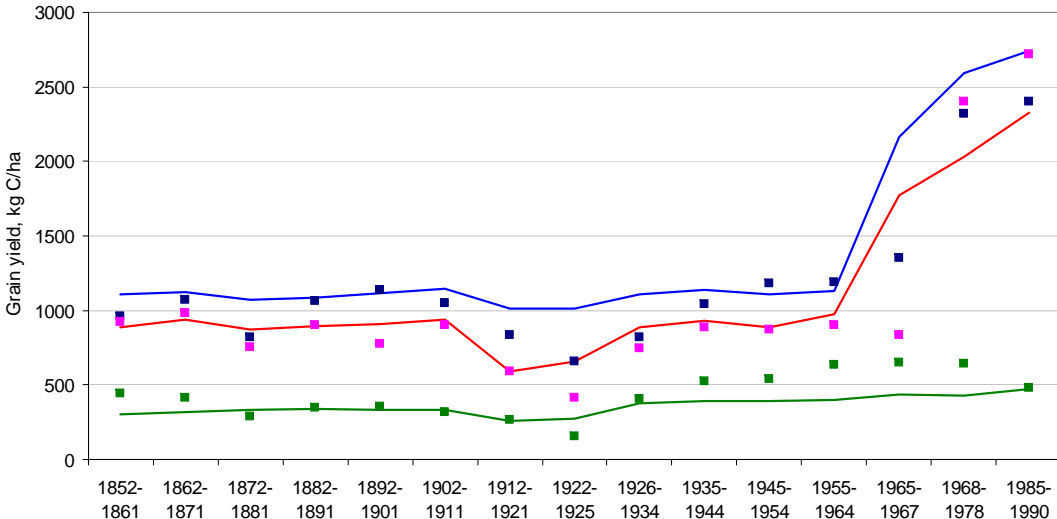
Soil Organic Carbon Dynamics at a Winter Wheat Field with Different Treatments in Rothamsted Agricultural Station in UK from 1840-1990
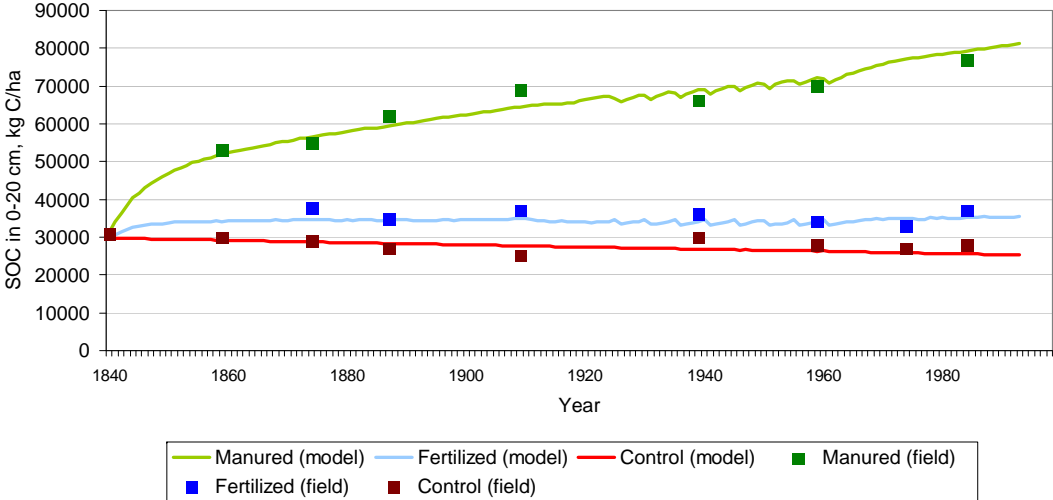
Observed and DNDC-Modeled Annual N$_2$O Fluxes for 69 Agricultural Sites with complete input data in U.S., Canada, U.K., Germany, Belgium, France, Swiss, New Zealand, China, Japan, and Costa Rica
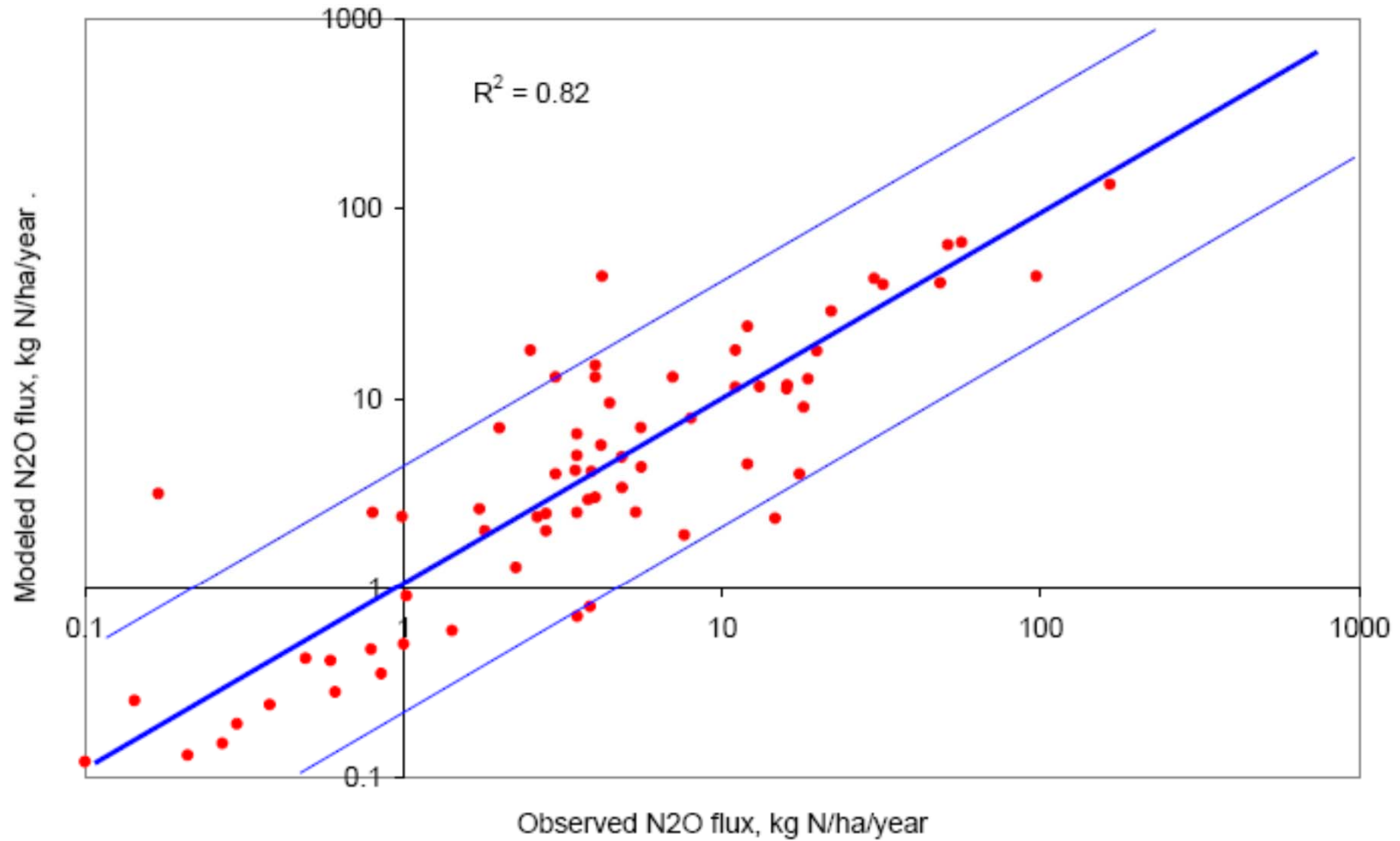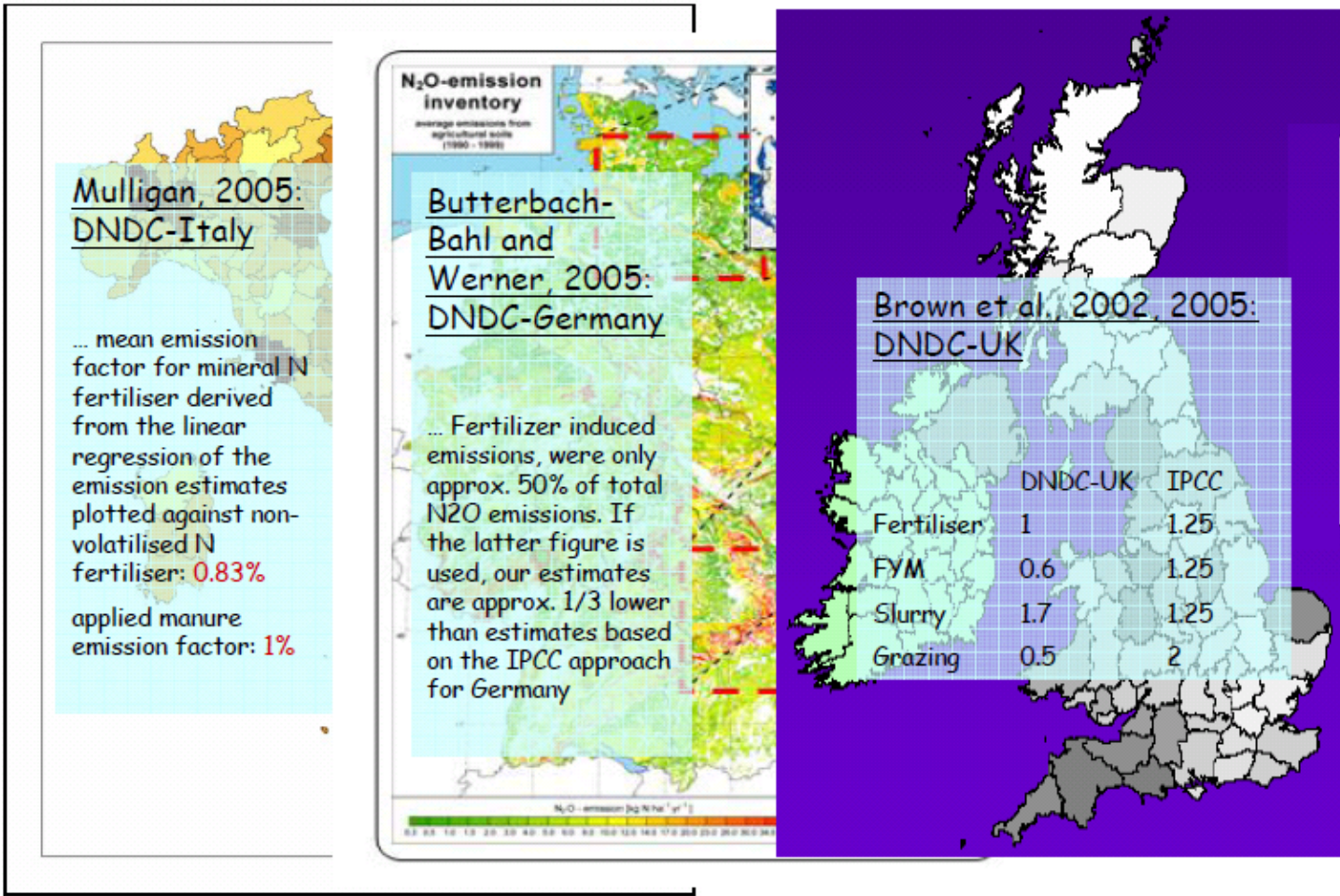
Observed and DNDC-modeled CH4 fluxes from rice paddies in China, Thailand, Japan, Italy and the U.S.

$R^2 = 0.948$

Measured CH4 flux, kg C/ha/yr

Modeled CH4 flux, kg C/ha/yr
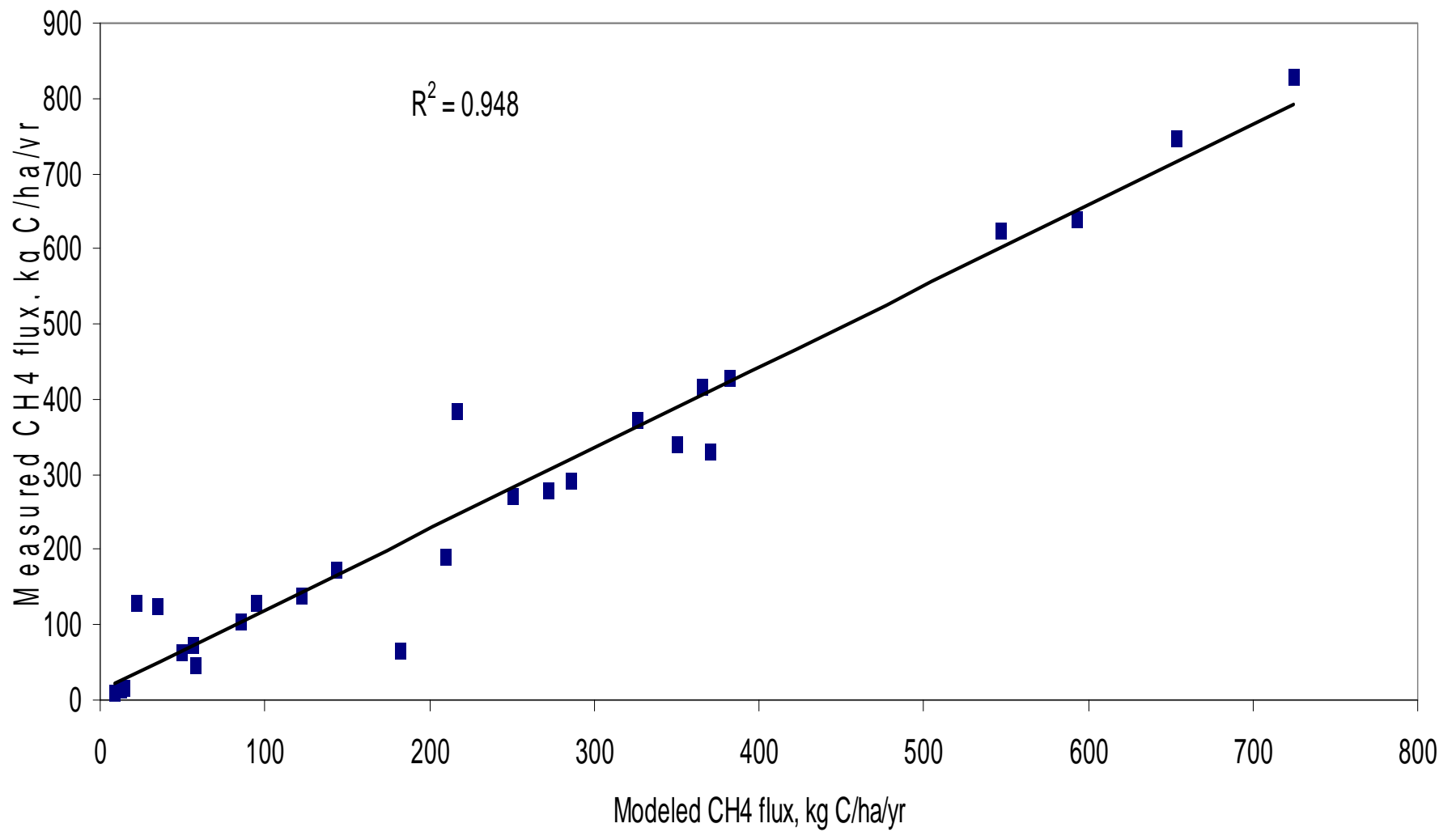
DNDC has been integrated with regional management databases to assess environmental services at national scale

Mulligan, 2005: DNDC-Italy

... mean emission factor for mineral N fertiliser derived from the linear regression of the emission estimates plotted against non-volatilised N fertiliser: 0.83%

applied manure emission factor: 1%

Butterbach-Bahl and Werner, 2005: DNDC-Germany

N₂O-emission inventory
average emissions from agricultural soils
(1990 - 1999)

... Fertilizer induced emissions, were only approx. 50% of total N2O emissions. If the latter figure is used, our estimates are approx. 1/3 lower than estimates based on the IPCC approach for Germany

Brown et al., 2002, 2005: DNDC-UK

	DNDC-UK	IPCC
Fertiliser	1	1.25
FYM	0.6	1.25
Slurry	1.7	1.25
Grazing	0.5	2

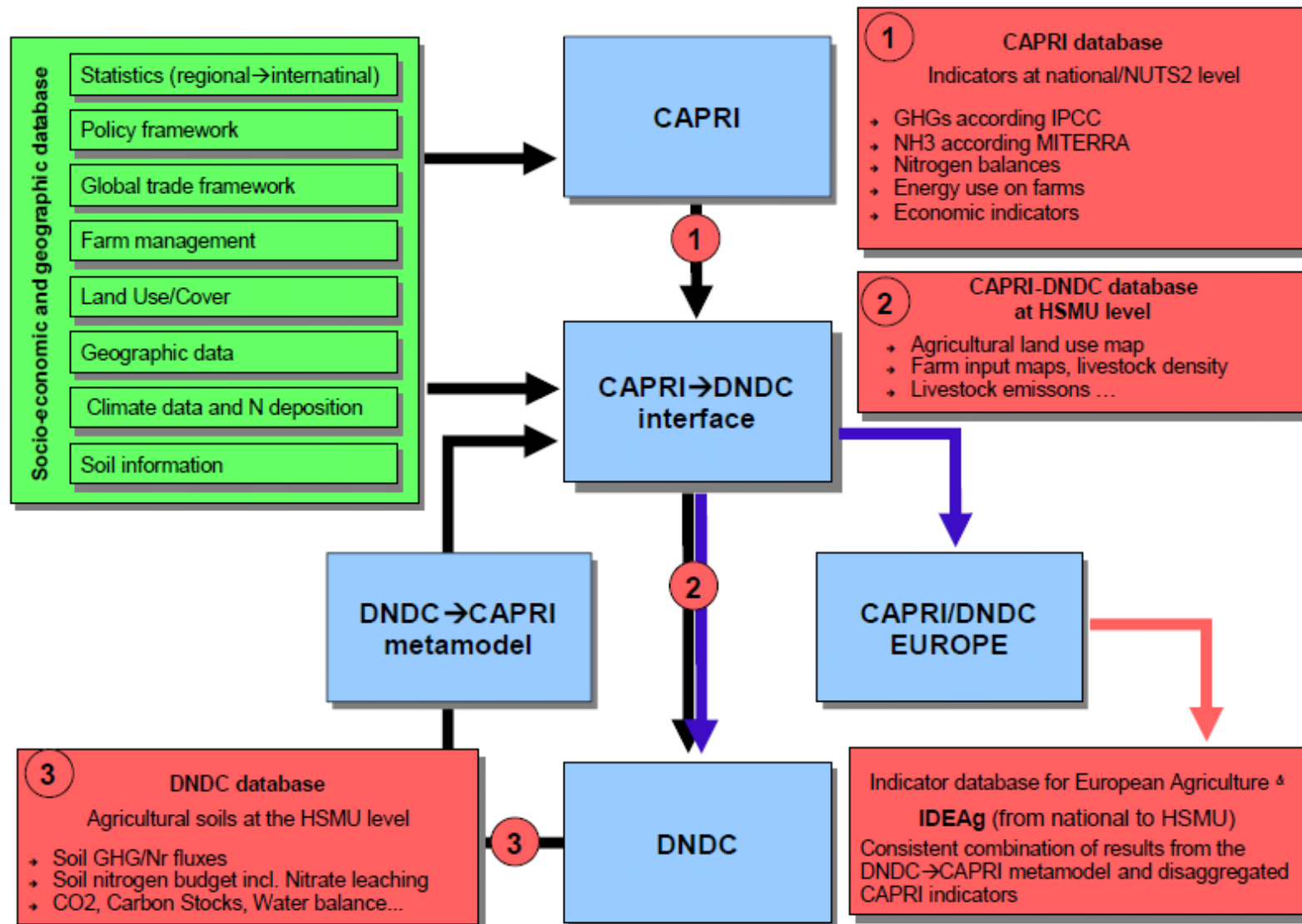## PROCESS-BASED MODELS

DNDC was integrated with a EU ag management model (CAPRI) to assess impacts of management alternatives on environmental sevices at large regional scale

CAPRI / DNDC-EUROPE: databases

**Socio-economic and geographic database**
- Statistics (regional→internatinal)
- Policy framework
- Global trade framework
- Farm management
- Land Use/Cover
- Geographic data
- Climate data and N deposition
- Soil information

CAPRI

CAPRI→DNDC interface

DNDC→CAPRI metamodel

CAPRI/DNDC EUROPE

DNDC

(1) CAPRI database
Indicators at national/NUTS2 level
- GHGs according IPCC
- NH3 according MITERRA
- Nitrogen balances
- Energy use on farms
- Economic indicators

(2) CAPRI-DNDC database at HSMU level
- Agricultural land use map
- Farm input maps, livestock density
- Livestock emissons …

(3) DNDC database
Agricultural soils at the HSMU level
- Soil GHG/Nr fluxes
- Soil nitrogen budget incl. Nitrate leaching
- CO_2, Carbon Stocks, Water balance...

Indicator database for European Agriculture ᵃ
IDEAg (from national to HSMU)
Consistent combination of results from the DNDC→CAPRI metamodel and disaggregated CAPRI indicators

& Name provisional

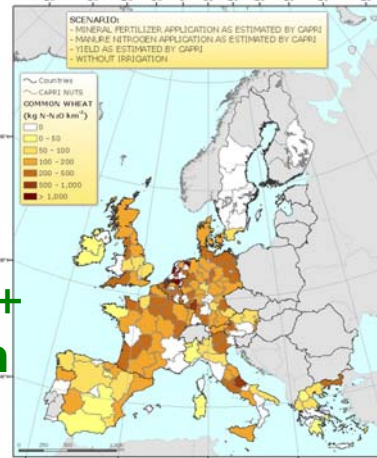# DNDC Emission Scenarios for EU
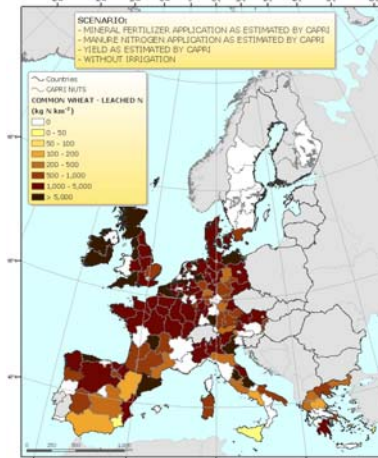

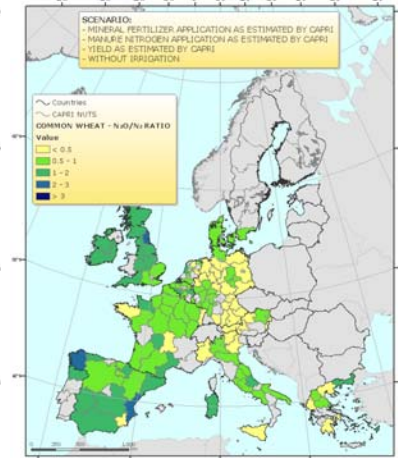**N-N2O** **Leached N** **N2O/N2 Ratio**

No nitrogen application
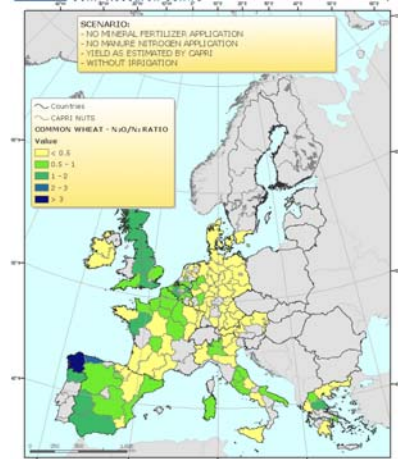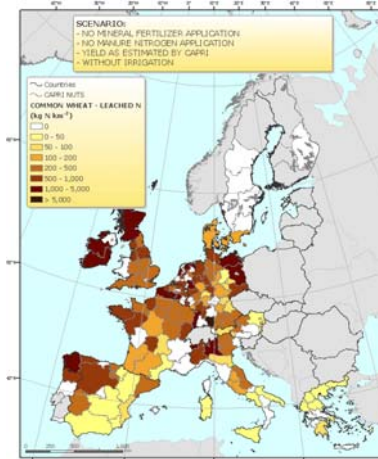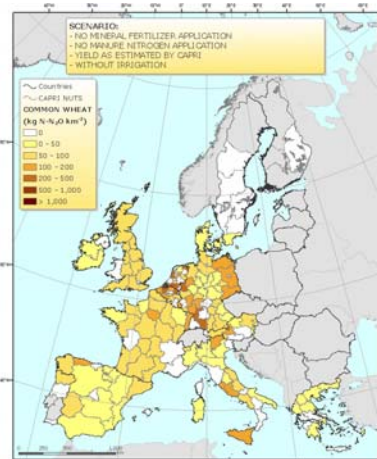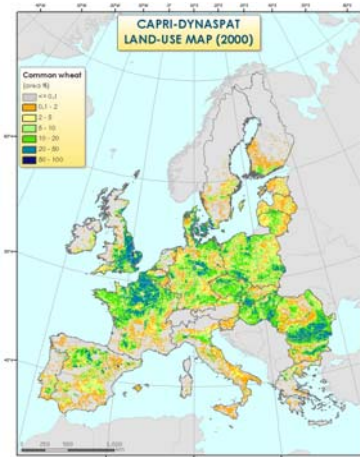
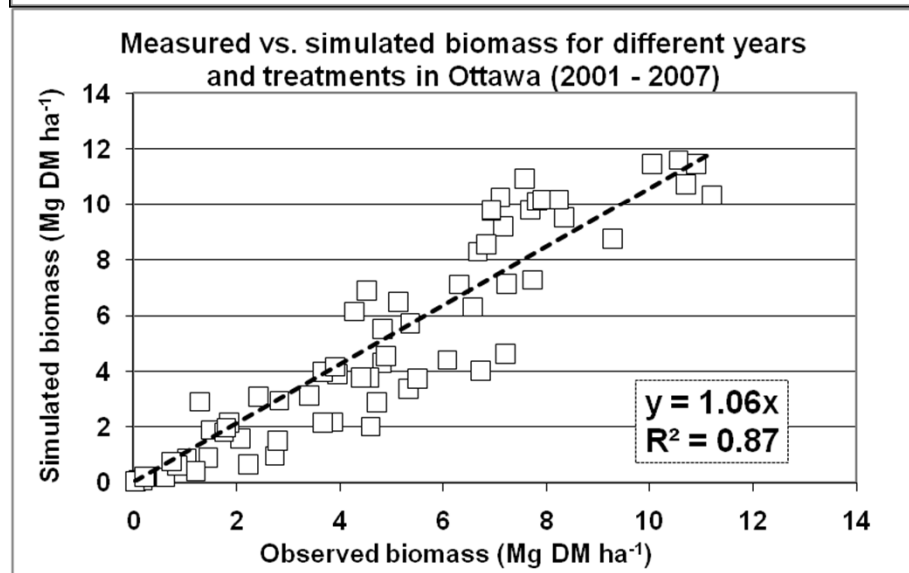**Mineral fertilizer+ manure nitrogen application**

max > 10 kg N/ha/year   max > 50 kg N/ha/year   max >3
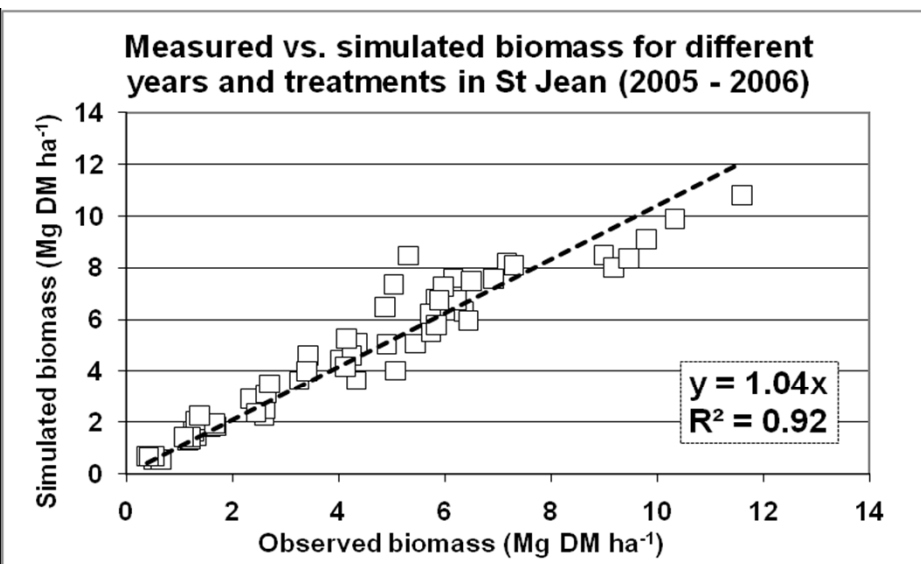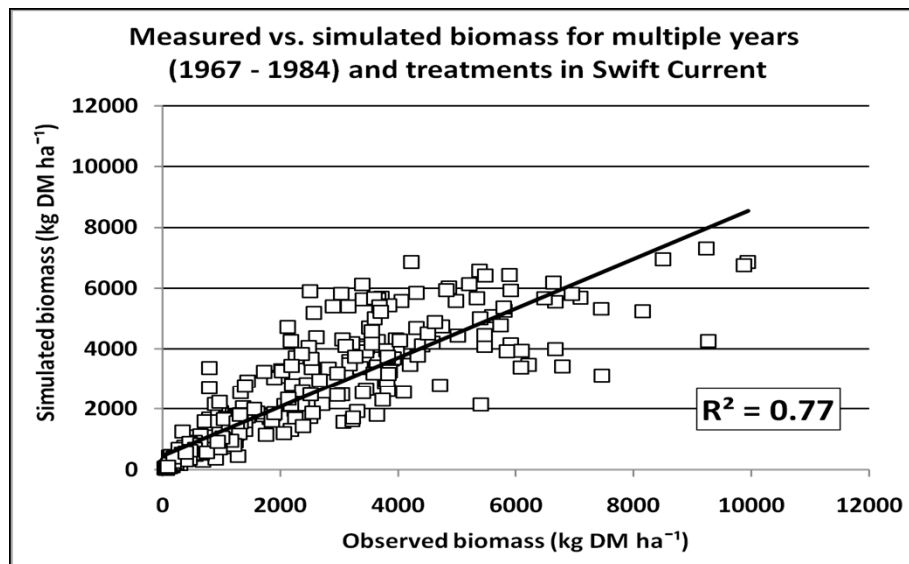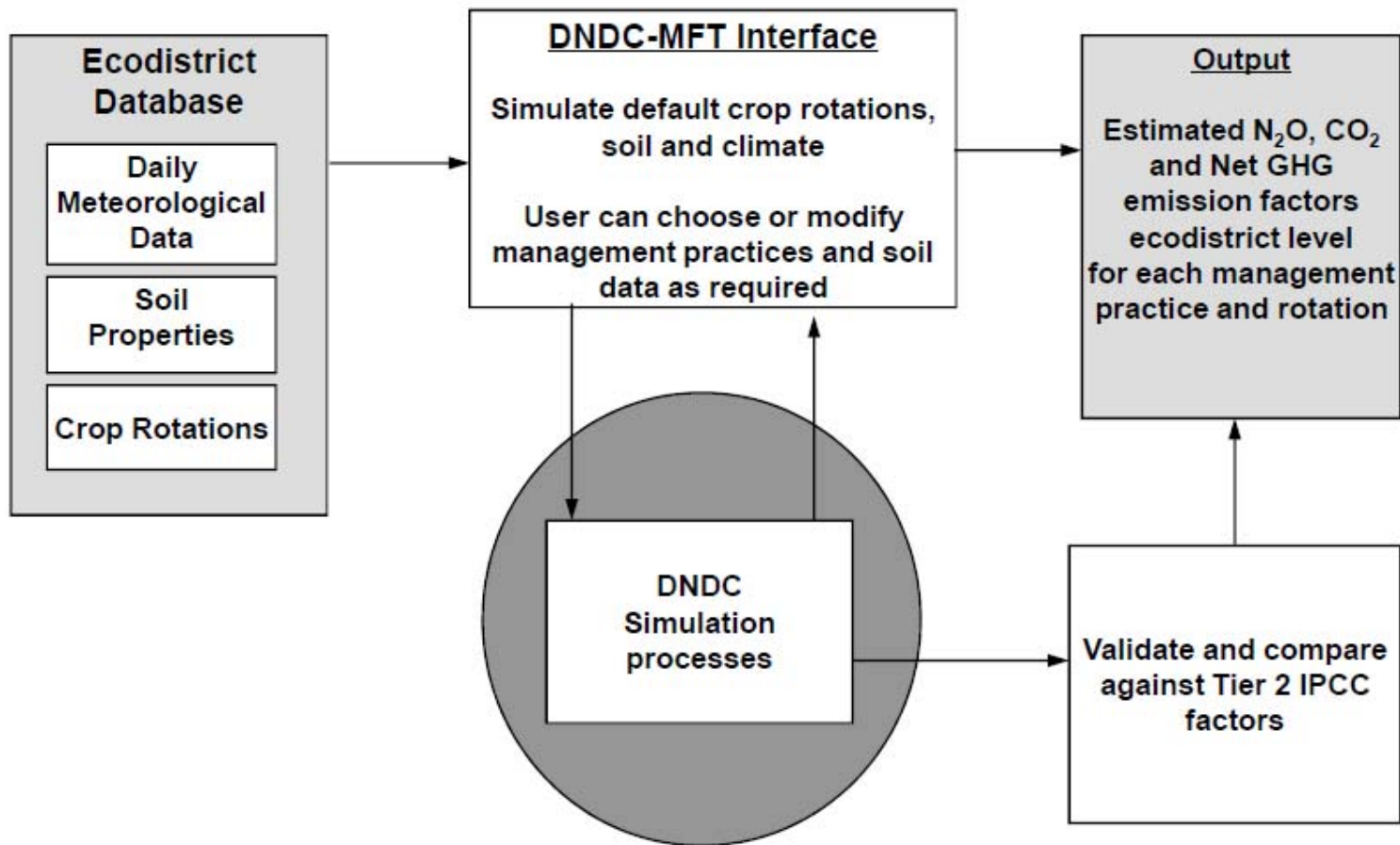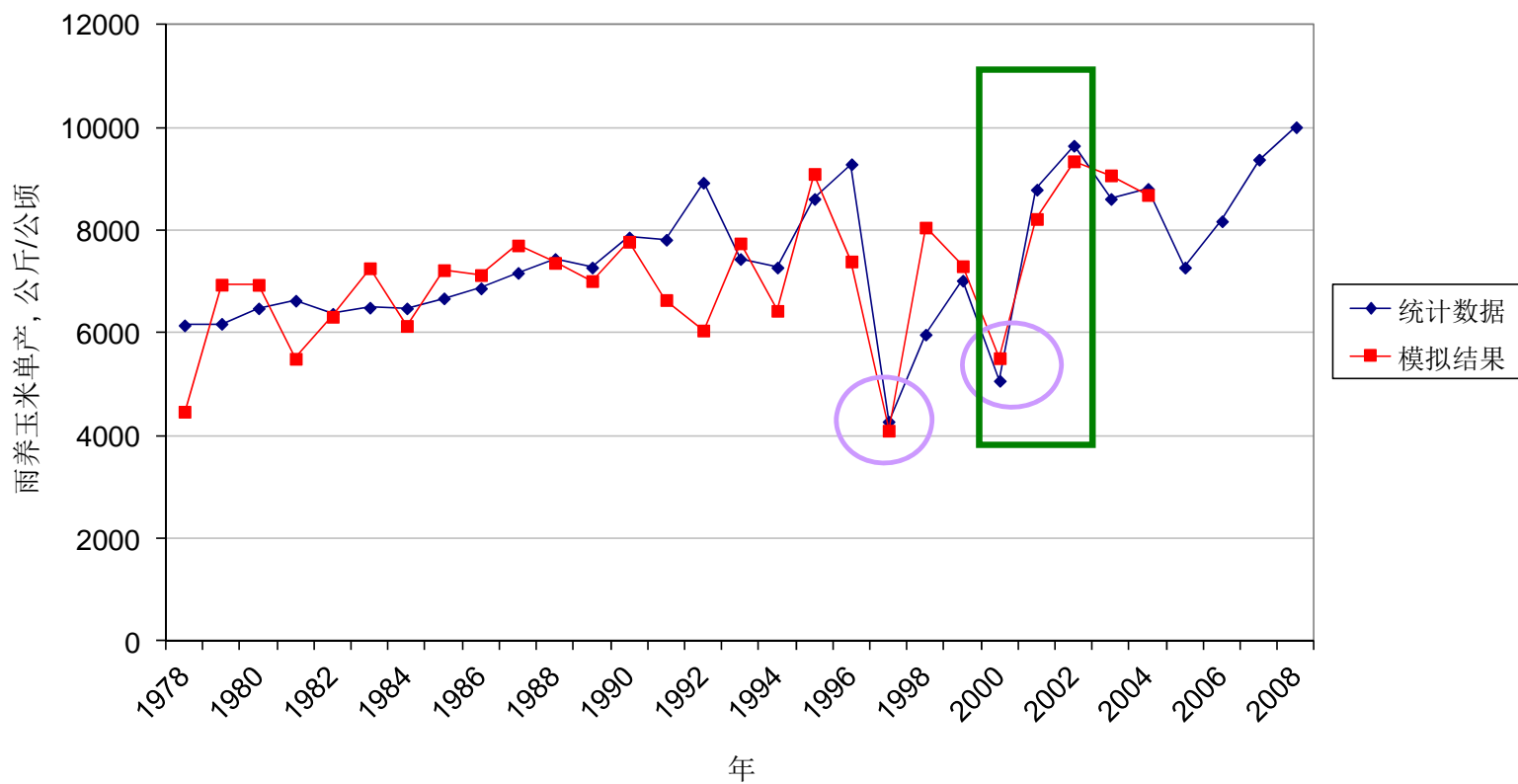
DNDC biomass simulations for Canada
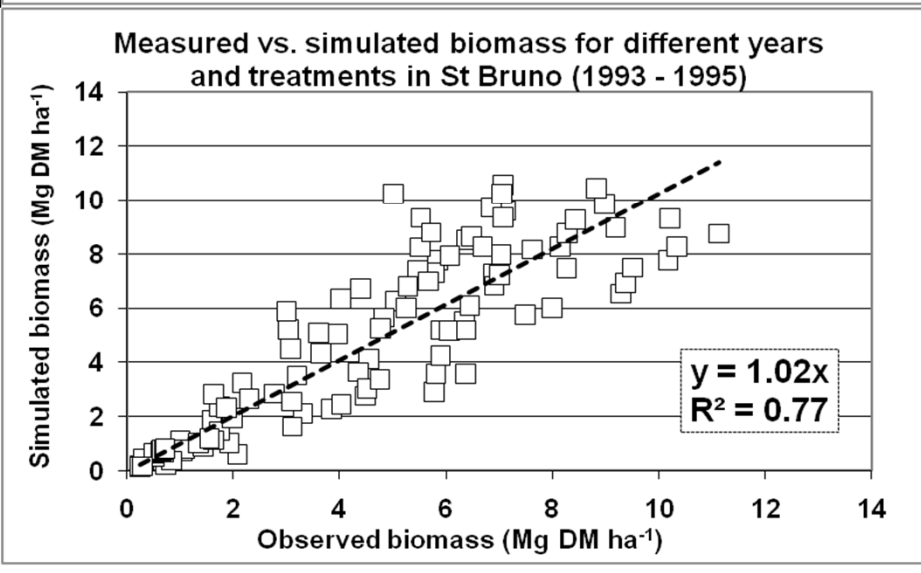
DNDC Management Factor Tool (DNDC-MFT) was developed by Agriculture-Canada for quantifying environmental services

DNDC simulated variation of maize yield in Liaoning, China
(field data from Ag. Census of China)

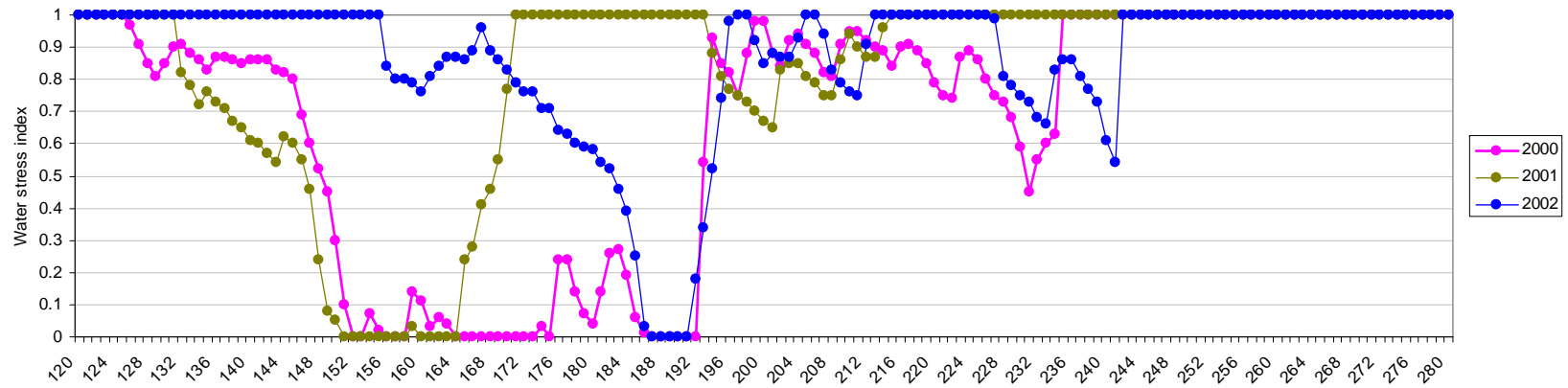统计数据和DNDC模拟的辽宁省昌图县雨养区玉米1978-2005年平均单产比较

DNDC-modeled soil moisture and crop growth in maize field in 2000, 2001 and 2002 in Liaoning, China

Soil moisture

for a corn field in Changtu Conuty, Liaoning in 2000 (dry), 2001 (normal) and 2002 (wet)

Crop biomass

Shoot biomass in 2000, 2001 and 2002
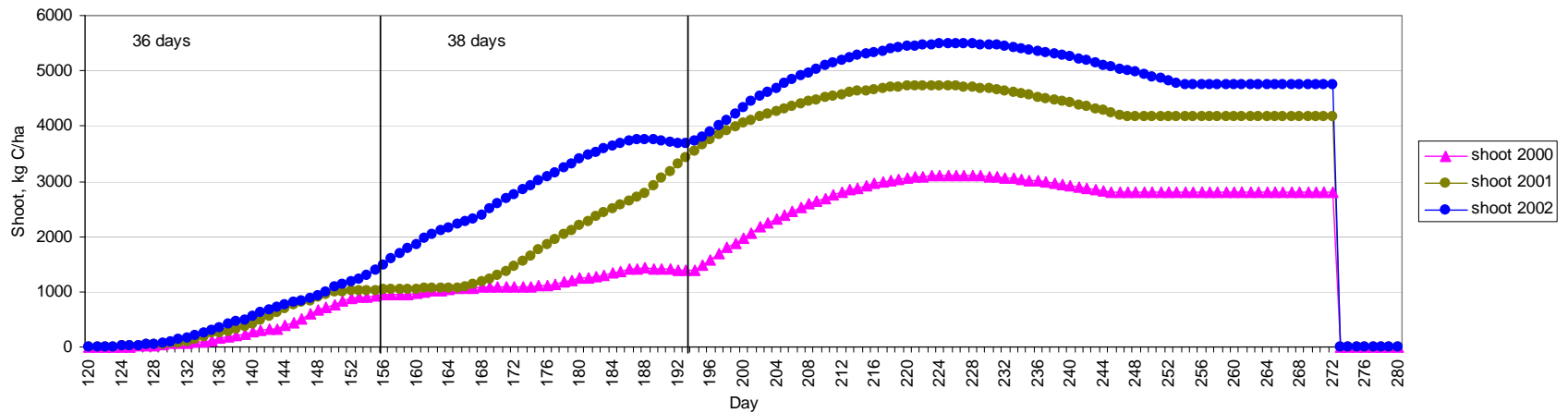
A DNDC-cored agroecosystem model is being utilized by Chinese governments for yield prediction and environmental impacts

Ag database of China
- Historical climate data
- Soil properties
- Crops
- Management

Real-time weather data

Data fusion

DNDC

Modeled results
- Soil temperature
- Soil moisture
- Soil N, P status
- Crop growth

Potential drought damage

Daily yield prediction report

Water resource
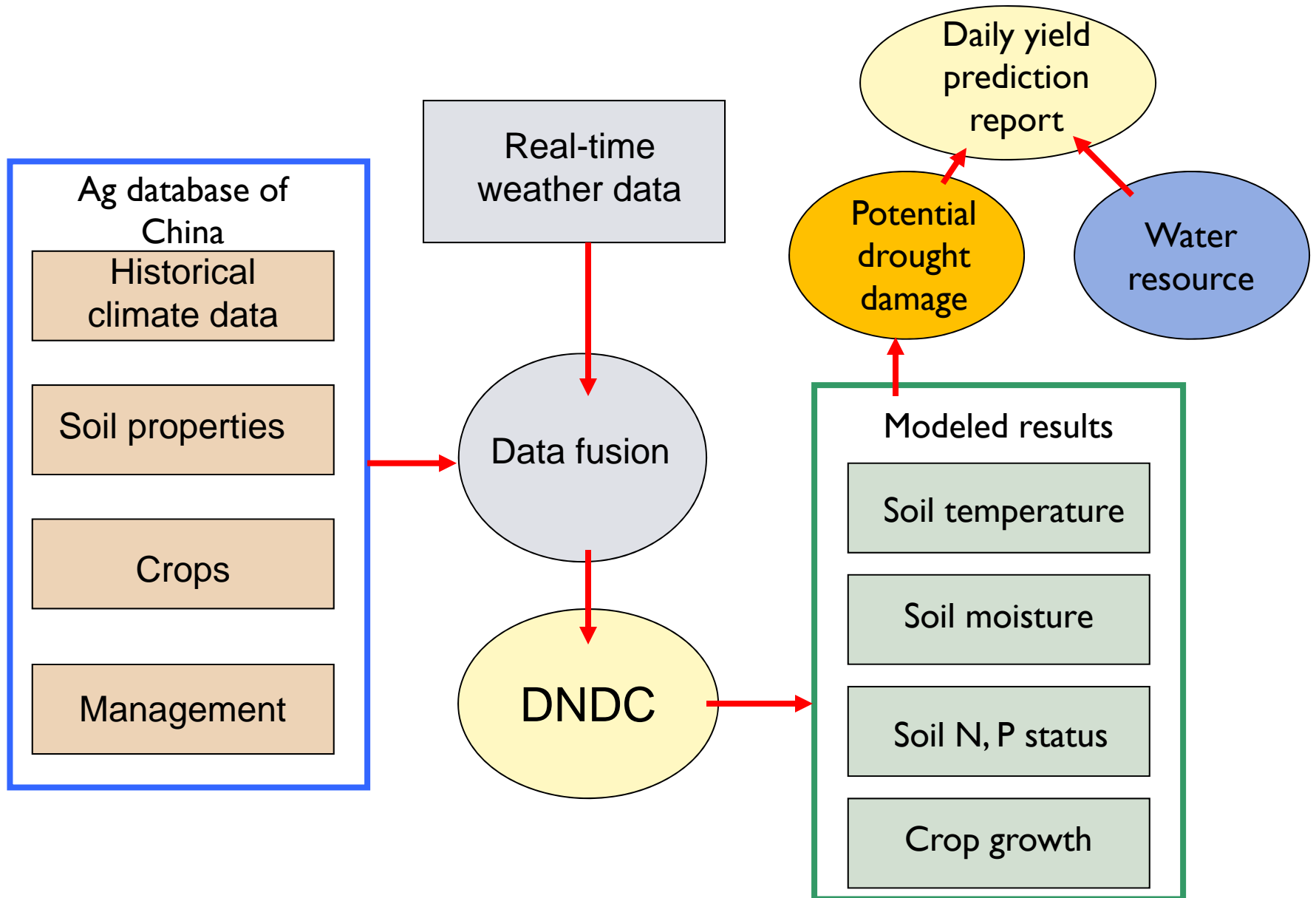
A data acquisition tool has been built up to help the US farmers to obtain input information through Internet to run DNDC at farm scale

DNDC-cored tools are being built up for quantifying ecosystem services at regional scale in the U.S.

Chesapeake watershed database
- Daily meteorological data
- Soil properties
- Farming management practices

User Interface
1. Allow user to select a farm or region from a map or table
2. Extract relevant input data from database for selected farm or region
3. Send input information to DNDC
4. Receive modeled results from DNDC
5. Convert modeled results to graphics or tables for output

DNDC simulation processes

Ecosystem Service Index

$$ESI = F \, (EP, NL, AV, GHG, CS)$$

Output
1. Milk/meat/crop/bio-fuel production (EP)
2. N leaching load (NL)
3. NH3 volatilization (NV)
4. CO2, N2O, CH4 emissions (GHG)
5. C sequestration & soil fertility (CS)

Summary

- Through the past two-decade international efforts, DNDC has been independently tested against about 400 datasets of crop yield, SOC, N2O, CH4 and N leaching observed worldwide with 298 peer-reviewed papers published till 2011;

- DNDC has been integrated in decision support systems to assess best management practices for cropland, pasture, forest, wetland or livestock manure systems in the U.S. , Canada, EU, New Zealand and China;

- A Global DNDC Network (http://www.globaldndc.net) has been established in New Zealand to coordinate international efforts for DNDC development and applications;

- In 2010, a firm DNDC-ART was established in New Hampshire to specially focus on DNDC applications in the U.S.

DNDC simulates soil climate, plant growth and soil chemistry to provide context for GHG simulations

Ecological drivers

| Climate | Soil | Vegetation | Management |

Soil climate
- Temperature
- Moisture
- Runoff and leaching flow
- Oxygen and Eh

Plant growth
- Phenology
- Yield
- Litter production
- Water and N uptake

Decomposition
- Fresh litter partitioning
- Microbial assimilation
- SOC turnover
- CO_2 production

Soil environmental factors

| Temperature | Moisture | pH | Eh | Substrates: NH_4^+, NO_3^-, DOC |

Denitrification
- Reduction of NO3
- NO3, NO2, NO, N2O, N2 production

Nitrification
- Oxidation of NH4
- NO2, NO, N2O, NO3 production

Fermentation
- DOC → CH4
- CO2 + H2 → CH4