Modeling Soil Carbon Sequestration at Site, Landscape, Regional and National Levels

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11:15 – noon, Dec. 8

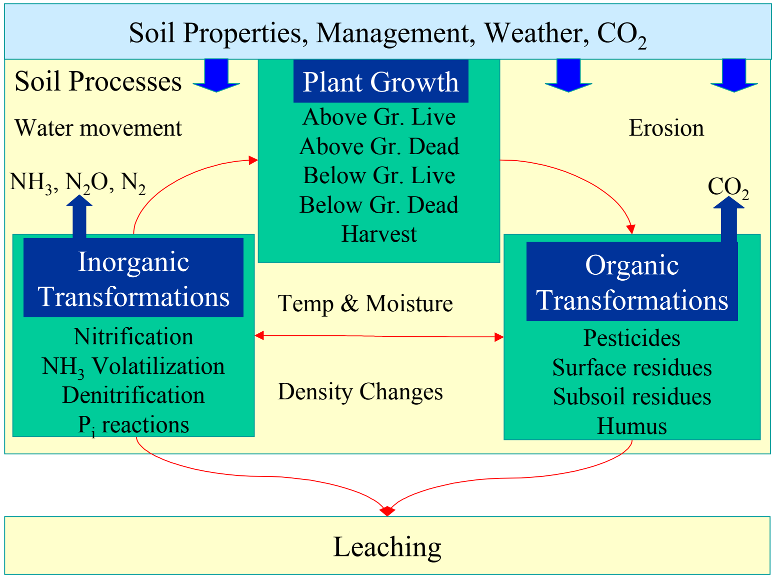
Objectives and Rationale

- **Overarching objective**
  - **To develop a mechanistic and holistic understanding of soil carbon sequestration**
- **Rationale**
  - **Process-based models of ecosystem processes can help us understand**
    - **Major controls of soil C sequestration**
    - **Coupled cycling of C and N in soils**
    - **Erosion-deposition effects on the C balance**
    - **Non-CO_2 gas fluxes**
  - **Field and lab experiments can provide insight on how to improve the representation of C and N processes in soils**

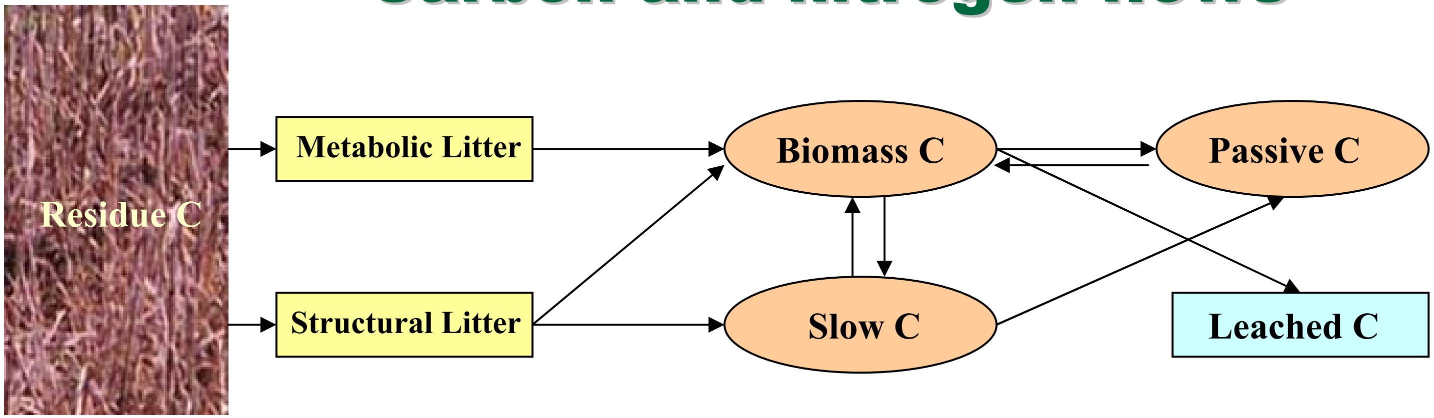
Two terrestrial ecosystem models

- Century
  - Century
  - DayCent
  - C-STORE
- EPIC
  - EPIC
  - APEX

Processes and drivers

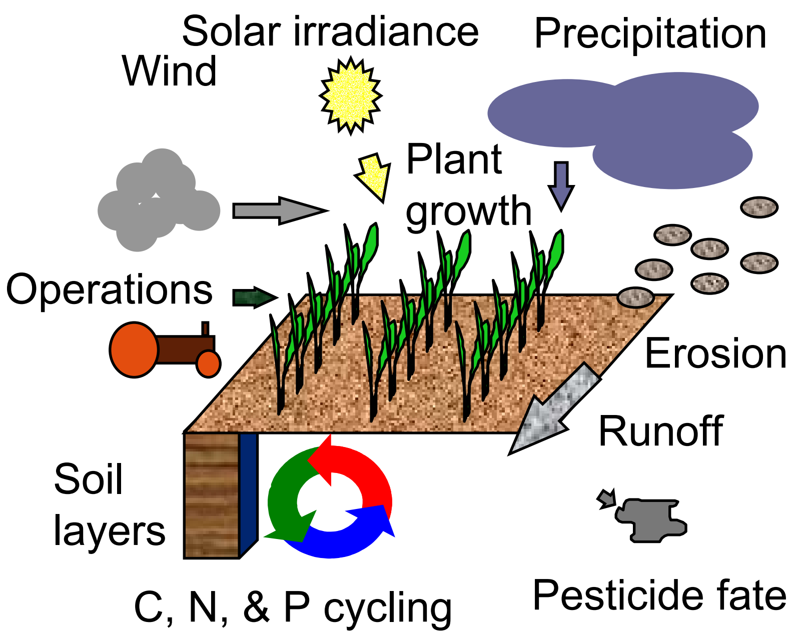


Carbon and nitrogen flows



Integrating soil and biological processes at landscape scale through simulation modeling

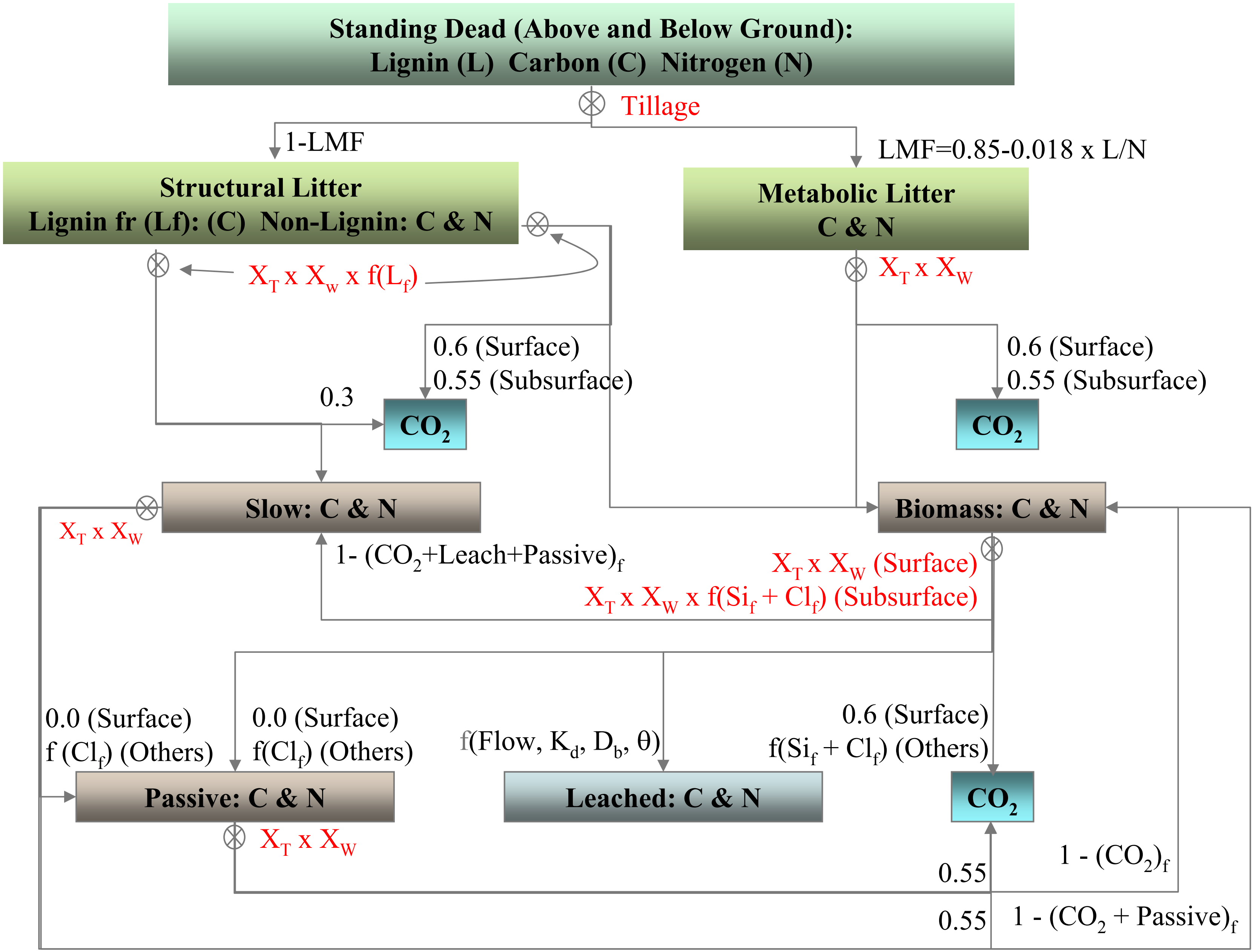
EPIC Model



Representative EPIC modules

Williams (1995)

- **EPIC is a process-based model built to describe climate-soil-management interactions at point or small watershed scales**
  - **Crops, grasses, trees**
  - **Up to 100 plants**
  - **Up to 12 plant species together**
- **Key processes simulated**
  - **Weather**
  - **Plant growth**
    - **Light use efficiency, PAR**
    - **CO_2 fertilization effect**
    - **Plant stress**
  - **Erosion by wind and water**
  - **Hydrology**
  - **Soil temperature and heat flow**
  - **Nutrient cycling**
  - **Tillage**
  - **Plant environment control: fertilizers, irrigation, pesticides**
  - **Pesticide fate**
  - **Economics**



C and N flows in EPIC

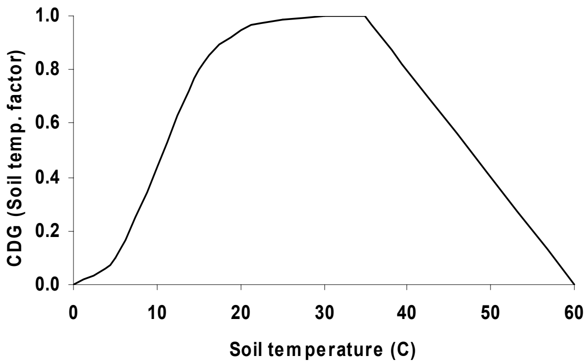
Izaurralde et al. (submitted)

Four distinctions between the Century and EPIC soil C models

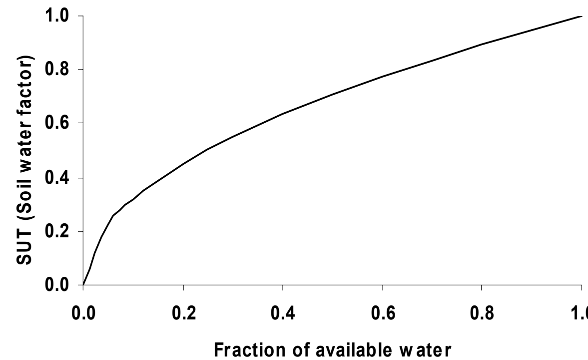
- Leaching of organic material in EPIC is based on sorption mechanisms and soil water content
- Temperature and water controls affecting transformation rates are calculated with equations currently in EPIC
- Surface litter fraction in EPIC has a Slow compartment in addition to the Metabolic and Structural Litter components in Century
- Lignin concentration in EPIC is modeled as a sigmoidal function of plant age, whereas in Century it is a function of annual precipitation

Temperature, water, oxygen, and tillage controls on decomposition rates of C and N in EPIC

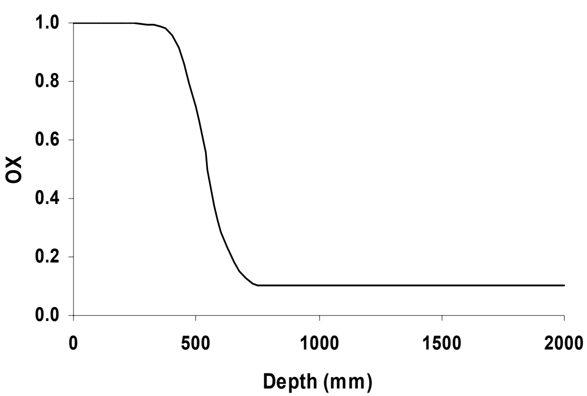
Temperature



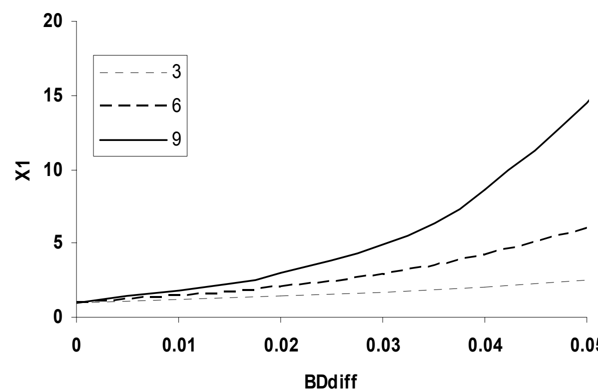
Water



Oxygen



Tillage



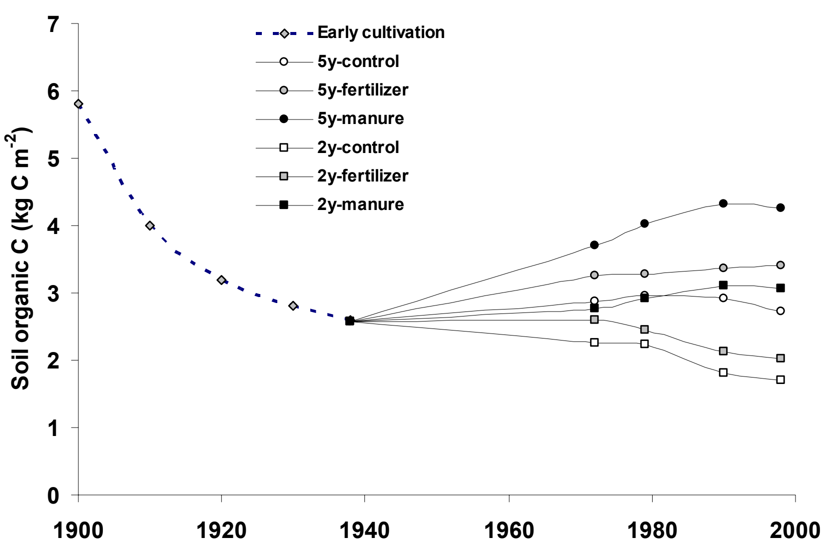
Izaurralde et al. (submitted)

Long-term experiments: essential tools to understand management effects on soil organic C dynamics

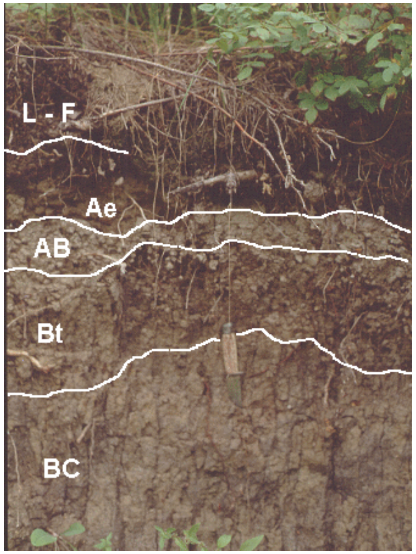
- Forest to agriculture (~1900)
- Breton Plots initiated in 1930
- Current treatments (1938)
  - Two crop rotations: a) fallow-wheat, b) five year (wheat-oats-barley-forage- forage)
  - Fertility treatments: a) control, b) fertilizer, c) manure

Aerial view of Breton Classical Plots

Photo: RC Izaurralde

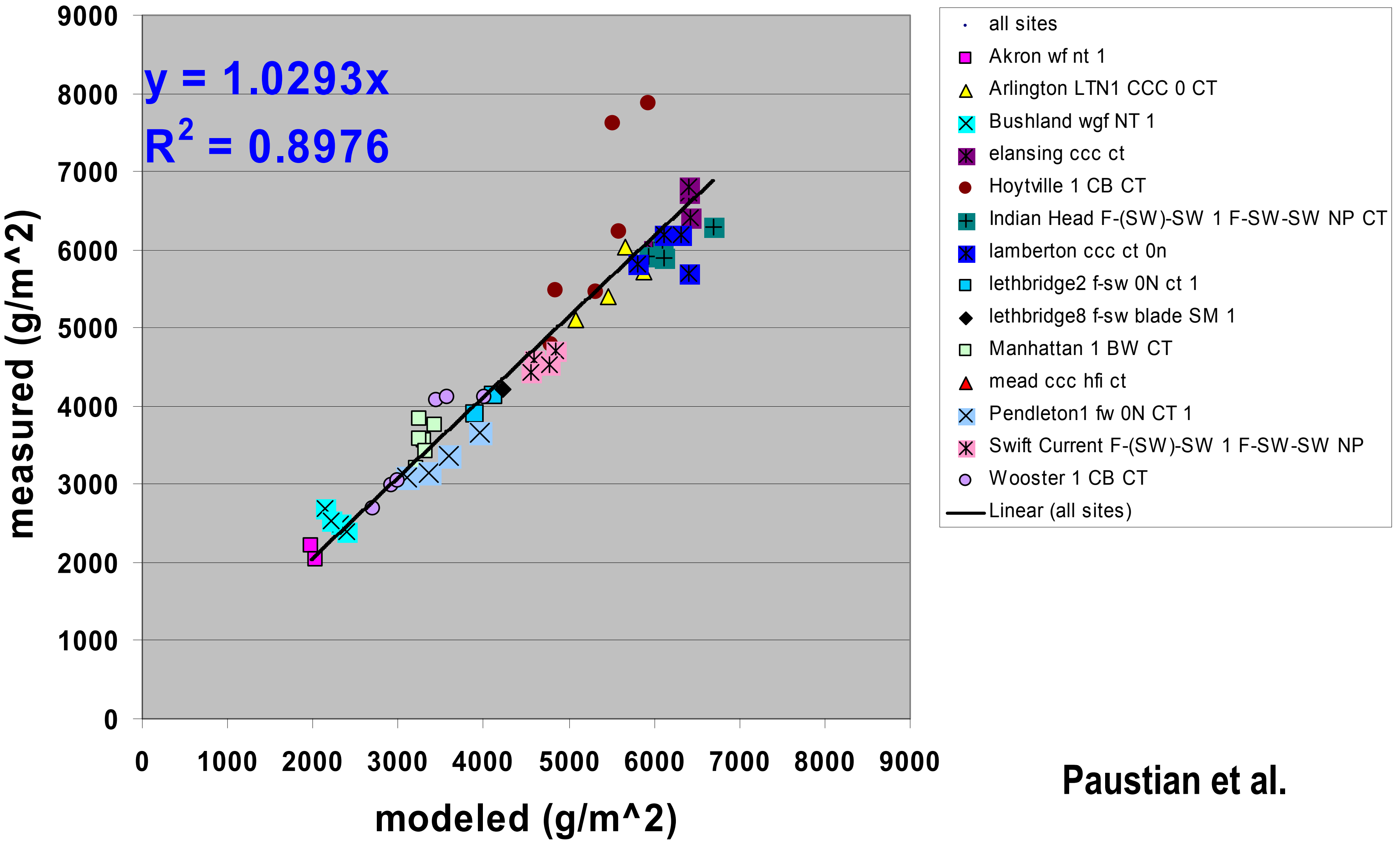


Izaurralde et al. (2001)

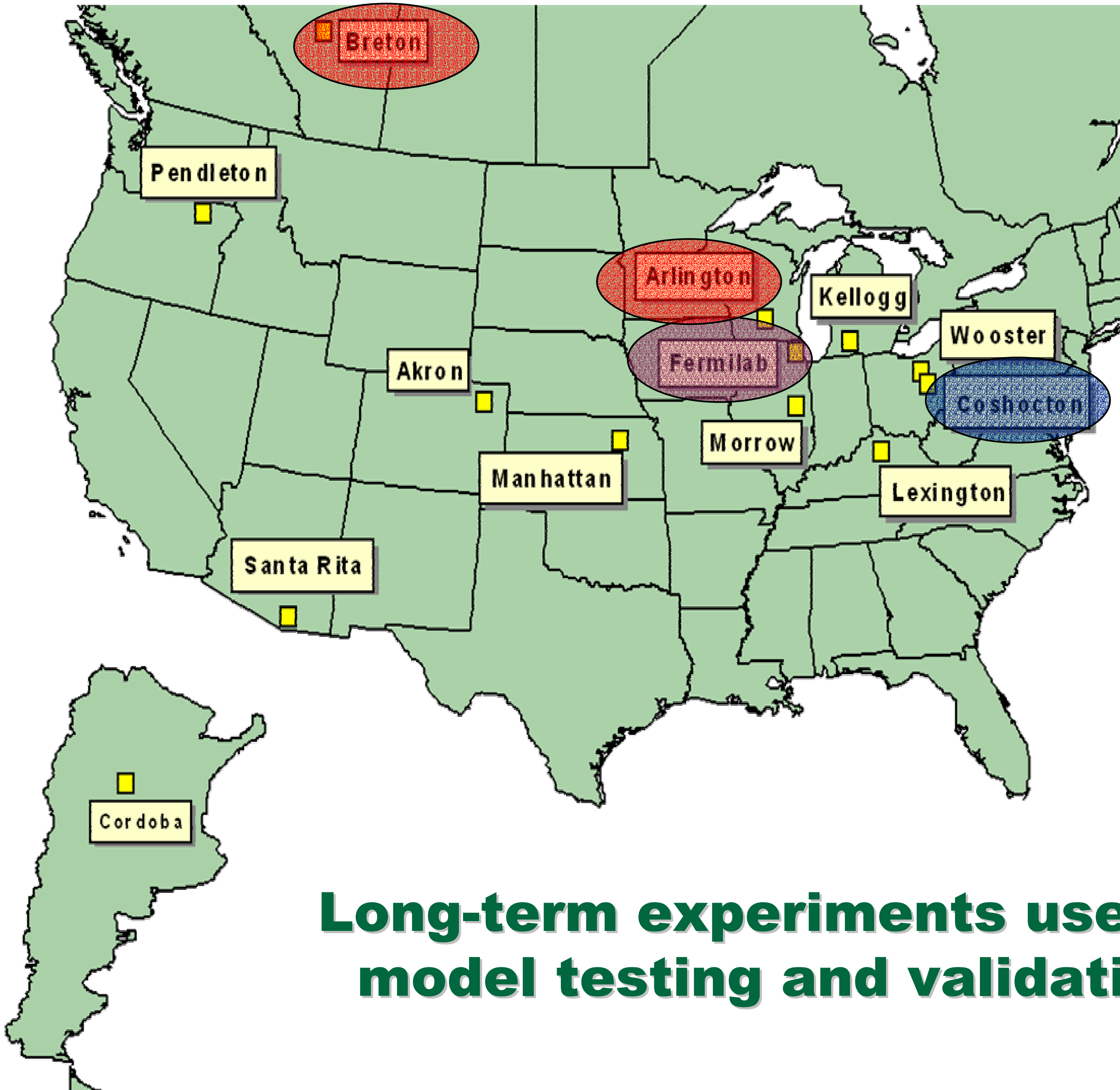


Breton loam

Simulation of long-term soil C changes using Century

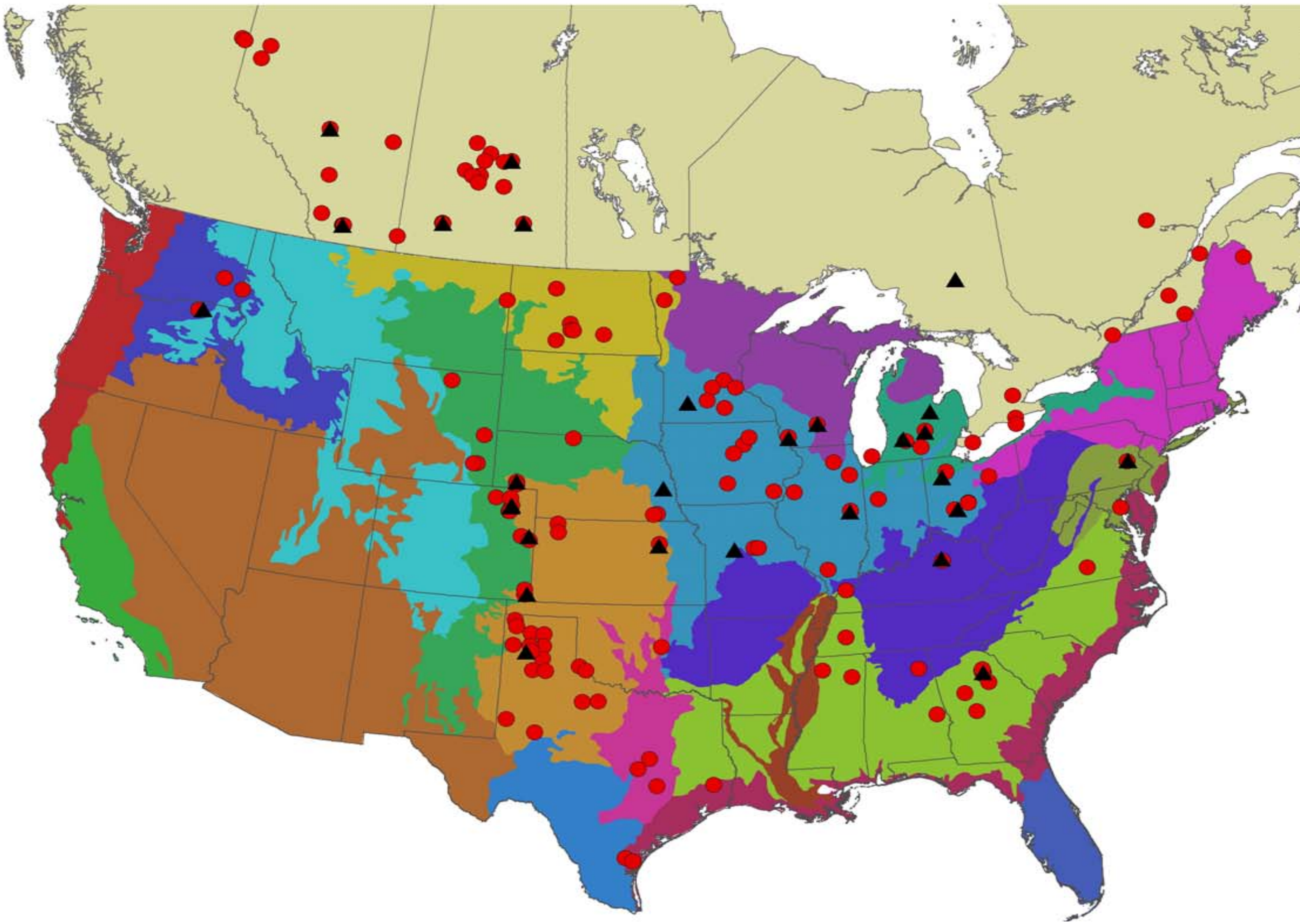


Paustian et al.

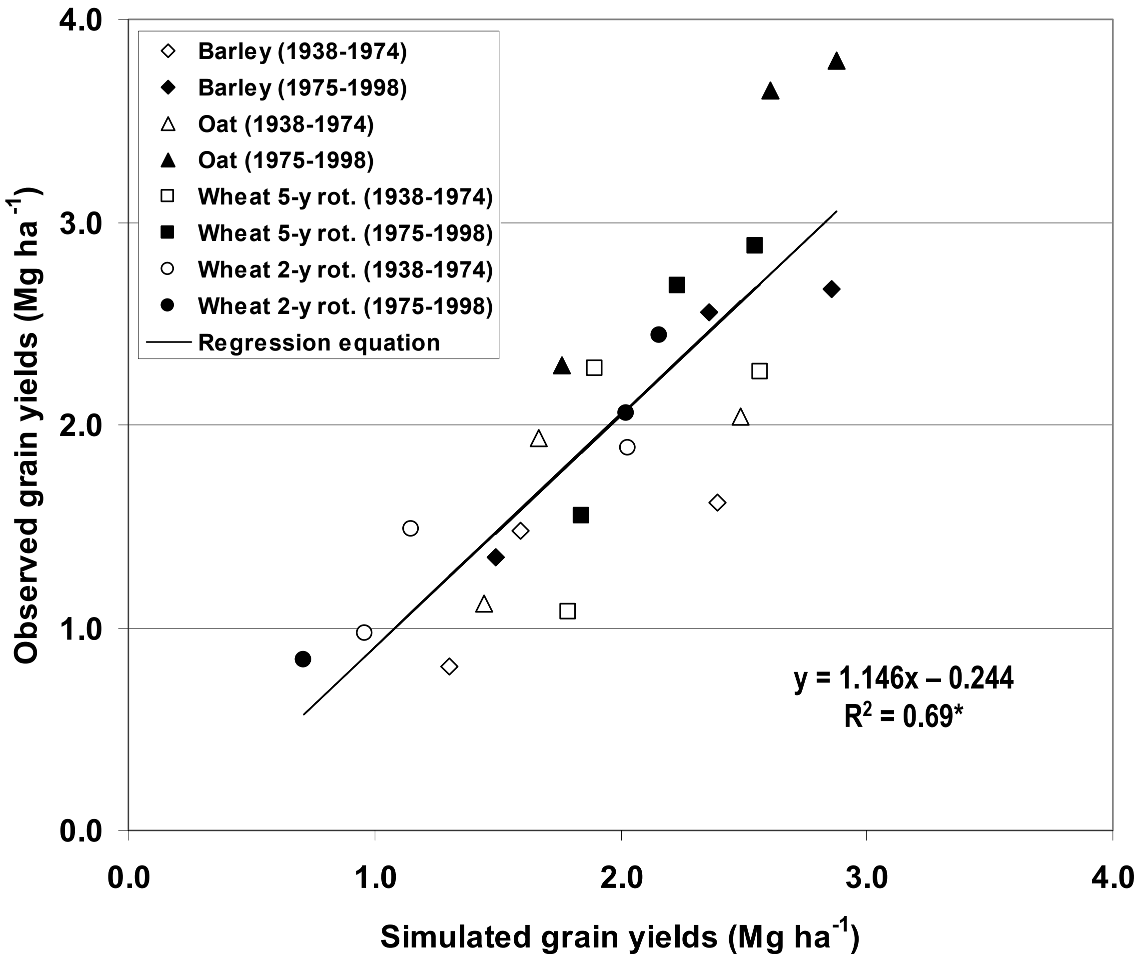


Long-term experiments used in model testing and validation

Extended long-term databases in the Canada and the U.S.

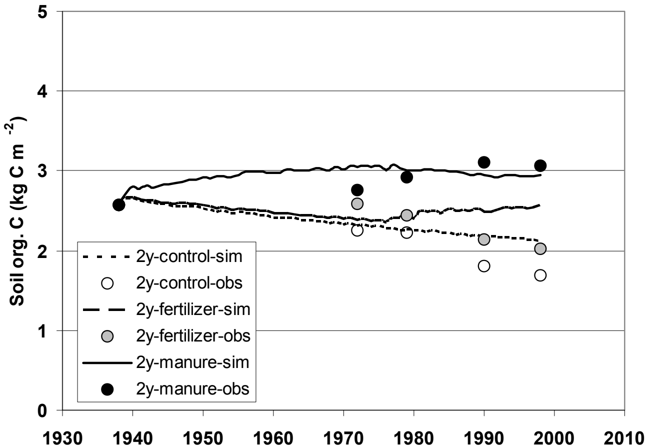


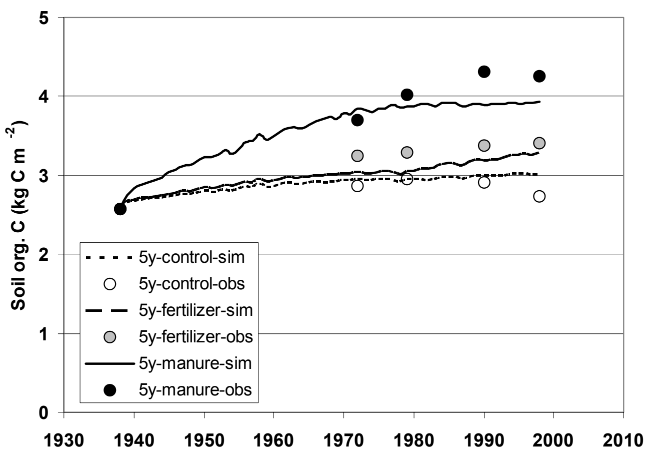
EPIC provided realistic yield simulations of cereal and forage crops at the Breton Classical Plots

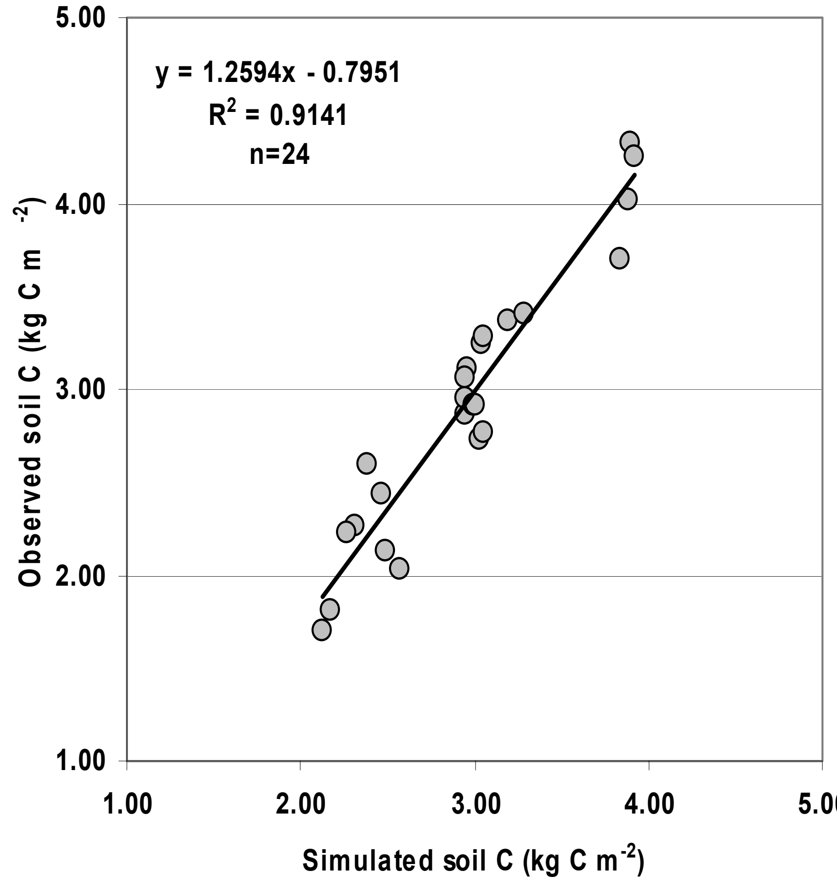


Izaurralde et al. (submitted)

EPIC captured the soil organic C (SOC) dynamics at Breton although it overpredicted at low SOC values and underpredicted at high ones

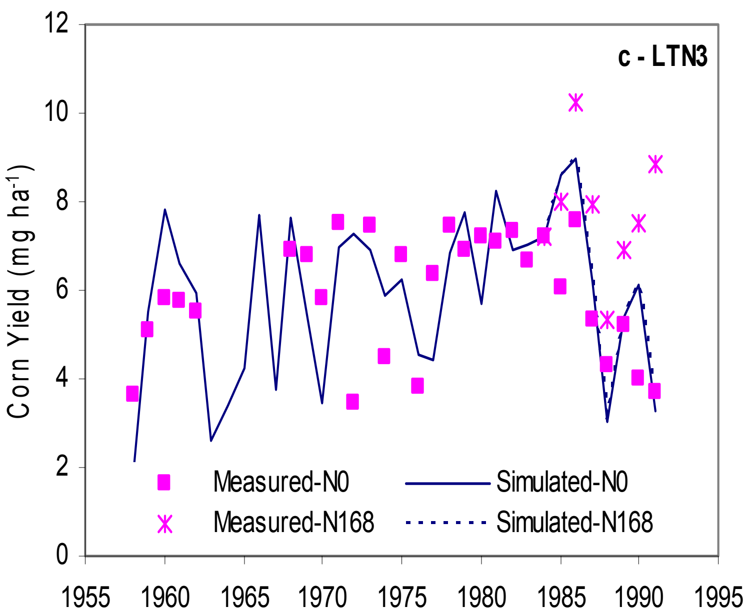




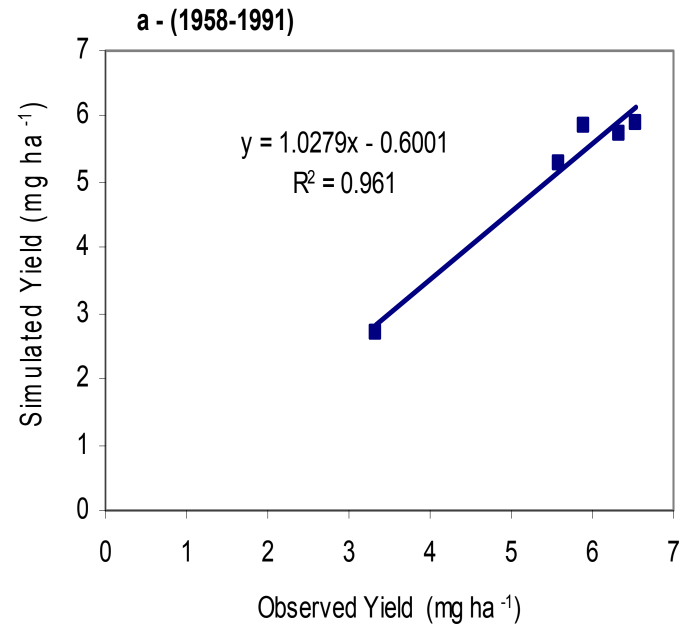


Izaurralde et al. (submitted)

EPIC did not fully capture the year-to-year variation in corn yields at Arlington, WI; however, it did capture trends in average yields



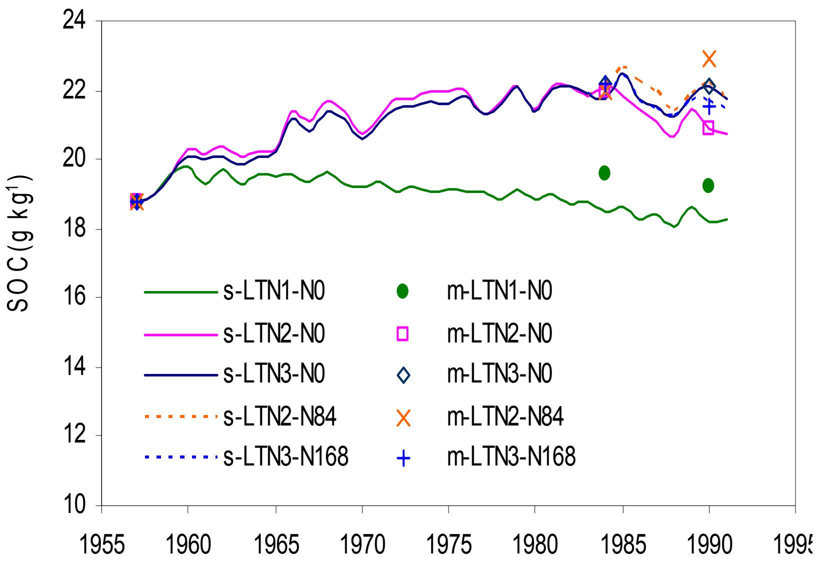
Simulated vs. observed **annual** corn yields



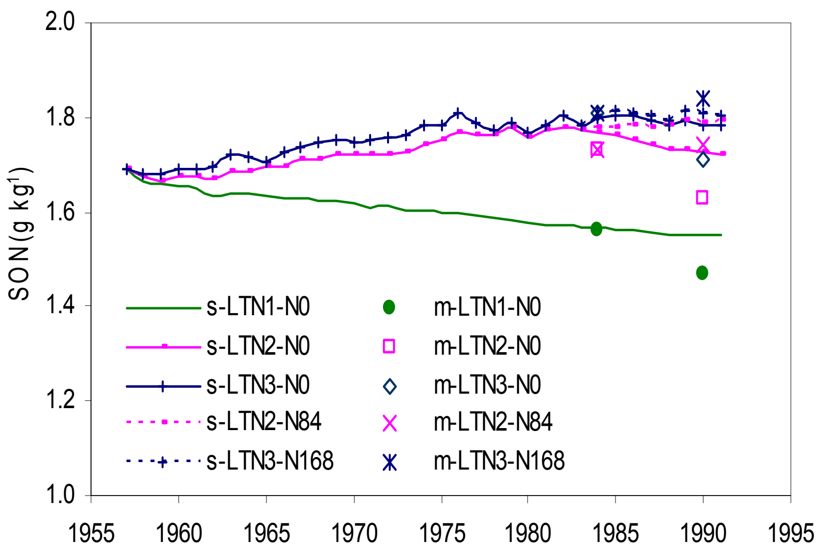
Simulated vs. observed **average** corn yields

He et al. (submitted)

EPIC was capable of mimicking the tight coupling of the C and N cycles in soil



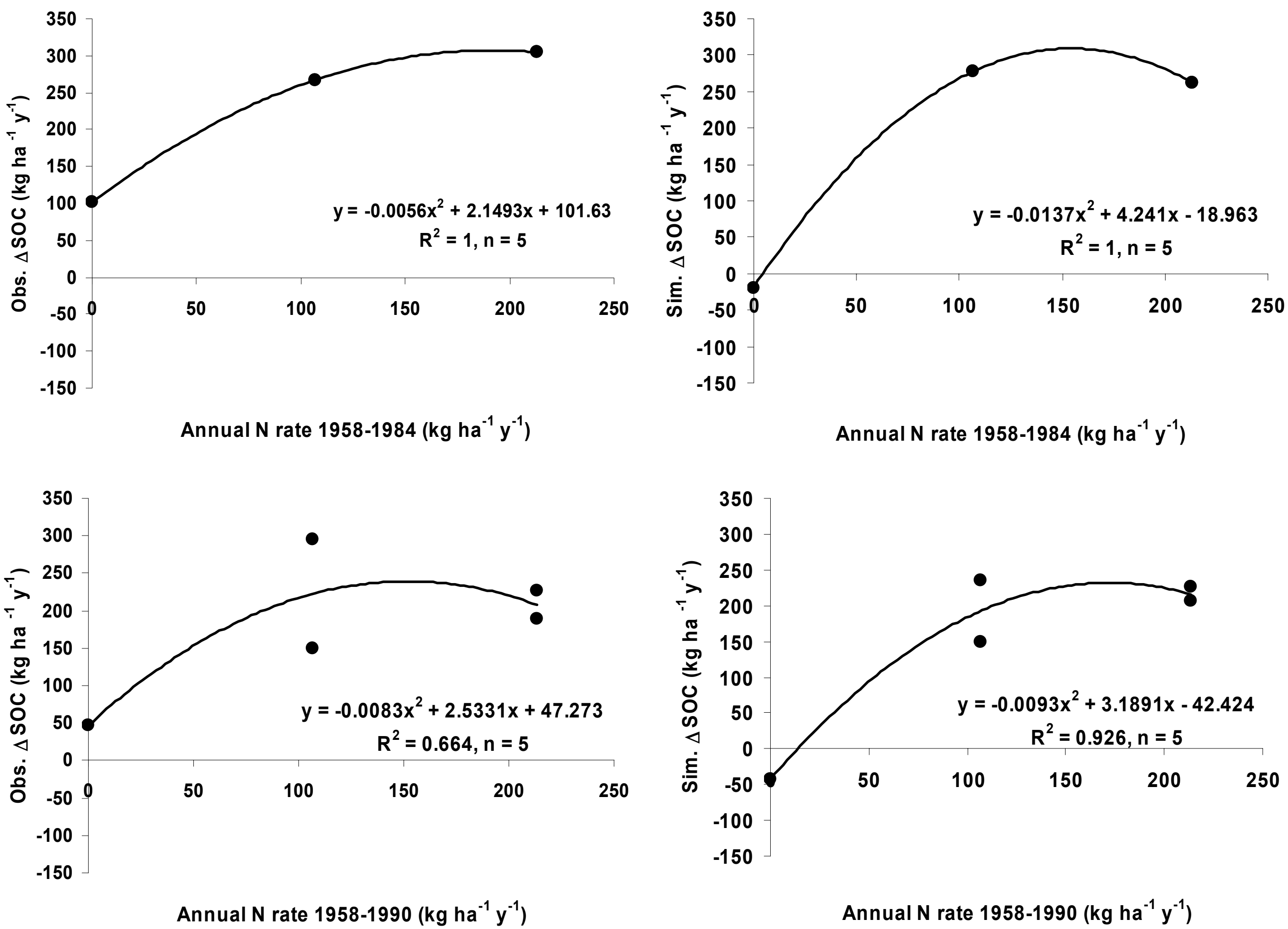
Soil C dynamics



Soil N dynamics

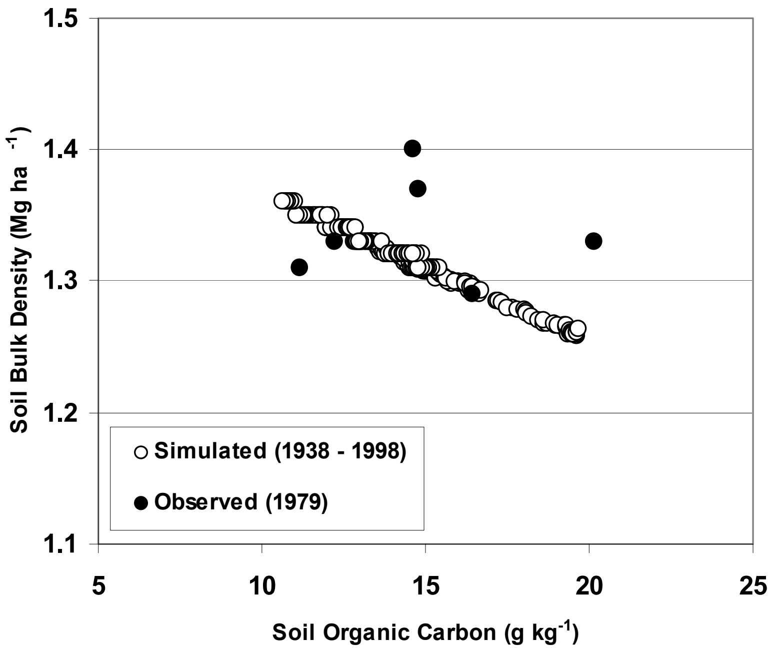
He et al. (submitted)

EPIC also reproduced the observed rates of soil carbon sequestration as a function of long-term N application

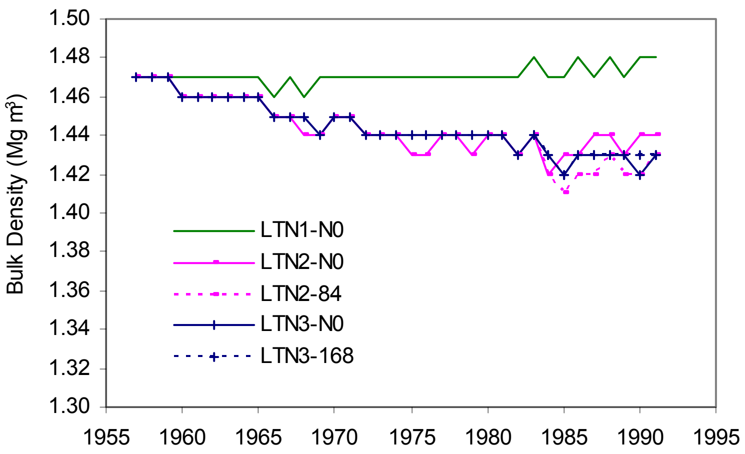


He et al. (submitted)

EPIC provides dynamic simulation of the effects of soil organic matter content on bulk density

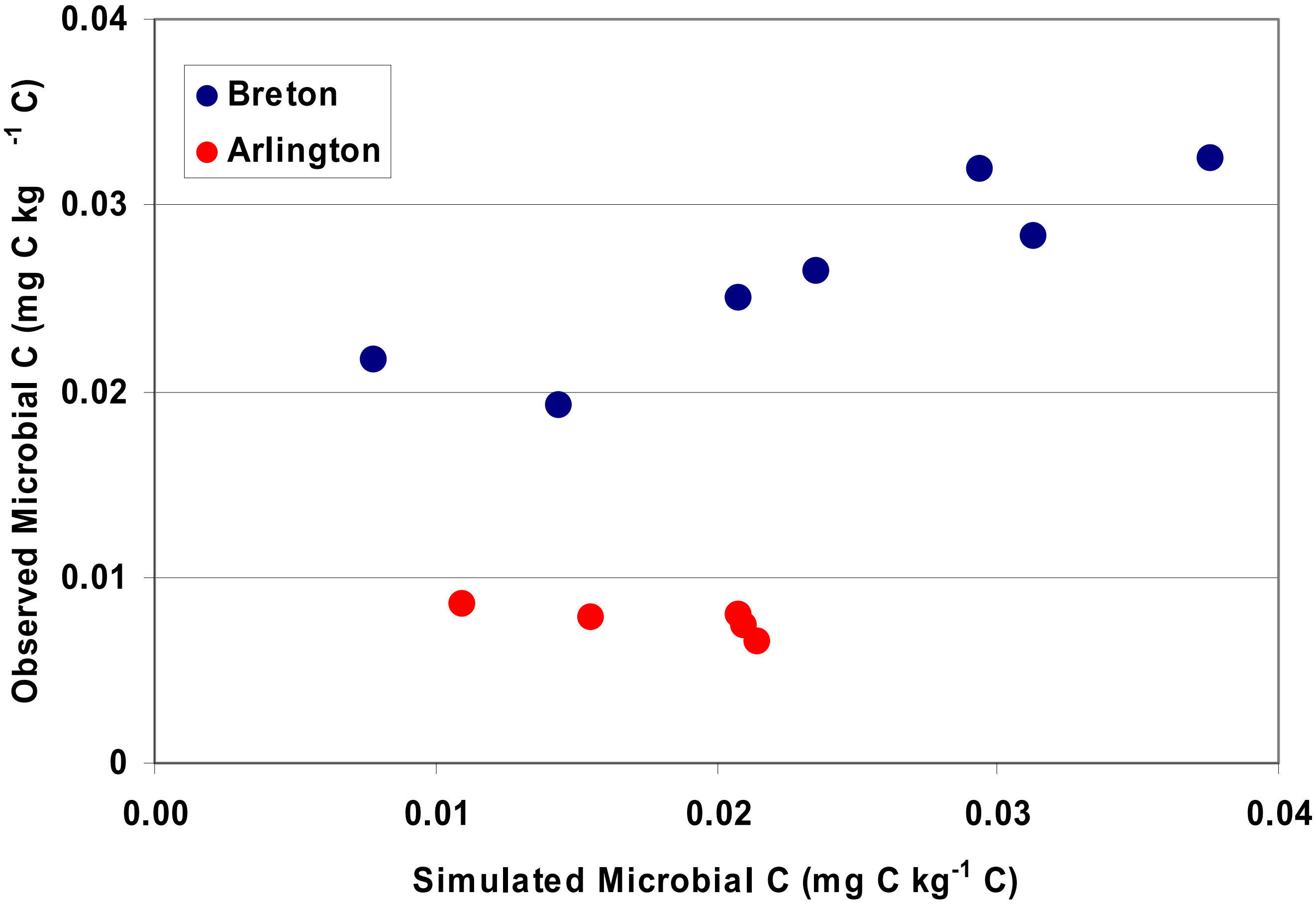


Izaurralde et al. (submitted)



He et al. (submitted)

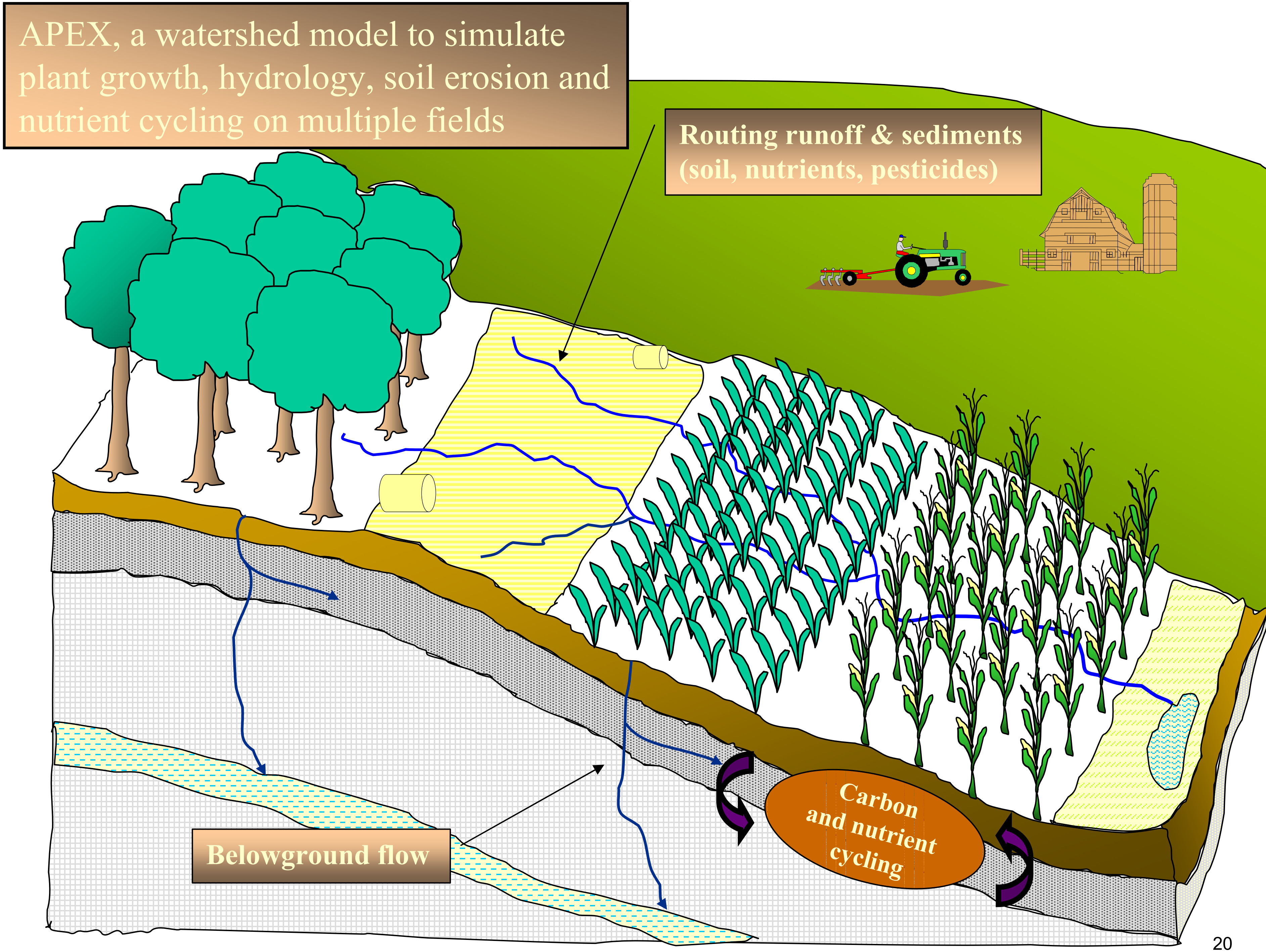
EPIC described the trends in microbial biomass C (MBC) at Breton but not at Arlington where observed MBC was insensitive to N fertilization



EPIC predicted N mineralization rates that were an order of magnitude lower than those obtained from lab-incubations

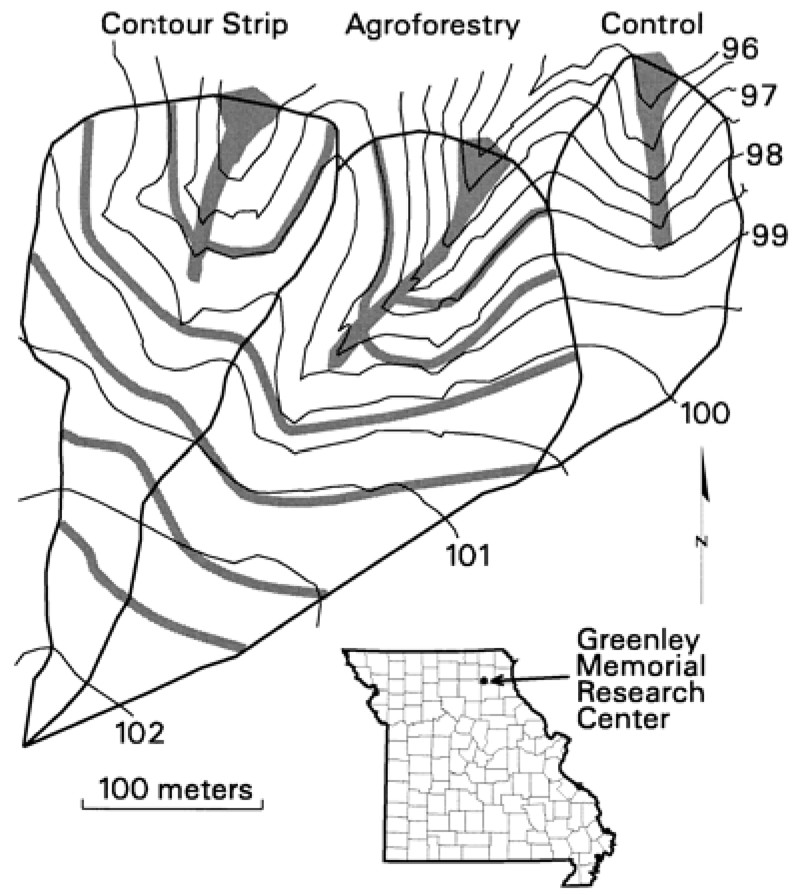
- **Lab incubations**
  - Stanford and Smith procedure
  - Disturbed soil samples
  - 35 °C
  - 85 kPa soil water potential
  - 280 days
- **Simulations**
  - Constant temperature
  - Irrigation triggered when soil water potential reached

	Sim. mg N kg^{-1}	Obs. mg N kg^{-1}
LTN1-N0	5	87
LTN2-N0	6	95
LTN3-N0	8	120
LTN2-N84	9	116
LTN3-N168	19	125


APEX, a watershed model to simulate plant growth, hydrology, soil erosion and nutrient cycling on multiple fields
Routing runoff & sediments (soil, nutrients, pesticides)
Belowground flow
Carbon and nutrient cycling

Current work with APEX

- Carbon and N algorithms from EPIC incorporated into APEX (Williams and Izaurralde, in review)
- A demonstration study using data from remote sensing was conducted for a watershed in Maryland (Thomson et al., 2003)
- Collaborations are underway to implement APEX and validate model results using historical observations from three watersheds
  - Coshocton, OH
  - Greenley Memorial Research Center, MO (picture on right)
    - CO_2 and N_2O flux data
    - Spatial distribution of soil C and N
  - Curitiba, Brazil



Agroforestry watersheds in Missouri.
From Udawatta et al. (2002)

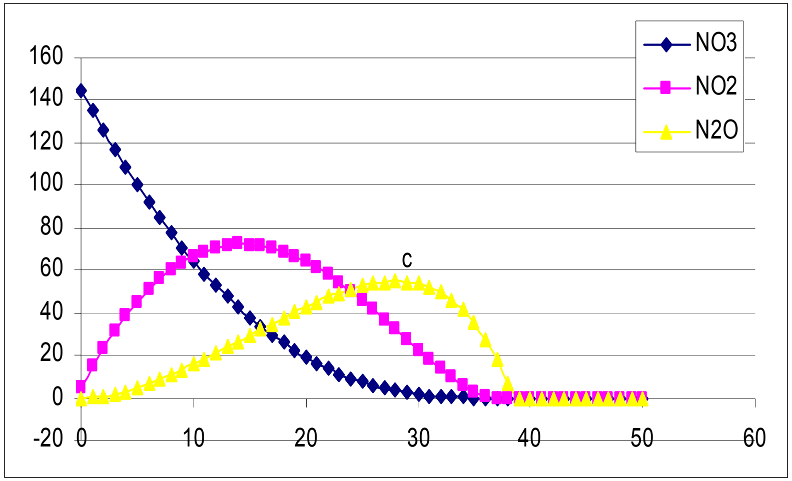
Accomplishments

- **Model**
  - **EPIC0005: Experimental version of EPIC with soil C model and gas transport subroutines – Tested with data from USA, Canada and Argentina**
  - **EPIC1015: Public version released with soil C model**
    - **This version is being tested / used by various research groups: Iowa St. Univ., USDA-NRCS, USDA-ARS**
  - **EPIC3060: Current version with revisions to N mineralization subroutine and soil bulk density model**
  - **APEX2110: Experimental version of APEX with soil C model incorporated from EPIC**
  - **204 representative farms prepared for US national runs with EPIC3060**
- **Publications / Technology transfer**
  - **Publications in Climatic Change, Adv. Agron., Science, BioScience, Soil Sci. Soc. Am. J.**
  - **Manuscripts submitted to Ecol. Modell. and Agron. J.**
  - **Four papers in conference proceeding, three abstracts**
  - **Eight invited presentations at workshops / symposia (CSiTE - CASMGS)**

Modeling denitrification with EPIC

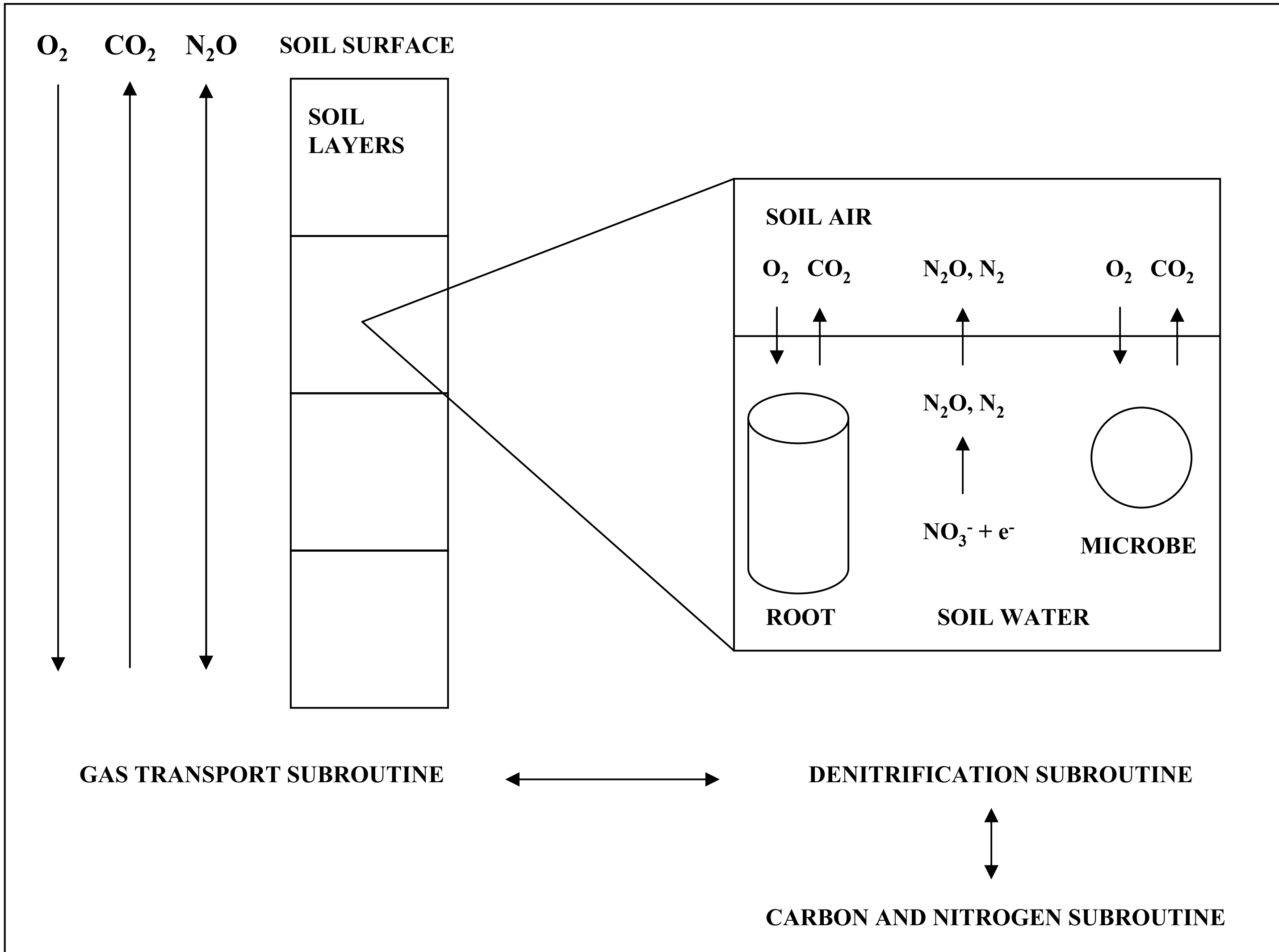
- Oxygen and oxides of N are electron acceptors
- Oxygen inhibits N reduction
- Oxides of N compete with each other for electrons
- Supply of O_2 controlled by diffusion to microsites
- Oxygen uptake by microbes and roots is described with Michaelis-Menten kinetic equations

Mass of NO_3^-, NO_2^-, and N_2O over time



McGill et al. (2004)

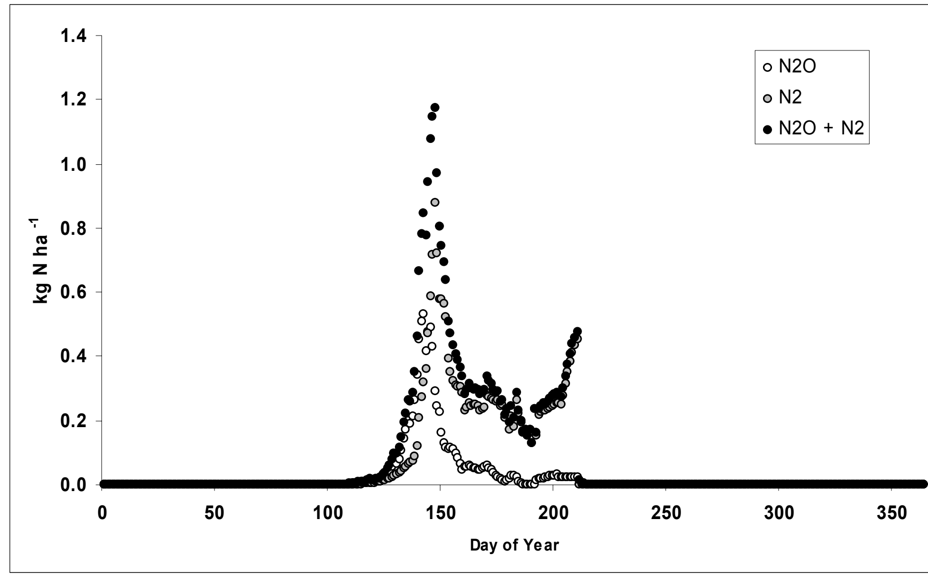
Modeling denitrification with EPIC (cont'd)



McGill et al. (2004)

Modeling denitrification with EPIC (cont'd)

- Preliminary tests of the model were conducted for a soil in Texas with 57% clay
- Annual N_2O-N flux was 8.7 kg ha^{-1}
- N_2O fluxes were simulated every month except during the first three months of the year
- N_2O fluxes during August - December were minimal
- A monthly N_2O flux of 6.3 kg N ha^{-1} in May was the highest simulated during the year and occurred during a rainy period (226 mm) in April and May
- A 8.7 kg N_2O-N ha^{-1} flux represented 27% of the total denitrification loss (N_2O + N_2)
- Model testing against experimental data will follow



McGill et al. (2004)

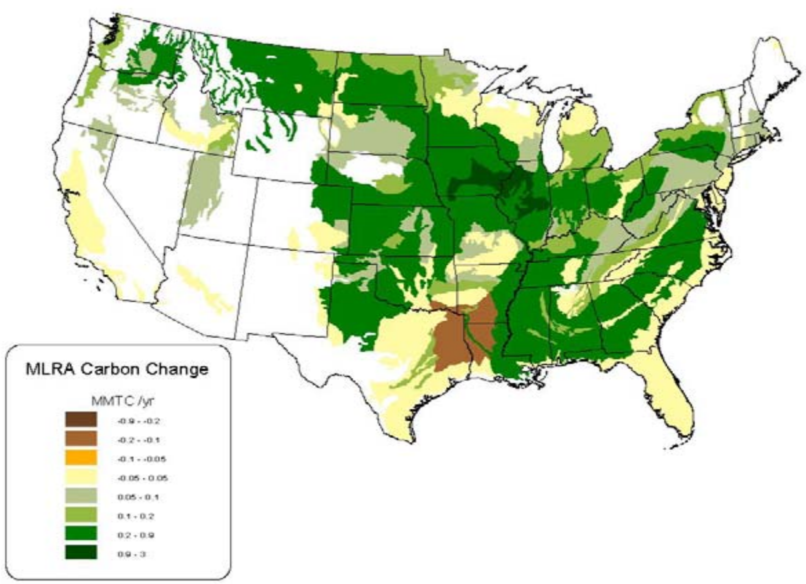
National runs with Century

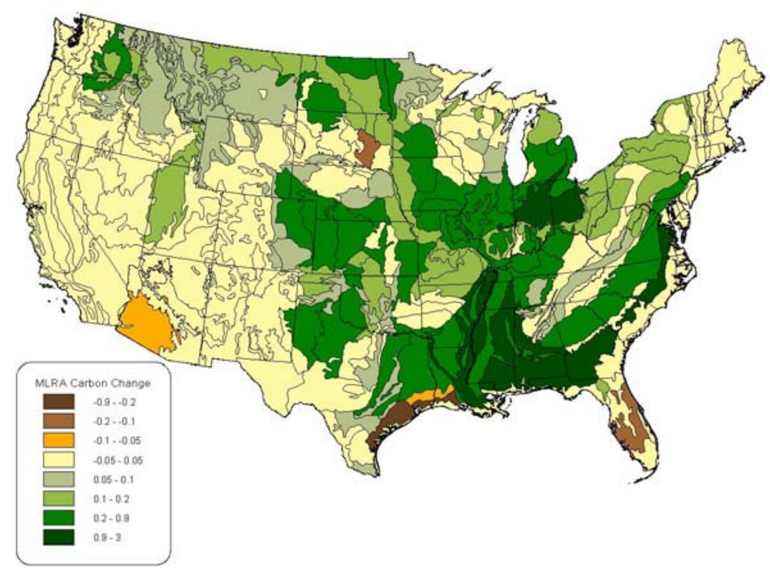
IPCC

18.4 MMTC yr^{-1}
on 168 Mha cropland

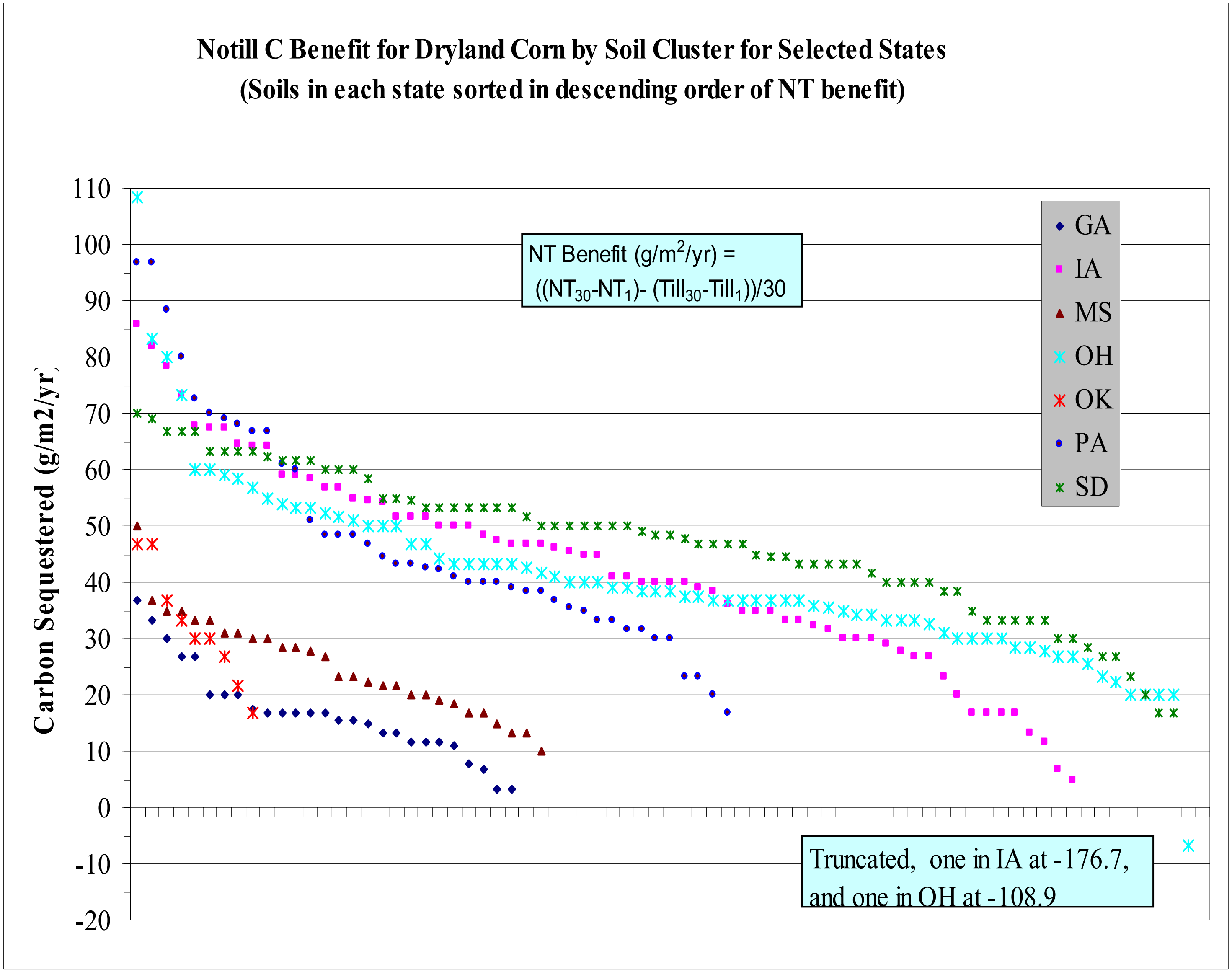
Century

21.2 MMTC yr^{-1}
on 149 Mha cropland





National runs with EPIC



Atwood et al. (2004)

Collaborations

- CSiTE
  - Task 1.1 (Post)
  - Task 2.4 (Sands and McCarl)
- National
  - Iowa St. Univ. (Gassman)
  - USDA-ARS (Doraiswamy, Vanotti)
  - USDA-NRCS (Atwood)
  - Univ. of Missouri (Motavalli)
- International
  - Univ. Nacional de Córdoba, Argentina (Apezteguía)
  - Univ. of Northern British Columbia, Canada (McGill)
  - Agriculture and Agri-Food Canada, Canada (Lemke, Desjardins, Hutchinson)
  - Universidade Federal do Rio Grande do Sul, Brazil (Tornquist)
  - Institute of Soils and Cultivated Plants, Poland (Faber)
  - China Meteorological Administration, PR China (Sun)

Next Steps

- Complete model tests and validation of EPIC3060
- Test and validate APEX2110 using data from USDA-ARS Coshocton and Missouri watersheds
- Simulate climate change impacts at site level
  - Two GCMs
    - HadCM3
    - NCAR
  - Two scenarios of development (A2 and B2)
  - Management options: land use change, tillage intensity, fertilization regimes
  - Analyze crop yields, soil C, N cycle, erosion
- Conduct experiment with EPIC and APEX regarding scaling using landscape data surrounding the tested long term sites