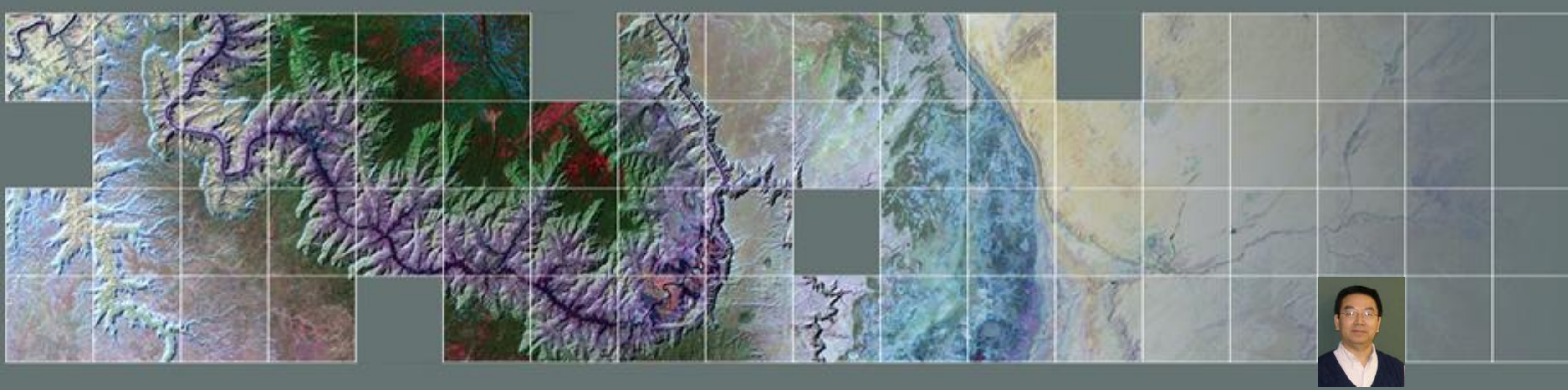
Climate and Land Use Change

Earth Resources Observation and Science (EROS) Center

Biophysical, Environmental and Economic Aspects of Rapid Land-Use Change in the Northern Great Plains



U.S. Department of the Interior
U.S. Geological Survey

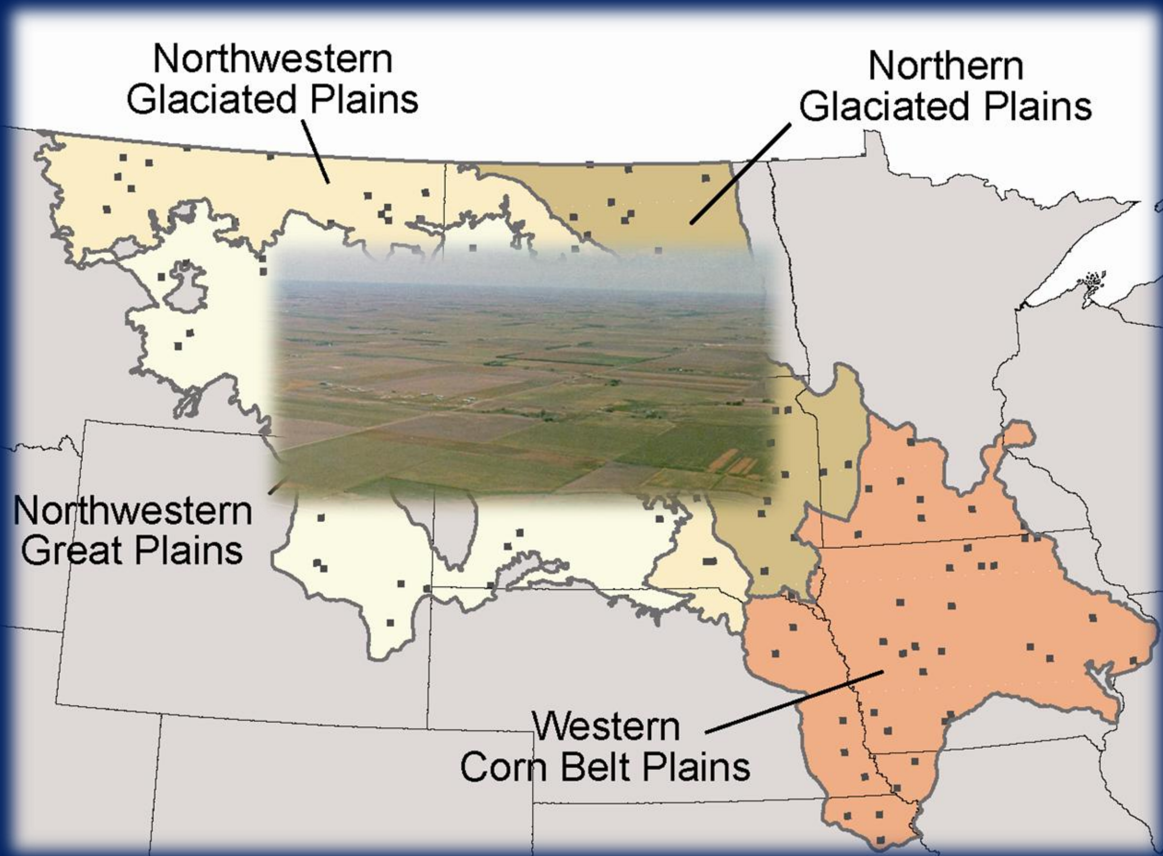
Shuguang (Leo) Liu
March 30, 2011

Acknowledgments

- **Team**
  - ✓ Shuguang (Leo) Liu (USGS/EROS, PI): Biogeochemical modeling (GEMS) and model integration
  - ✓ Terry Sohl and Kristi Saylor (USGS/EROS): Land use projection (FORE-SCE)
  - ✓ Steve Polasky and Haochi Cheng (U Minn): Econometric modeling and optimization
  - ✓ Alisa Gallant (USGS/EROS): Climate data downscaling and habitats
  - ✓ Rock Wu and Terry Tan (ARTS/EROS): SWAT and GEMS
  - ✓ Ben Sleeter (USGS/Menlo Park): Land use change scenarios
- **NASA LCLUC program**

Background

Is land use essentially stabilized in the Great Plains?



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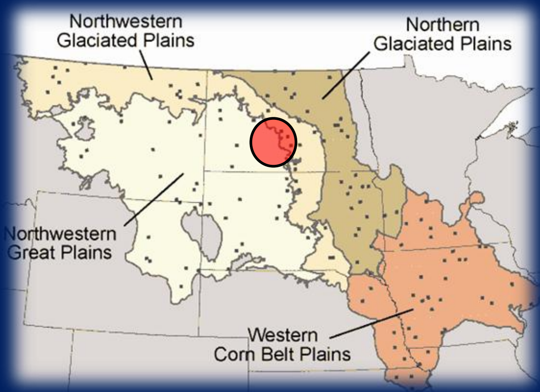
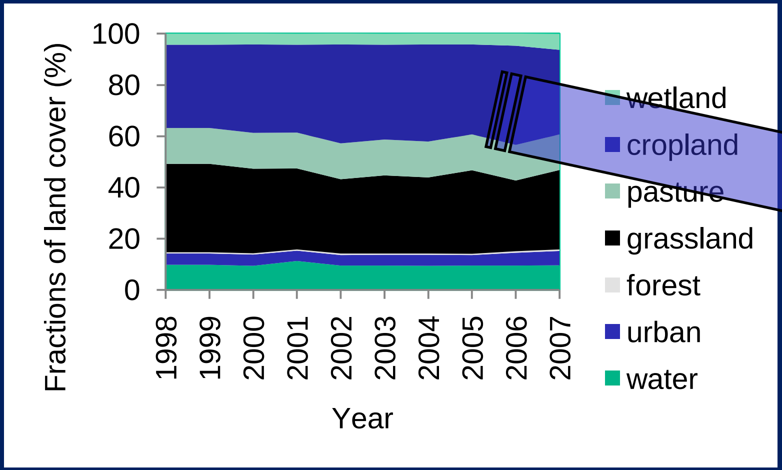
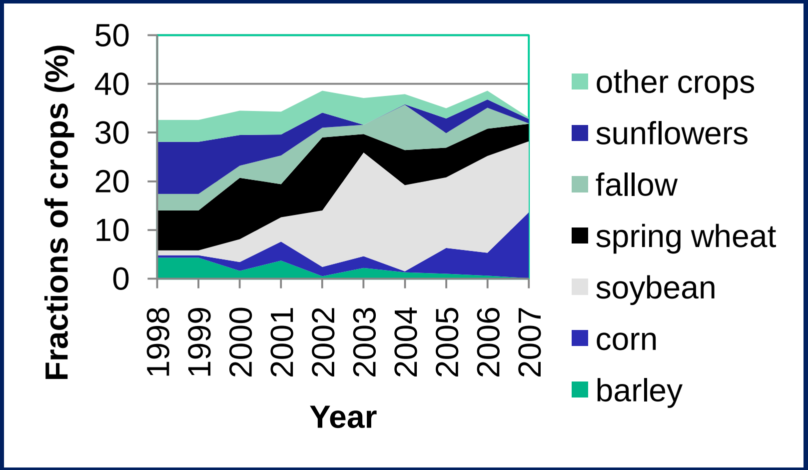


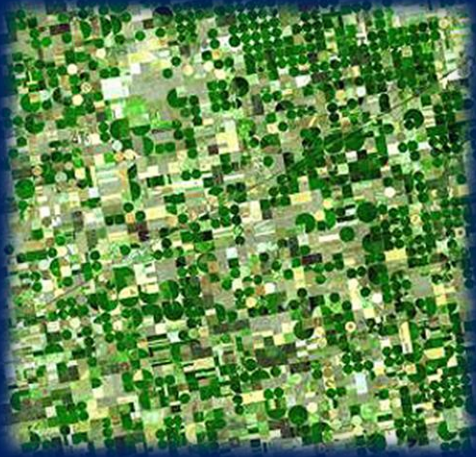
Stutsman County, ND

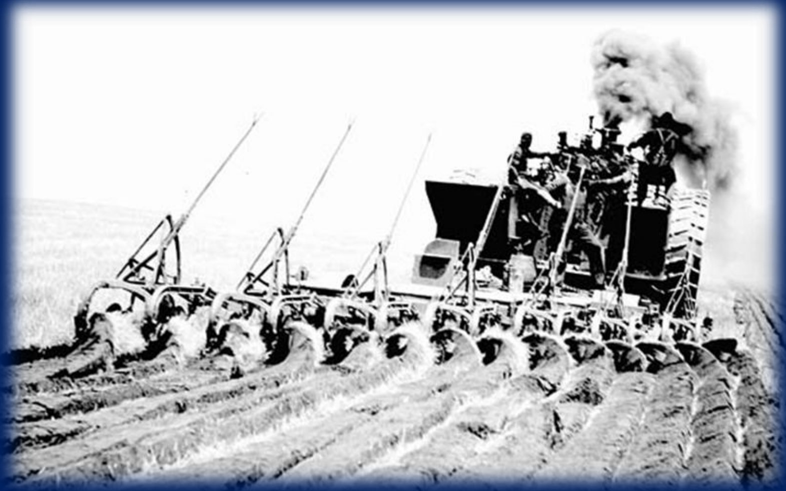




Background

Land use change is more than land cover change

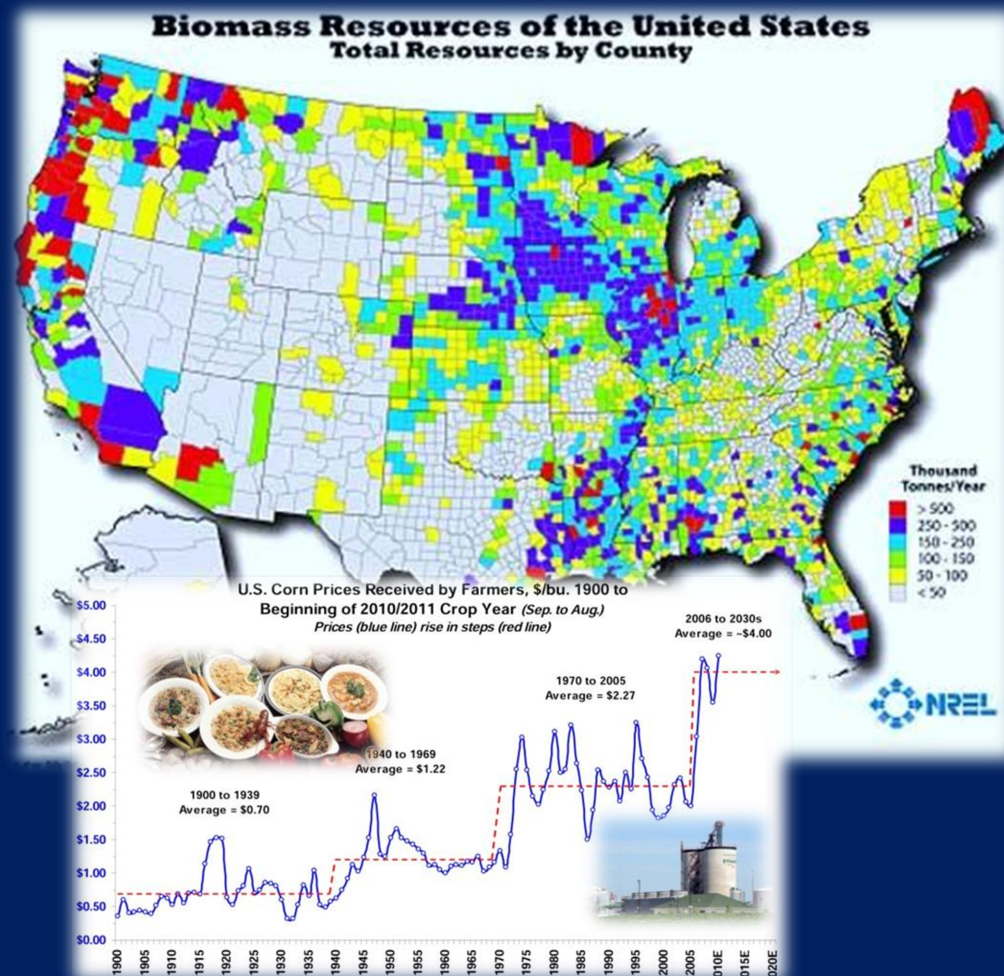




Background

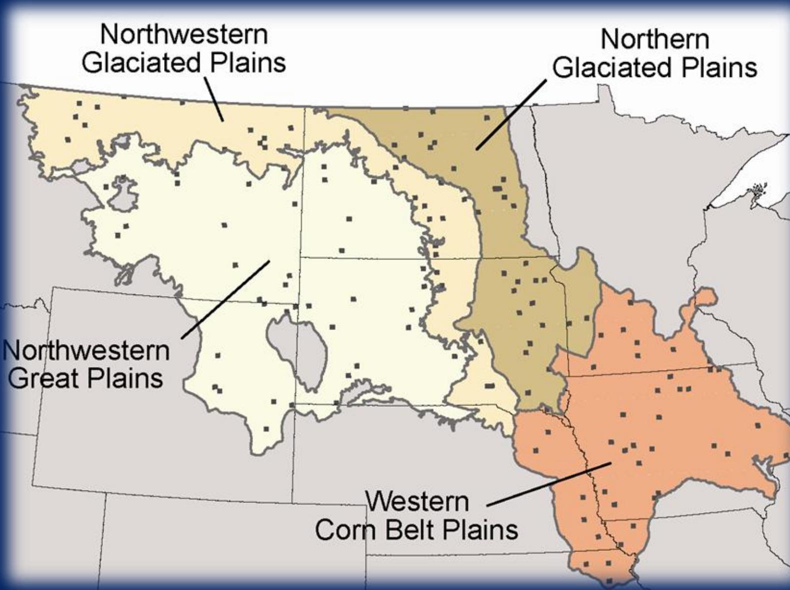
Land Use

- ❖ Area is limited
- ❖ Multiple needs (food, fiber, bioenergy, etc.)
- ❖ Multiple consequences (economics, environment, sustainability, …)
- ❖ A trade-off issue

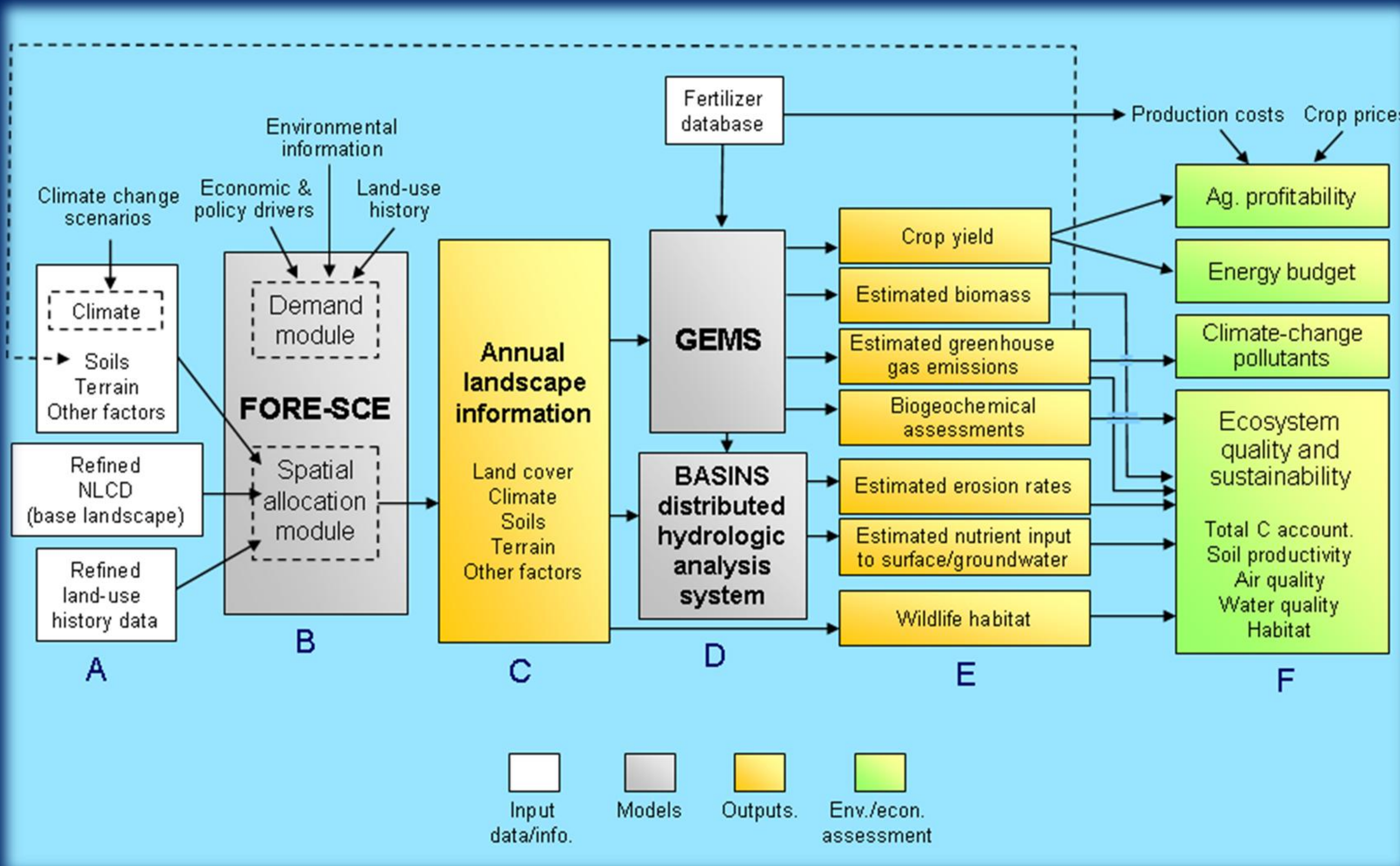


Biofuels Research Questions

1. What landscape patterns are likely to result from an expanded biomass-for-biofuel economy and what are our estimates of the uncertainties?
2. What are the environmental consequences of biomass production for energy?
3. What are the full economic costs and benefits of biomass production for energy (energy and carbon accounting), including agricultural sector profitability?
4. How will projected climate change impact agricultural production and profitability?
5. How will projected climate change impact the provision of ecosystem services, both directly and indirectly through changes in landscape patterns?
6. What are the feedbacks among land-use change, economic and policy drivers, climate, biophysical processes, and a variety of ecosystem services?
7. What are the most important factors and constraints in implementing a long-term, sustainable biomass-for-energy industry?



Integrated Modeling

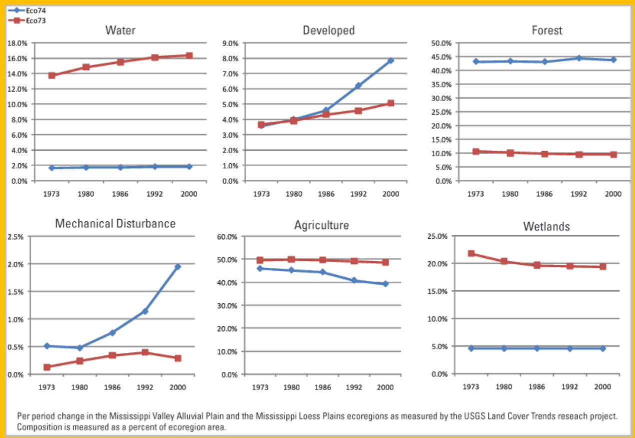


US Land Use Change Scenarios

- **In support of the USGS LandCarbon, Land Cover Trends project, and Northern Great Plains biofuels project, we are developing a first-of-its-kind set of *Land Use and Land Cover Scenarios* consistent with Global Environmental Change assessments (IPCC)**
  - **15+ LULC classes**
  - **84 ecological regions (CONUS) + Alaska**
  - **LULC change projected to 2100 at 5-year intervals**
  - **Annual maps of LULC (FORE-SCE)**
- **Combination of sources to produce Land Use Scenarios:**
  - **Global Integrated Assessment Models (IMAGE)**
  - **Land Use Histories (Land Cover Trends)**
  - **Land Change Experts**
    - **Recently conducted workshop at EROS to incorporate expert opinion into land use scenario downscaling model (January 24-28, 2011)**
    - **20+ participants with a range of expertise in land use science**
    - **Provided both qualitative (narrative storylines) and quantitative (model parameters) input to scenario downscaling effort**
    - **Preliminary scenario results at national scale nearly complete and will be a one-of-kind product used in a wide range of environmental assessments and studies**

Reference Scenario Components

LULC Histories
USGS Land Cover Trends



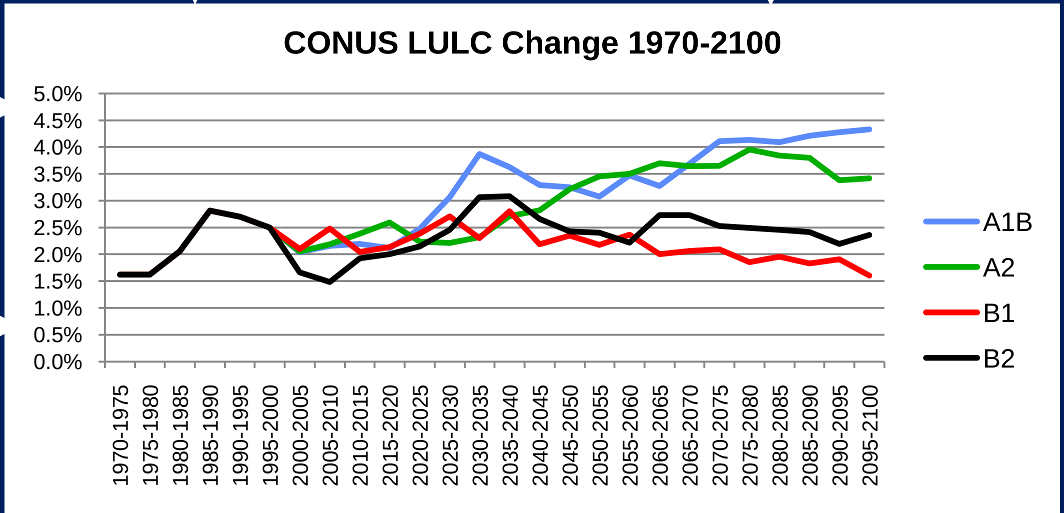
Scenario Literature
SRES, RPC, MA, CCSP

Other Inventories
NLCD, U.S. Population Census, Agricultural Census, NRI, FIA, PAD

External Modeling
ICLUS, Forest Service RPA, FASOM-GHG, Econometric

IPCC Modeling
SRES and RCP's
IMAGE, MiniCAM, AIM,

Expert Knowledge
National Workshops, Regional Consultations



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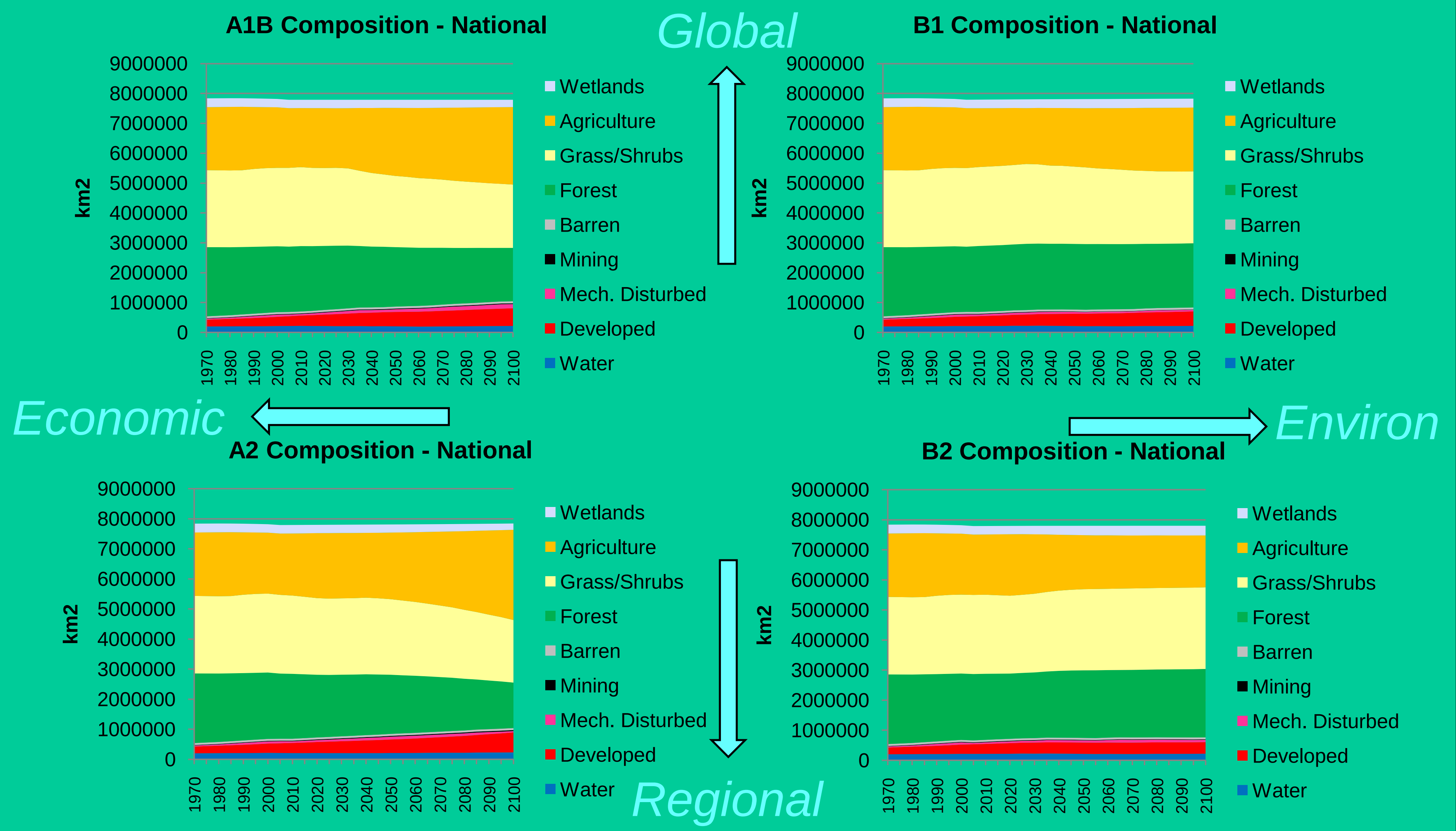
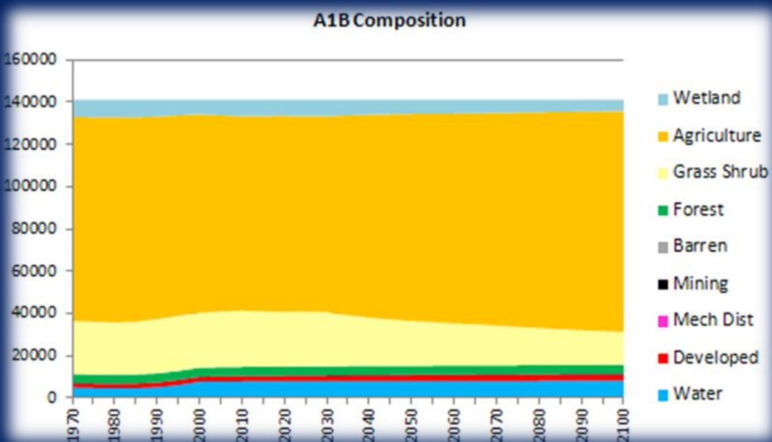
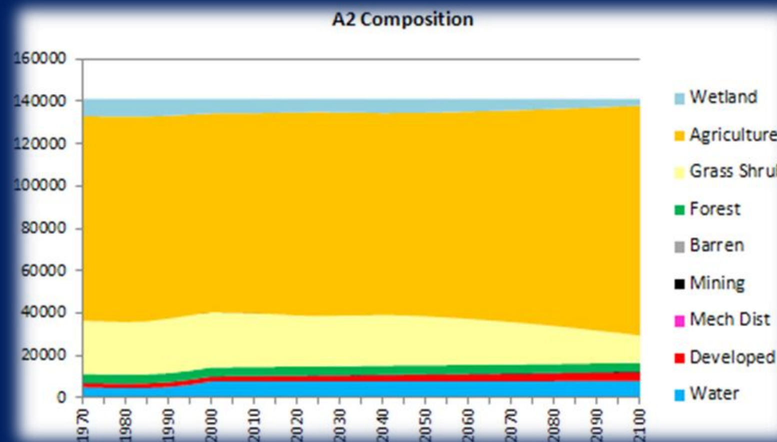
National Land Use Change Scenarios



Northern Glaciated Plains (1970 – 2100)

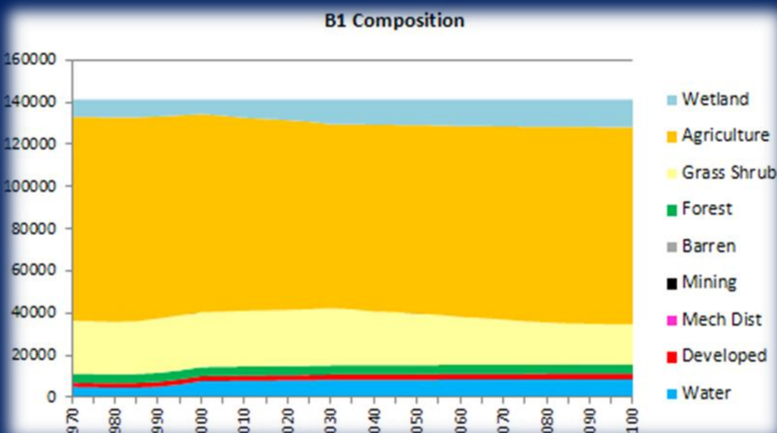
Economic

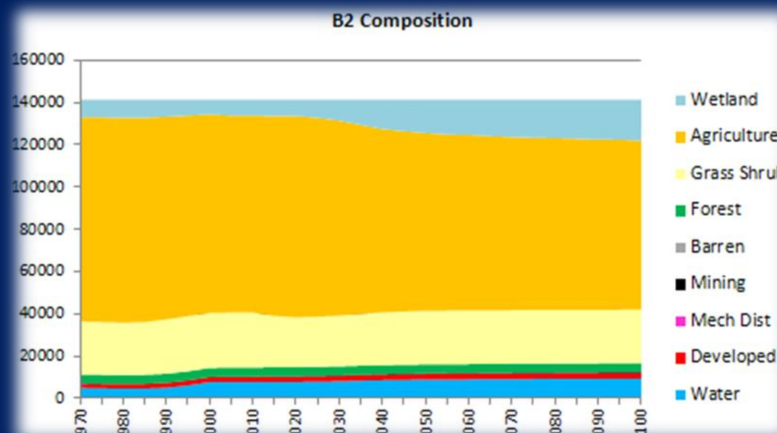




Global

Regional





Environmental

Economics Module Overview

- A bottom-up approach
  - Spatial explicit Individual land use decision-making—(Agricultural profits)
  - Aggregated Market demand and supply—(Equilibrium price)
- Updated land use probability (Economic outputs)
- Input for land use and biogeochemical projections (Environmental Consequences)

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Individual Decision Making

Given

- market conditions (prices, demand)
- Policy instruments (tax, subsidy)

To Optimize

- The best land use choices:
  - Corn ;
  - Soybeans;
  - Wheat;
  - Switchgrass;
  - CRP (potential)
- The best management practices to grow certain crop:
  - Tillage: (conventional; reduced; none tillage)
  - N, P, K inputs
  - Residual harvesting: (stover 30%-70% removal rate)
  - Irrigation
  - Crop rotation (potential)

Individual Decision Making

- Land use alternatives (crops, grass, CRP…)
- Economic profits:
  1) Revenue of JFD i for land use j:

$$R_{ij} = P_j Y_{ij}$$

(Expected crop price: P_j ;Expected yield: Y_{ij})

  2) Cost of JFD i for land use j:

$$C_{ij} = \sum_{k=1}^{K} C_{ijk} = \sum_{k=1}^{K} P_k x_{ijk}$$

(Input price: P_k, Inputs for land use j: x_{ijk})

  3) Individual expected profit of JFD i for alternative j:

$$\pi_{ij} = R_{ij} - C_{ij}$$

Market Equilibrium

Expect supply from the study region

Estimated supply from other regions

↓

Aggregate domestic supply: S(p)

Domestic demand for crops and biofuels: D(p)

↓

Market equilibrium price p*: D(p*)≈S(p*)

Outcome:

- Optimal Land use choices;
- Optimal management practices;
- Crop production profits;
- Environmental consequences

Market equilibrium

- **Expected supply for each crop j:**

$$S_j = \sum_{i=1}^{I} Y_{ij} \Pr_{ij}(\pi_{ij})$$

- **Demand for each crop:** $D_j(P_j)$
- **Equilibrium prices** P_j^***:** $D_j(P_j)$ ≈ $S_j(P_j)$
- **Updated individual profit and land use choices probabilities:**

$$\pi^*_{ij} = R_{ij}(P_j^*) - C_{ij}$$

Economic Optimization

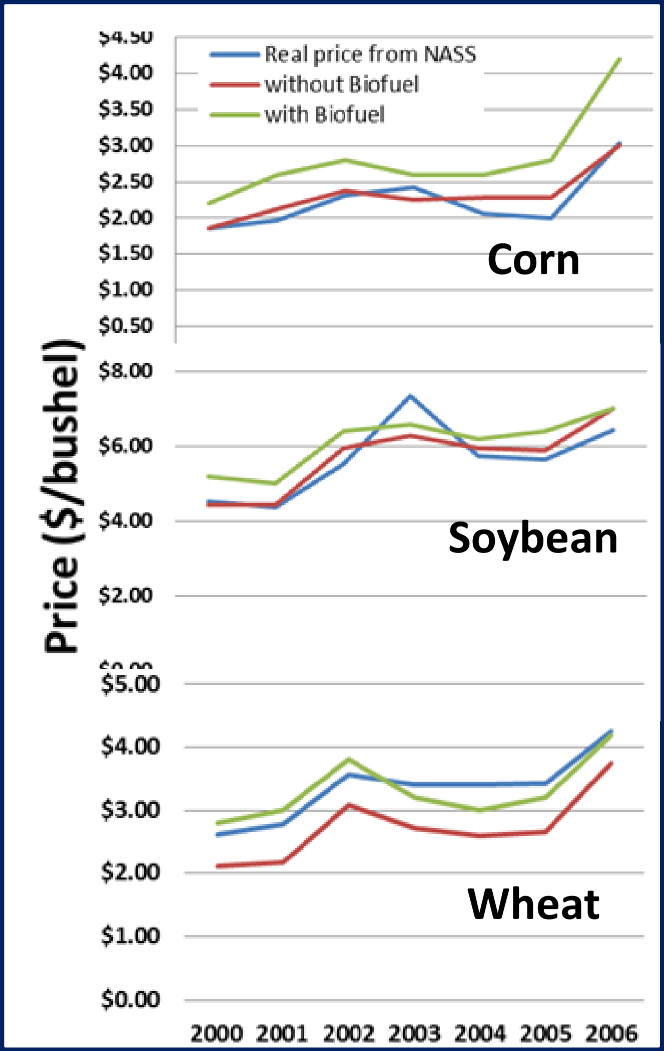
Preliminary model runs used yields and cost information from four counties in Iowa as the experimental study region for 2000 to 2006 time period:

1. Demand: Food and Agricultural Policy Research Institute (FAPRI); will be replaced with scenarios generated from this project
2. Supply: National Agricultural Statistics Service (USDA NASS)
3. Cost: The Farm Financial Management Database (Univ. Minnesota FINBIN)

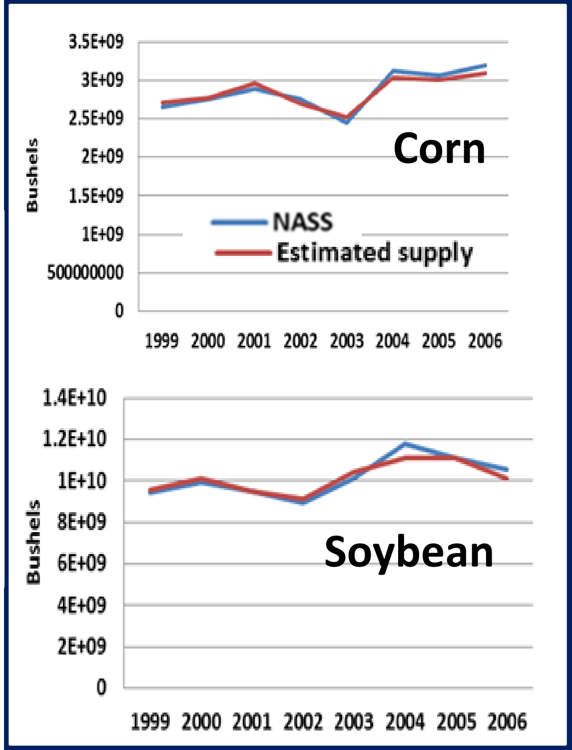
Economic Optimization

- Simulated prices and supplies were close to historical records

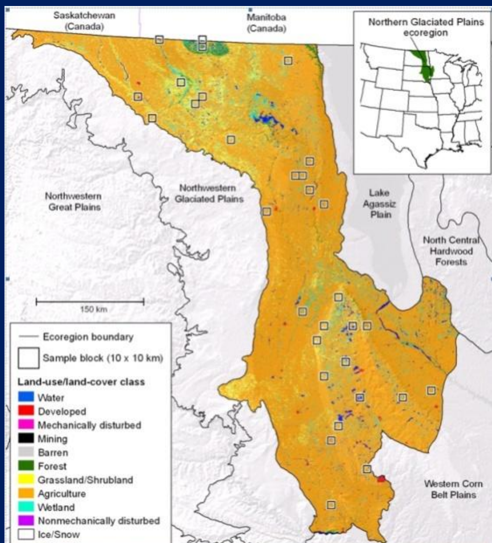
- Biofuel stimulates prices



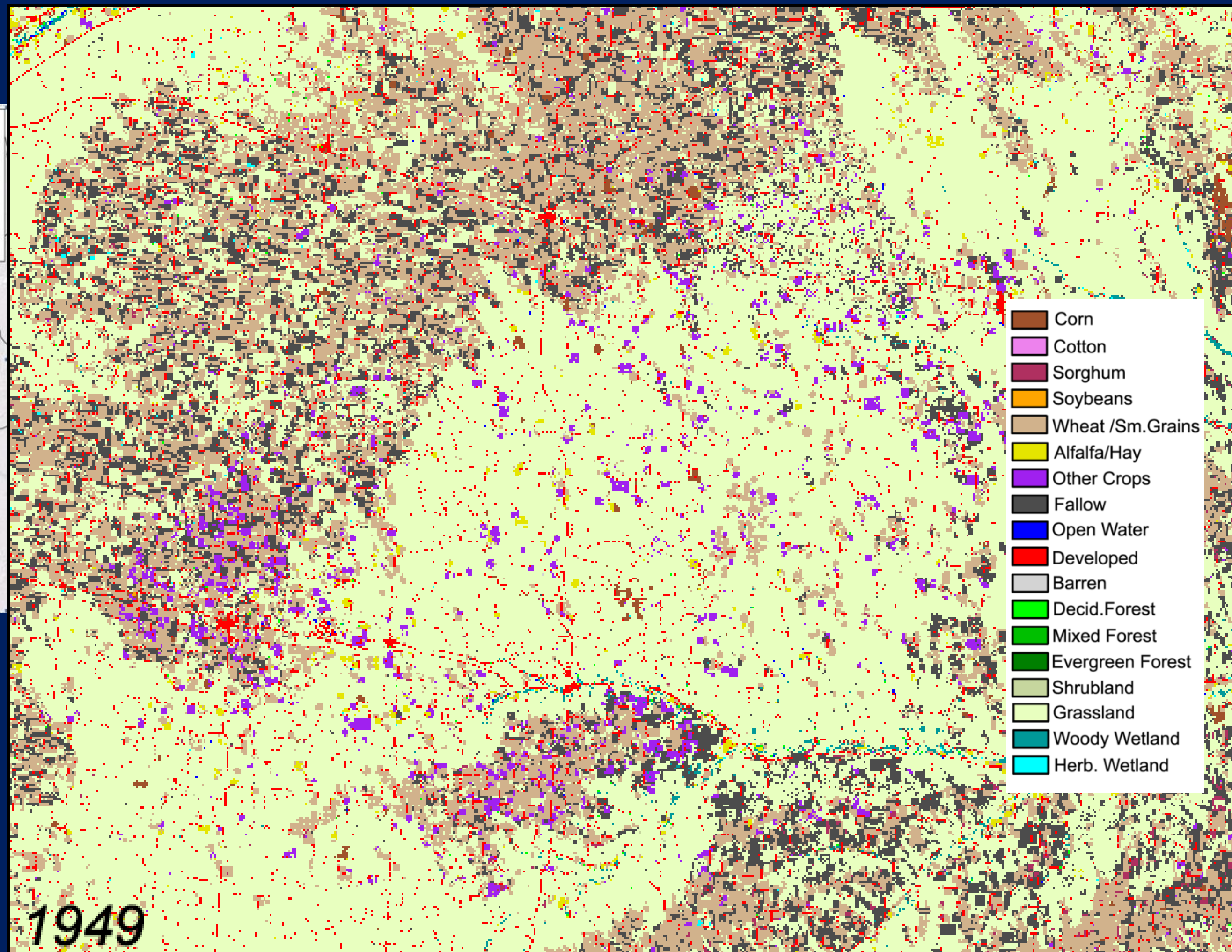
Supply



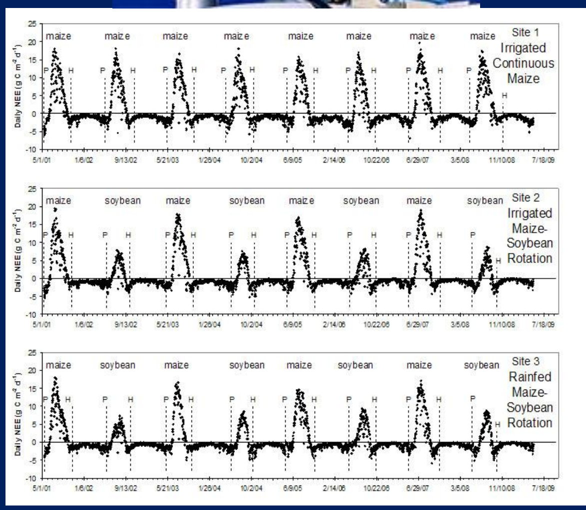
Land Use Patterns (FORE-SCE)

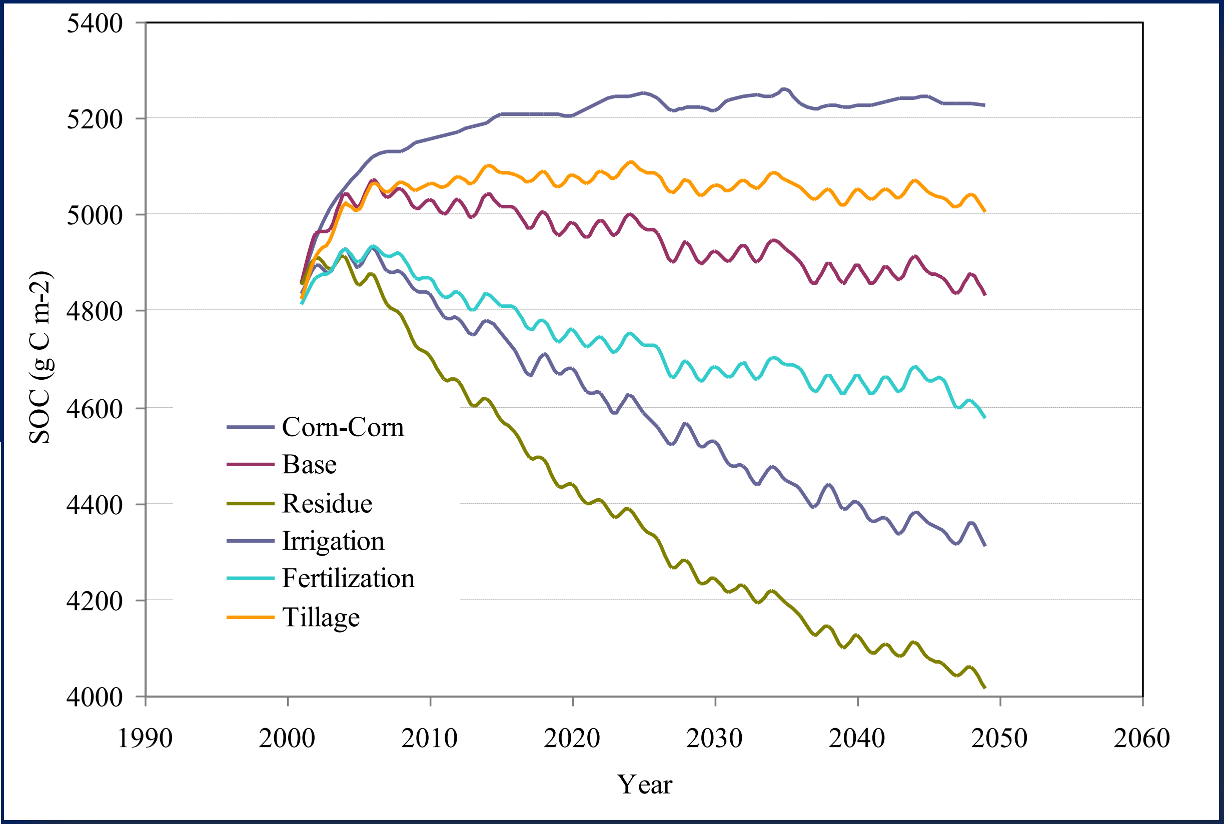


Northern Glaciated Plains

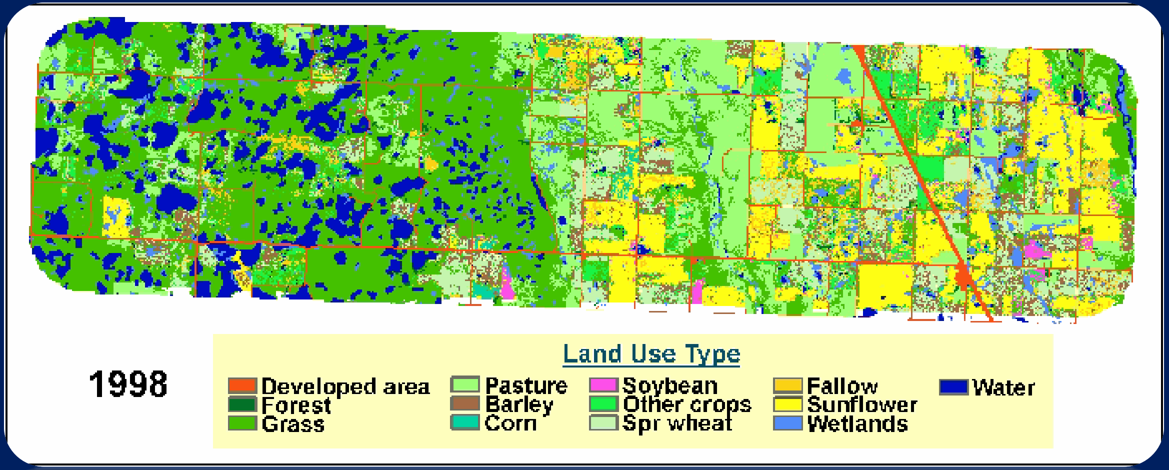


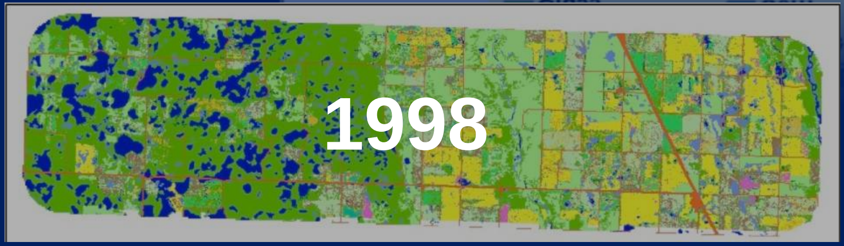
Impacts on Biogeochemistry

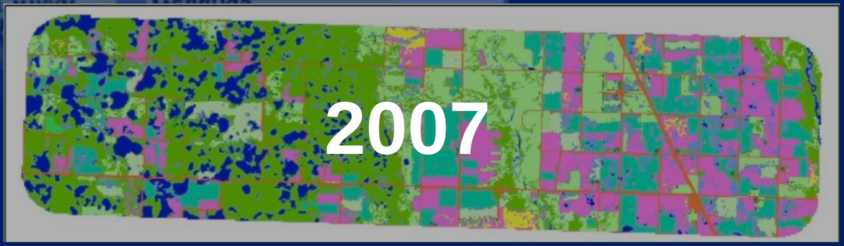


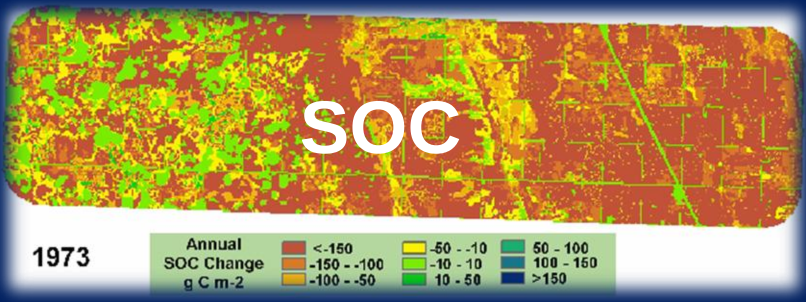


Impact on Biogeochemistry (SOC)









Impacts on Water (SWAT)

Land Use Scenario	Description	% of the basin area†
A	Reference scenario (0% of Corn stover removal rate)	-
B	40% of corn stover removal rate on all corn fields	40
C	80% of corn stover removal rate on all corn fields	40
D	100% of corn stover removal rate on all corn fields	40
E	10% of corn fields changed to switchgrass	4
F	10% of corn fields changed to miscanthus	4
G	100% of native grass changed to switchgrass	5.7
H	100% of native grass changed to miscanthus	5.7

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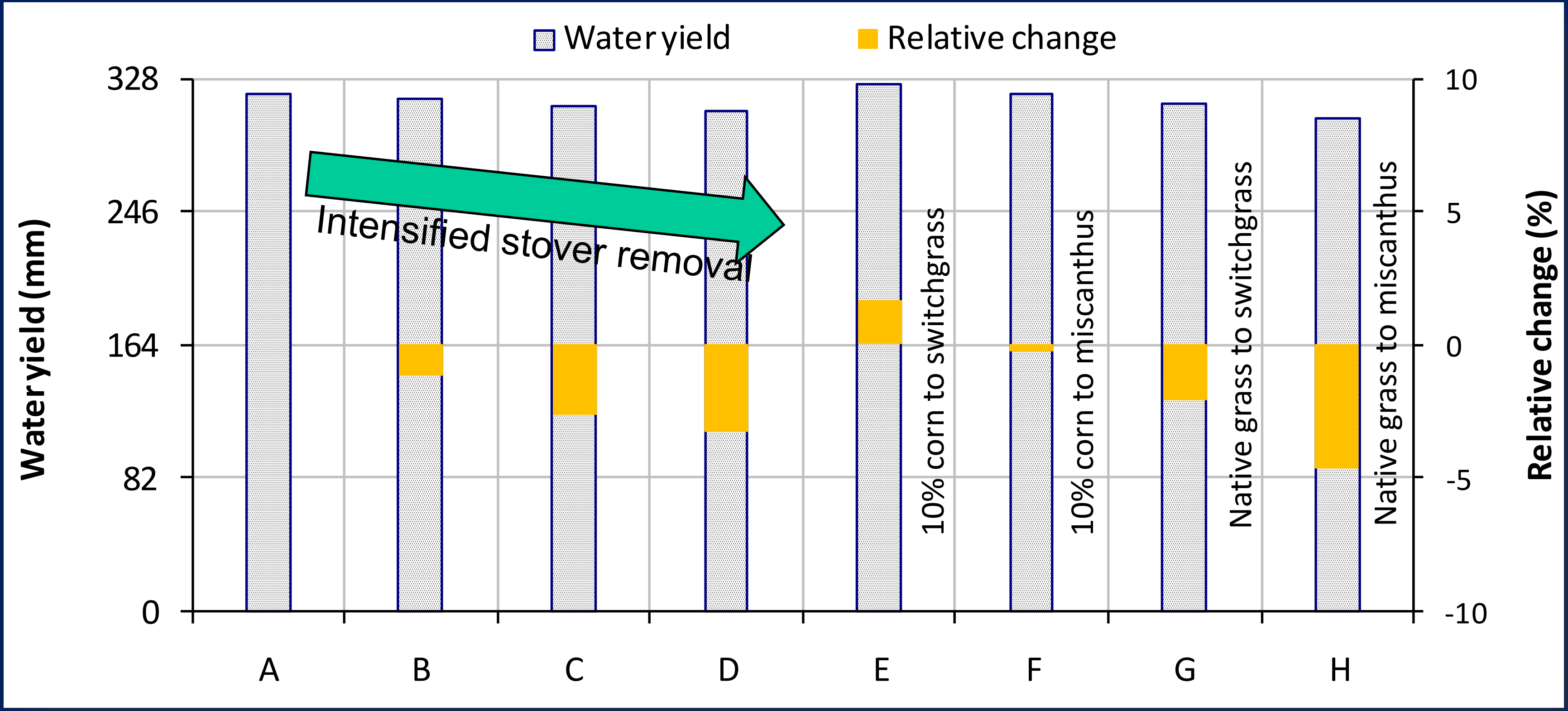
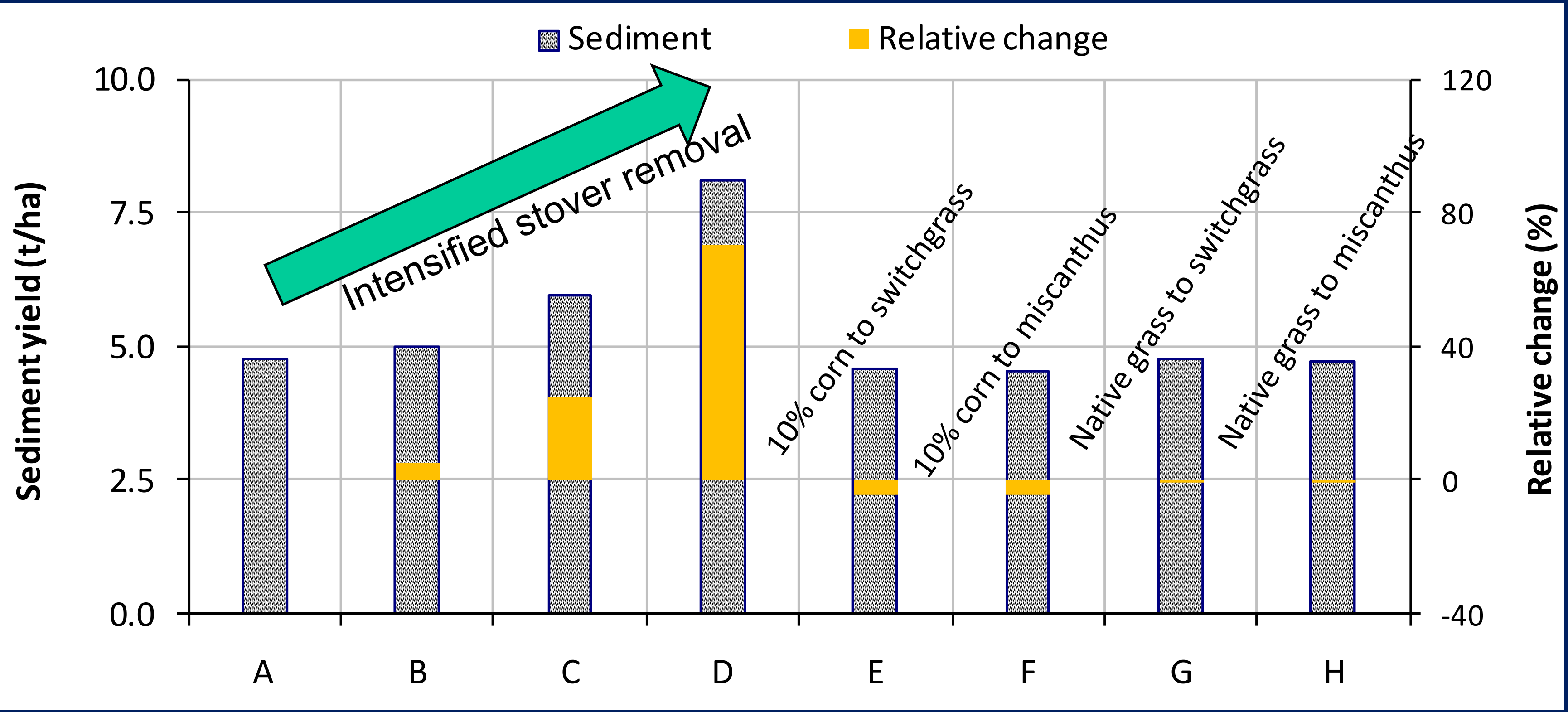
Impacts on Water Yield



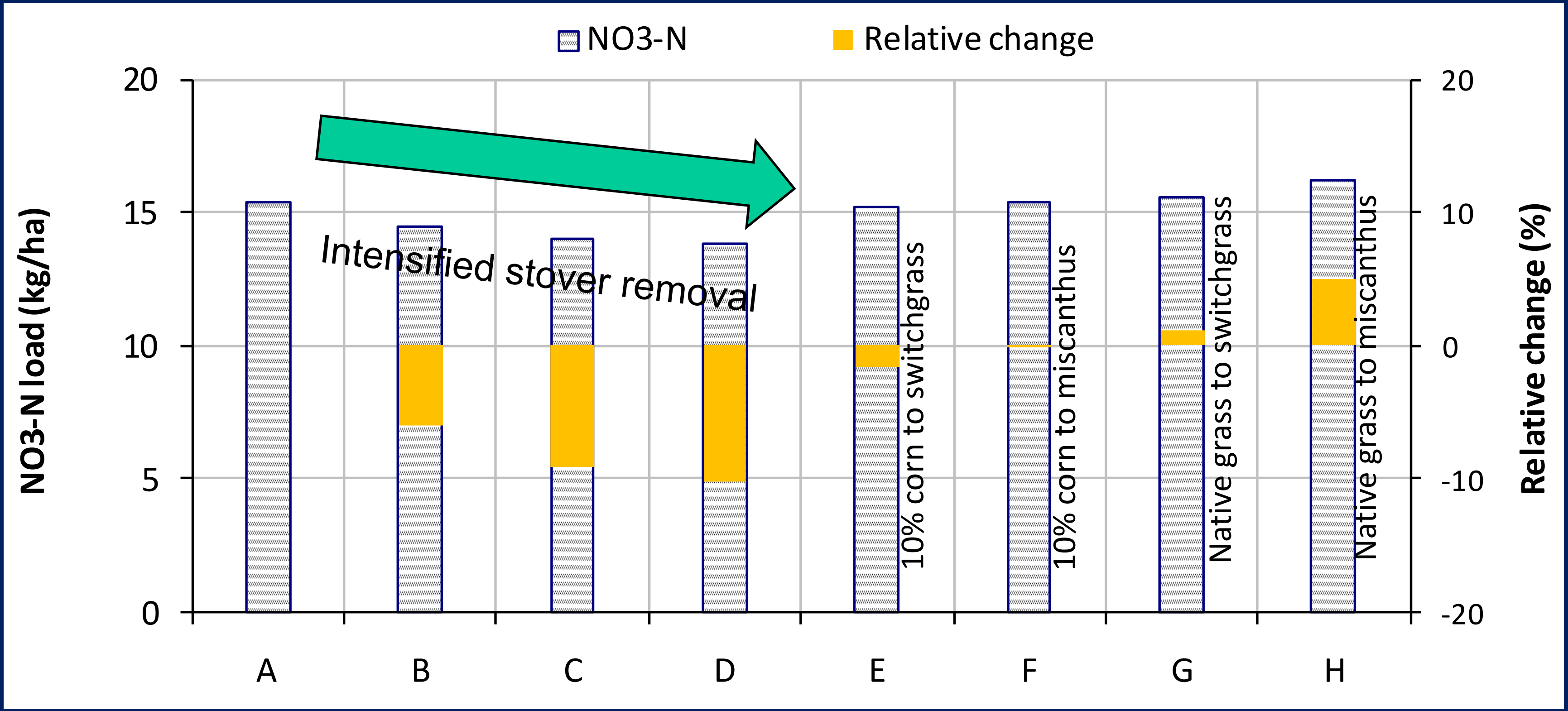
Increased corn stover removal led to increased soil evaporation

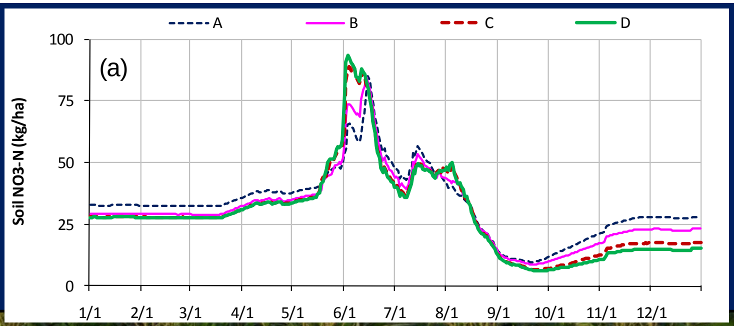
Land cover change from grassland to bioenergy crops increased transpiration and evaporation

Impacts on Soil Erosion



Impacts on NO_3-N load





Under the higher corn stover removal rate, soil NO3-N concentration is higher in the growing season due to fertilization and lower in the non-growing season

Summary

- Pieces are tuned and ready, …., and integration is underway.
- Biofuel feedstock supply is just one of the many ecosystem services that lands can provide.
- Biofuel production is intrinsically in competition for land resources with other land uses.
- Estimating biofuel feedstock supply (or any other land-use related ecosystem services) is an art (science) of balancing various needs (trade-offs).
- Integrated multi-scale interdisciplinary modeling systems are required for future land use projections to inform policy makers and land managers.
- Applications to other regions, national and global scales