An Integrated Biogeochemical, Biophysical, and Economic Analysis of Bioenergy Crops

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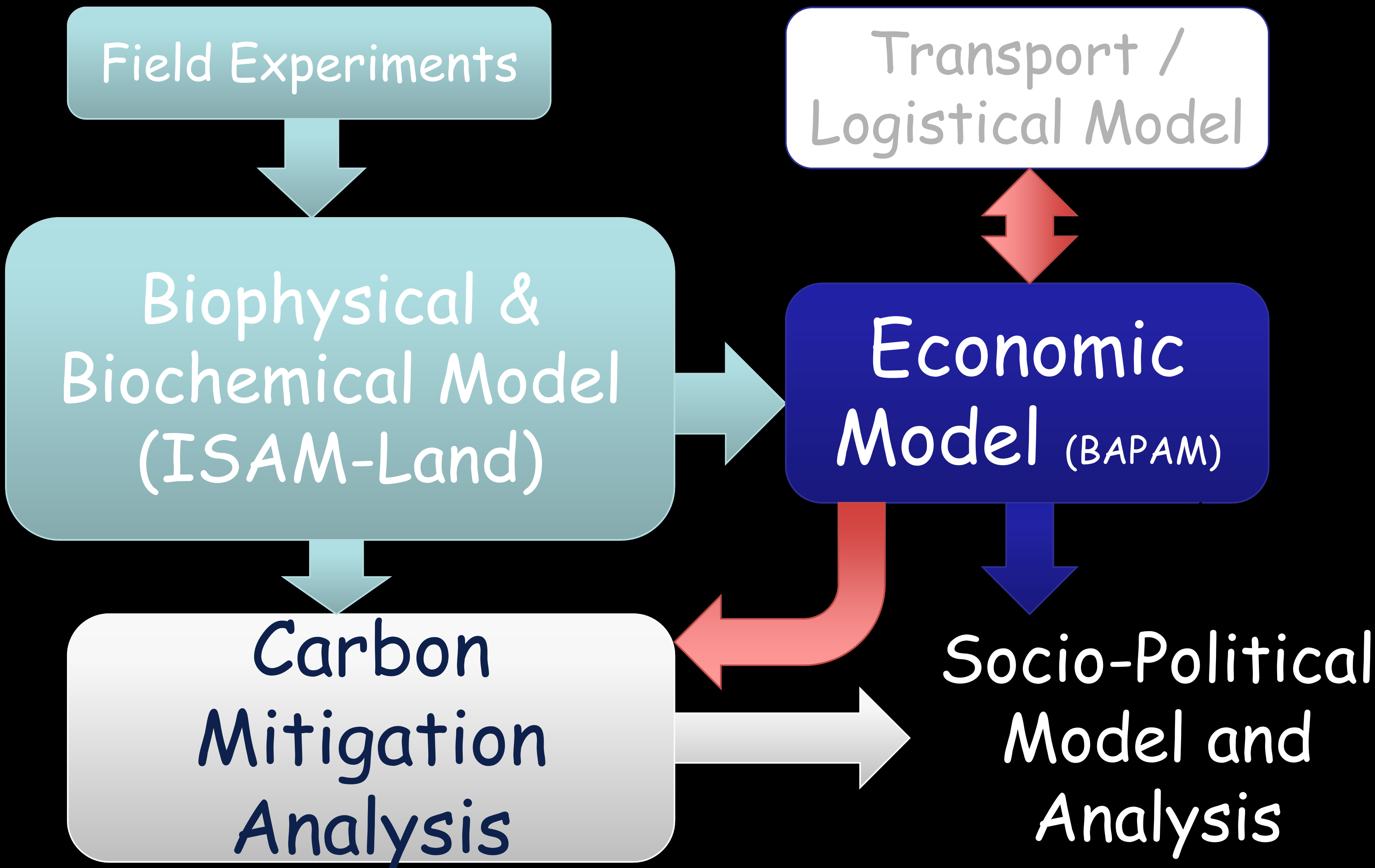
Study Objectives

- Examine the biophysical (in terms of yields) and economic potential (in terms of costs) of producing bioenergy crops
  - Determines spatial variability of this potential in the US.
- Integrate biophysical model of bioenergy crop yields with economic analysis of the costs of bioenergy crops
  - Assess how the yields and costs differ across bioenergy crops and across different locations and how they are related to each other.

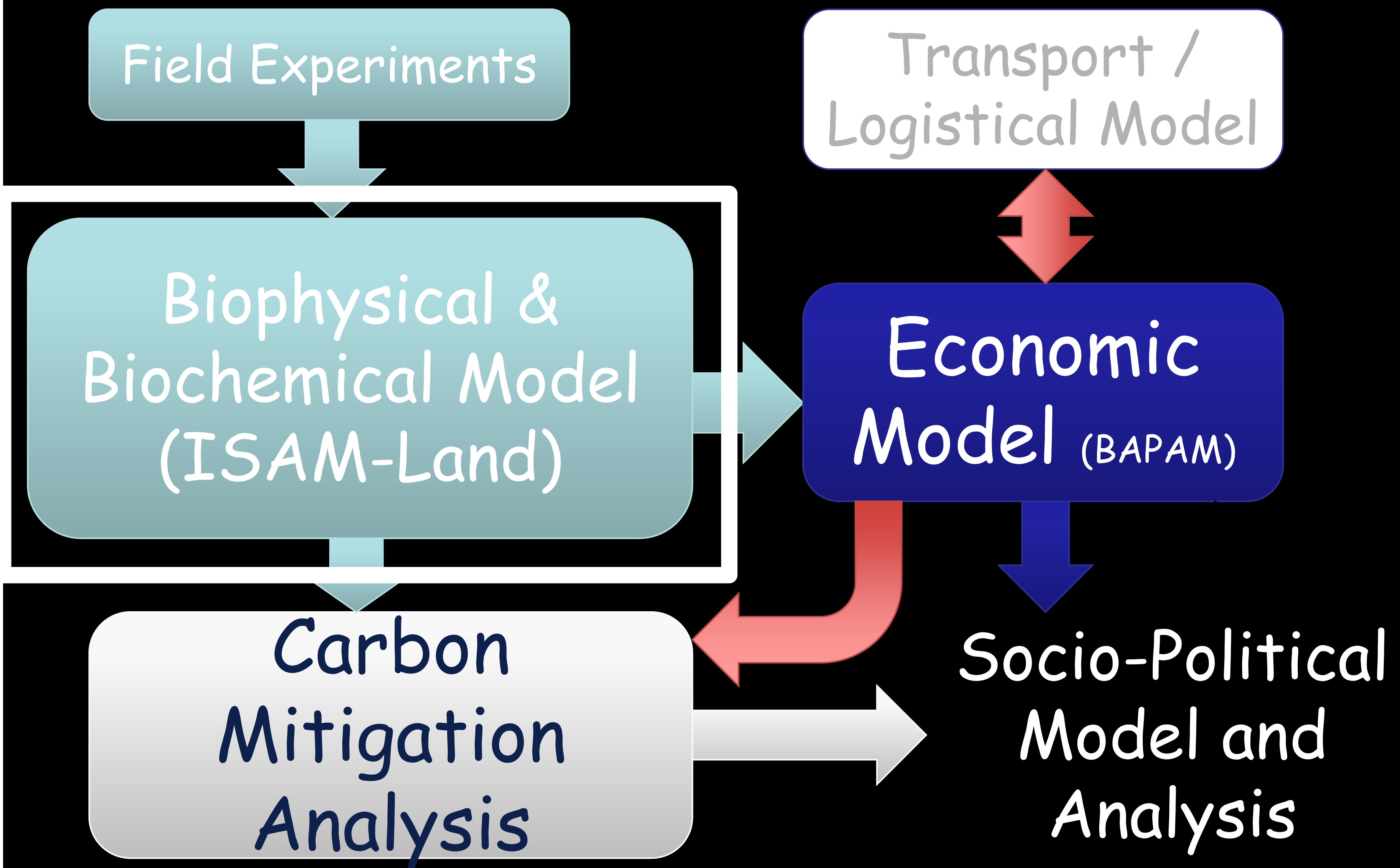
Bioenergy Crops Considered

This Presentation Focuses on Miscanthus

Modeling Framework



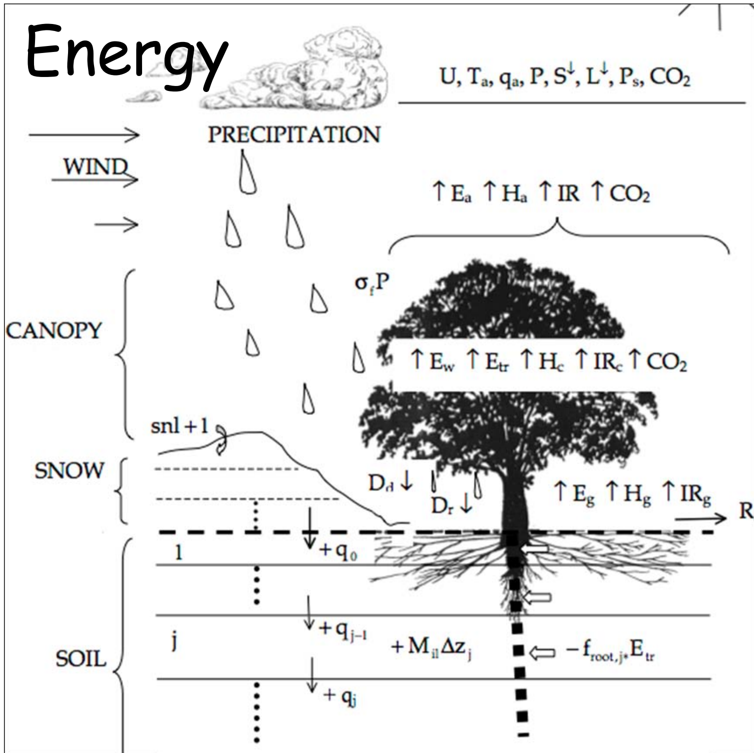
Modeling Framework

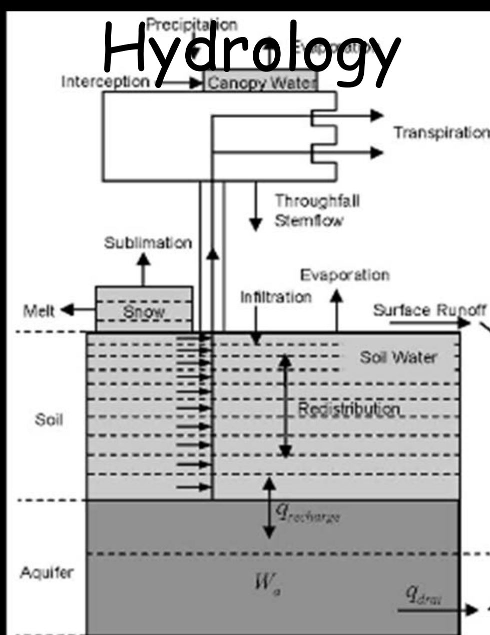


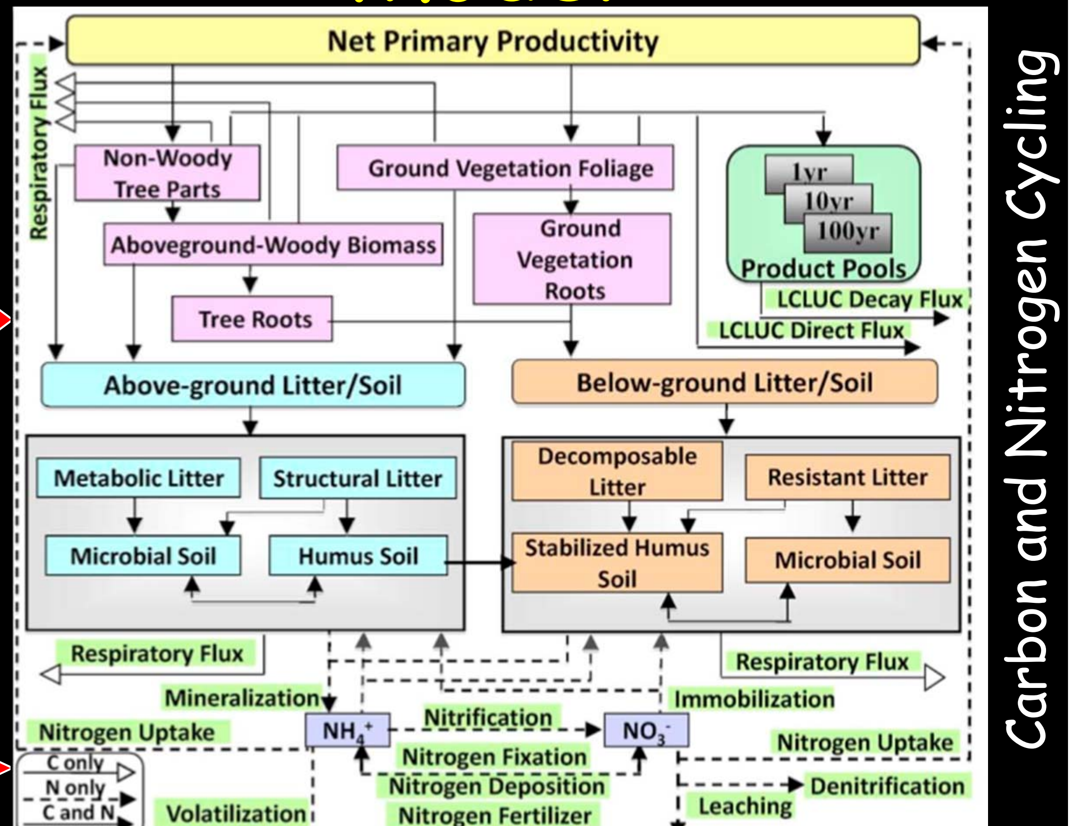
ISAM Land Model

- Energy processes
  - Canopy temperature, photosynthesis and stomatal conductance based on two-big-leaf (sunlit and shaded) scheme
  - two-stream approximation model of radiation transfer
- Soil/snow hydrology
  - 15 layers for soil and up to 5 layers for snow
- Biogeochemistry
  - Carbon-Nitrogen cycling in soils and vegetation

ISAM-Land-Surface Model

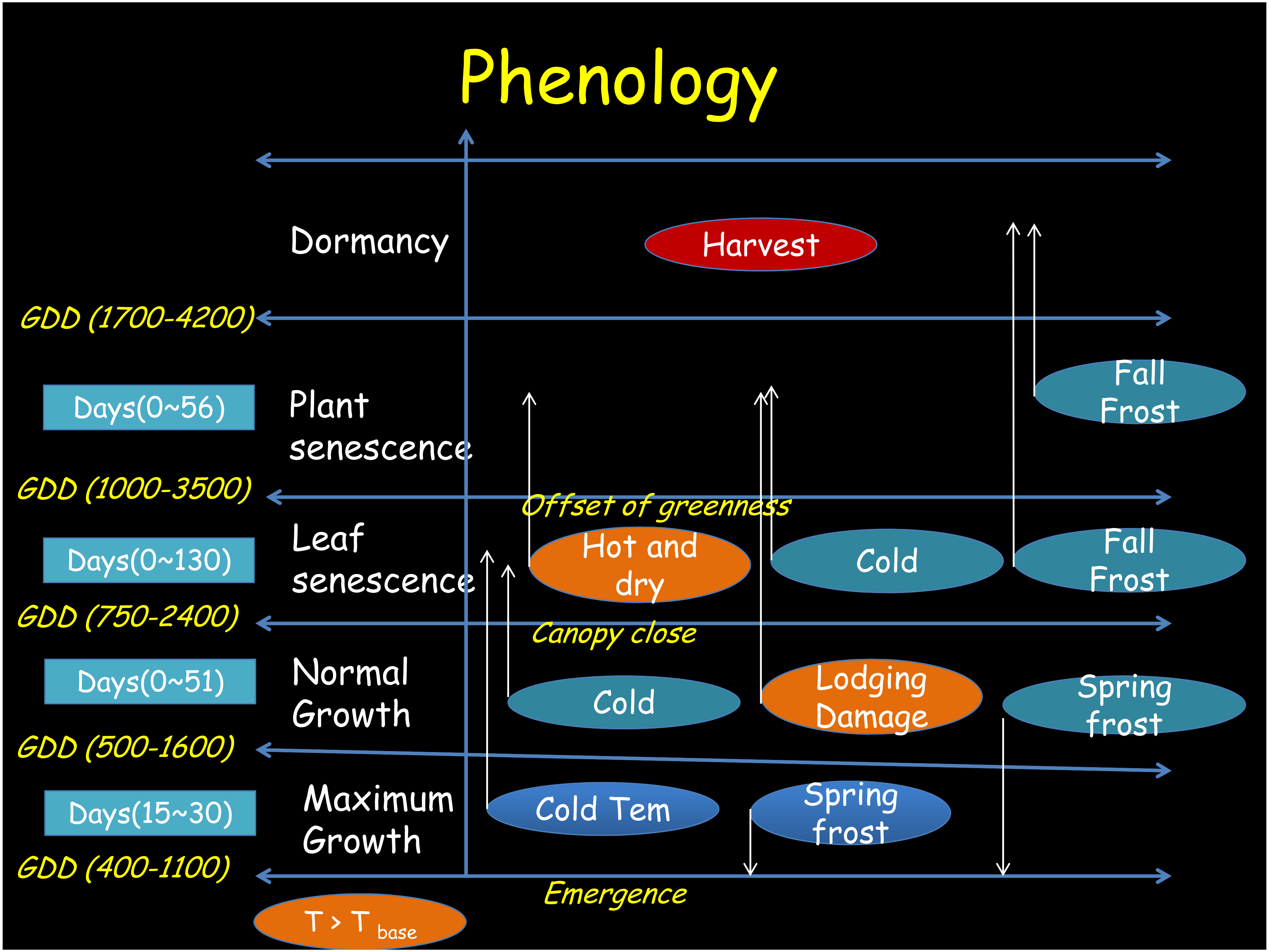




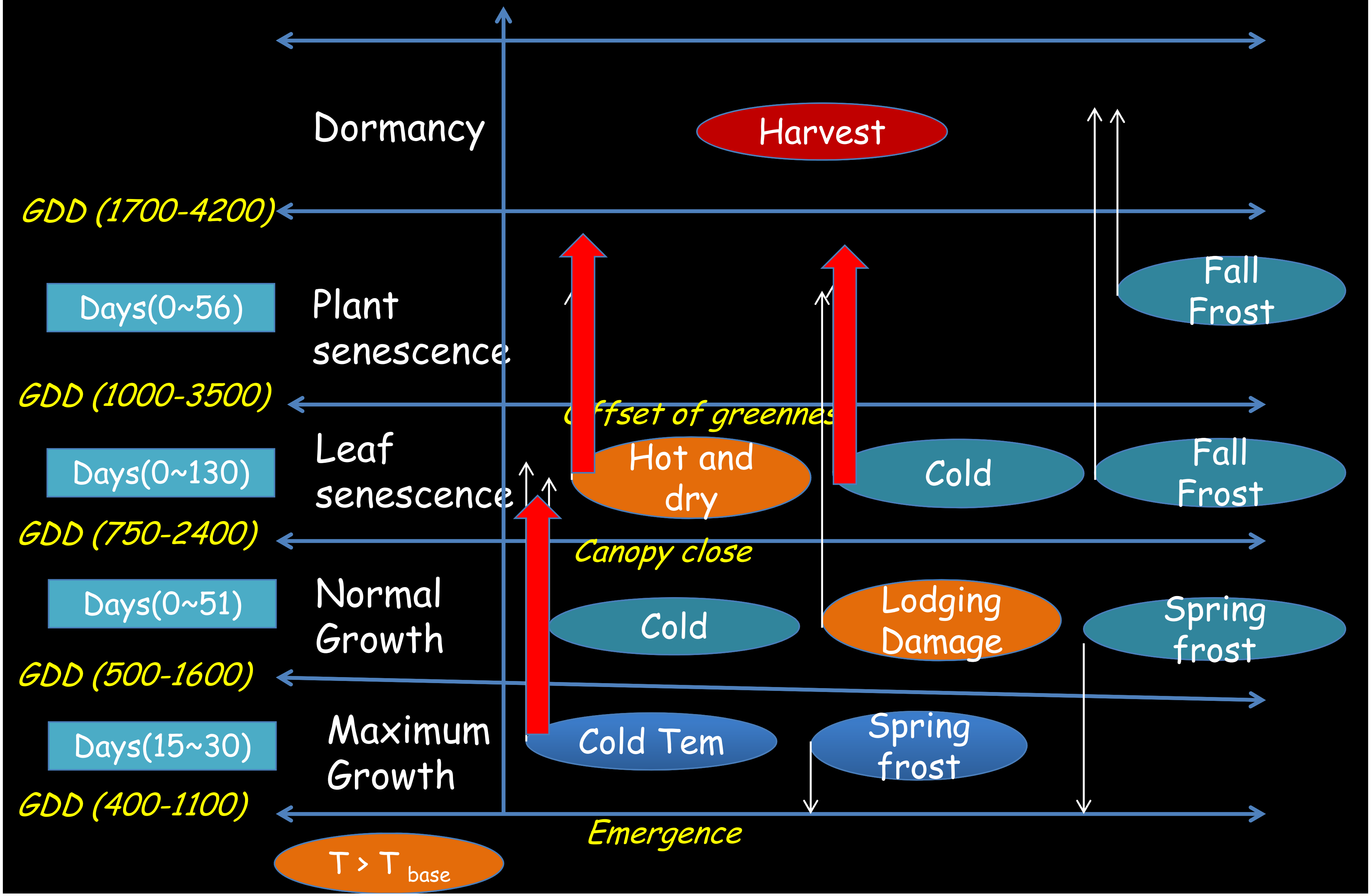


Calculate fluxes of carbon, nitrogen, energy, water, and the dynamical processes that alter these fluxes

- 18 Biome types 0.5 x 0.5 degree resolution
- 30 minutes temporal scale
- Season-to-interannual variability (penology)


Phenology
Dormancy
Harvest
GDD (1700-4200)
Days(0~56)
Plant senescence
Fall Frost
GDD (1000-3500)
Offset of greenness
Days(0~130)
Leaf senescence
Hot and dry
Cold
Fall Frost
GDD (750-2400)
Canopy close
Days(0~51)
Normal Growth
Cold
Lodging Damage
Spring frost
GDD (500-1600)
Days(15~30)
Maximum Growth
Cold Tem
Spring frost
GDD (400-1100)
Emergence
T > T base

Phenology



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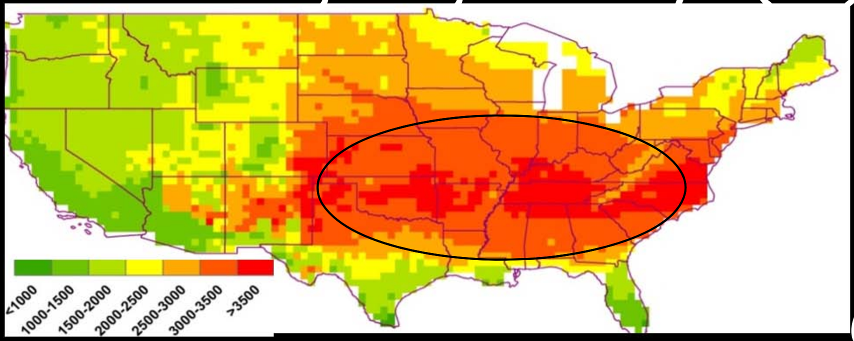
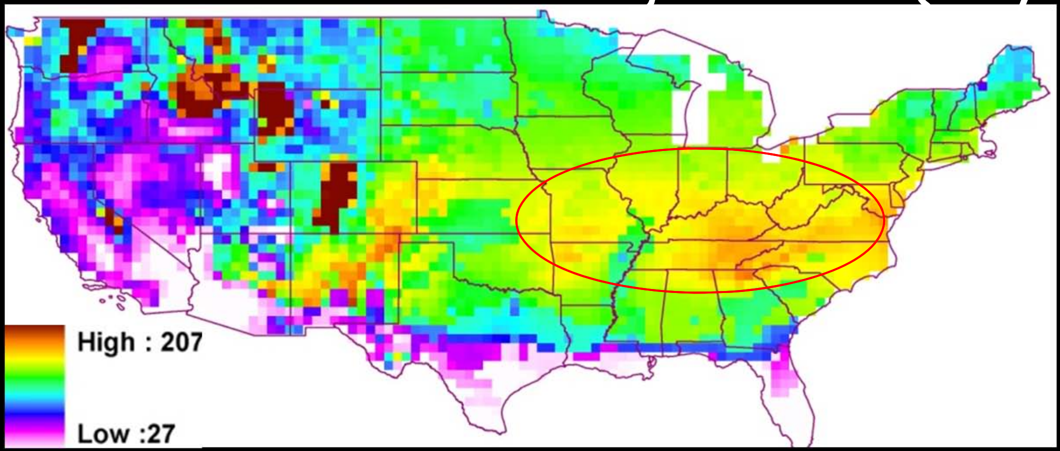
Average for the Period 2006-2010

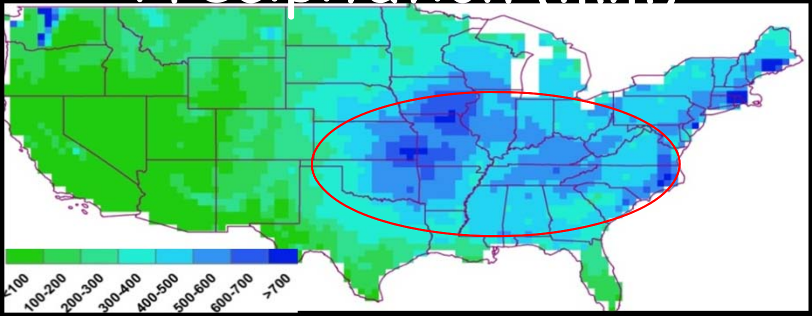
Growing Degree Days (^{o}C)



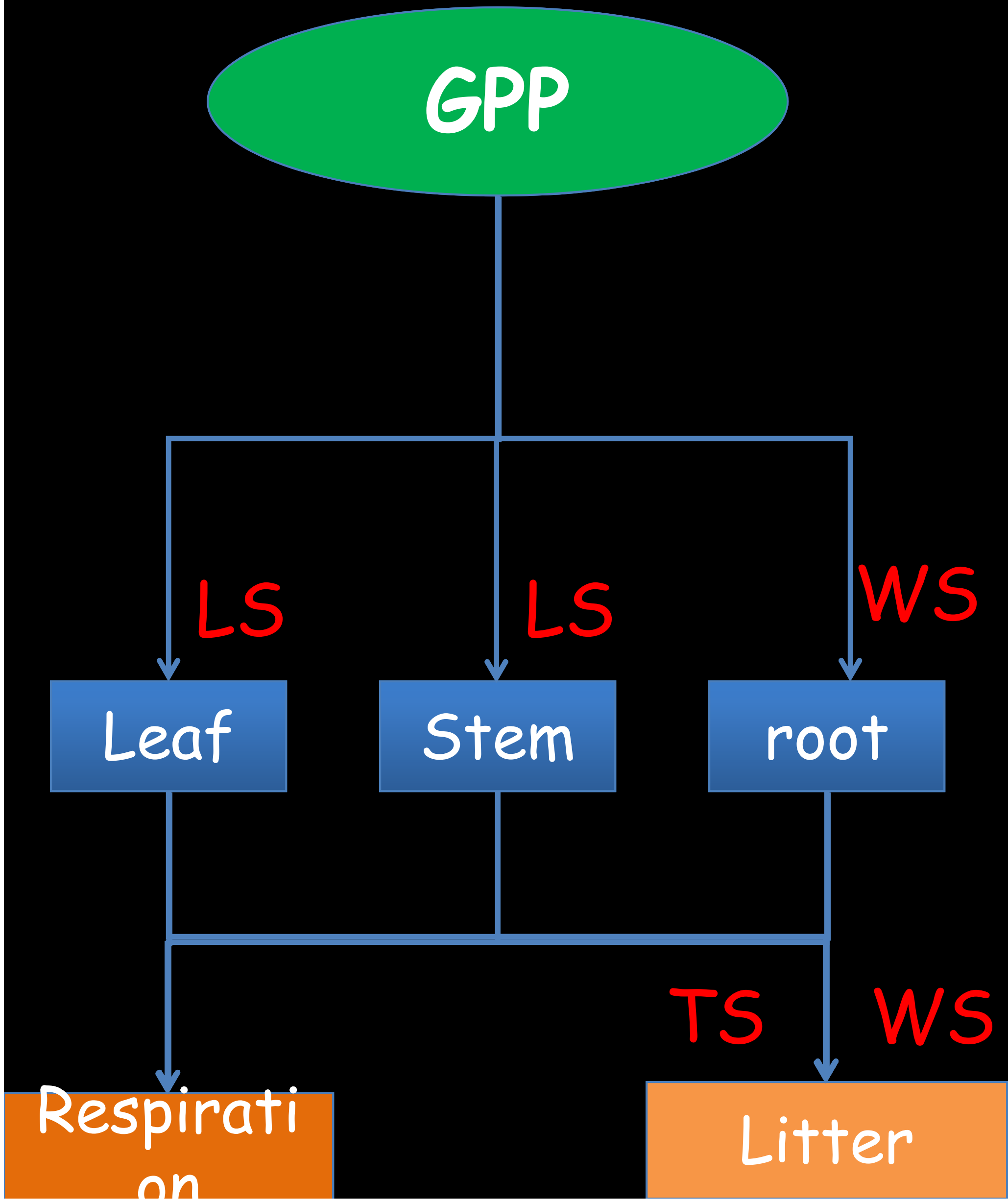
Growing Season (Days)



Precipitation (mm)



Dynamic Carbon Allocation



- Soil water stress (WS) - Advantageous allocation to roots
- Light stress (LS) - Advantageous allocation to leaves and stem
- Water stress (WS) and Temperature stress (TS) - Advantageous leaf loss to litter

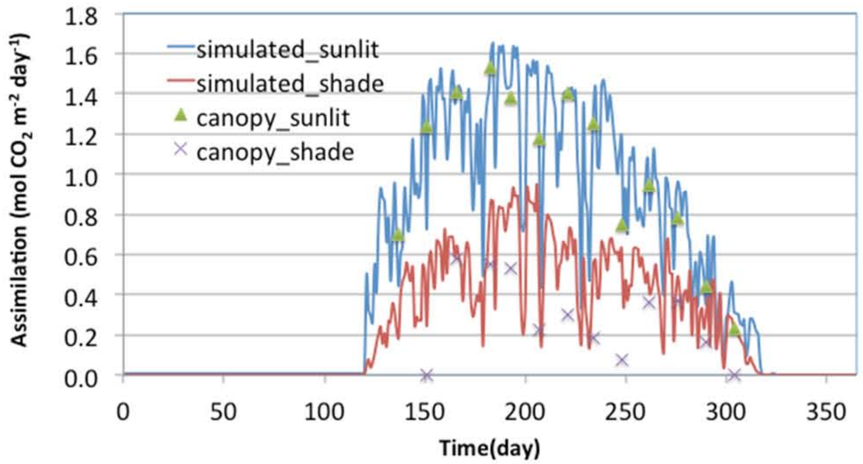
Source: Arora and Boer (2005)

Model Evaluation

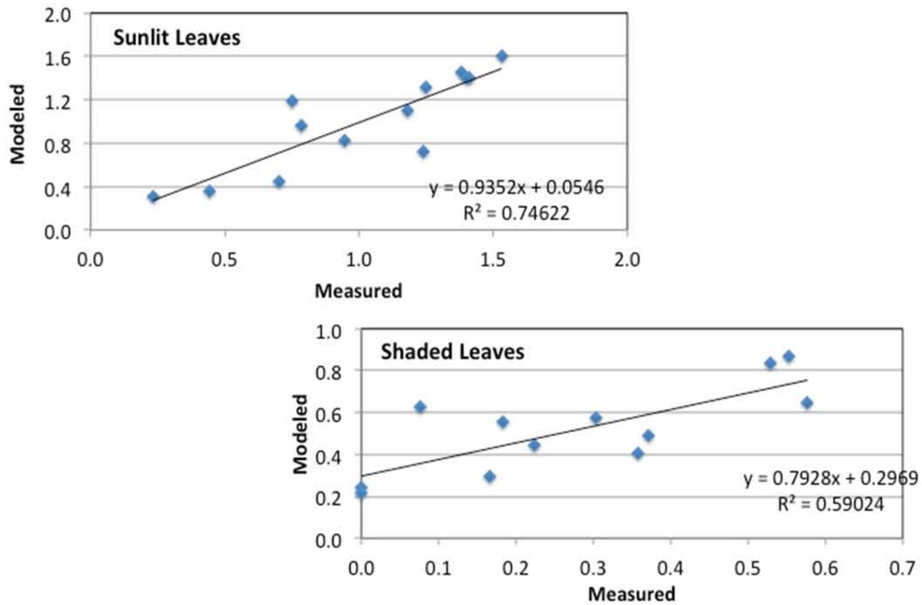
- Evaluated ISAM model parameters based on the measurements of different variables at Urbana, IL site:
  - Leaf Area Index (LAI)
  - Carbon assimilation rates (sunlit and shaded)
  - Above ground biomass
  - Evapotranspiration
  - Soil water content
  - others

Assimilation Rates – Modeled vs. Measured

Daily Carbon Assimilation Rates per Unit Canopy Area (2007)



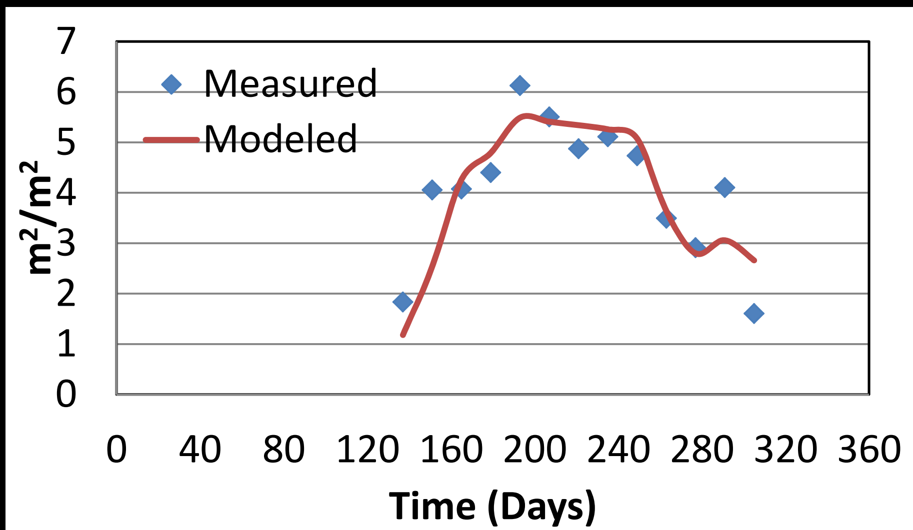
Modeled vs. Measured Daily Carbon Assimilation Rates per Unit Canopy Area (2007)

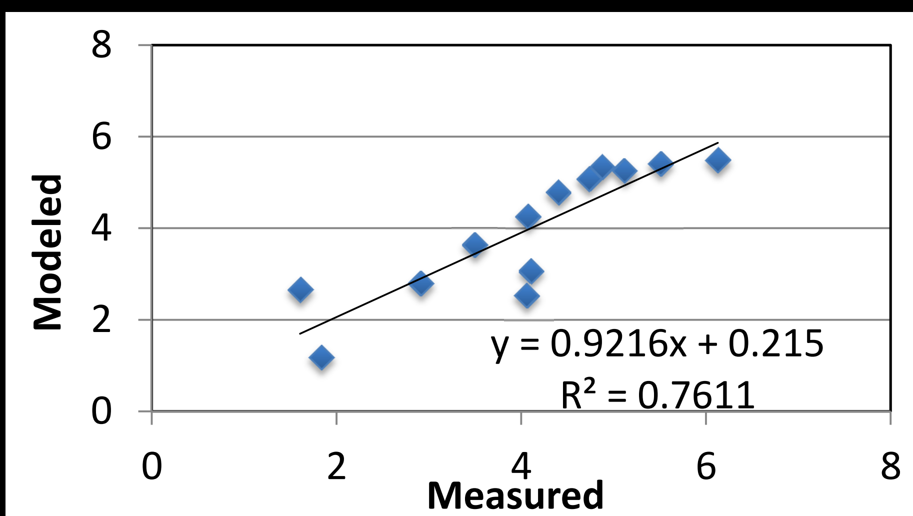


Field data and validated parameter sources:
Dohleman and Long (2009)
Dohleman et al. (2009)
Bonan et al. (2011)

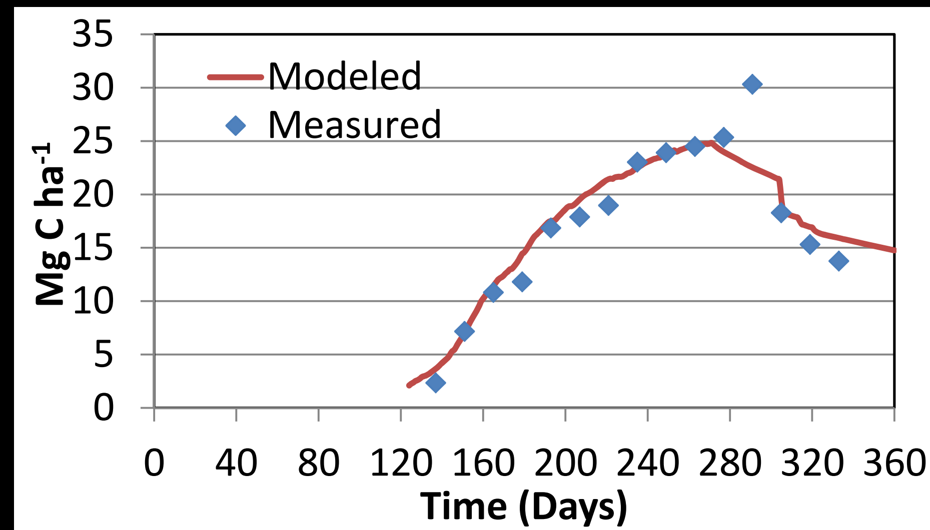
Modeled vs. Measured LAI & AG C for Urbana Site (2007)

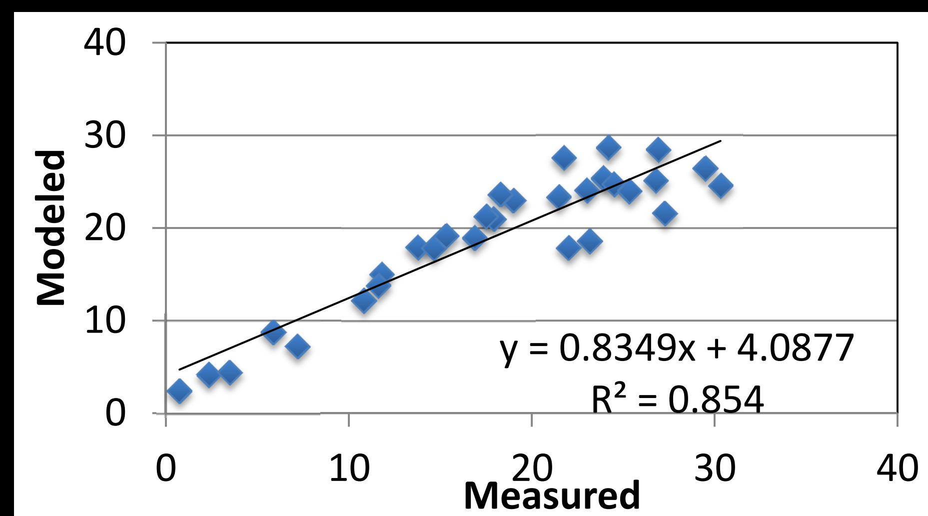
LAI





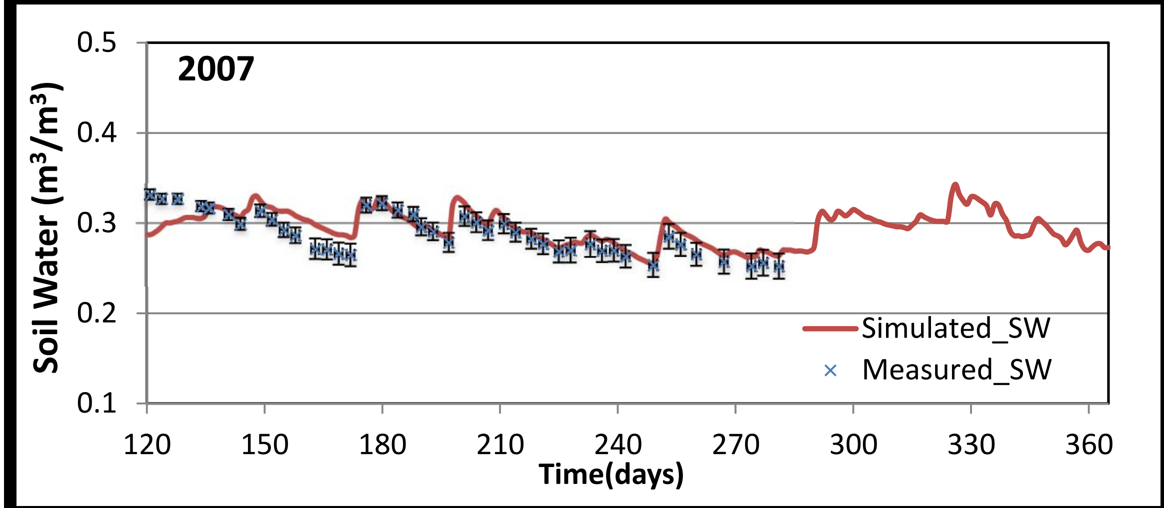
Above Ground Carbon

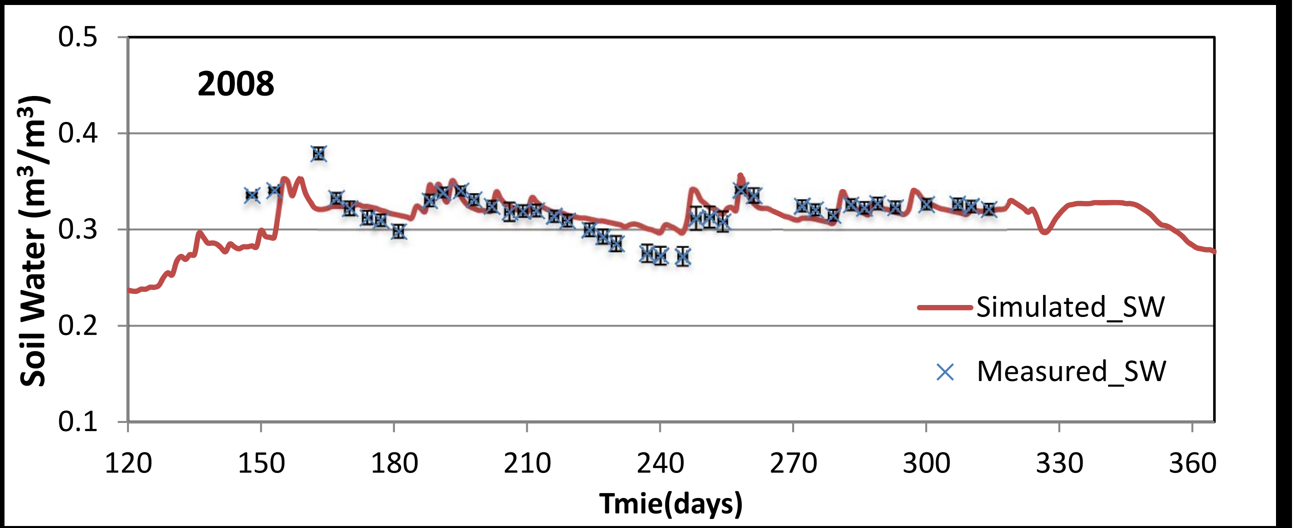




Observed data sources: Dohleman and Long (2009

Modeled vs. Measured Soil Water Content (0-90 cm) in Miscanthus

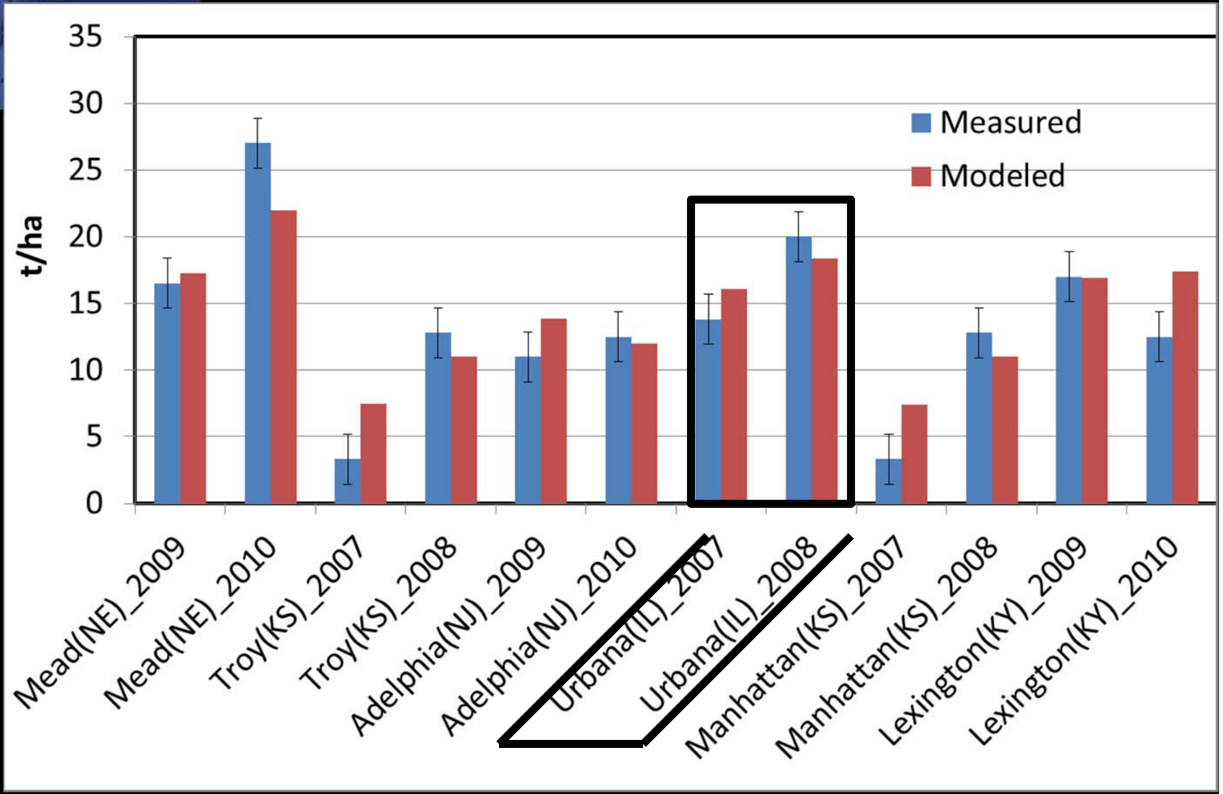




Observed data sources: McIsaac et al (2010)

Model Validation for Miscanthus Harvest Yield (t/ha)

Model is calibrated for Urbana, IL site and validated for 5 other sites (NE, KS, NJ,KY)



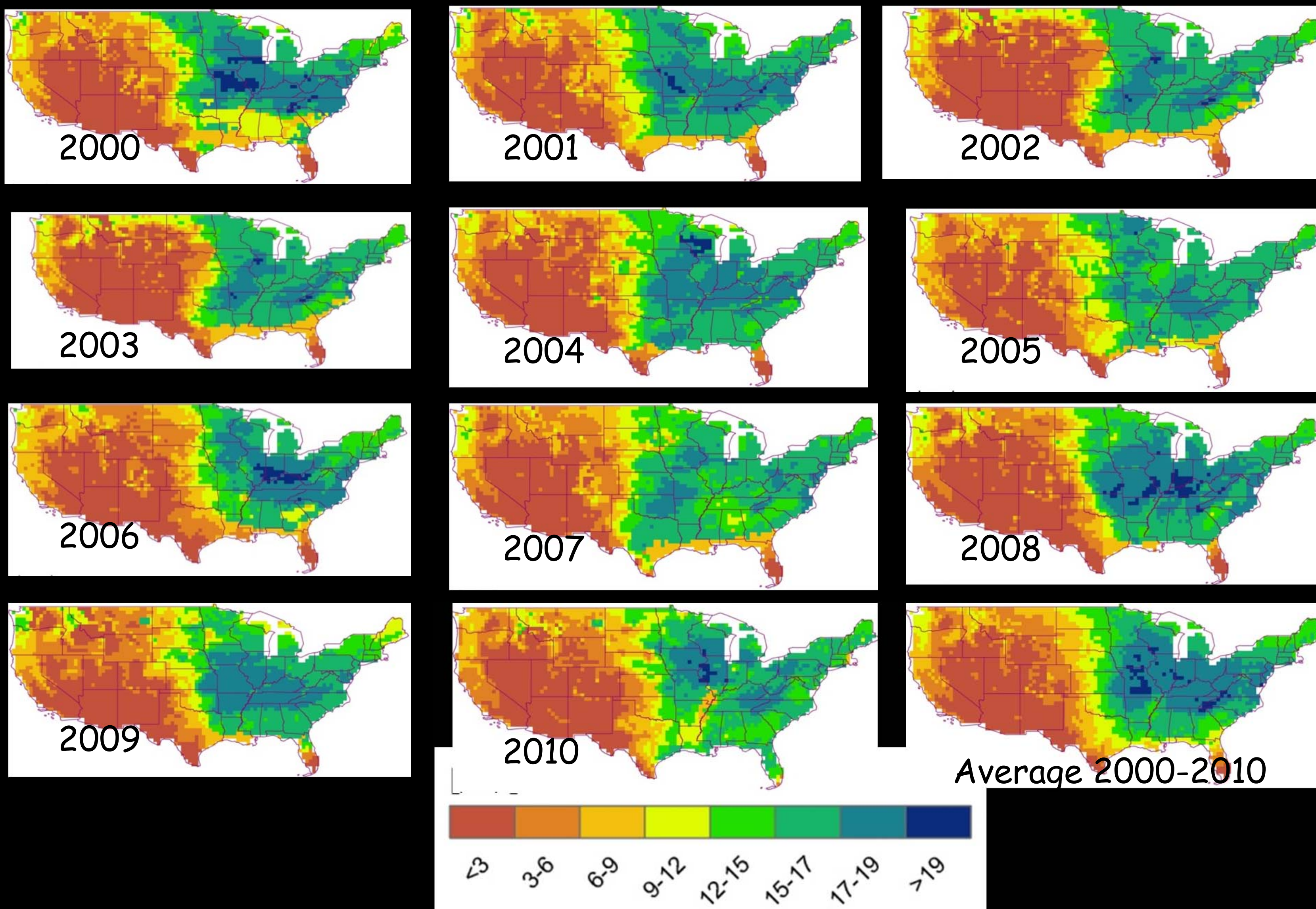
<u>Source of Data</u>:
Sun Grant/DOE Regional Biomass Feedstock Partnership
Maughan, M. (http://bioenergyfeedstocks.igb.uiuc.edu/ppt/2011/matt_maughan.pdf)
Dohleman and Long (2009) ; Propheteret al., 2010

Estimated Miscanthus Yield in the US

- ISAM Land Model
- Projects seasonal biomass (before and after senescence) for the time period 2000-2010
- Input data based on NARR Reanalysis (surface temperature, precipitation, wind, pressure, specific humidity and incoming solar radiation)

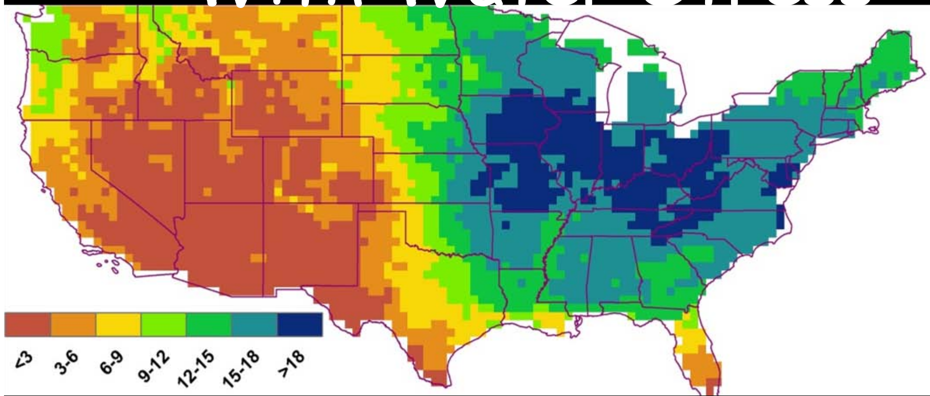
Modeled Miscanthus Yield (t/ha)

Yearly and Average for the Period 2000-2010

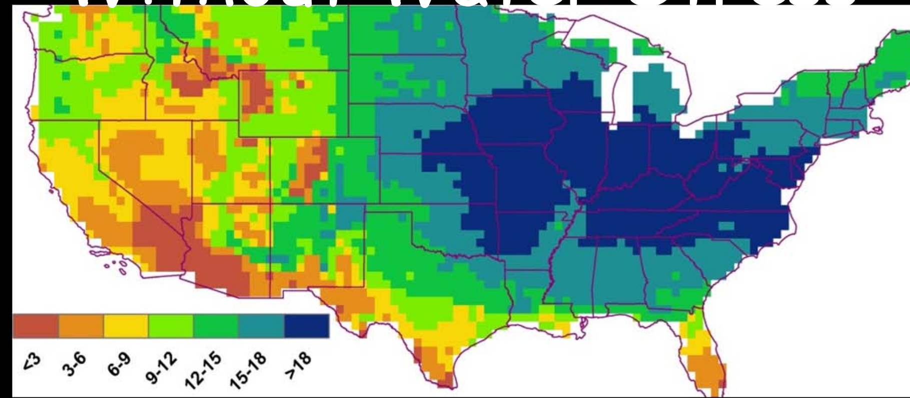


Average (2006-2010) Miscanthus Yield (t/ha) With and Without Water Stress

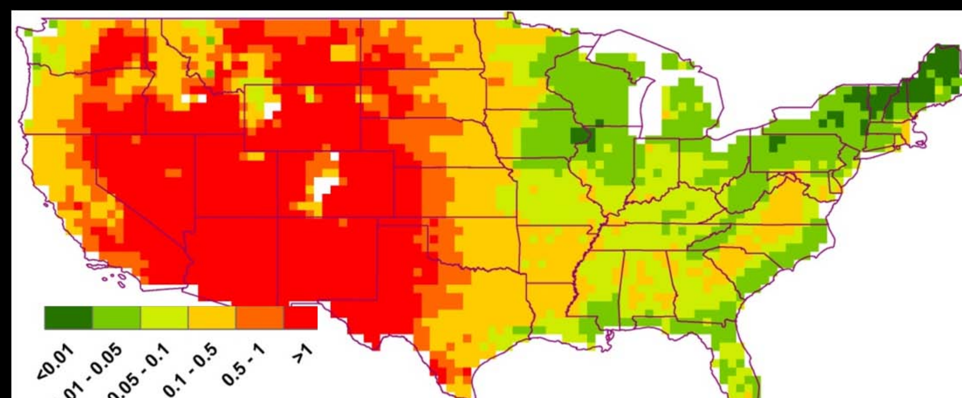
With Water Stress



Without Water Stress

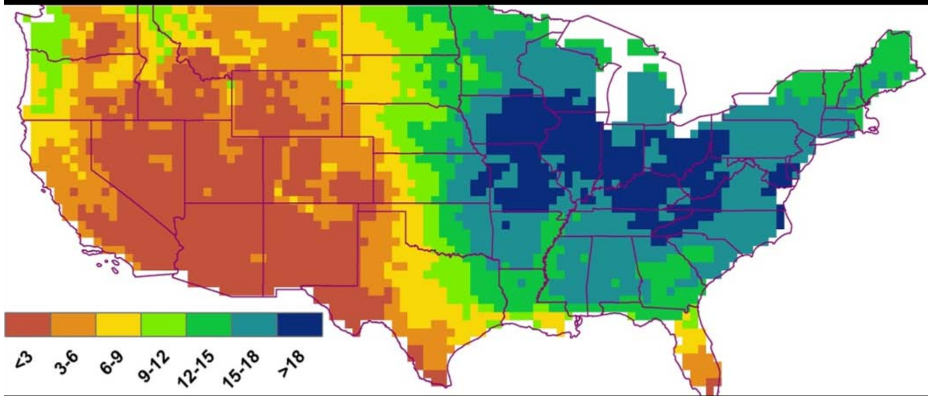


Fraction of Yield Change Due to Water Stress

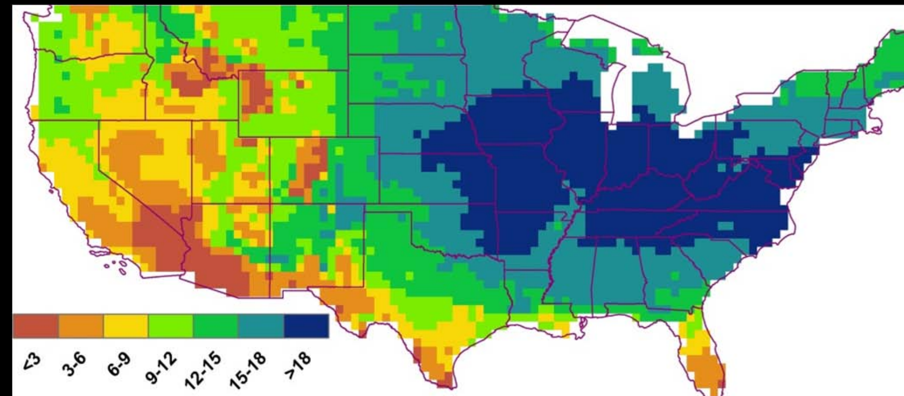


Average (2006-2010) Miscanthus Yield (t/ha) With and Without Water Stress

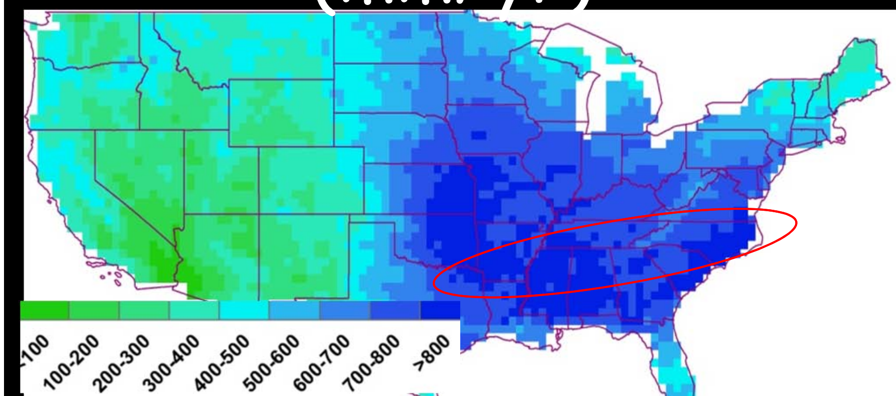
With Temp. & Water Stresses



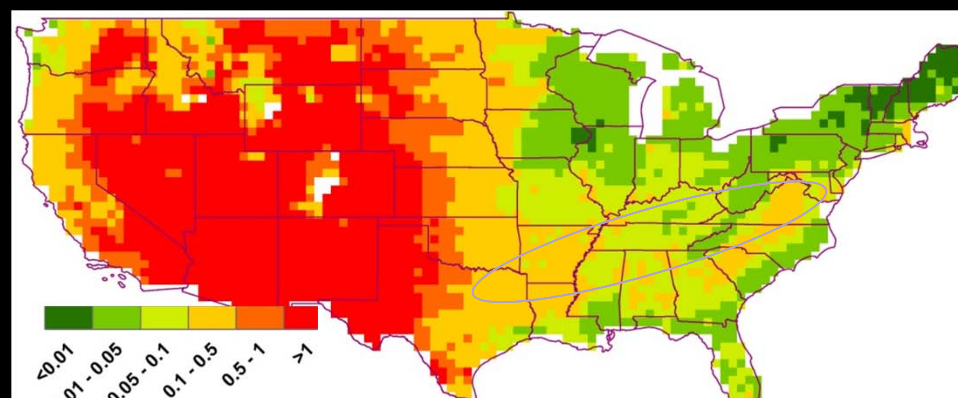
With Temp. & Without Water Stress



Evapotranspiration (mm/yr)

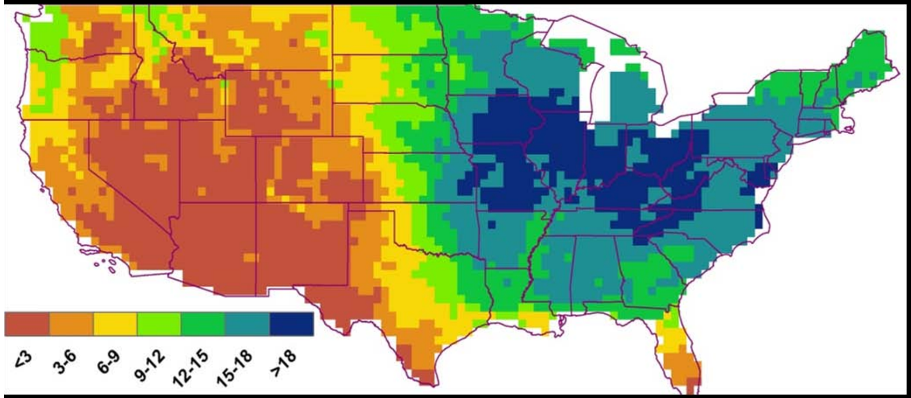


Fraction Yield Change Due to Water Stress

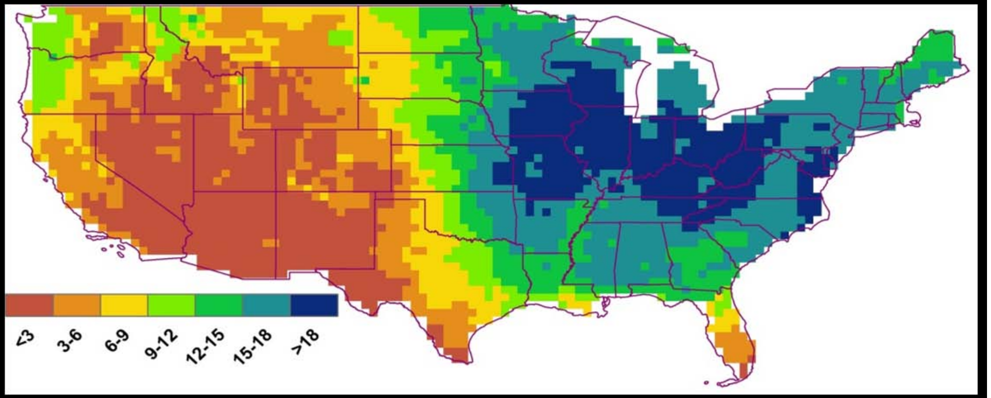


Average (2006-2010) Miscanthus Yield (t/ha) With and Without Temperature Stress

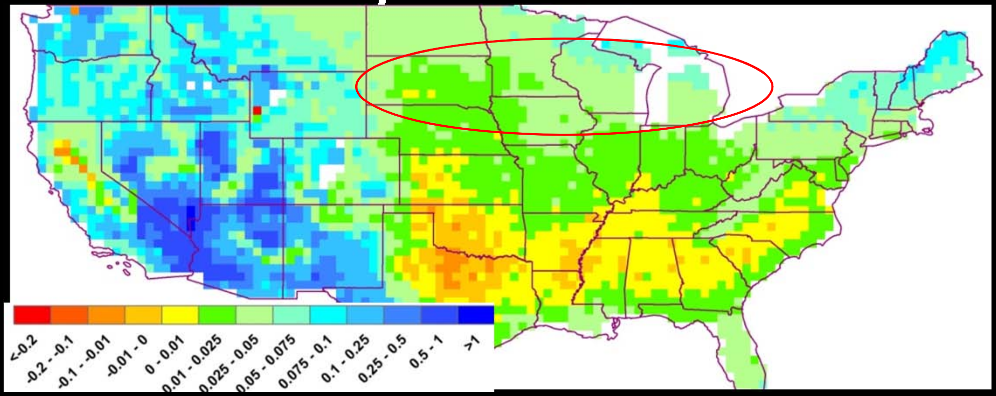
With Temp & Water Stress



With Water & Without Temp. Stress



Fraction Yield Change Due to Temperature Stress



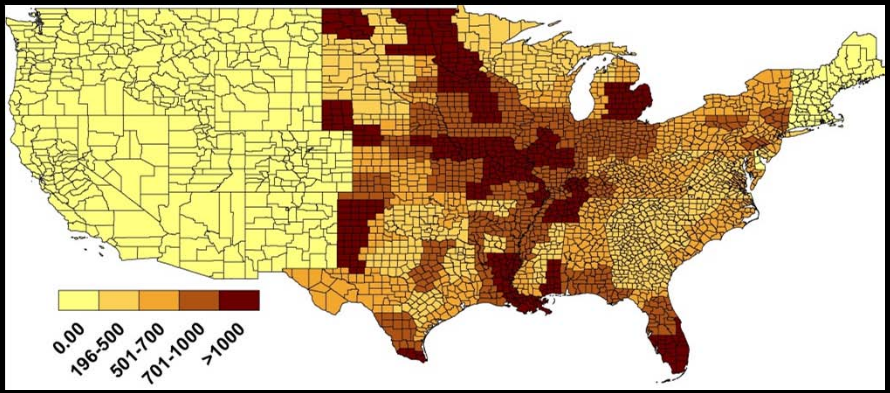
Costs of Miscanthus

- Cost of the bioenergy crop per hectare:
  - *cost of production + opportunity cost (CL)*
- Cost of production :
  - Cost of inputs, such as chemicals, fertilizers and seeds
  - Cost of equipment
  - Cost of storage
  - Per hectare costs of land, overhead (such as farm insurance and utilities).
- Opportunity cost or land cost:
  - Foregone profits from the best alternative use of the land

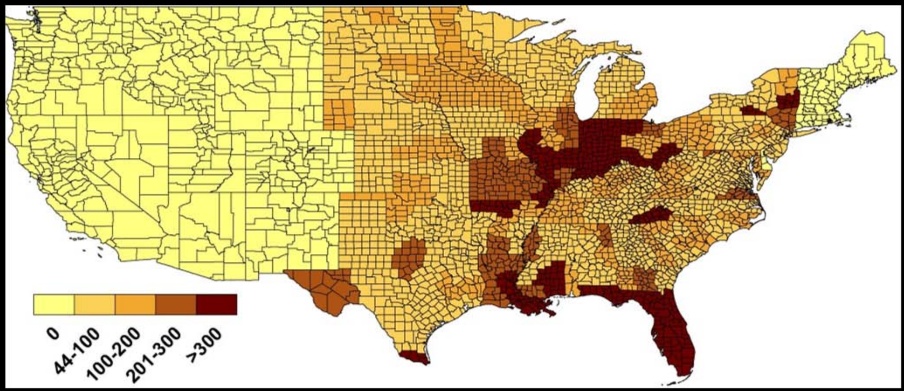
Jain et al. (2010); Khanna et al.(2008, 2009)

Land ($/ha) and Production ($/t DM) Costs by County

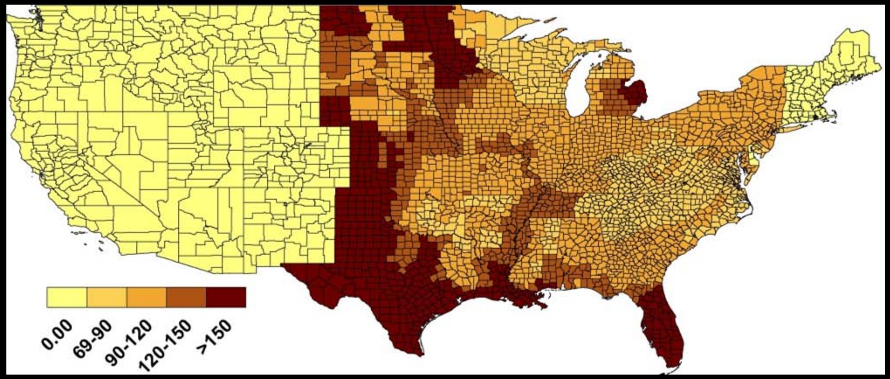
Land Cost: Cropland



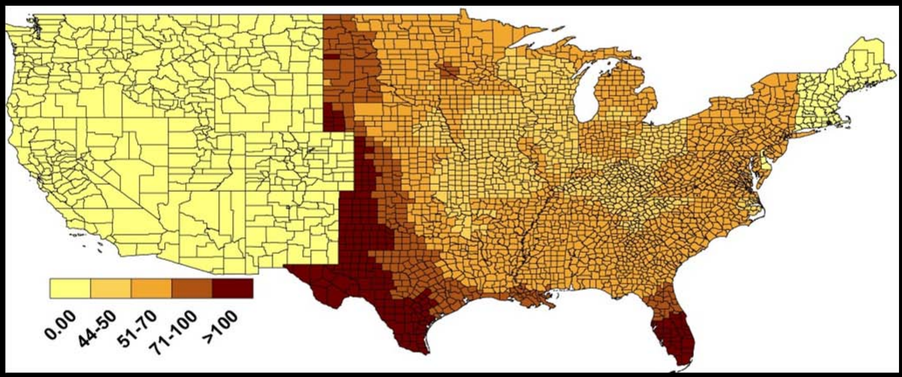
Land Cost: Pastureland



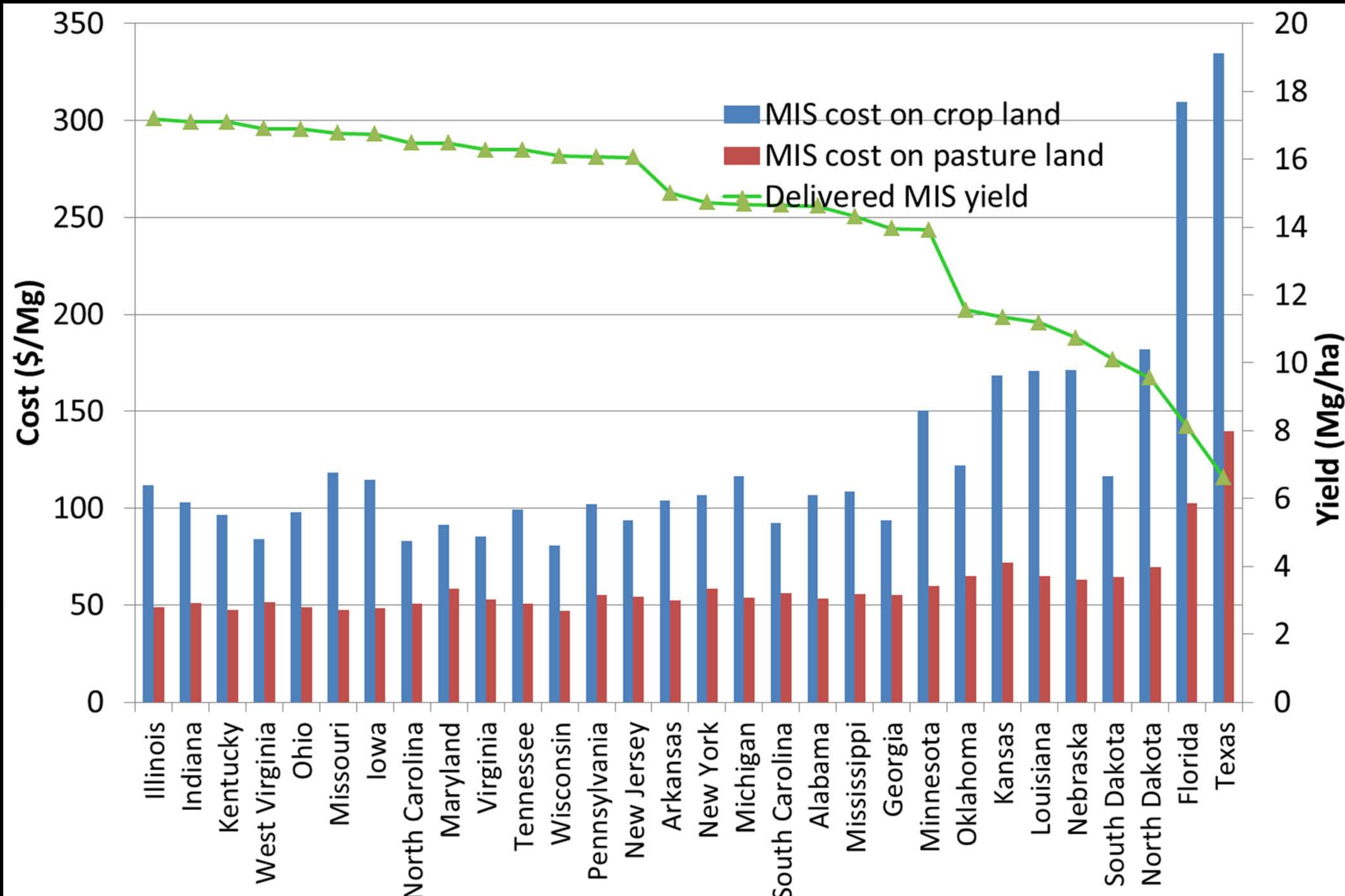
Production Cost: Cropland



Production Cost: Pastureland



Costs and Yields by States



Conclusions

- Miscanthus yields are highly sensitive to the weather conditions
- Yields are substantially higher in Mid-West counties and lower in northern and southern counties.
  - Warmer and wetter summers drive higher yields
  - Warmer and drier summers cause lower yields
  - and colder winters cause greater losses of above ground plant material, which lead to increased plant-available nutrients
- Water limitation effect yields in Midwest US.
- The costs of production are as high as $150 $/t on croplands and $100 $/t DM on pasturelands across the US.
- The opportunity cost of land accounts for a large part of the total cost, particularly for growing on cropland

Thank You