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Cellulosic Biofuel Potential of a Winter Rye Double Crop across the U.S. Corn-Soybean Belt

Gary W. Feyereisen[1], Ph.D., P.E.

Research Agricultural Engineer

G.G. Camargo[2], R.E. Baxter[2], J.M. Baker[1], and T.L. Richard[2]

[1]*USDA-ARS Soil & Water Management Research Unit, St. Paul, MN*

[2]*Pennsylvania State University, University Park, PA*

Thank you, Gary.

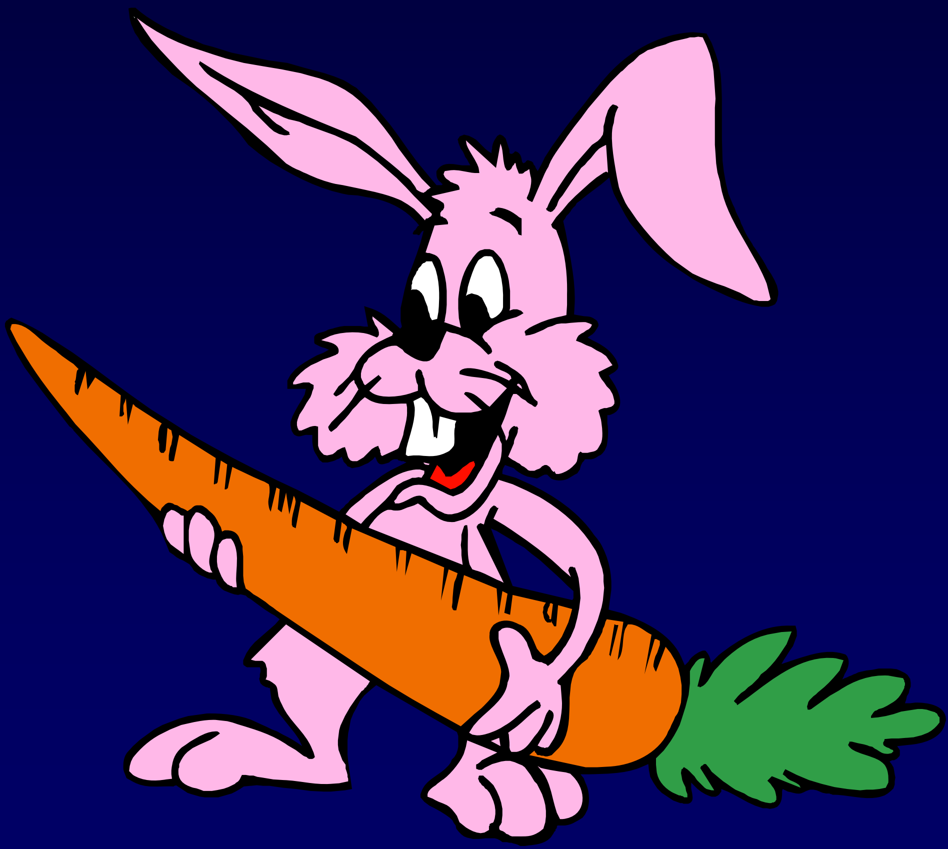
The question addressed in this presentation is . . . for a cellulosic double crop (winter rye in a corn-soybean rotation) . . .

. . . how much E can be harvested on C-Sb land in the U.S.?

How big is the bio E carrot?

- small

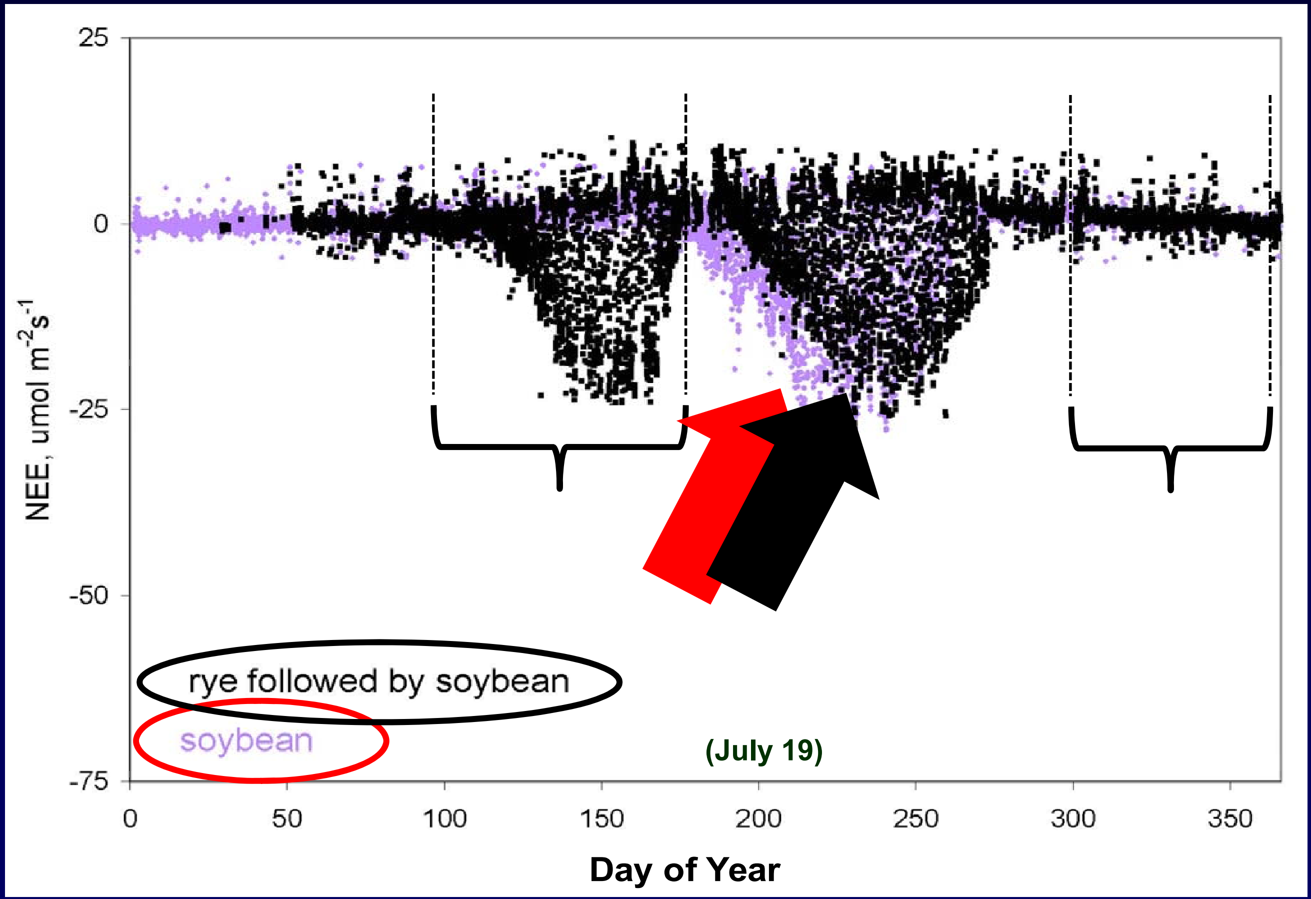
- BIG



Rationale

- Produce cellulosic biomass for energy w/o reducing food-feed harvest
  - Convert solar radiation before/after summer crop
    - Corn – Soybean Belt of U.S.
    - Winter Rye

Convert "Unused" Solar Radiation



NEE is Net Ecosystem Exchange of CO_2. Figure adapted from Baker and Griffis, 2009[1].

[1] **Baker, J.M., and T.J. Griffis. 2009. Evaluating the potential use of winter cover crops in corn-soybean systems for sustainable co-production of food and fuel. Agric. For. Meteorol. 79: 2120-2132.**

In spring, the rye continues to take up water and nitrogen, reducing drainage volume and nitrate-N concentration

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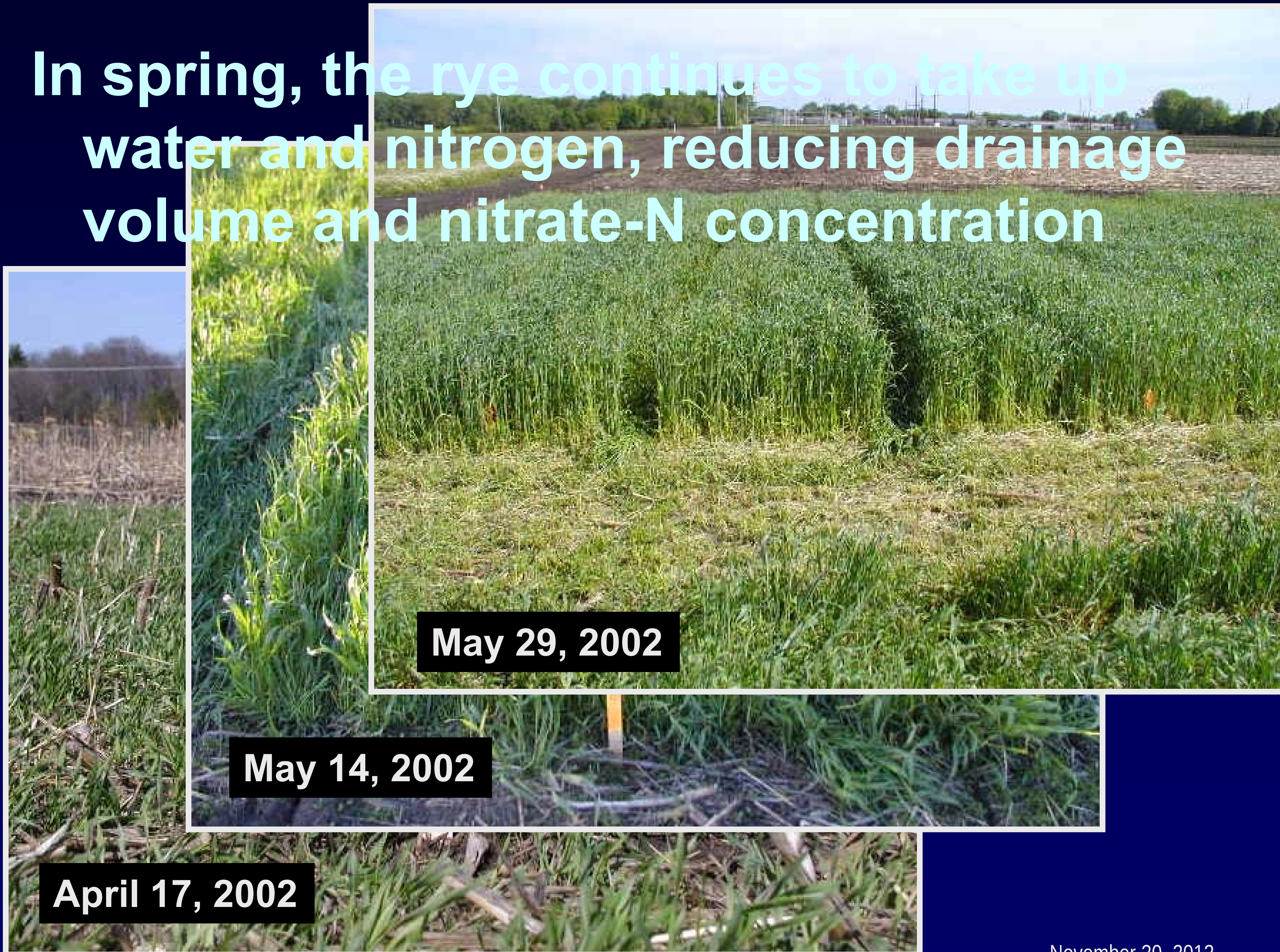

High rye biomass tonnages are possible

Photo provided by Dr. Tyson Ochsner, Oklahoma State University

High rye biomass tonnages are possible

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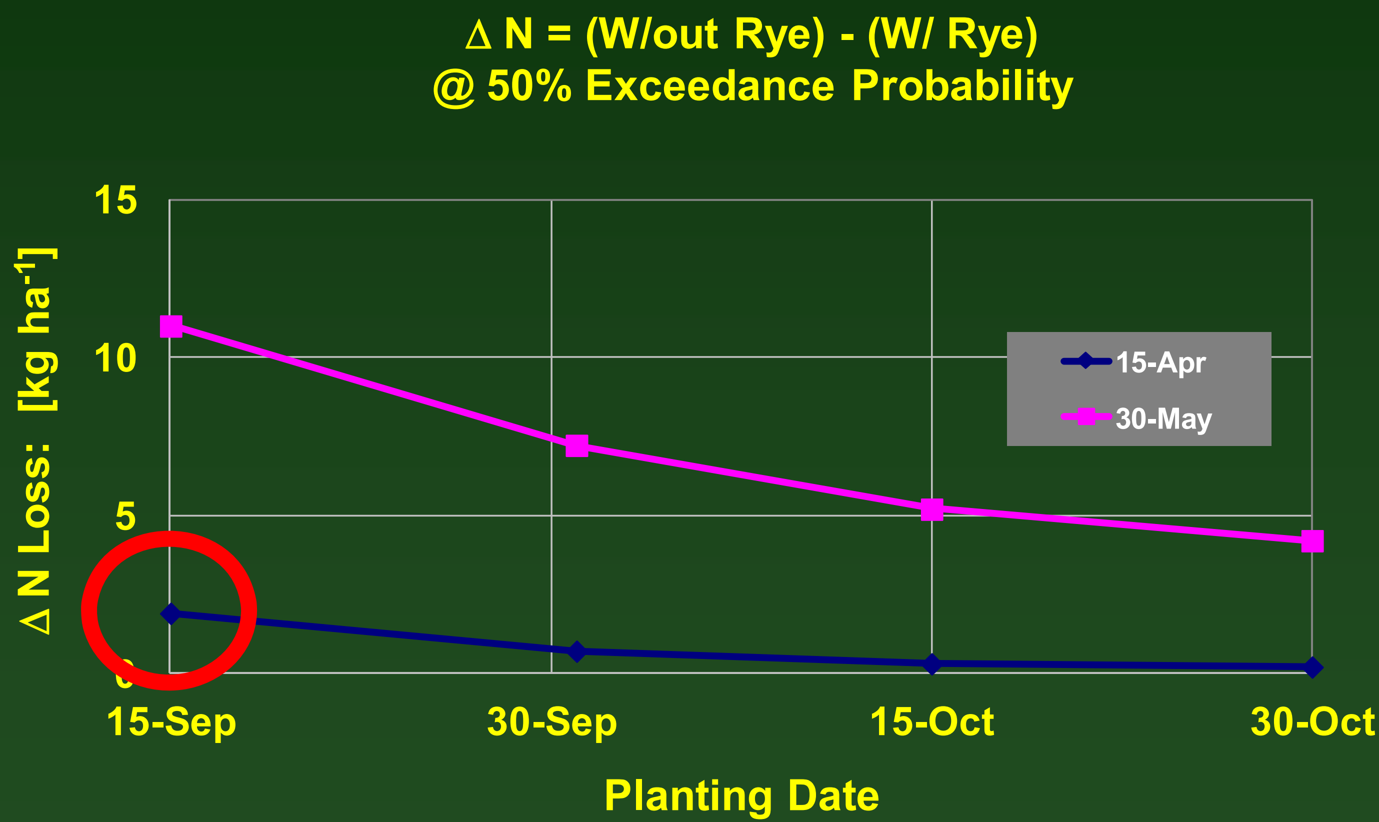
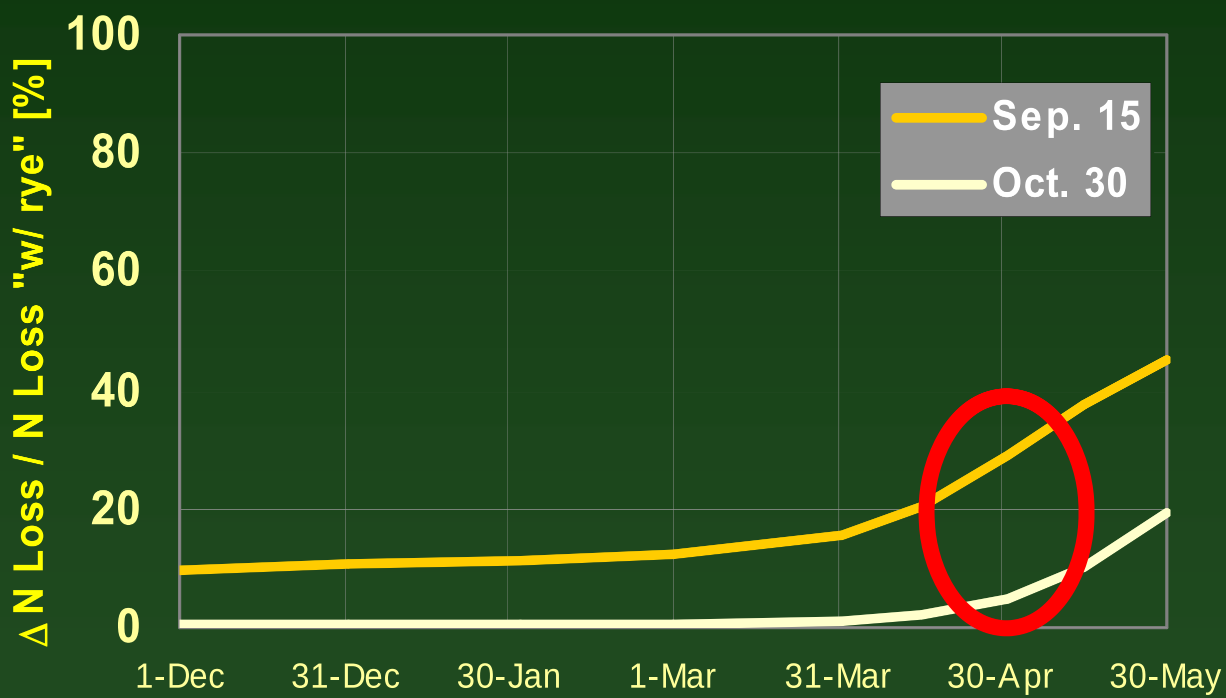
Challenge: establishing the cover crop early enough in fall

Rye can be seeded by helicopter into standing crops to provide soil cover after harvest. We are examining the factors that affect the success of aerial seeding.

Subsurface Drainage N Loss: Influence of Planting Date (Lamberton, MN)



Subsurface Drainage N Loss:
% Reduction w/ Rye



Mean values after 500 years of stochastic weather generation

Challenge: a winter cover crop can use water in the spring that is needed by the subsequent crop.

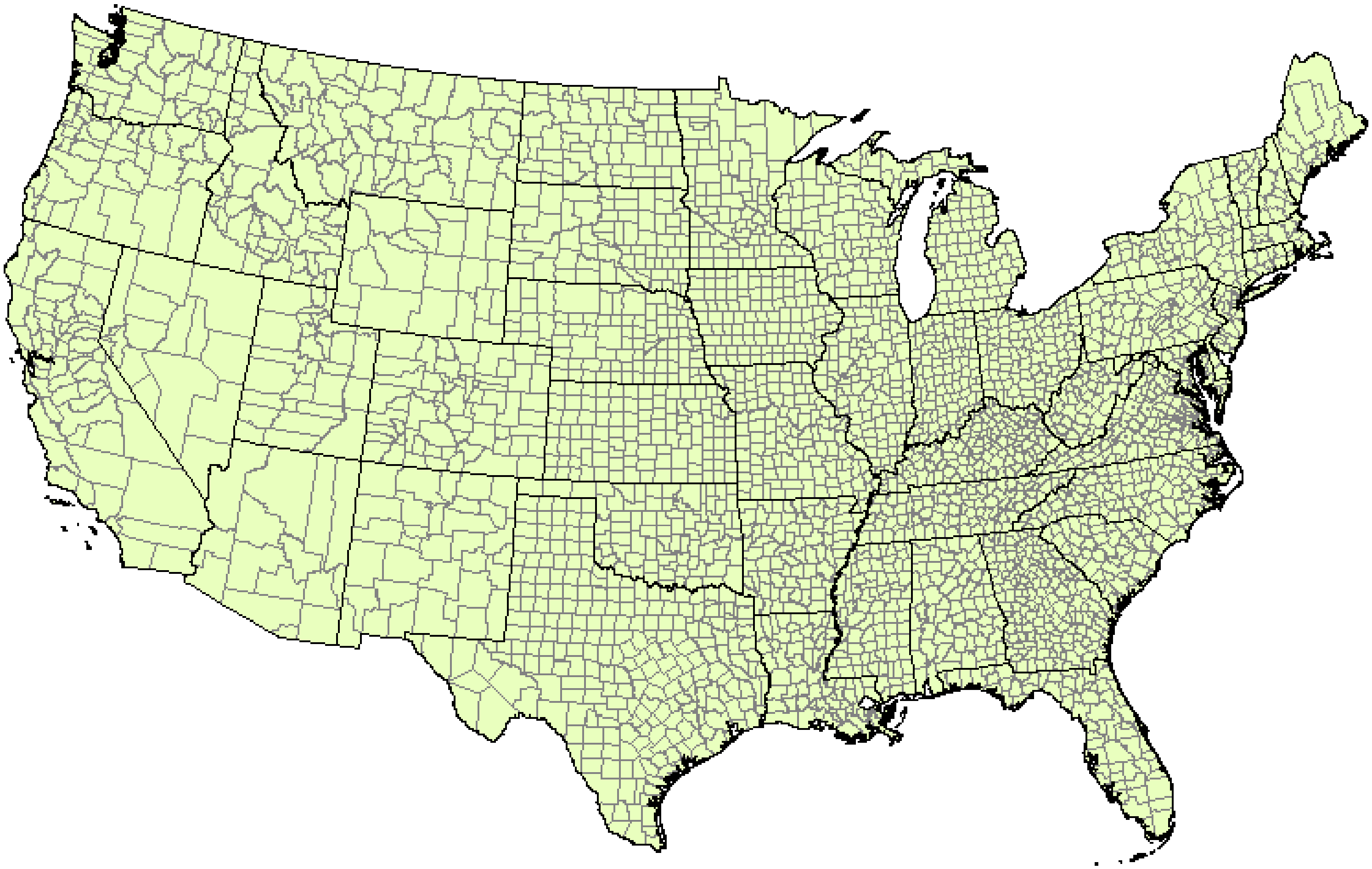
Picture Taken 7/30/2007

Materials & Methods

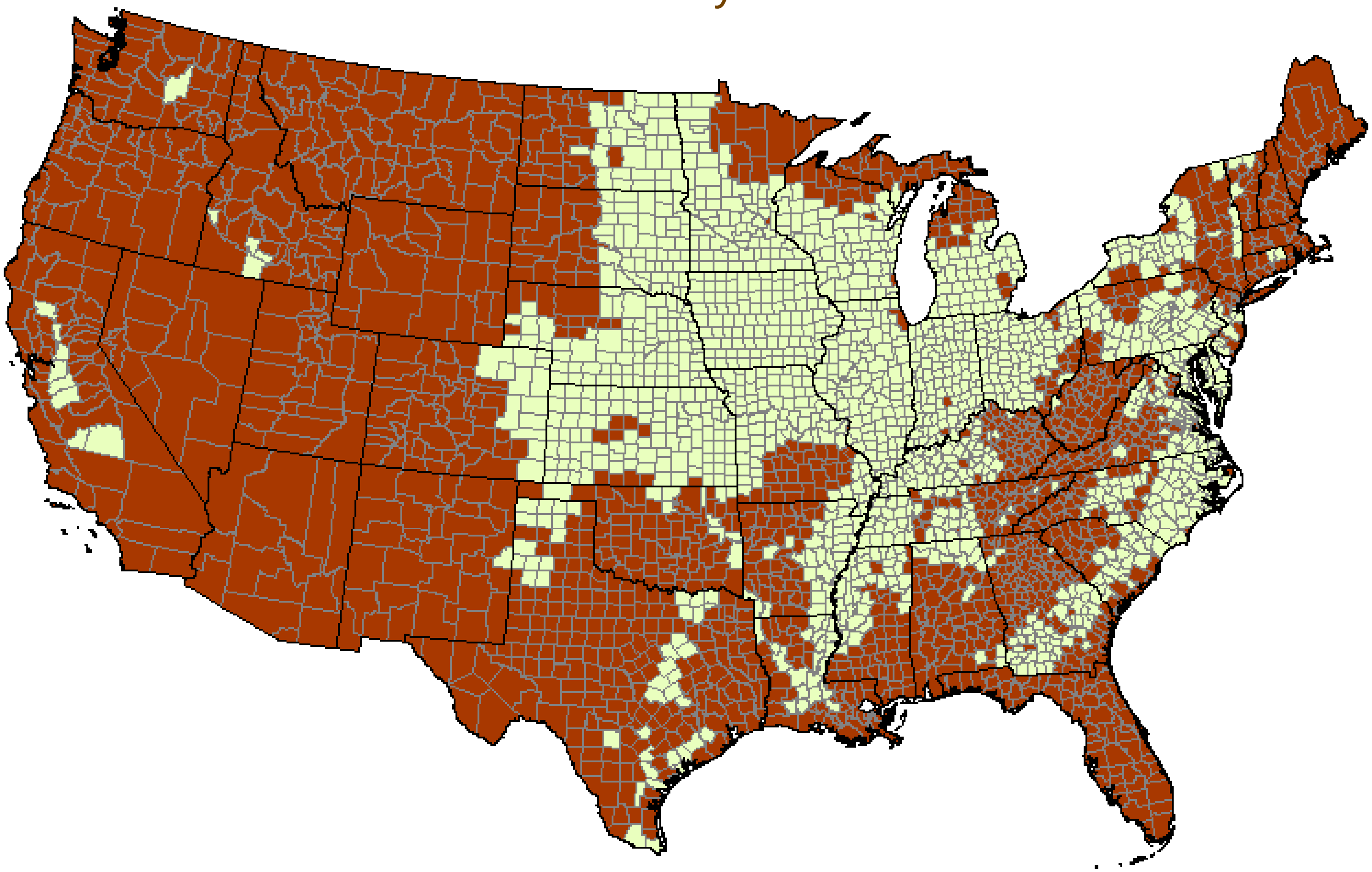
- Determine suitable C-Sb area
- Run plant-soil-atmosphere model at 30 locations for 14 y
- Develop a regression model based on T_{air} and Precip
- Imbed regression model in GIS model
  - Identify subset of C-SB area suitable
  - Use PRISM weather inputs (30 y)
  - Estimate biomass by county

Selection of Cropping Area

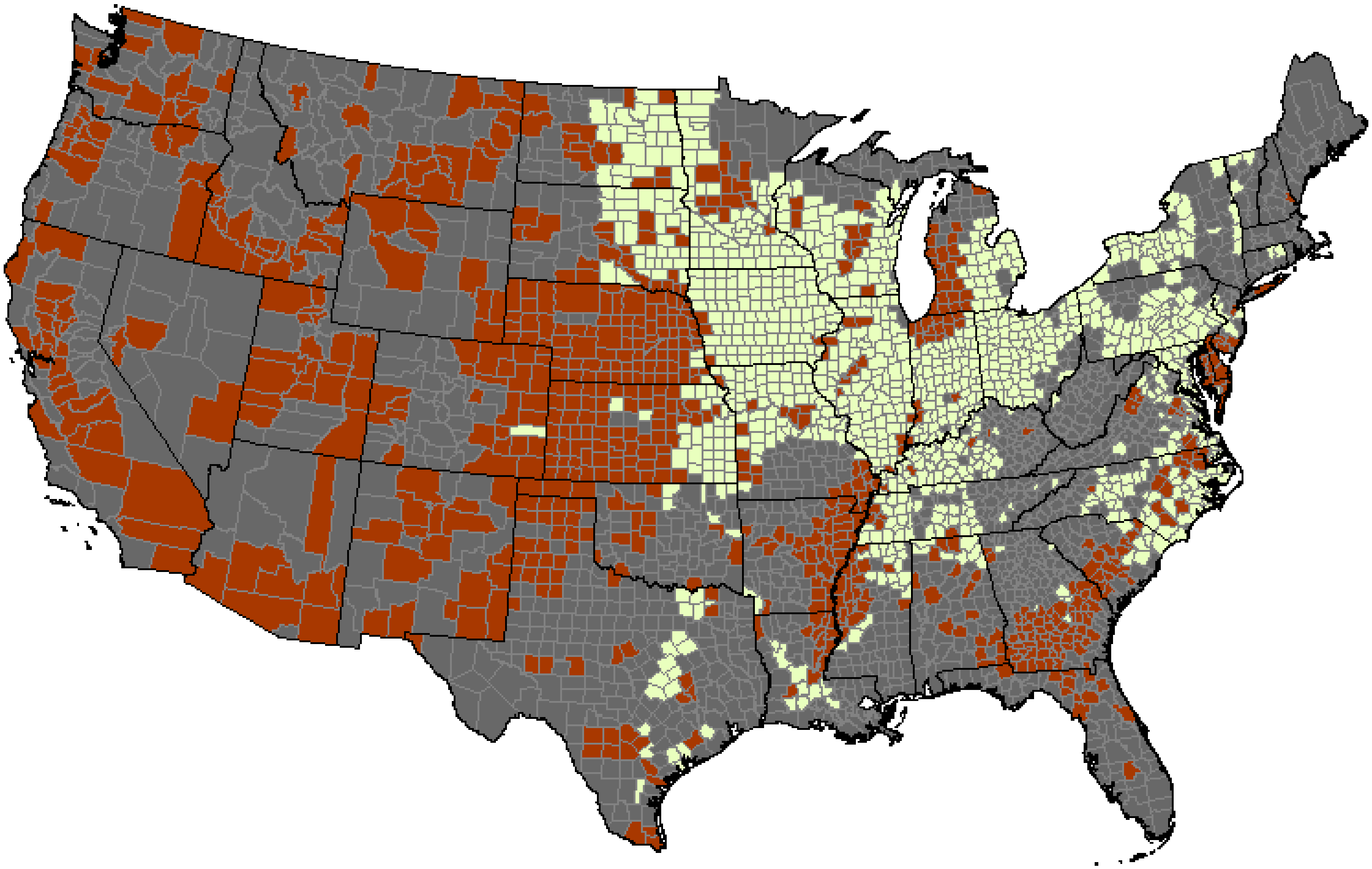
United States Counties



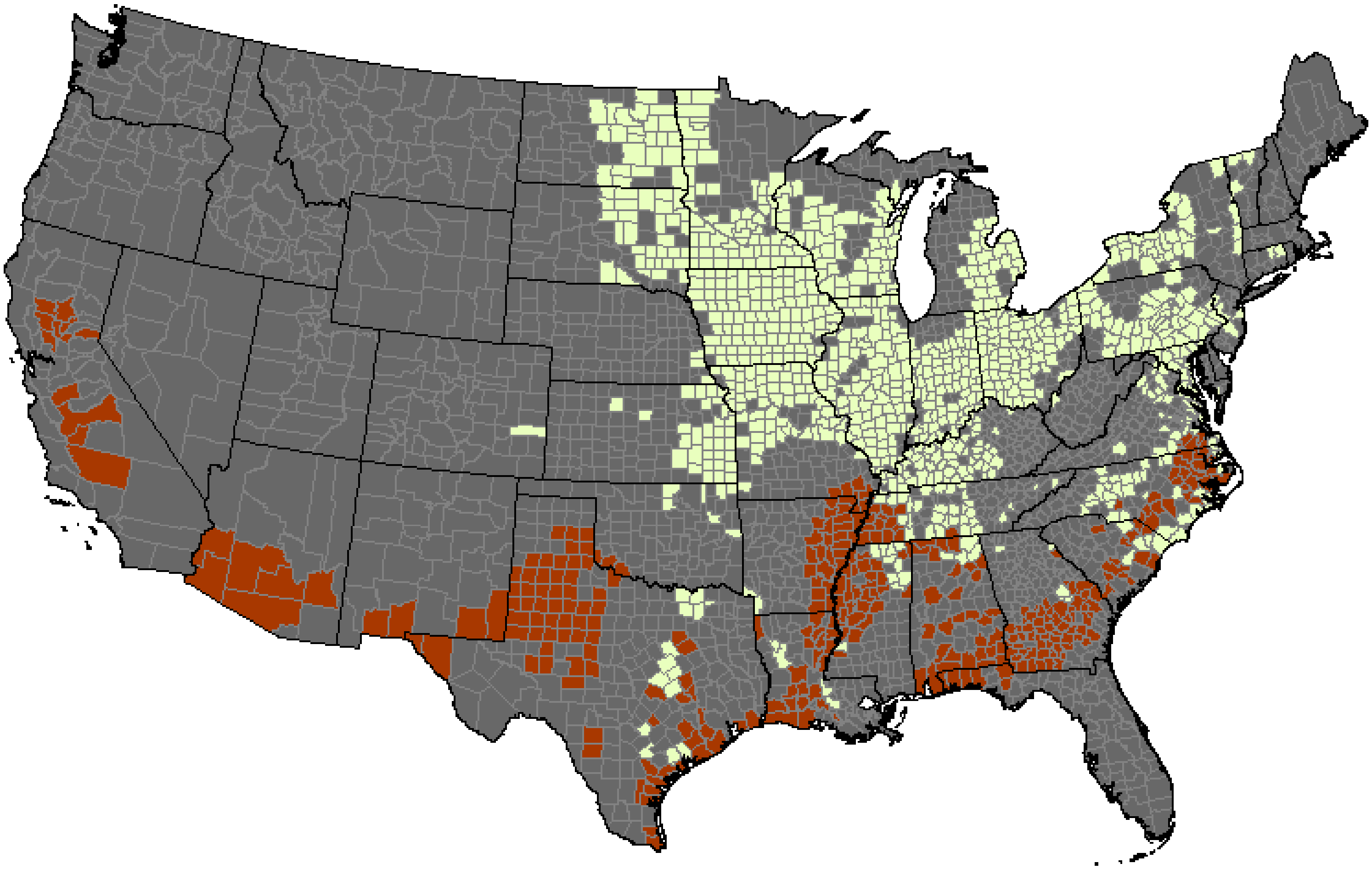
Red: Counties where less than 2% of total county area is producing corn or soybeans



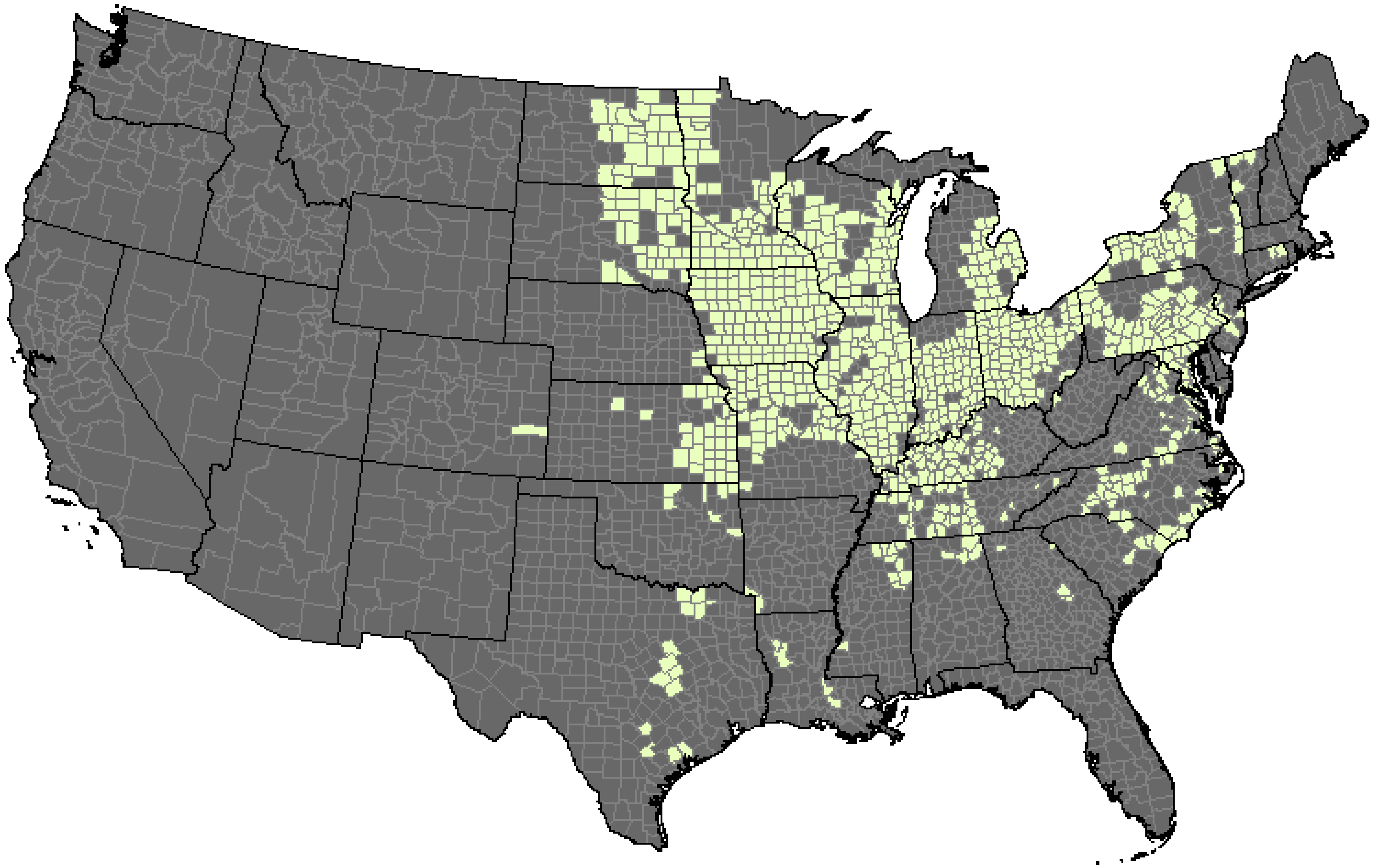
Red: Counties where greater than 5% of corn acreage is irrigated



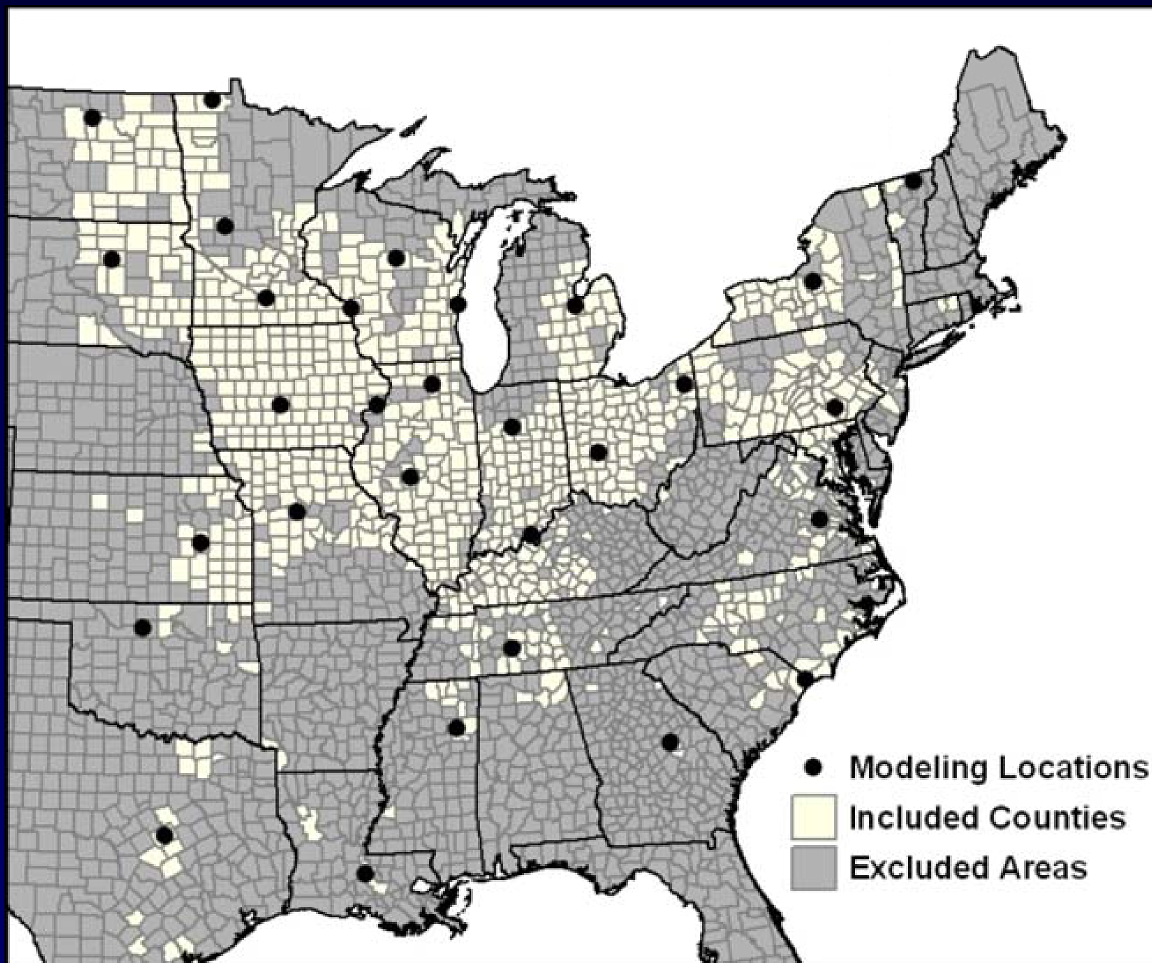
Red: Counties where greater than 10% of total cropland is producing rice or cotton



96.6 million ac (≈ 28% of U.S. cropland)



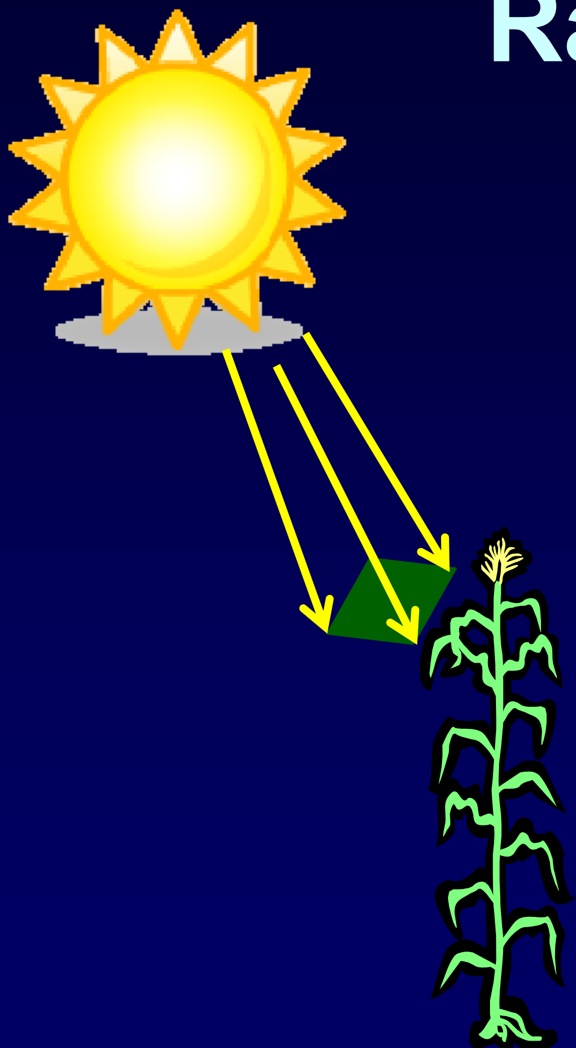
RyeGro Model Locations



Simulation Model: RyeGro

- Uses solar radiation interception concept (Monteith,1977)
- Infiltration concept of Holtan (1961)
- Point scale; daily time step
- Simple; robust

Plant Growth Modeling Strategy: Radiation Use



$$A_{nPOT} = \varepsilon \int f_{PAR} \; PAR \; dt$$

For each 1 mega Joule per of solar energy falling on each sq. meter of surface per day, 2.8 g of dry matter will be produced.

In RyeGro, the potential dry matter (or “biomass”) is modified by air temperature and soil moisture status.

Validation

- Compared BM prediction to mechanistic model of Baker-Griffis (2009)
  - Based on CO_2 assimilation (Collatz et al., 1991)
  - 8 locations in Midwest C-Sb Belt
- Same soil assumptions
- Assumed no nutrient limitations – “Best Case Scenario”

Validation (cont'd)

- Compared biomass to field studies in Iowa and Illinois

RyeGro Application

- Planting date assumptions
  - NASS dates on state basis
- Rye harvesting cases:
  - 14 days and 7days prior to spring planting

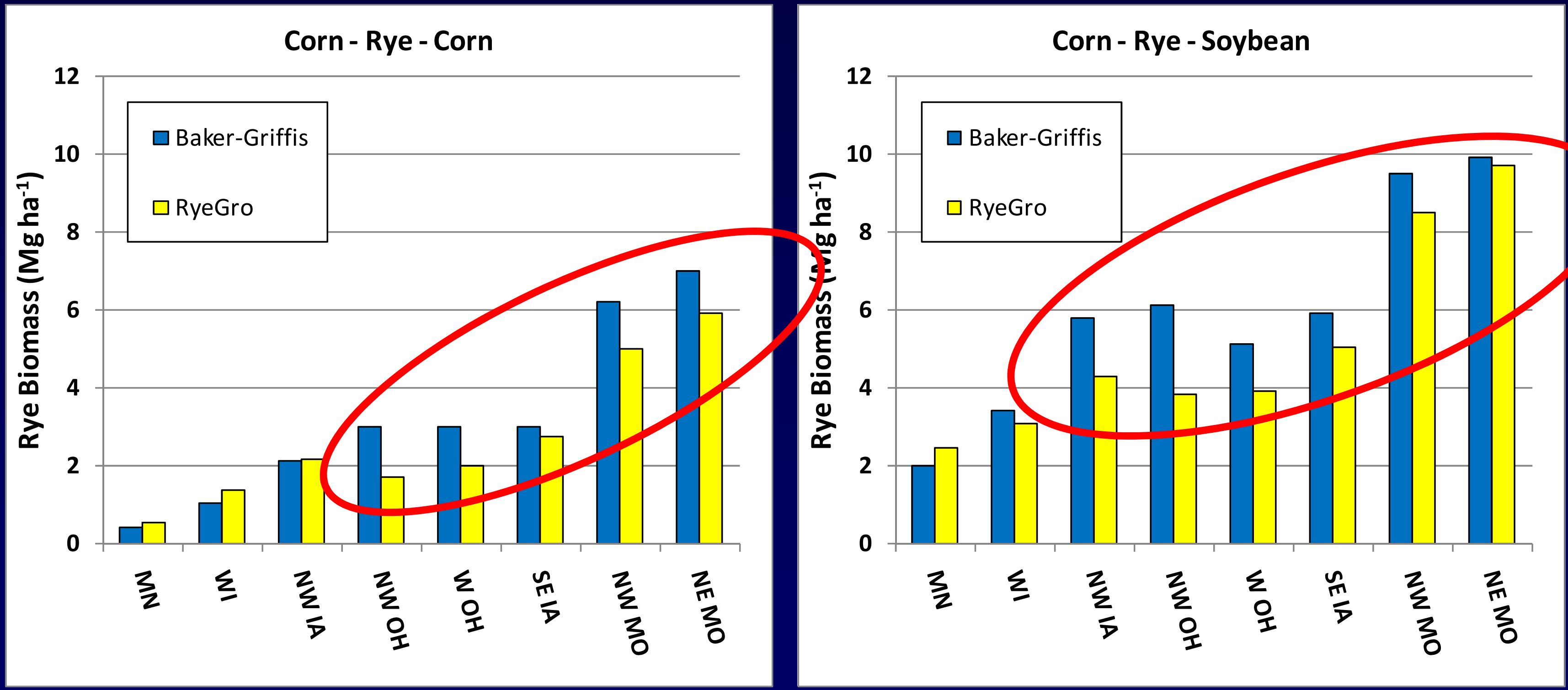
Model Scenarios

- Rye planted 2 days after C or Sb harvest
- Rye harvested 14 days before planting:
  - Corn – Rye – Corn
  - Corn – Rye – Soybean
  - Soybean – Rye – Corn
- Rye harvested 7 days before planting, same 3 crop sequences

Results: Model Validation

RMSE = 0.83 Mg ha^{-1}
NSE = 0.85
PBIAS = 17%

RMSE = 1.17 Mg ha^{-1}
NSE = 0.78
PBIAS = 15%



Comparison with Field Data

Study	Location	Year	Rye BM Obs. (Mg/ha)	Rye BM Est. (Mg/ha)
Kaspar	Boone, IA	2003-04	1.5	1.5
		2004-05	2.7	1.5
Miguez &	Champaign, IL	2001-02	0.6	1.1
Bollero		2002-03	2.4	3.3
Ruffo	Urbana, IL	1999-00	4.5	6.9
	Brownsville, IL	1999-00	3.3	4.9
Singer	Ames, IA	2003-04	5.7	5.0
		2004-05	6.0	4.3
Westgate	Boone, IA	2001-02	6.0	7.1
		2002-03	5.6	5.1

Comparison with Field Data

Study	Location	Year	Rye BM Obs. (Mg/ha)	Rye BM Est. (Mg/ha)
K				
M				
R				
S				
W				
		2002-03	5.6	5.1

Modeling Statistics (“How good is the model”)

Average Observed: 3.83 Mg/ha   Average Estimated: 4.07 Mg/ha

Percent Bias: 6.2% overprediction “Very Good”

Modeling efficiency (NSE): 0.60 “Satisfactory”

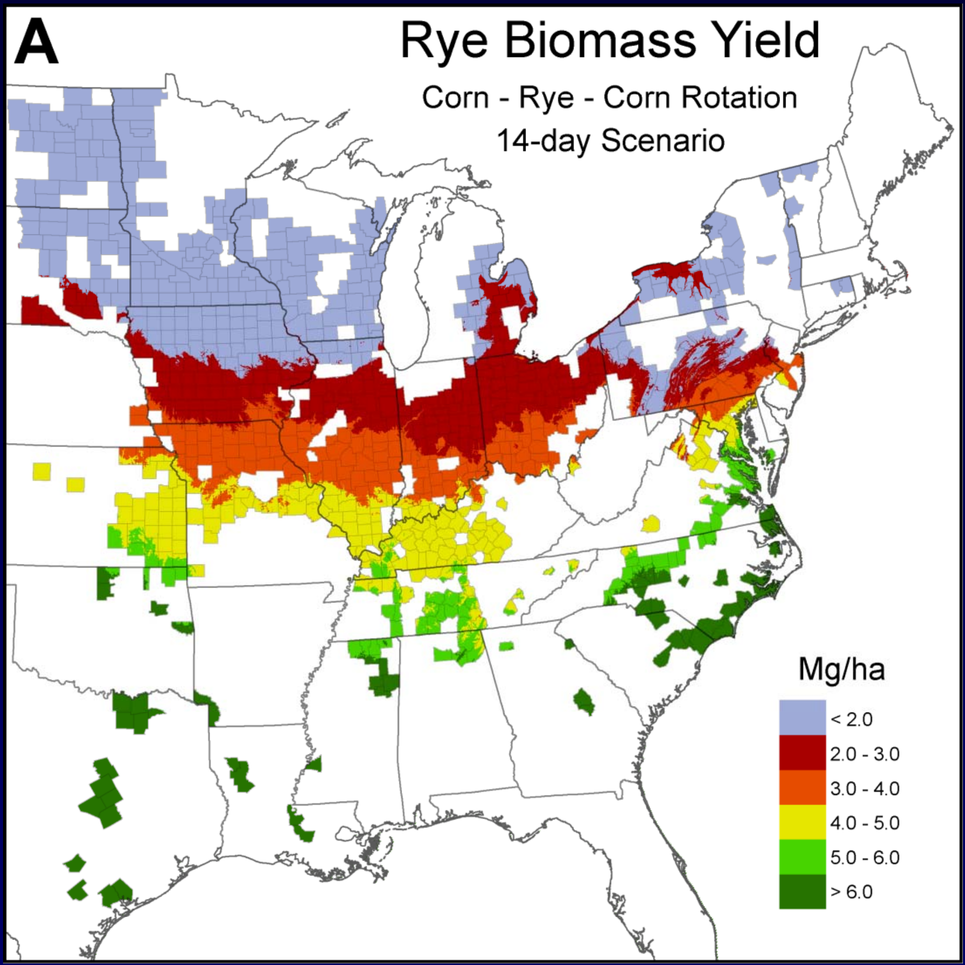
Root mean square error: 1.26 Mg/ha

Ratio of RMSE and Obs. Std Dev.: 0.63 “Satisfactory”

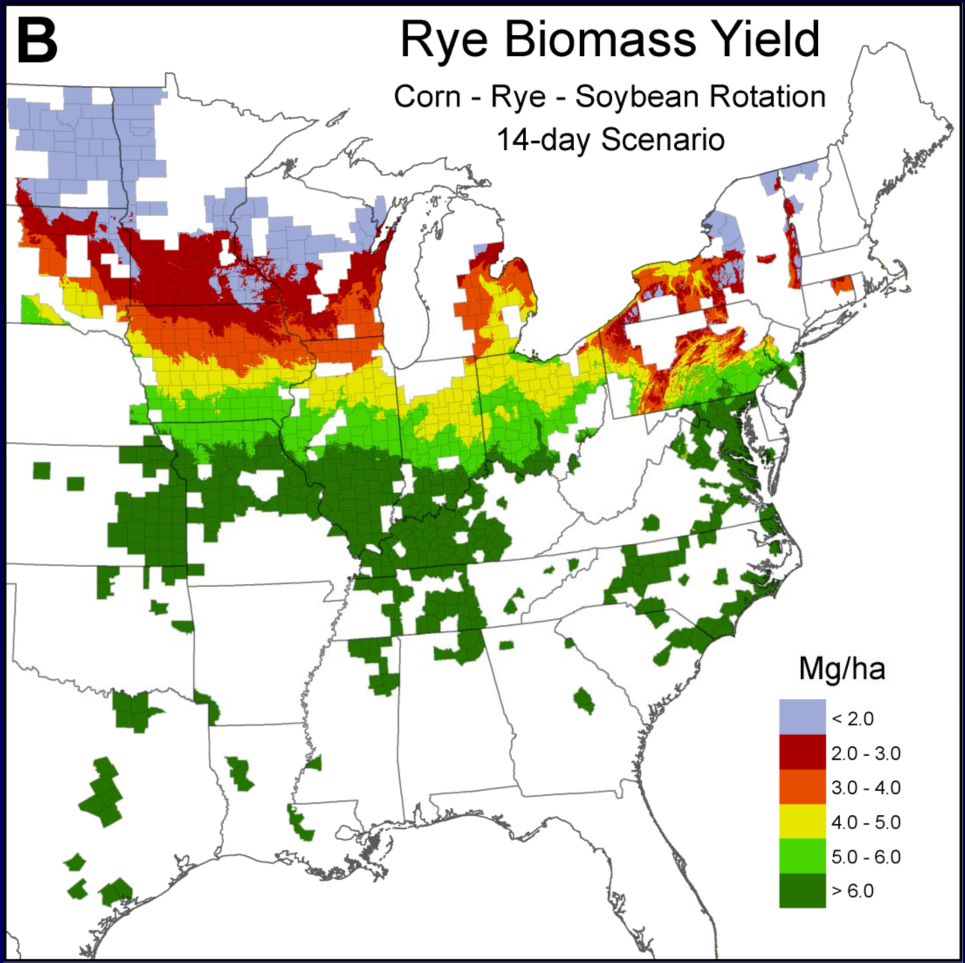
Regression Modeling

- PRISM T_{air} and Precip inputs
- Run at 800-m resolution
- Regression model yields compared to RyeGro yields: 30 locations
  - R^2, RMSE, PBIAS=0
- Results summed to county level
- Following 3 maps are for 14-d scenario

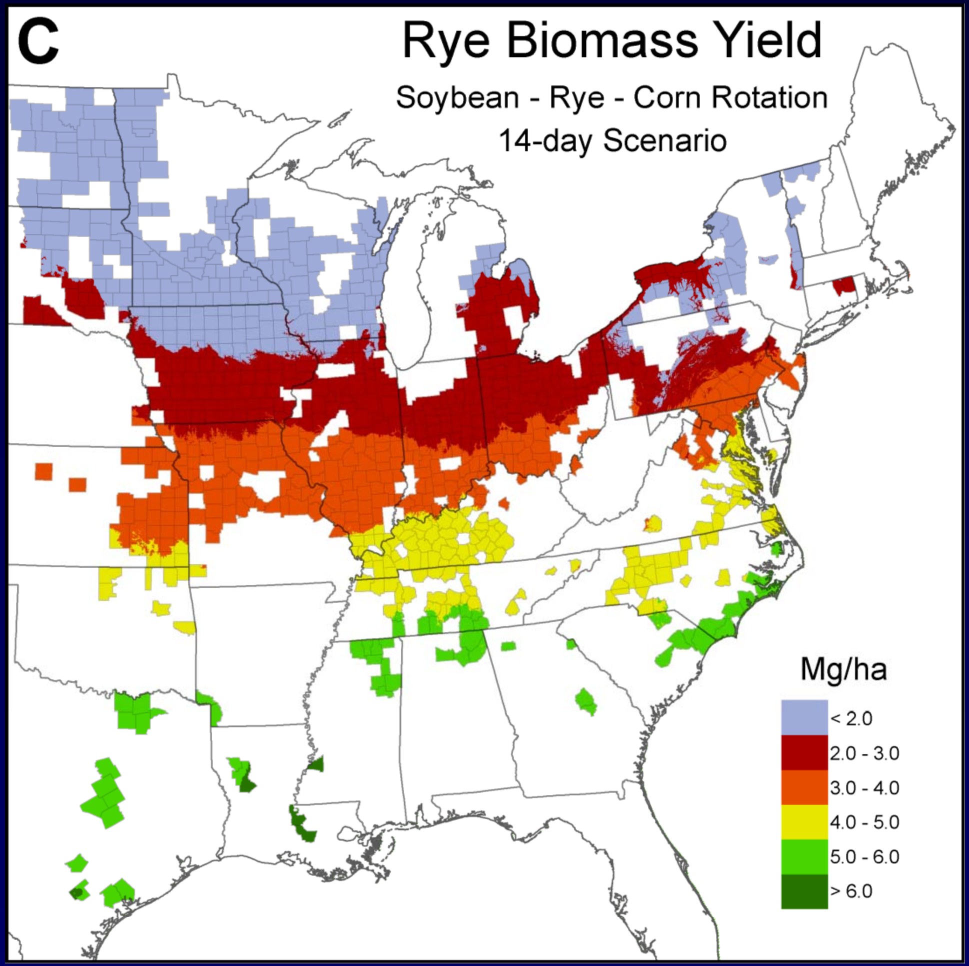
Corn – Rye – Corn: 14d



Corn – Rye – Soybean: 14d



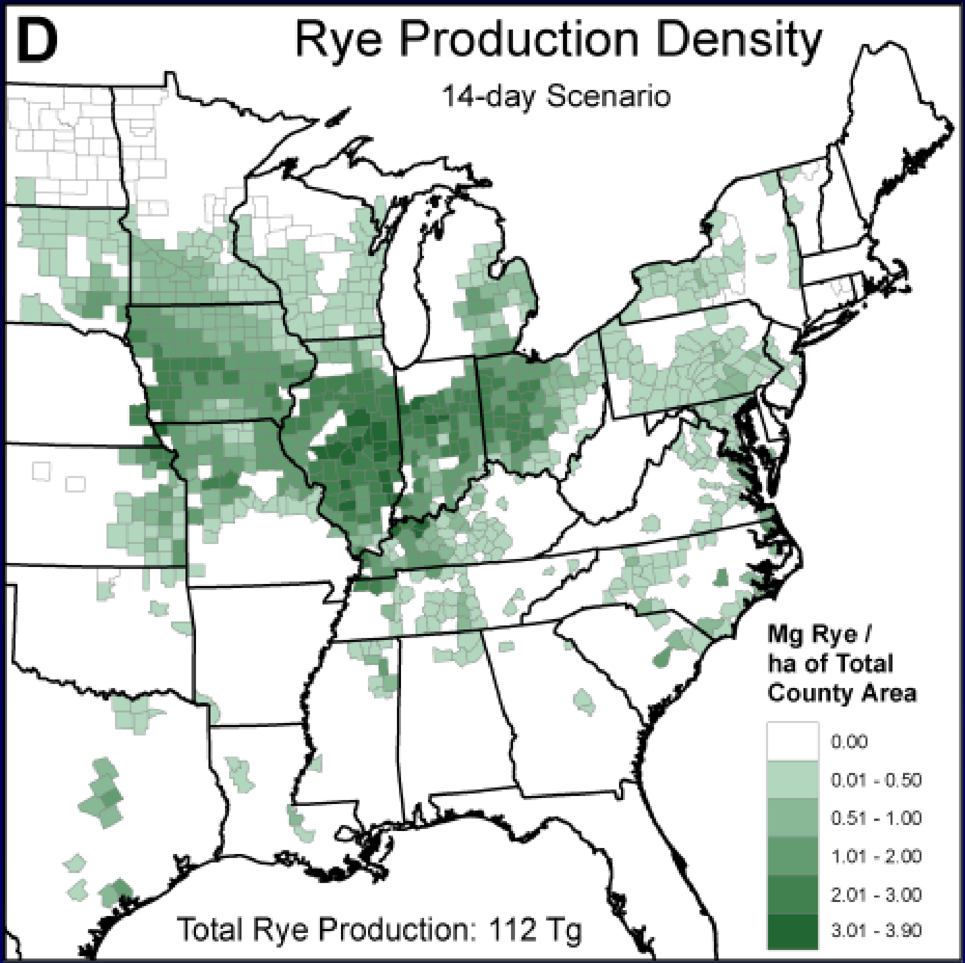
Soybean – Rye – Corn: 14d



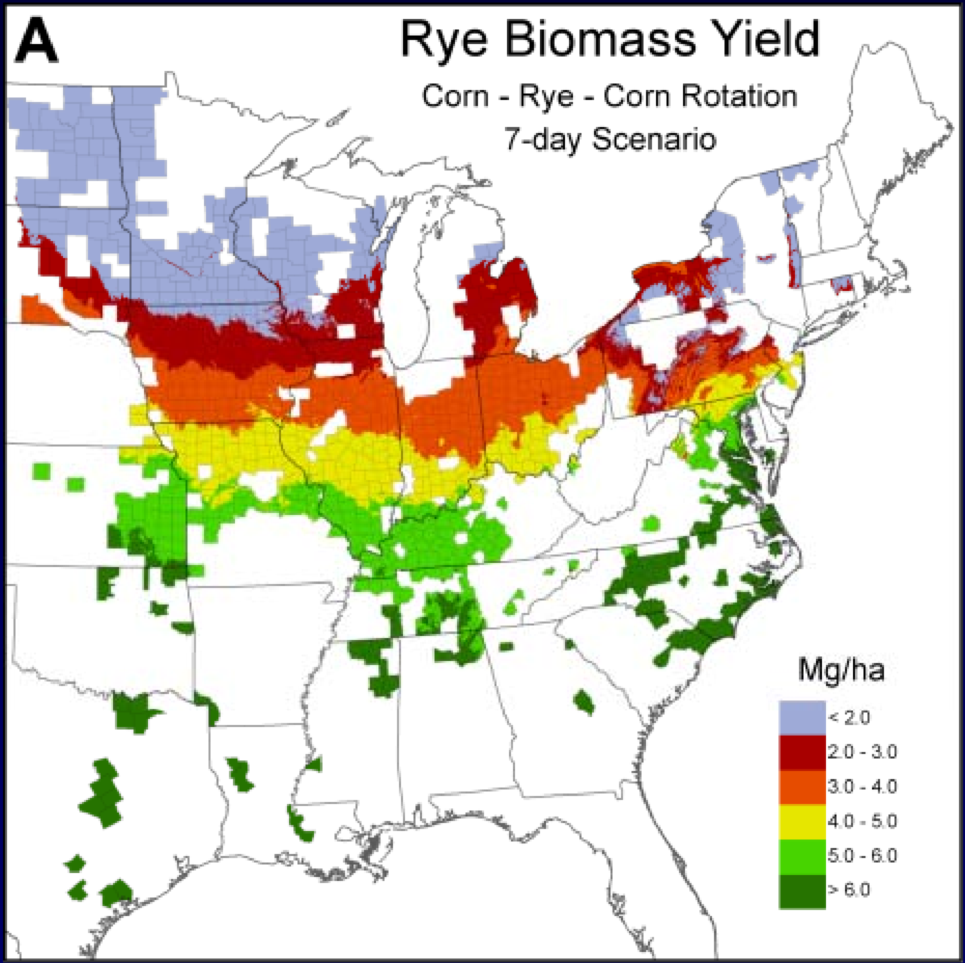
Production Density

- Rye BM yields multiplied by available corn-soy and corn-corn area
- Total BM divided by total county area = "Production Density"

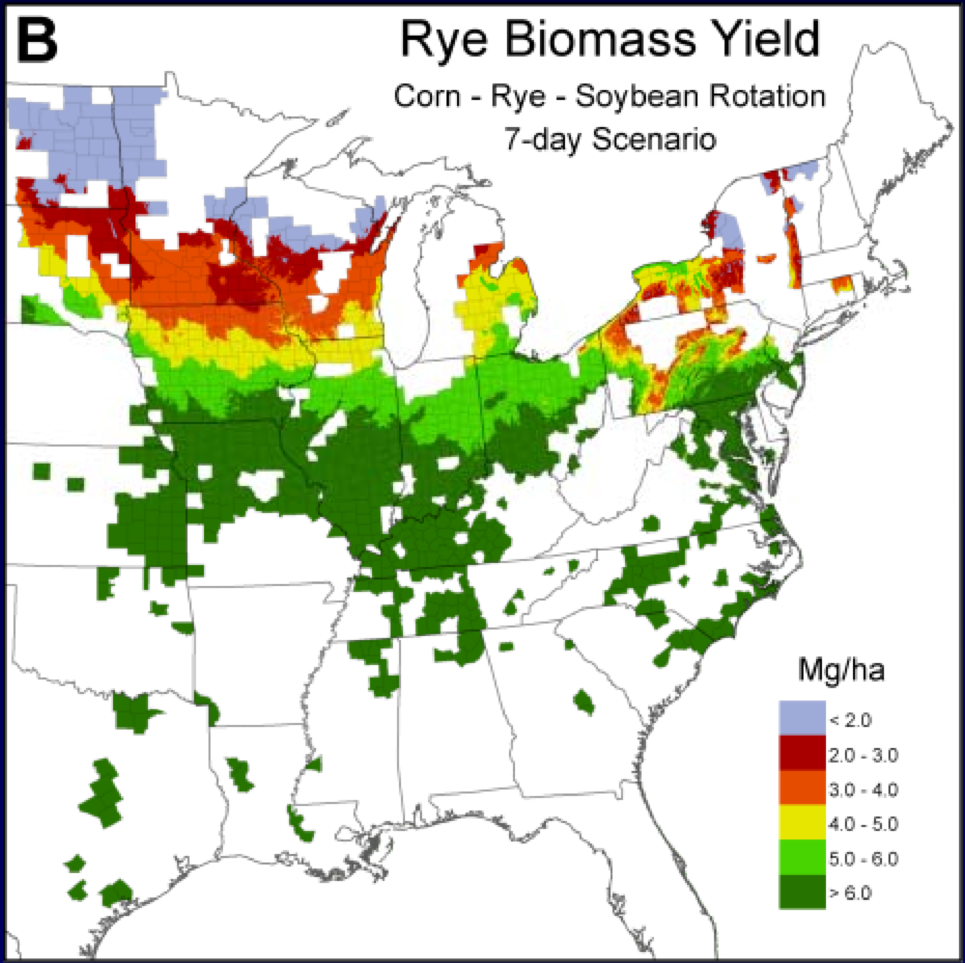
Production Density: 14d



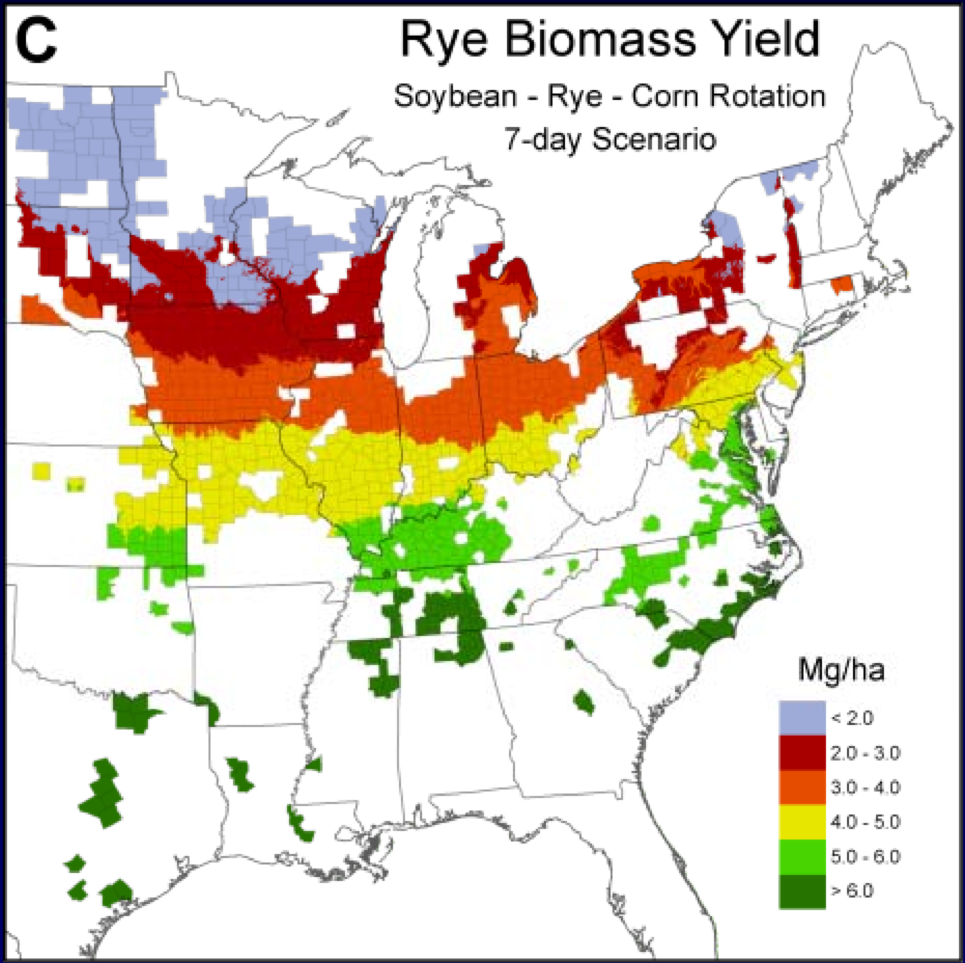
Corn – Rye – Corn: 7d



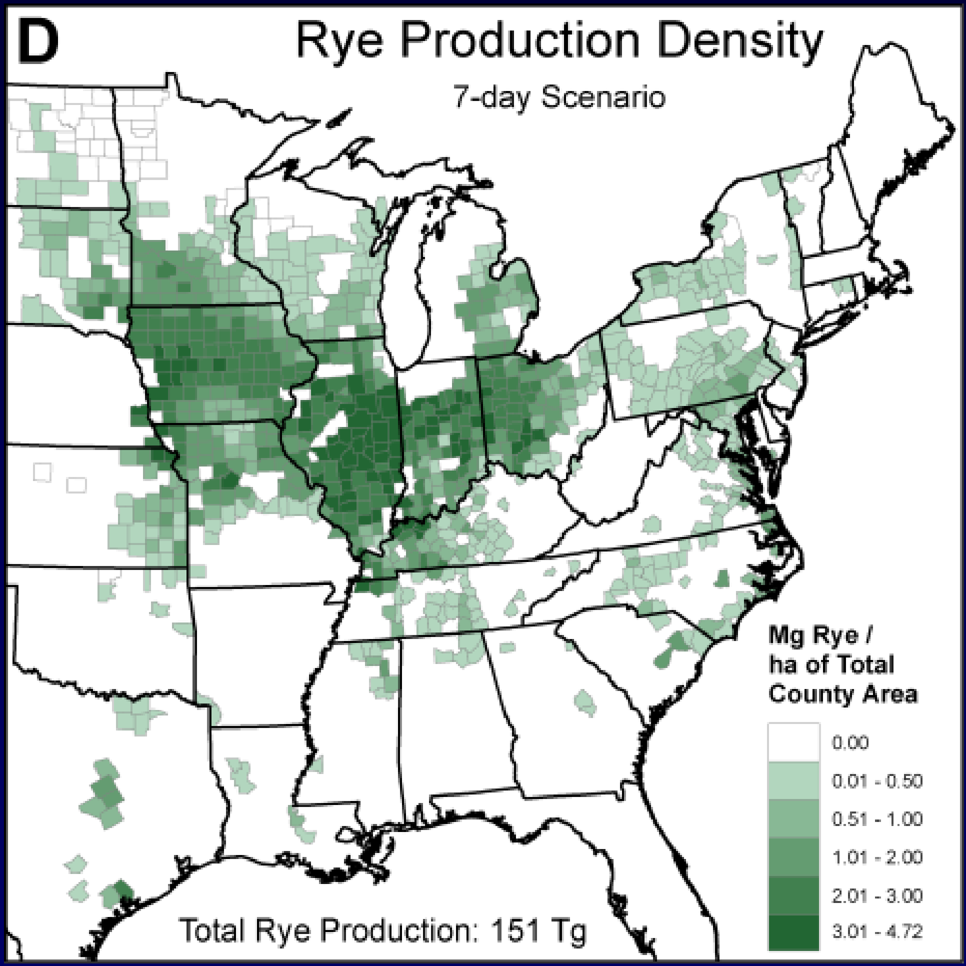
Corn – Rye – Soybean: 7d



Soybean – Rye – Corn: 7d



Production Density: 7d



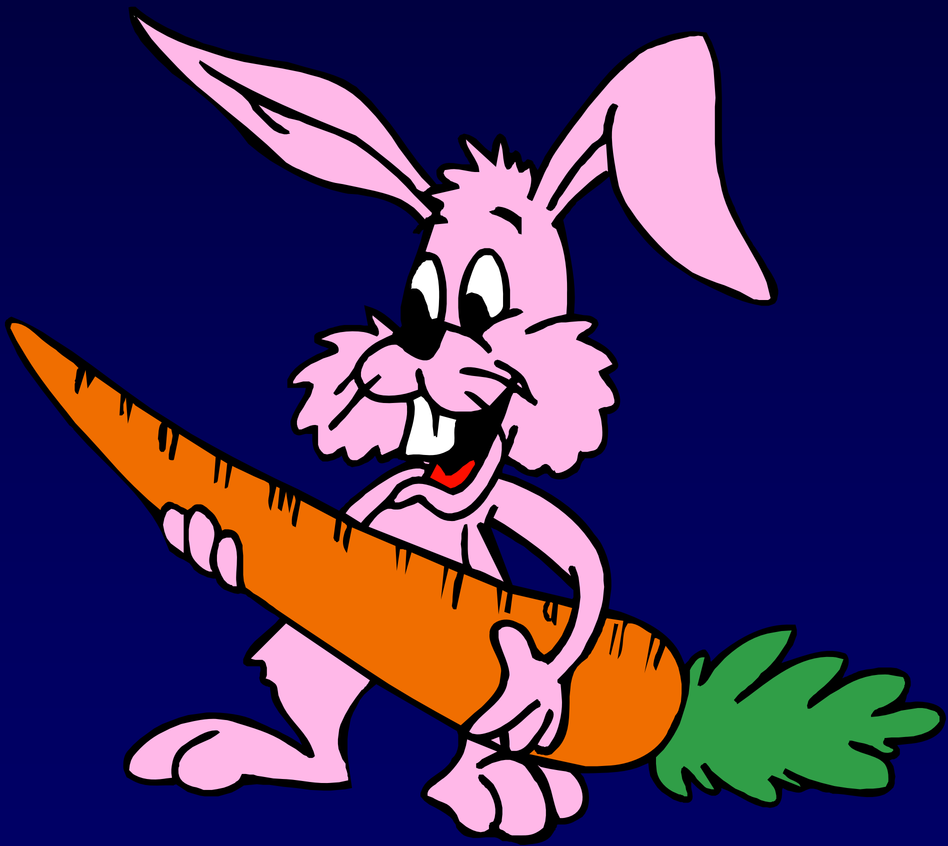
Total Rye BM Production

Scenario	Rye BM (U.S. ton)	Quads (10^{15} BTU)
14d	120,000,000	1.9
7d	170,000,000	2.5

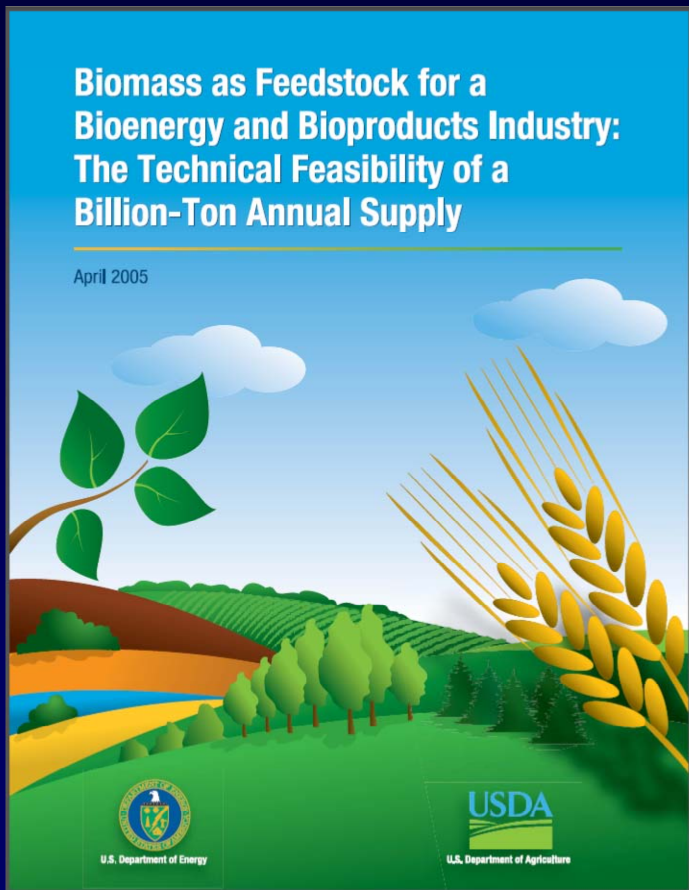
How big is the bio E carrot?

- small

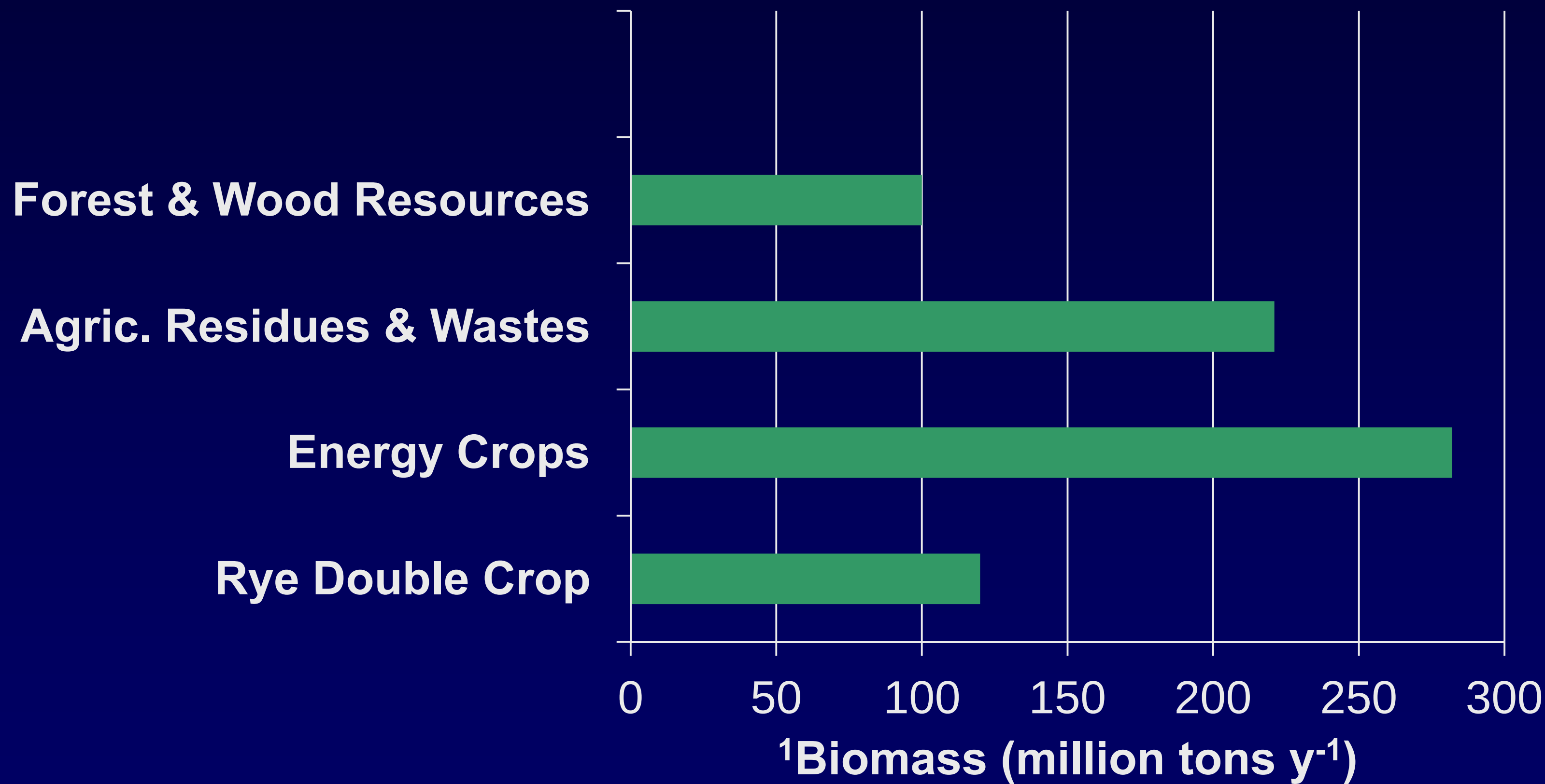
- BIG



USDA-DOE 2005, 2011



Billion-Ton Update: 2022 est.



Adapted from Perlack and Jones. 2011. U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry. p.148. U.S. Department of Energy – Oak Ridge National Laboratory, Oak Ridge, TN.

[1]Baseline assumptions and biomass price of <$60 ton^{-1}.

How much E?

- "It depends . . ."
  - Local climate, available water, cropping and management practices
  - Acceptable risk to subsequent summer crop
- What will it take? What will it cost?

Energy Matrix

Energy Source	Size of Contribution	Pro's	Con's
Oil			
Coal			
Nuclear			
Natural Gas			
Biofuels			
Solar			
Wind			
Hydrogen			
Conservation			

Politics

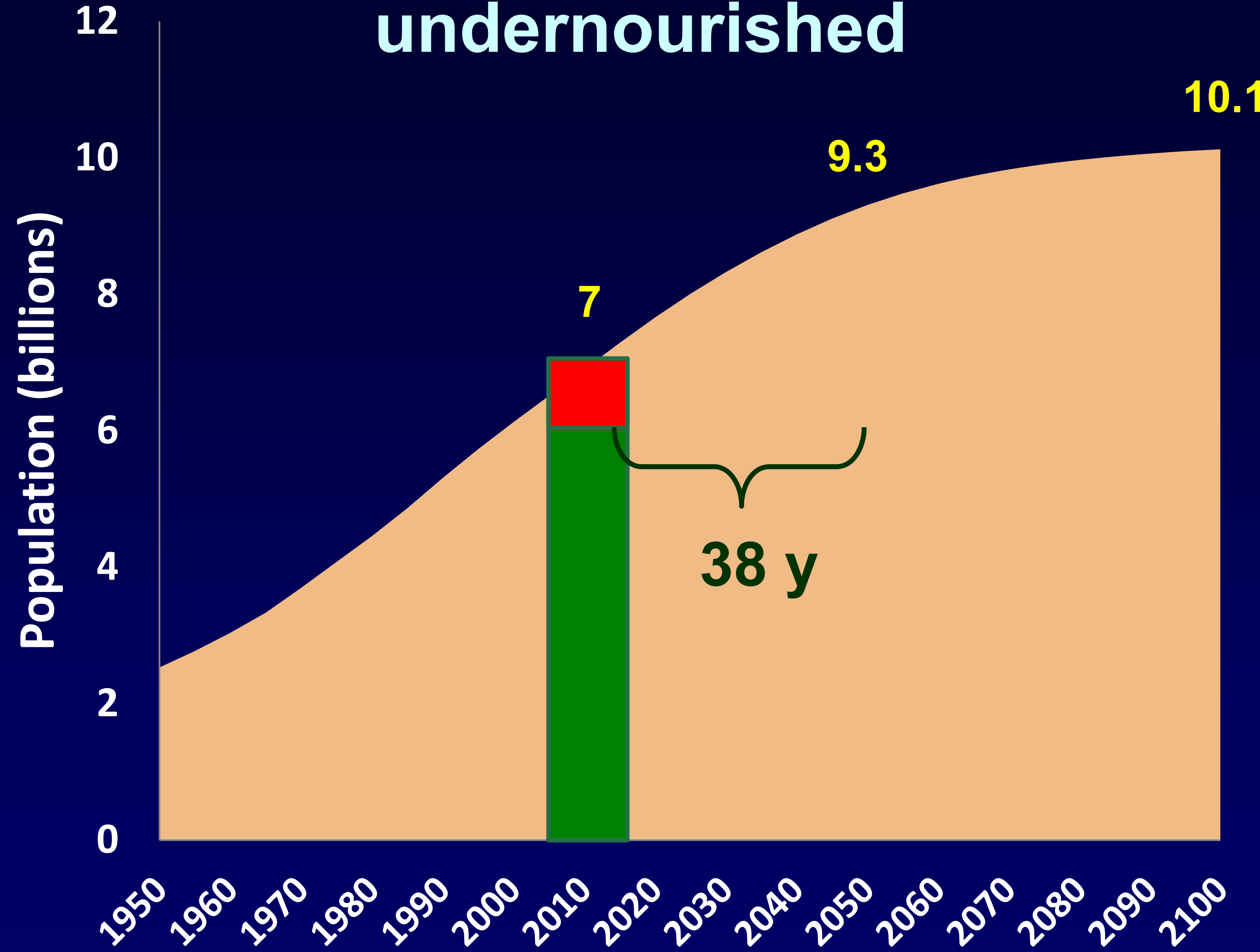
Economics

How will this particular biofuel production impact water supply / quality?

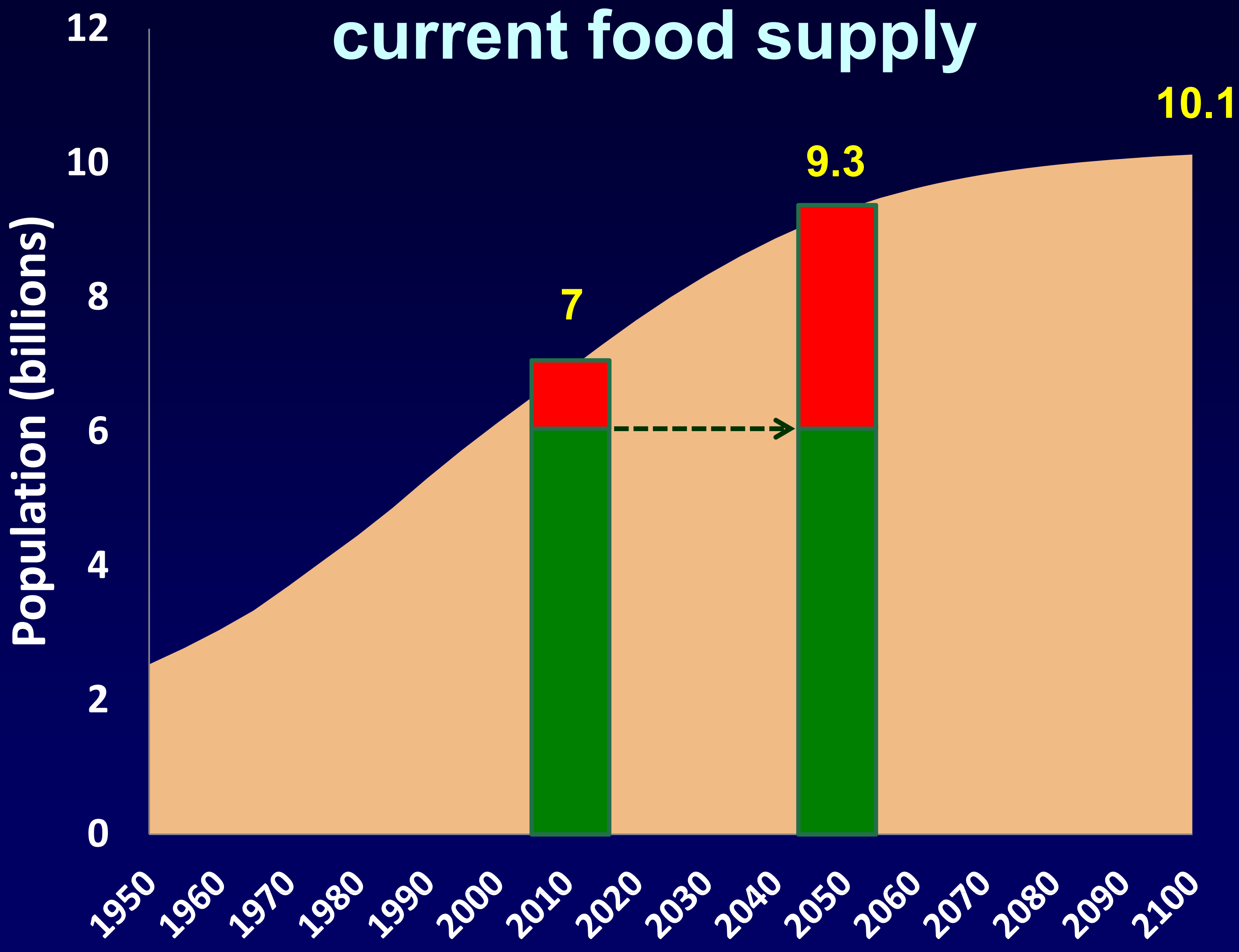
- Good questions. Further research on the topic has begun.
- One thing is for sure: biofuel supplies will be more variable than traditional sources of energy.

How will various biofuel production strategies impact food supply?

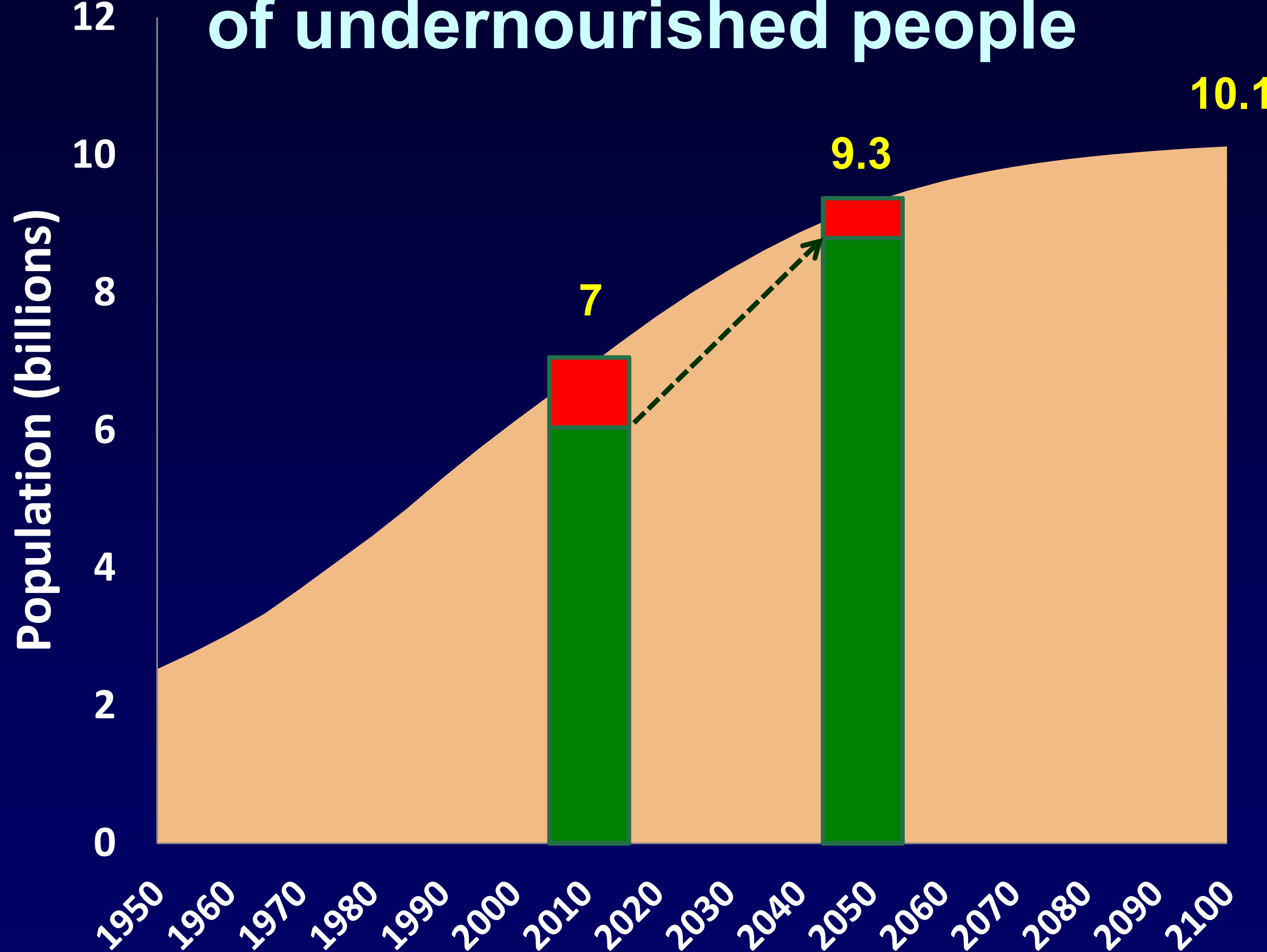
Currently: 2B people are undernourished



Situation: Only maintain current food supply



Desired Situation: Reduced no. of undernourished people



Summary

- Capture of solar energy during season after-harvest and before-planting (primarily south of I-80)
- Biomass roughly equivalent to current corn stover available
- Concerns over subsequent crop yields need to be addressed
- Water impacts being researched

Thank you!