Carbon, Climate, & Energy Connections Associated with Short Rotation Woody Crops

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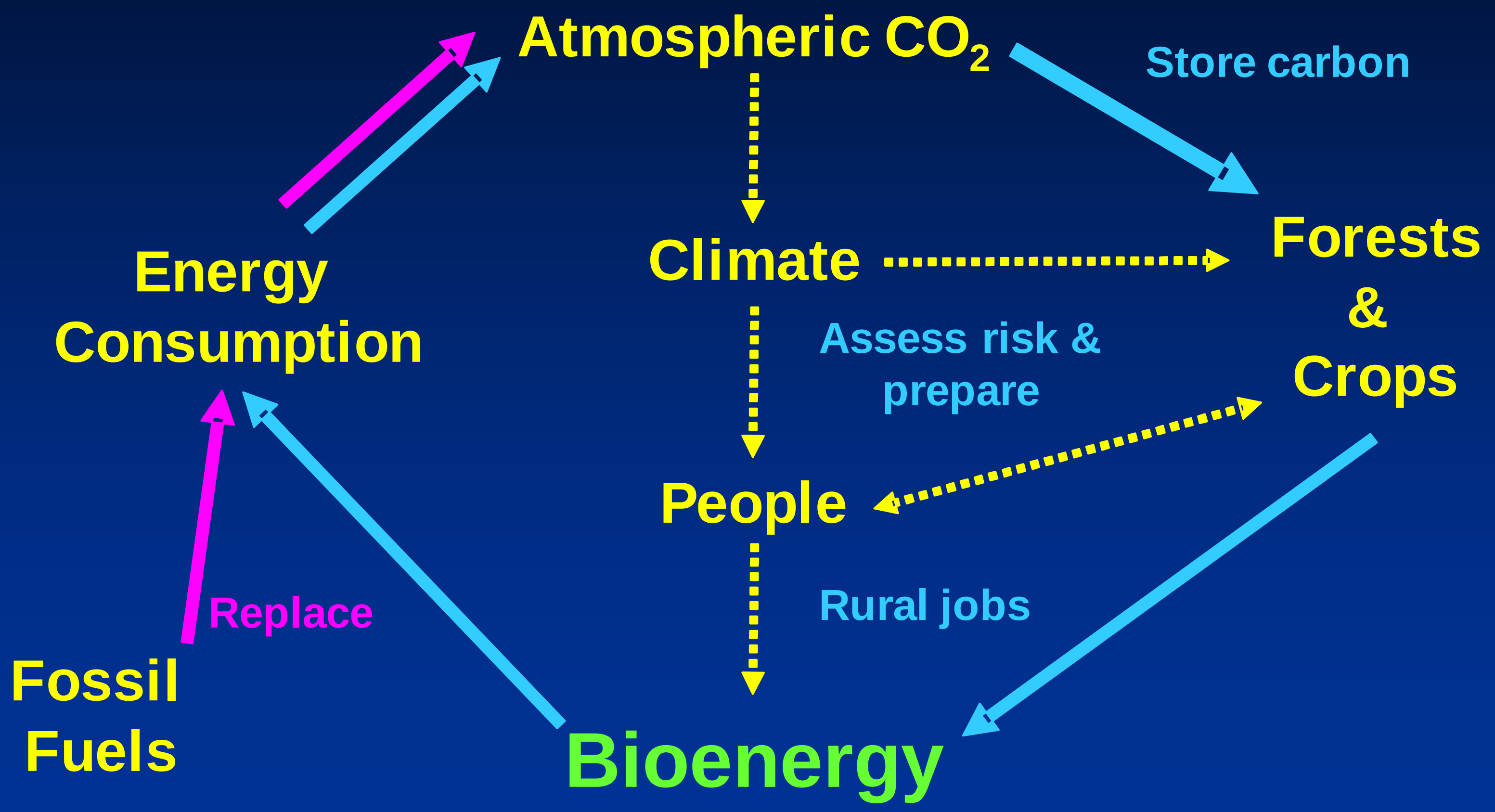
Genetics & Energy Crop Production Unit

Our objective is to use the link between energy, climate, & tree genetics to:

1) develop fast-growing tree crops as energy feedstocks;
2) develop sustainable forest biomass removal strategies;
3) understand climate change effects on natural & plantation forests;
4) fill critical knowledge gaps in 1), 2), & 3).

- Short rotation woody crops for fiber, energy, & phytotechnologies
- Ecological sustainability of using forest residues for energy
- Carbon sequestration & climate change adaptation of conifers

Carbon, Climate, & Energy



Atmospheric CO_2

Store carbon

Energy Consumption

Climate

Forests & Crops

Assess risk & prepare

People

Replace

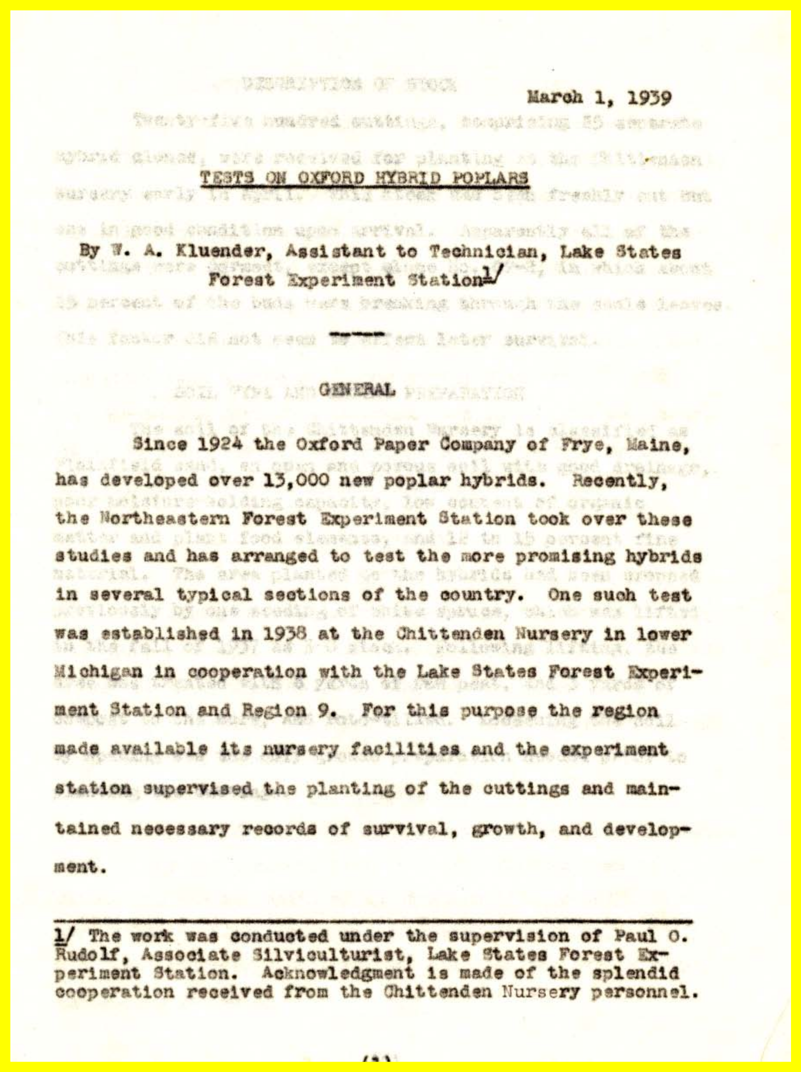
Rural jobs

Fossil Fuels

Bioenergy

Poplar Genetics Research

- **Northeastern - 1920's**
  - 1924 to 1939: 13,000 hybrids
- **Lake States**
  - 1950's (IL), 1960's (MN), 1980's (IA & WI)
- **Pacific Northwest - 1960's**
- **USFS**
  - 1937 - 1940: 25 Oxford Paper Company varieties planted in lower Michigan
  - 1950: LSFES rejected Schreiner's idea for collaborative study
  - 1983: Poplar genetics research began



March 1, 1939

TESTS ON OXFORD HYBRID POPLARS

By W. A. Kluender, Assistant to Technician, Lake States
Forest Experiment Station[1]

GENERAL

Since 1924 the Oxford Paper Company of Frye, Maine, has developed over 13,000 new poplar hybrids. Recently, the Northeastern Forest Experiment Station took over these studies and has arranged to test the more promising hybrids in several typical sections of the country. One such test was established in 1938 at the Chittenden Nursery in lower Michigan in cooperation with the Lake States Forest Experiment Station and Region 9. For this purpose the region made available its nursery facilities and the experiment station supervised the planting of the cuttings and maintained necessary records of survival, growth, and development.

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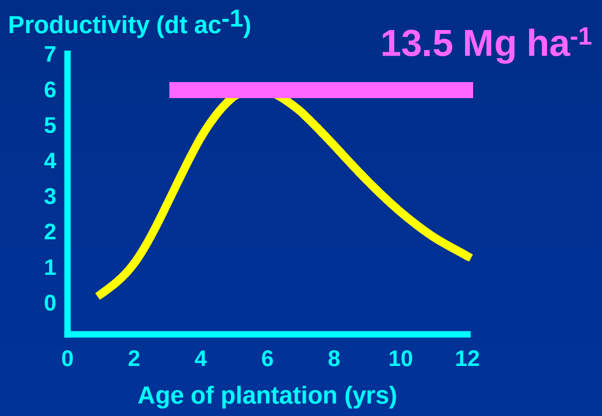
[1] The work was conducted under the supervision of Paul O. Rudolf, Associate Silviculturist, Lake States Forest Experiment Station. Acknowledgment is made of the splendid cooperation received from the Chittenden Nursery personnel.

Why Poplars?

- Broad economic & environmental benefits
- Well-studied (silviculture, physiology, & genetics)
- Base populations exhibit tremendous diversity
- Grown on marginal lands not suitable for agriculture
- Very productive



Why Poplars?

	Realized Productivity
Switchgrass	20 Mg ha^{-1} yr^{-1}
Willow	18 Mg ha^{-1} yr^{-1}
Poplar	16 Mg ha^{-1} yr^{-1}

Potential Productivity
>22 Mg ha^{-1} yr^{-1}

Depends on genotype environment interactions

15-Year-Old Poplar

Arlington (1995)

Hybrid Aspen

‘Crandon’ (*P. alba* *P. grandidentata*)

- * Discovered in 1950’s
- * 10.3 Mg ha^{-1} yr^{-1} at 6 yrs
- * 24.0 Mg ha^{-1} hr^{-1} at 10 yrs

32 Hybrids

- * 17 to 26 Mg ha^{-1} yr^{-1} at 11 yrs
- * 190,000 to 300,000 sprouts ha^{-1}

Hall, R.B. 2008. Woody bioenergy systems in the United States. NRS-GTR-P-31.

Additional Advantages

- **Energy per biomass unit:**

  $1.9\ \ 10^{10}$ to $2.0\ \ 10^{10}$ J Mg^{-1} (16.5 to 17.2 MBtu dt^{-1})

- **Energy returned on energy invested (EROEI)**
- **Can be stored on the stump until harvest**
- **Harvest throughout the year**
- **Minimal fertilization**
- **Extended haul distances**
- **Used in crop rotations to improve soil tilth**
- **Elevated rates of soil carbon storage**
- **Superior genotypes replace existing clones**

Cellulose	2 to 55
Willow	13
Poplar	12
Sugar Cane	8
Switchgrass	5.4
Soybean	2.5
Corn	1.34

Sources: 1.) http://ngm.nationalgeographic.com/2007/10/biofuels/biofuels-interactive.
2.) Schmer et al. 2008. Net energy of cellulosic ethanol from switchgrass. PNAS 105(2):464-469.

Traditional Products

- Pulpwood
- Chips (oriented strand board)
- Engineered Lumber Products
- Veneer

Critical Reviews in Plant Sciences, 24:1–21, 2005
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ISSN: 0735-2689 print / 1549-7836 online
DOI: 10.1080/07352680590910393

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Bioenergy Crops and Carbon Sequestration

R. Lemus and R. Lal
Carbon Management and Sequestration Center, The Ohio State University, Columbus, OH

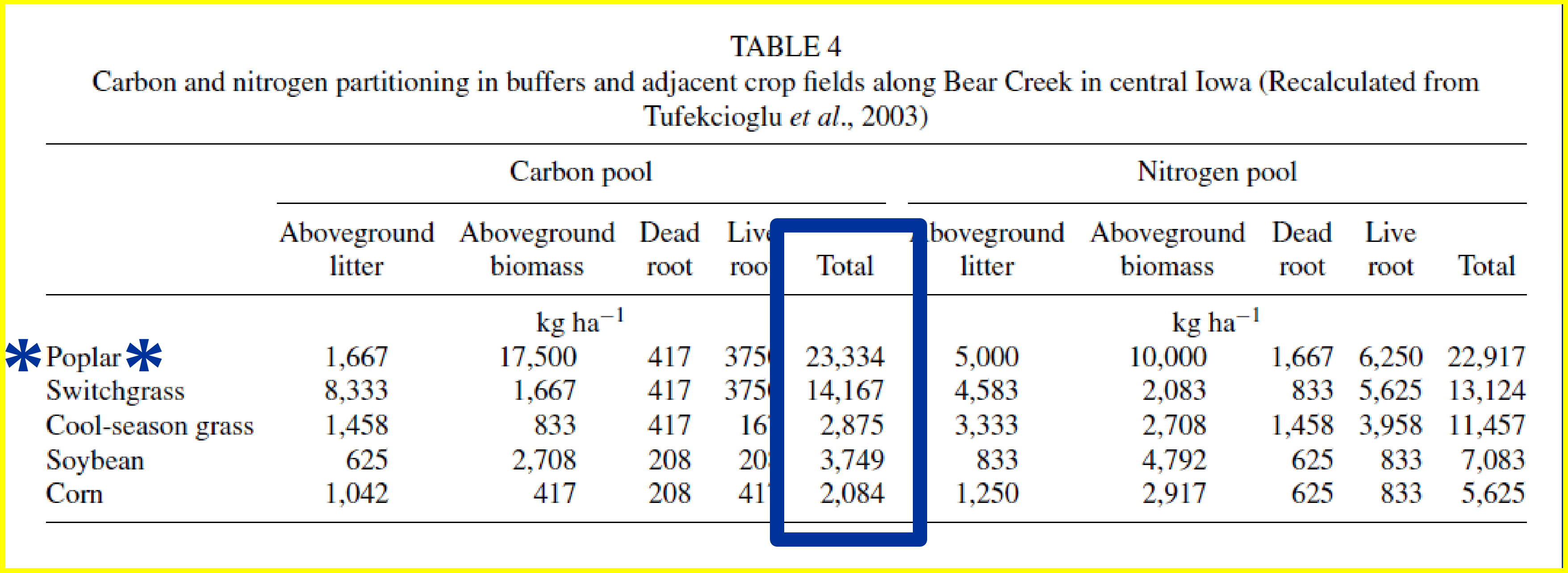

TABLE 4
Carbon and nitrogen partitioning in buffers and adjacent crop fields along Bear Creek in central Iowa (Recalculated from Tufekcioglu *et al.*, 2003)

	Carbon pool					Nitrogen pool				
	Aboveground litter	Aboveground biomass	Dead root	Liv roo	Total	boveground litter	Aboveground biomass	Dead root	Live root	Total
		kg ha^{-1}					kg ha^{-1}			
✱ Poplar ✱	1,667	17,500	417	375	23,334	5,000	10,000	1,667	6,250	22,917
Switchgrass	8,333	1,667	417	375	14,167	4,583	2,083	833	5,625	13,124
Cool-season grass	1,458	833	417	16	2,875	3,333	2,708	1,458	3,958	11,457
Soybean	625	2,708	208	20	3,749	833	4,792	625	833	7,083
Corn	1,042	417	208	41	2,084	1,250	2,917	625	833	5,625

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Bioenergy Crops and Carbon Sequestration

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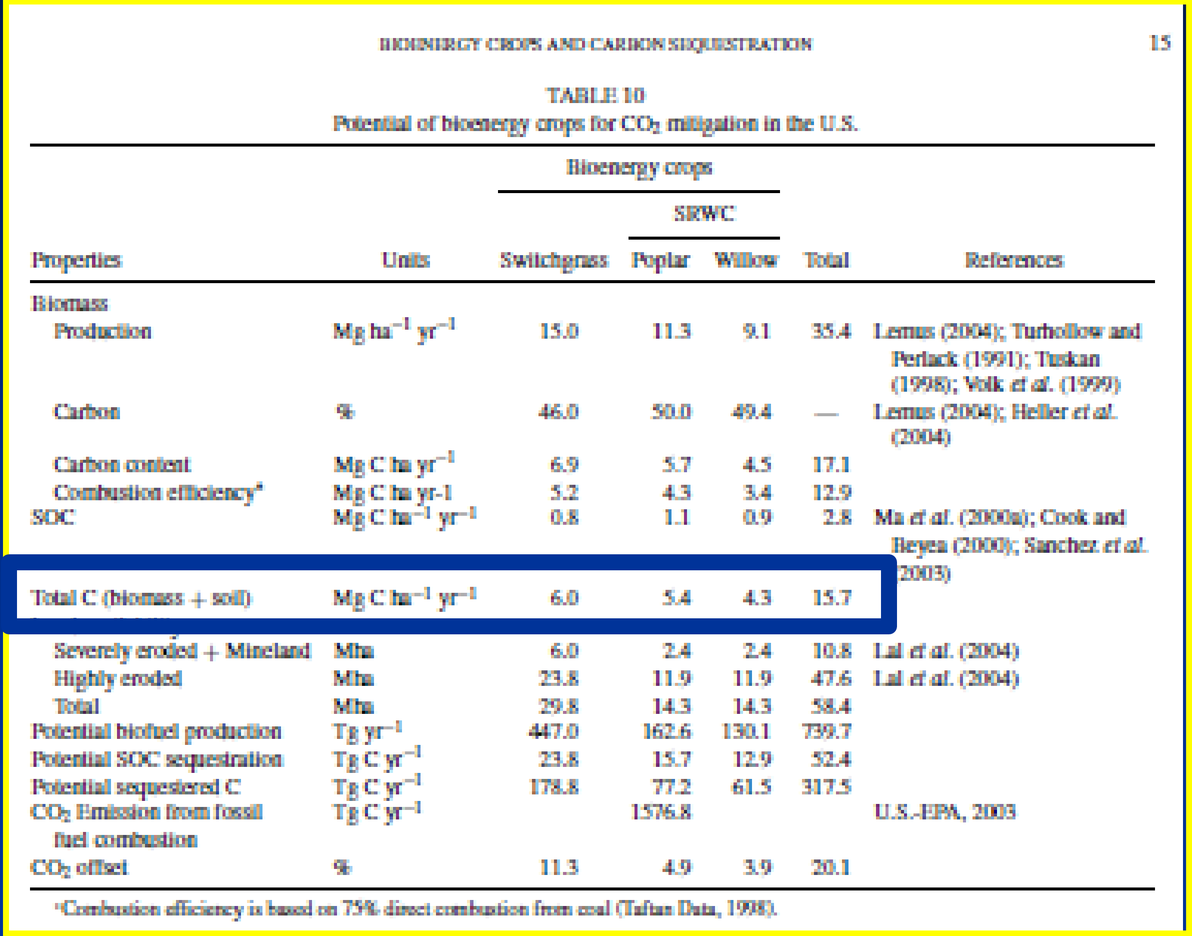


TABLE 10
Potential of bioenergy crops for CO_2 mitigation in the U.S.

		Bioenergy crops				
			SRWC			
Properties	Units	Switchgrass	Poplar	Willow	Total	References
Biomass						
Production	Mg ha^{-1} yr^{-1}	15.0	11.3	9.1	35.4	Lemus (2004); Turhollow and Perlack (1991); Tuskan (1998); Volk *et al.* (1999)
Carbon	%	46.0	50.0	49.4	—	Lemus (2004); Heller *et al.* (2004)
Carbon content	Mg C ha yr^{-1}	6.9	5.7	4.5	17.1	
Combustion efficiency^{a}	Mg C ha yr-1	5.2	4.3	3.4	12.9	
SOC	Mg C ha^{-1} yr^{-1}	0.8	1.1	0.9	2.8	Ma *et al.* (2000a); Cook and Beyea (2000); Sanchez *et al.* (2003)
Total C (biomass + soil)	Mg C ha^{-1} yr^{-1}	6.0	5.4	4.3	15.7	
Severely eroded + Mineland	Mha	6.0	2.4	2.4	10.8	Lal *et al.* (2004)
Highly eroded	Mha	23.8	11.9	11.9	47.6	Lal *et al.* (2004)
Total	Mha	29.8	14.3	14.3	58.4	
Potential biofuel production	Tg yr^{-1}	447.0	162.6	130.1	739.7	
Potential SOC sequestration	Tg C yr^{-1}	23.8	15.7	12.9	52.4	
Potential sequestered C	Tg C yr^{-1}	178.8	77.2	61.5	317.5	
CO_2 Emission from fossil fuel combustion	Tg C yr^{-1}		1576.8			U.S.-EPA, 2003
CO_2 offset	%	11.3	4.9	3.9	20.1	

[a] Combustion efficiency is based on 75% direct combustion from coal (Tafian Data, 1998).

Soil Carbon

- Soil C dynamics during conversion to poplar SWRCs are conflicted (Cowie et al. 2006)
  - Rapid declines immediately after conversion (Grigal & Berguson 1998, Hansen 1993)
  - Minimal differences (Coleman et al. 2004)

MORE WITH TREES OVER TIME

* Cowie AL, et al. (2006) Mit Adapt Strat Glob Change 11:979-1002
* Grigal DF, Berguson WE (1998) Biomass Bioenergy 14:371-377
* Hansen EA (1993) Biomass Bioenergy 5:431-436
* Coleman MD, et al. (2004) Env Mgmt 33:S299-S308

Soil Carbon

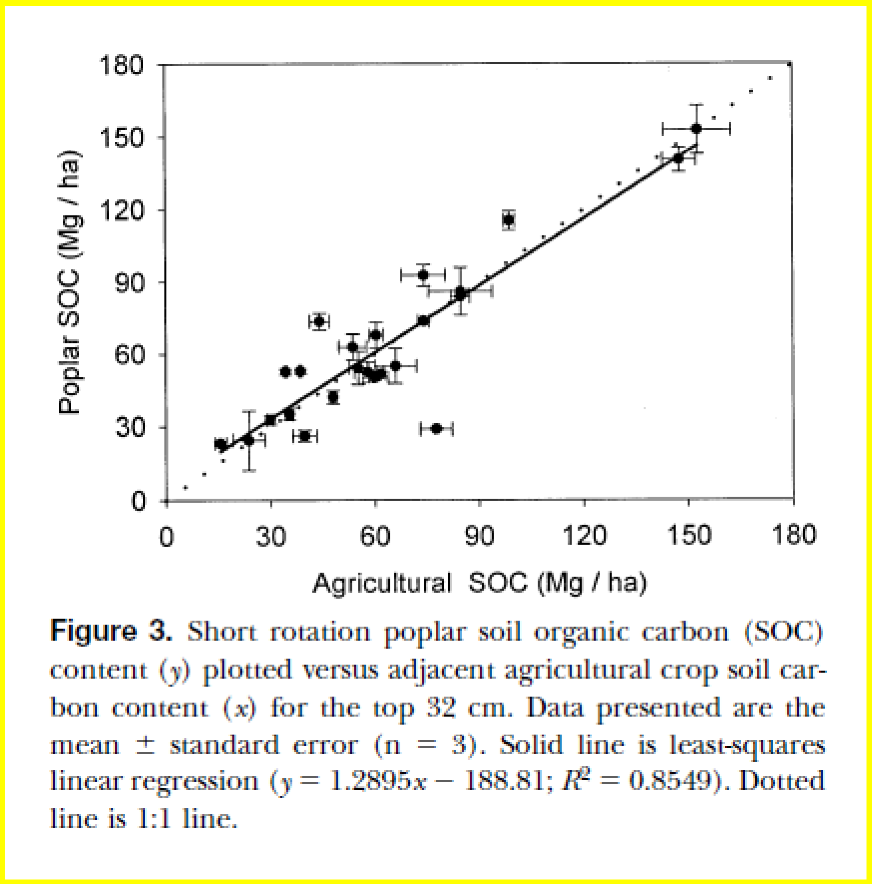


Figure 3. Short rotation poplar soil organic carbon (SOC) content (y) plotted versus adjacent agricultural crop soil carbon content (x) for the top 32 cm. Data presented are the mean ± standard error (n = 3). Solid line is least-squares linear regression ($y = 1.2895x - 188.81$; $R^2 = 0.8549$). Dotted line is 1:1 line.

Coleman et al. (2004)

Grigal & Berguson (1998)

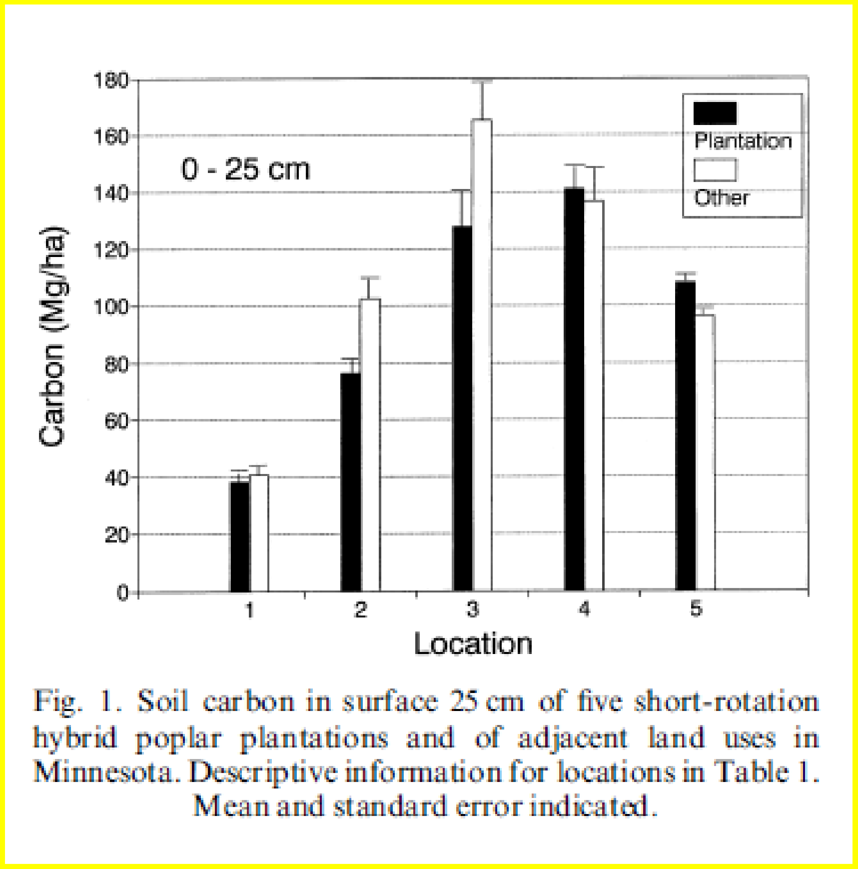
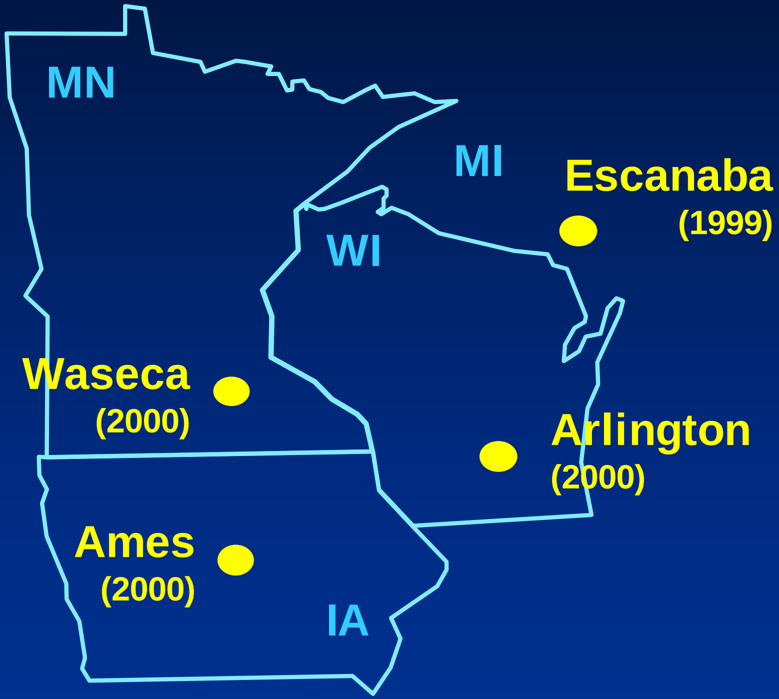
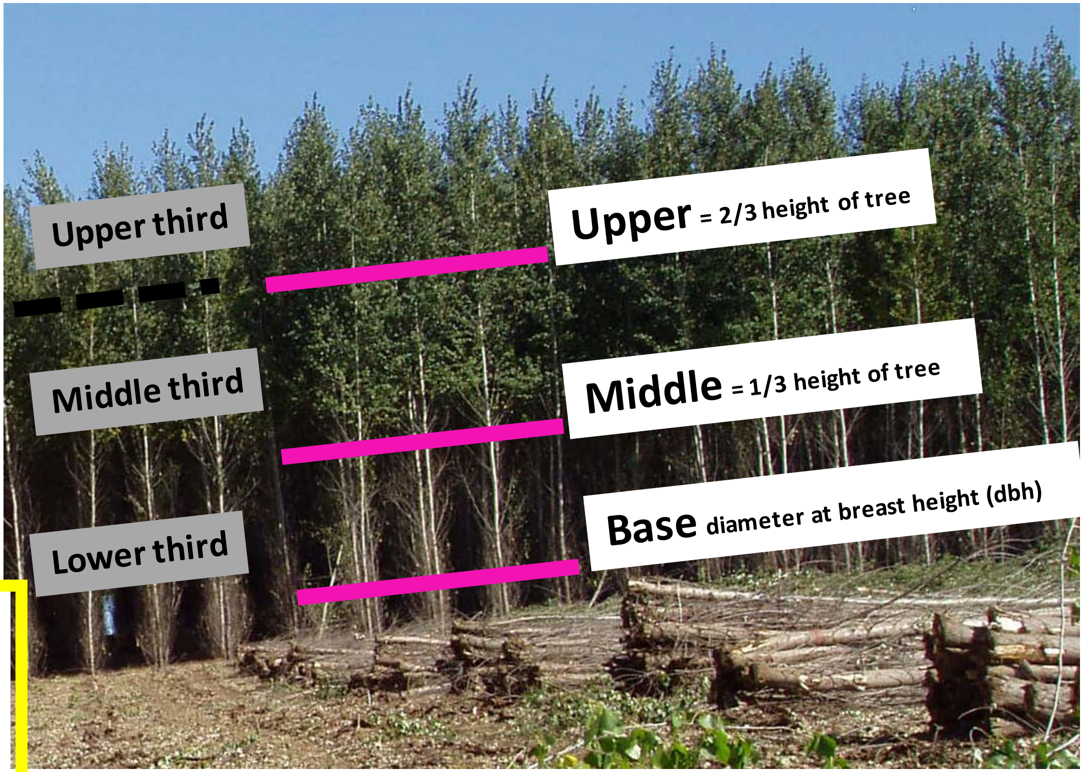


Fig. 1. Soil carbon in surface 25 cm of five short-rotation hybrid poplar plantations and of adjacent land uses in Minnesota. Descriptive information for locations in Table 1. Mean and standard error indicated.

Aboveground Carbon Stocks



Position of Three Stem Cookies



Tree Top

Tree Bole

Upper third

Middle third

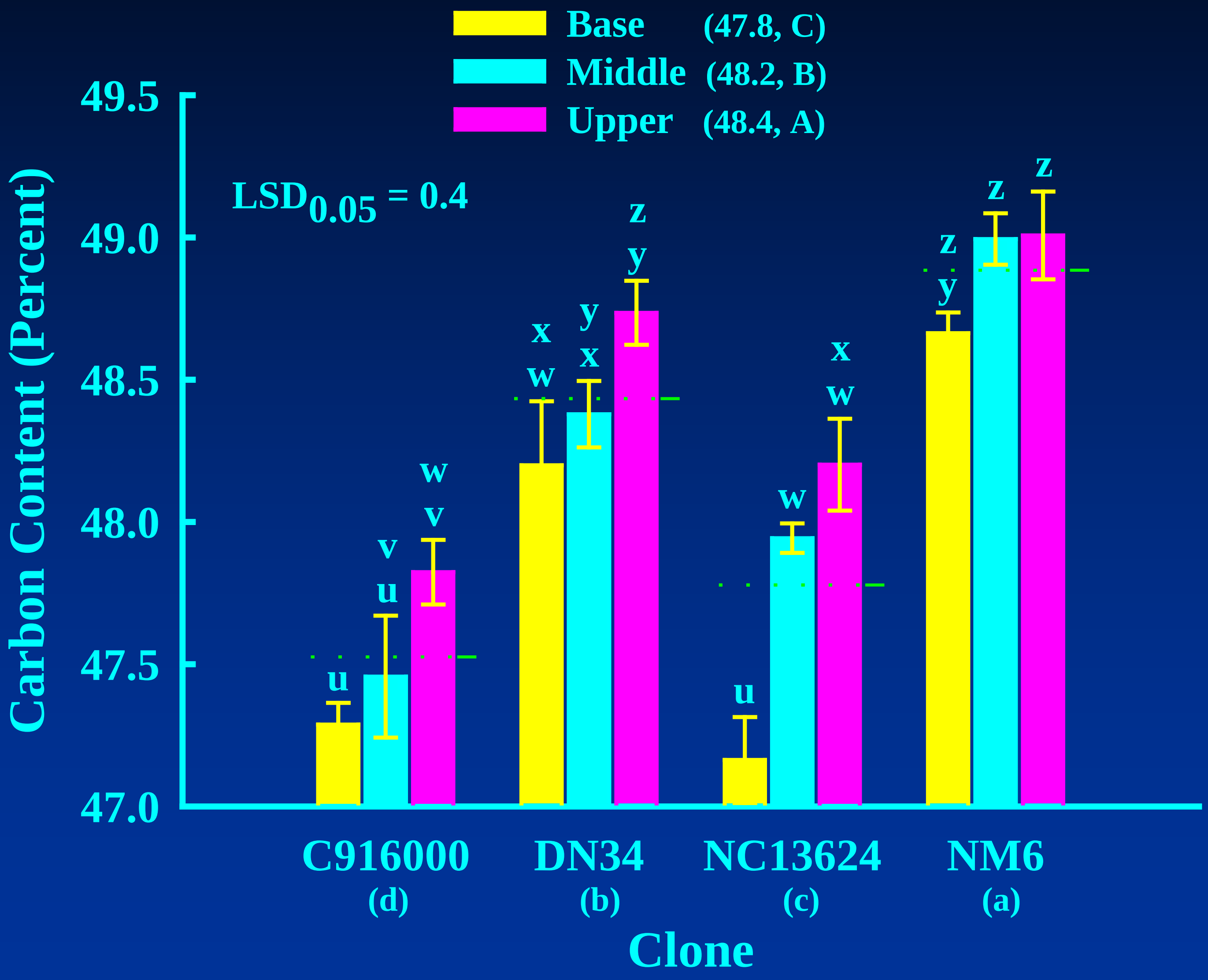
Lower third

Upper = 2/3 height of tree

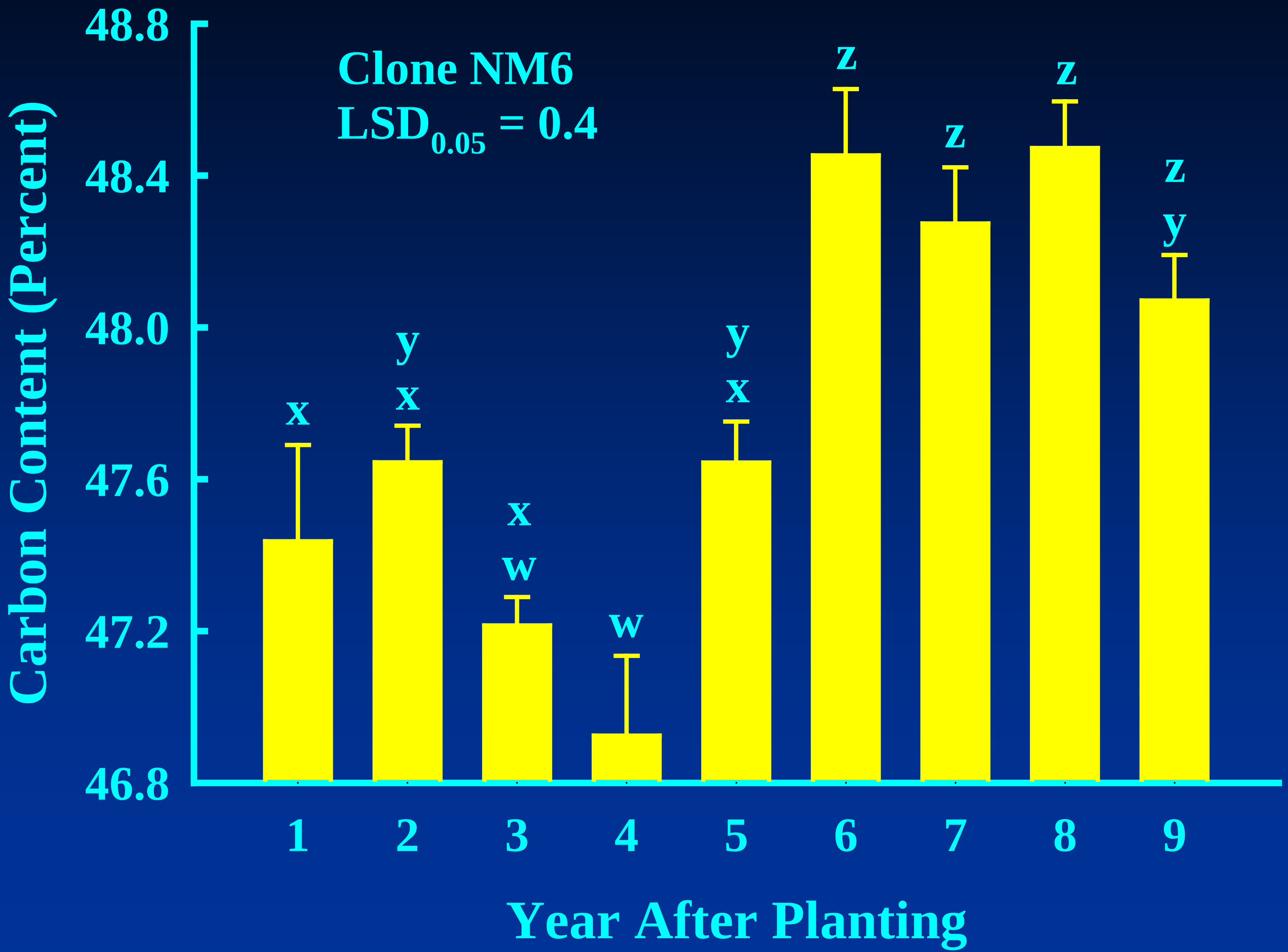
Middle = 1/3 height of tree

Base diameter at breast height (dbh)

Positional Effects



Tree-ring Analysis

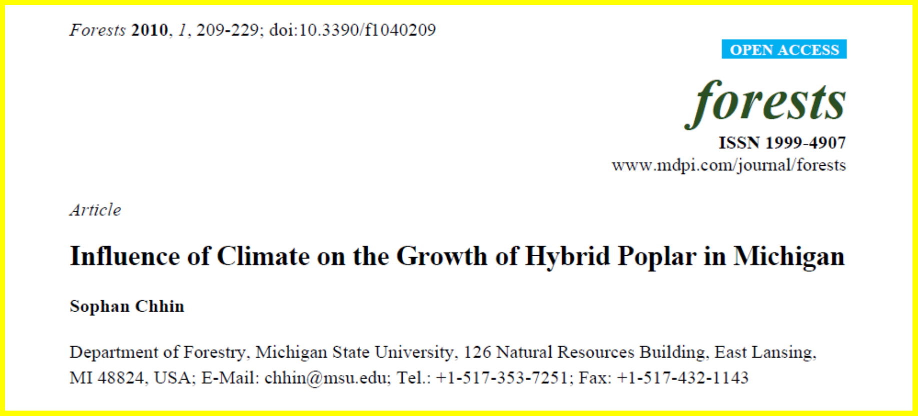


Climate

- Global average surface temperatures have increased by 0.74 °C from 1906 to 2005 (IPCC 2007)
- 11 of 12 years between 1995 & 2006 are ranked within the 12 warmest since 1850 (1998 & 2005 are warmest)
- Projections of climate change based on general circulation models & different emission scenarios of greenhouse gases indicate a further warming of 1.1 to 6.4 °C by the end of the 21st century (IPCC 2007)
- Regional climate forecasts for the Great Lakes Region indicate that average temperatures will rise 3 to 11 °C in the summer & 3 to 7 °C in the winter (Kling et al. 2003)

Chhin, S. 2010. Influence of climate on the growth of hybrid poplar in Michigan. Forests, 1: 209-229.

Climate-Growth Relationships



Forests **2010**, *1*, 209-229; doi:10.3390/f1040209

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forests
ISSN 1999-4907
www.mdpi.com/journal/forests

Article

Influence of Climate on the Growth of Hybrid Poplar in Michigan

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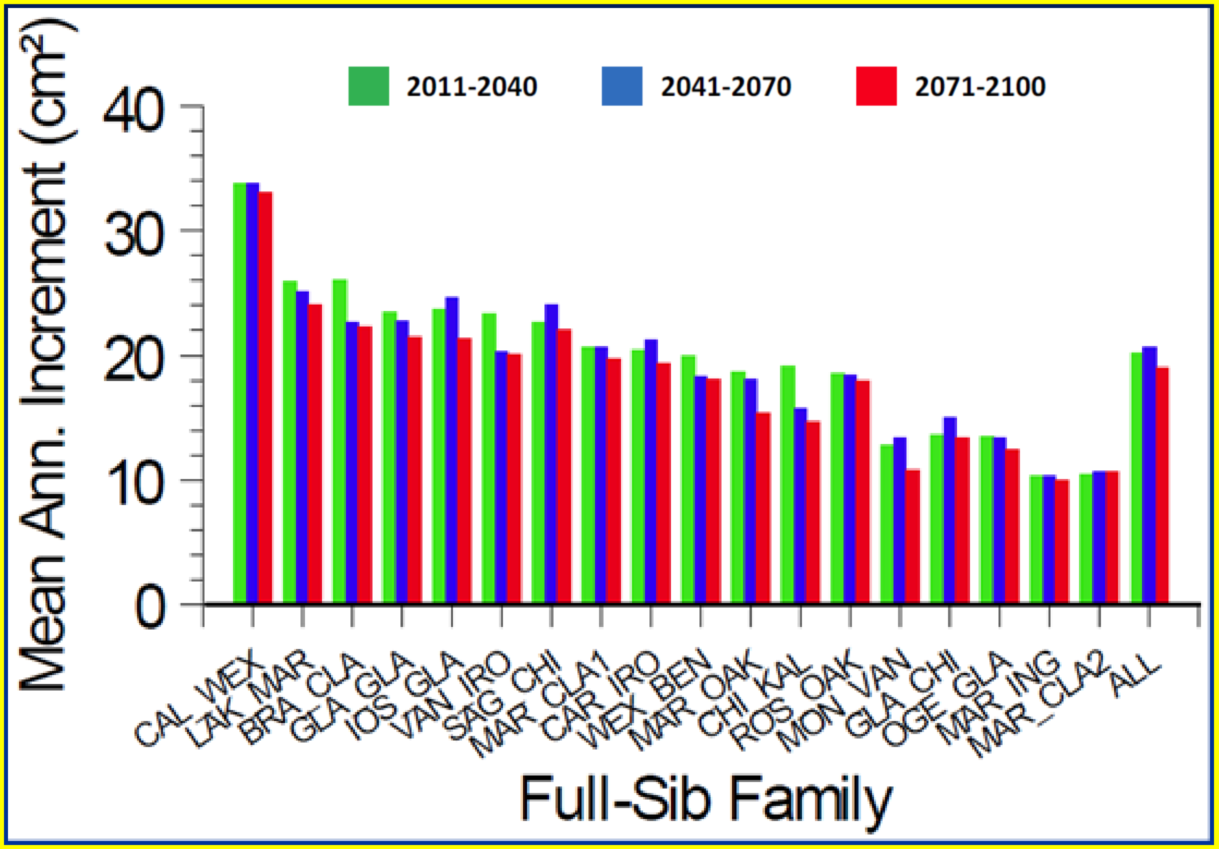
- Tree-ring analysis used to retrospectively assess sensitivity to climatic stressors

Growth was mainly affected by the degree of late summer to fall moisture stress in both the current & previous growth season

Source: S. Chhin; Michigan State University.

Climate-Growth Relationships

Future growth projections of 18 full-sib hybrid poplar families under a future climate change scenario (based on IPCC A1B emission scenario) of a moisture index (precipitation minus potential evapotranspiration) for three 30-year periods in the 21st century



Source: S. Chhin; Michigan State University (unpublished data).

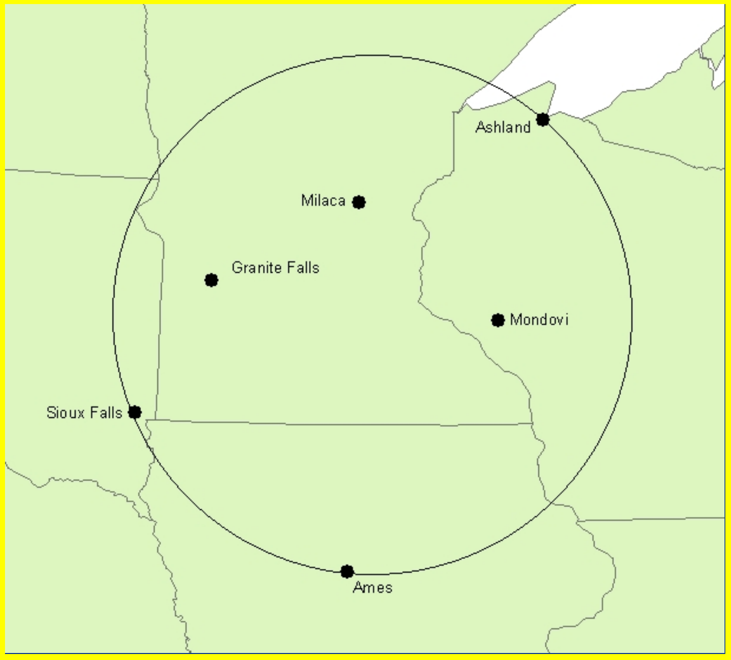
Climate-Growth Relationships

Objectives:

1. Develop a simple, climate-based model of hybrid poplar growth for the north-central United States
2. Use the model to estimate the potential impact of climate change on tree growth

Model Development:

- Modeled tree height based on age, precipitation, & temperature
- Used 3 sites for model development (Ames, Ashland, Sioux Falls) & 3 others for validation (Milaca, Mondovi, Granite Falls)



OBJ. 1: PRECIPITATION IS KEY

Source: W. Headlee, Iowa State University (unpublished data).

Climate-Growth Relationships

Predictions of Future Conditions:

Scenario 1: temp increase of 5 °F, precip increase of 25%

(per Hadley model – National Assessment Synthesis Team, 2001)

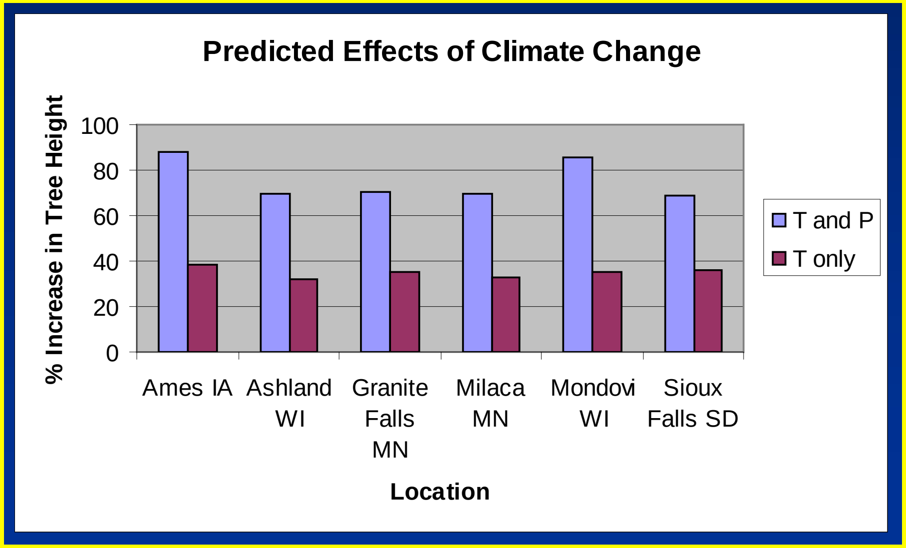
Scenario 2: temp increase of 5 °F, no precip change

(simulate “no effective increase” in precip that might occur if increases come in form of high-intensity rain events)

Increase in Tree Height:

Scenario 1 = 68 to 88%

Scenario 2 = 32 to 39%



OBJ. 2: PRECIPITATION DISTRIBUTION IS KEY

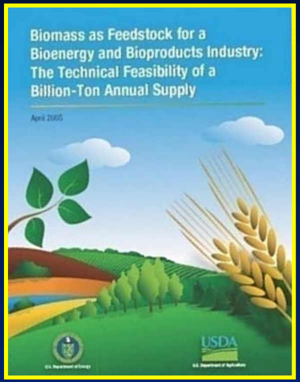
Source: W. Headlee, Iowa State University (unpublished data).

Energy

- Biofuels
- Bioenergy
- Bioproducts

Renewable Fuel Standard

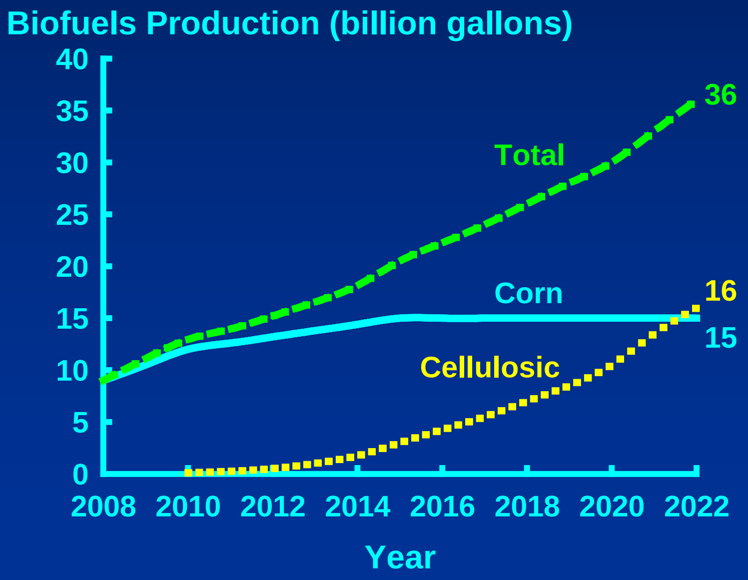
Energy Independence & Security Act of 2007



Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

April 2005

- Annual production of 36 billion gallons of biofuels by 2022
- Ethanol production from corn capped at 15 billion gal yr^{-1}
- Remaining 21 billion gallons from advanced biofuels
- 16 billion gallons from cellulosic biofuels
- Seven-fold increase in current biomass production from 190 million dry tons to 1.36 billion dry tons
- DOE / USDA goal of replacing 30% petroleum consumption with biofuels by 2030

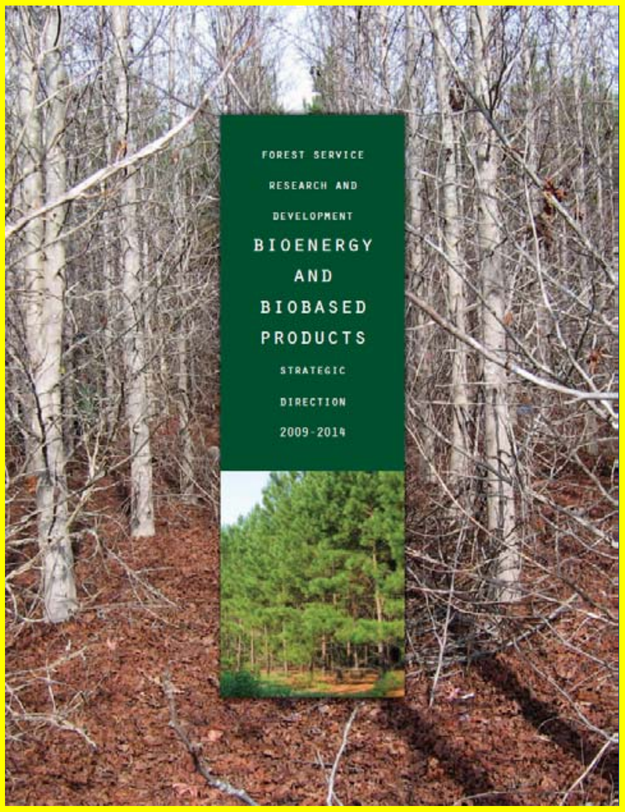


Perlack, R.D. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. DOE-USDA. DOE/GO-102995-2135. ORNL/TM-2005/66

Source: Renewable Fuels Association. http://www.ethanolrfa.org/resource/standard

National Level Activities/Directions

- **FS R&D BIOENERGY & BIOBASED PRODUCTS Strategic Direction (09-14)**
- **Update to Billion Ton Report (2005)**
- **USDA Regional Biomass Research Centers**
- **G20 Summit**



FOREST SERVICE
RESEARCH AND
DEVELOPMENT
BIOENERGY
AND
BIOBASED
PRODUCTS
STRATEGIC
DIRECTION
2009-2014

BIOMASS FEEDSTOCK RESOURCE AVAILABILITY:
UPDATE TO THE BILLION-TON RESOURCE ASSESSMENT

DRAFT

A Study Sponsored by
Office of the Biomass Program
U.S. Department of Energy

July 2010

Prepared by
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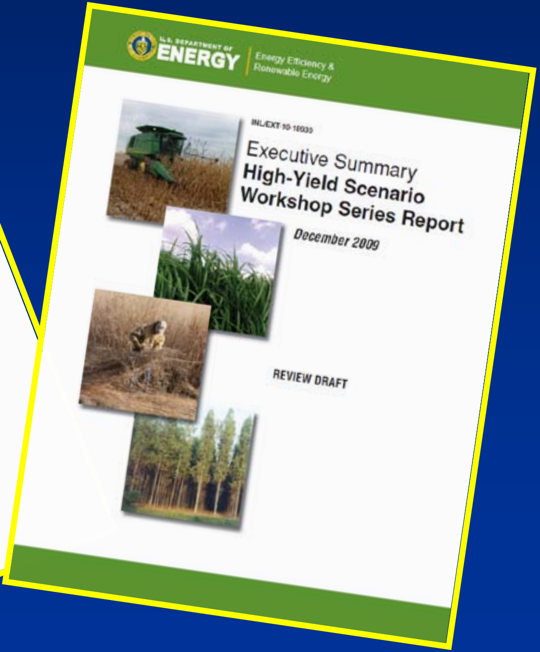


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

INL/EXT-10-18930

Executive Summary
High-Yield Scenario
Workshop Series Report

December 2009

REVIEW DRAFT

Energy from Native Forests

Assessing the environmental sustainability & capacity of forest-based biofuel feedstocks within the Lake States region J. Bradford, S. Fraver, R. Kolka, B. Palik + (Univ. WI, MN, MO)

Impacts of woody biomass harvesting on saproxylic communities, nutrient availability, & productivity in aspen ecosystems J. Bradford, S. Fraver, R. Kolka, B. Palik + (Univ. MN)

Wood energy developments in the Northeast J. Wiedenbeck, B. Adams + (PSU)

Developing biofuels in the Appalachians: what are the limits of sustainability? B. Adams, J. Wiedenbeck + (WVU)

Guidelines for integrating biomass marketing opportunities into restoration of degraded stands S. Stout + (PSU)

A full life-cycle carbon calculator for forest landowners & policy makers in the Northeast M. Twery

NED decision support systems for forest management for multiple values M. Twery

Characterizing lessons learned from federal biomass removal projects P. Jakes

Forest biomass & carbon estimation, information, & data delivery L. Heath

Changes in the Lake States pellet industry from 2005 to 2008 B. Luppold

Impacts of harvesting forest residues for bioenergy on nutrient cycling & community assemblages in northern hardwood forests D. Donner, R. Zalesny + (UW, USGS, R9)

Soil carbon & nutrient cycling in northern hardwood forests R. Zalesny, D. Donner + (UW, USGS, R9)

Energy from Tree Plantations

Influence of alternative biomass cropping systems on short-term ecosystem processes R. Kolka + (ISU)

Breeding & selecting poplar for biofuels, bioenergy, & bioproducts
R. Zalesny + (ISU, MSU, Univ. WI, MN)

Biofuels, bioenergy, & bioproducts from short rotation woody crops
R. Zalesny + (ISU, MSU, Univ. WI, MN)

Land-use, soil health, & water quality changes with woody energy crop production in Wisconsin & Minnesota R. Zalesny, D. Donner

Ecological assessments of bioenergy feedstocks from plantations & forests in the Midwest
R. Zalesny + (ISU, MSU)

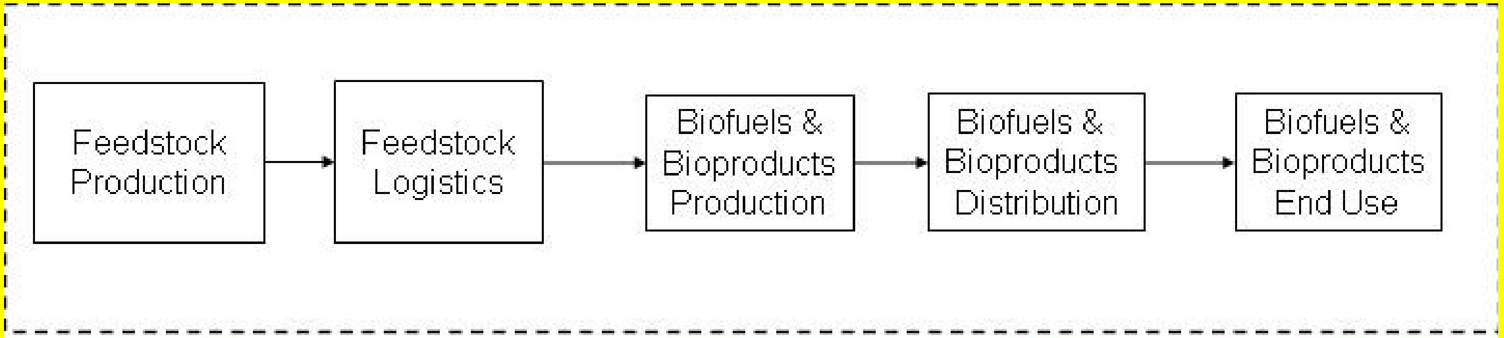
Carbon sequestration potential of poplar energy crops at regional scales R. Zalesny + (ISU, MSU)

High productivity & low recalcitrance poplar for biochemical conversion R. Zalesny + (FPL, ISU, MSU)

Sustainable production of woody energy crops with associated environmental benefits R. Zalesny

Development of technical innovations to reduce impacts of invasive species & enhance energy crop production
R. Zalesny

Energy



Feedstock Production → Feedstock Logistics → Biofuels & Bioproducts Production → Biofuels & Bioproducts Distribution → Biofuels & Bioproducts End Use

Short Rotation
Woody Crops

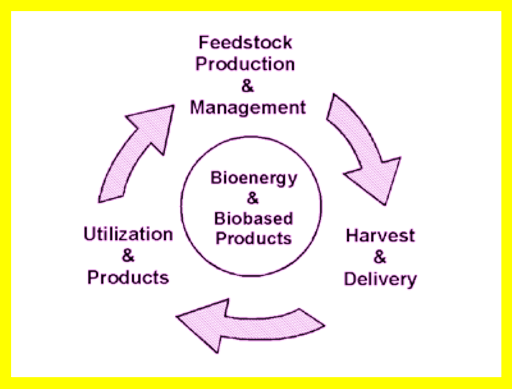
Harvesting
Collecting
Transportation

Manufacturing
Co-firing
Combustion
Gasification
Hydrolysis
Digestion
Pyrolysis
Extraction
Separation

Ethanol
Other Liquid Fuels
Hydrogen
Electricity and Heat
Composites
Specialty Products
New Products
Chemicals
Traditional Products

Transportation
Fuels
Chemicals
Other Products

Forest bioenergy & bioproducts supply chain



Feedstock Production & Management

Harvest & Delivery

Utilization & Products

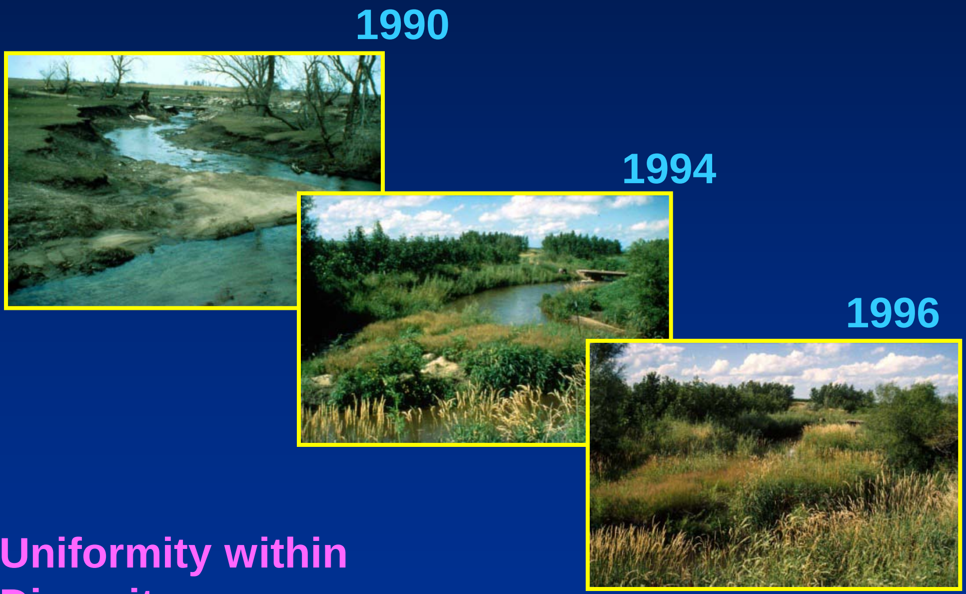
Bioenergy & Biobased Products

Source: USDA National Biofuels Action Plan

Sustainability

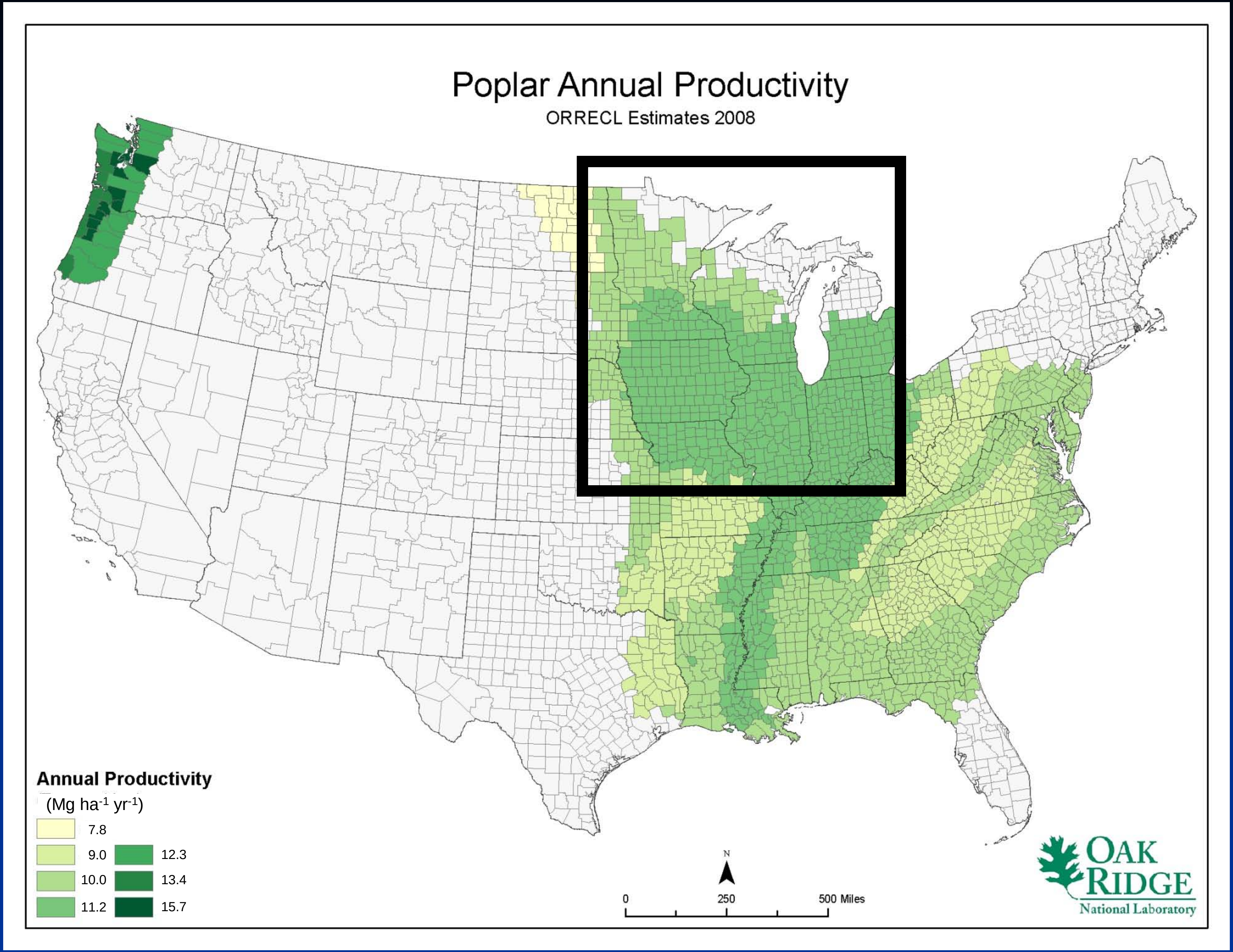
Short rotation woody crops are one of the most sustainable sources of biomass, provided we strategically place them in the landscape & use cultural practices that…

- Conserve soil & water
- Recycle nutrients
- Maintain genetic diversity

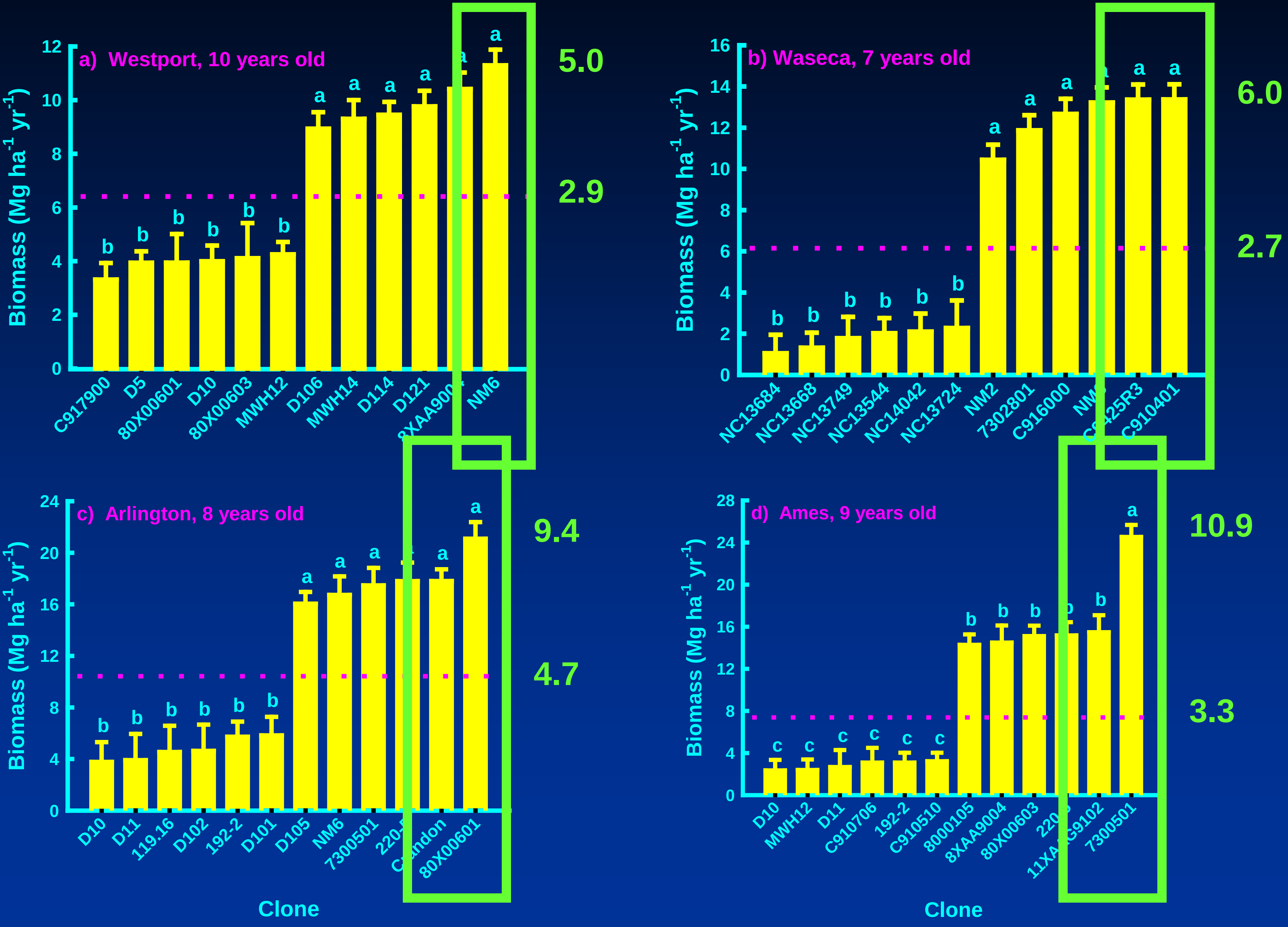


*Uniformity within
*Diversity among
*4 ha clone^{-1}

Hall, R.B. 2008. Woody bioenergy systems in the United States. NRS-GTR-P-31.


Poplar Annual Productivity
ORRECL Estimates 2008
Annual Productivity
(Mg ha^{-1} yr^{-1})
7.8
9.0
10.0
11.2
12.3
13.4
15.7
N
0
250
500 Miles
OAK RIDGE
National Laboratory

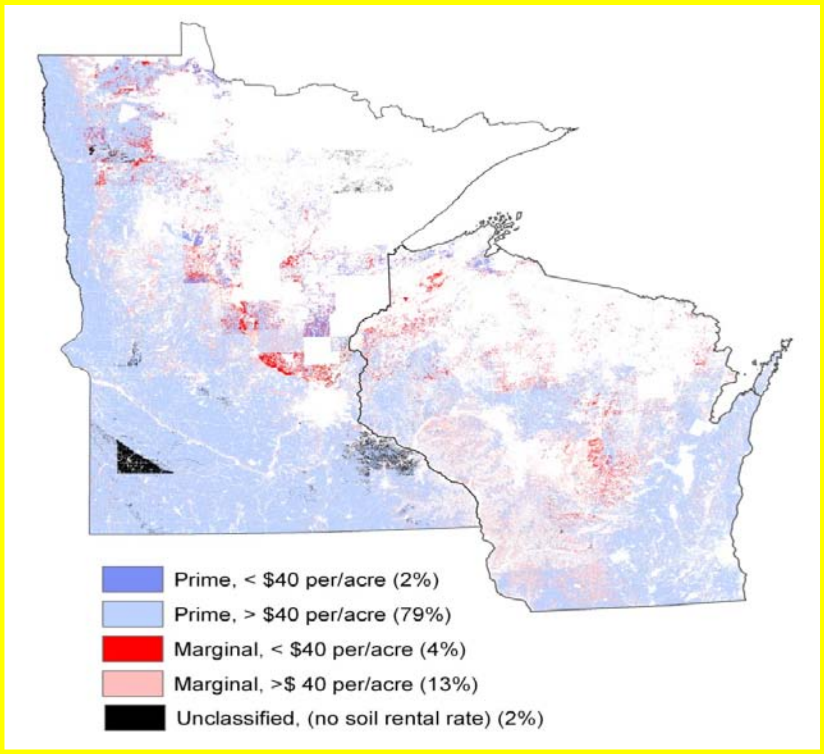
Production Potential



Zalesny, R.S. Jr., et al. 2009. Biomass and genotype × environment interactions of *Populus* energy crops in the Midwestern United States. BioEnergy Research 2:106-122.

Regional Sustainability

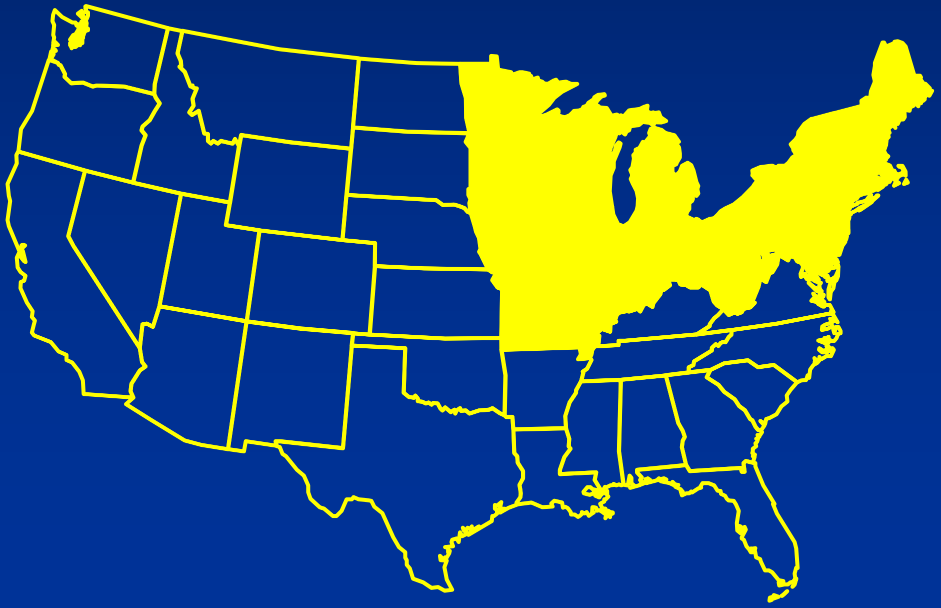
Social ↔ **Economic**



Ecological ↔ **Biological**

Long-Range Goal

Develop a protocol for identifying suitable testing & deployment sites of poplar energy production systems in the Midwest, USA **(& beyond…)**



Northern
RESEARCH STATION
USDA Forest Service

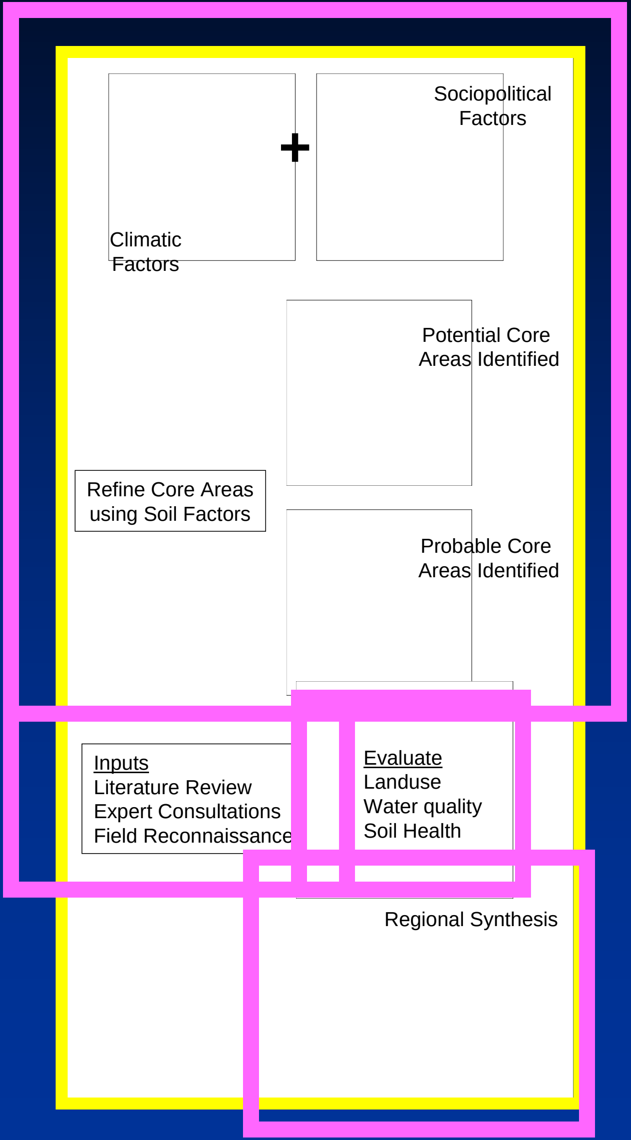
Objectives

1. **Develop coarse & fine resolution digital maps of environmental & sociopolitical constraints to identify candidate core areas**

2. **Construct database of poplar growth & development, apply information within areas**

3. **Evaluate land-use, soil health, & water quality changes within areas**

4. **Synthesize results to assess potential impacts of deploying poplars across region**



Zalesny, R.S. Jr., et al. 2009. Land-use, soil health, & water quality changes w/ woody energy crop production in Wisconsin & Minnesota. WI FOE EERD Proposal.

Map Development

Constraints Considered

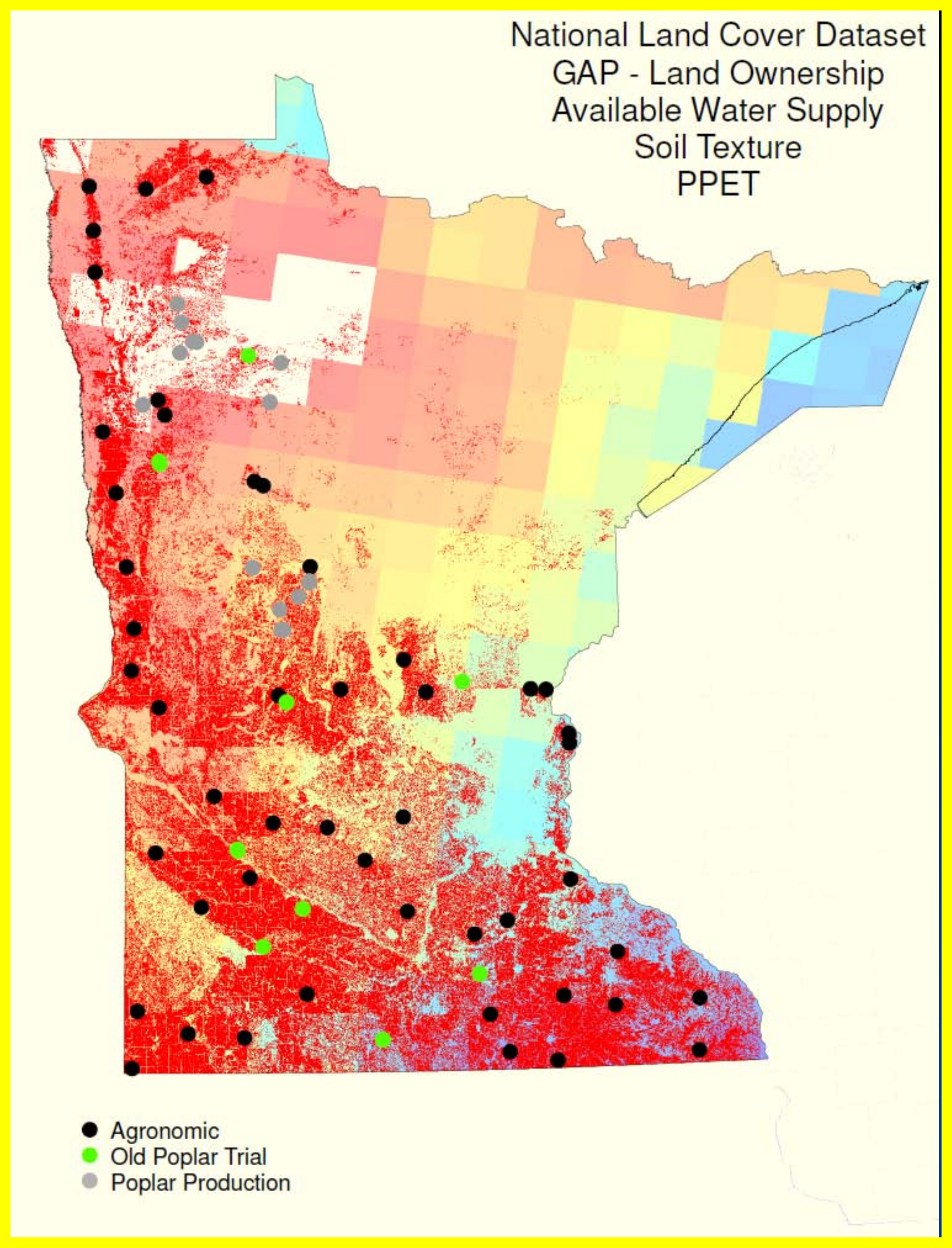
- Land cover class
- Land ownership
- Available water storage capacity
- Water deficit (P – PET)
- Soil texture
- Precipitation / temperature
- Flood frequency
- Depth to bedrock
- Patch size

Map Development

Final Constraints

CONSTRAINTS	DEFINITION OF CONSTRAINTS USED
National Land Cover Dataset (NLCD 2001)	Grassland/Herbaceous, Pasture Hay, Cultivated Crops
GAP Stewardship 2008 (Land Ownership)	Federal, Tribal, State, County (excluded)
Available Water Storage Capacity (SSURGO)	≥7 cm (assuming 0 to 50 cm depth, 0.15 fraction available water)
Precipitation – Potential Evapotranspiration (PPET)	PPET for the months of April and May combined
Soil Texture (SSURGO)	Clay Loam, Coarse Sandy Loam, Coarse Silty, Fine Sandy Loam, Gravelly Loam, Gravelly Sandy Loam, Loam, Loamy Coarse Sand, Loamy Sand, Mixed, Sandy Clay Loam, Sandy Loam, Sandy Over Loam, Silt Loam, Silty, Silty Clay Loam, Very Fine Sandy Loam

Field Sites



- ● **Agronomic**
- ● **Old US DOE poplar trials**
- ● **Production plantings**

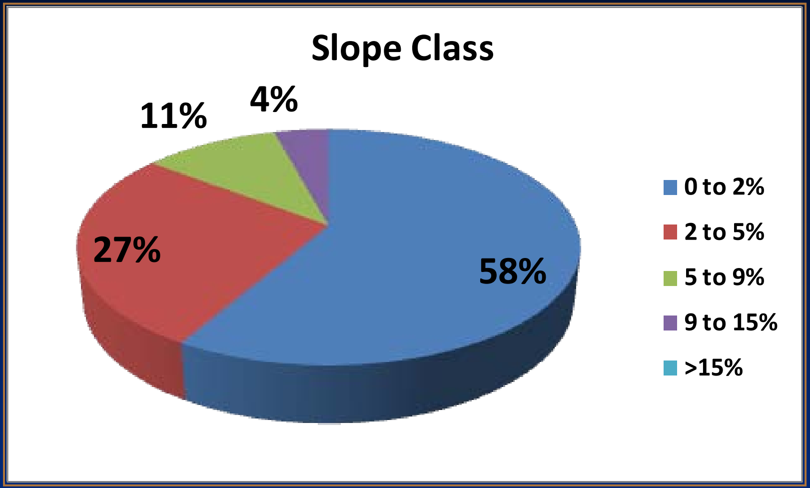
48 agronomic sites

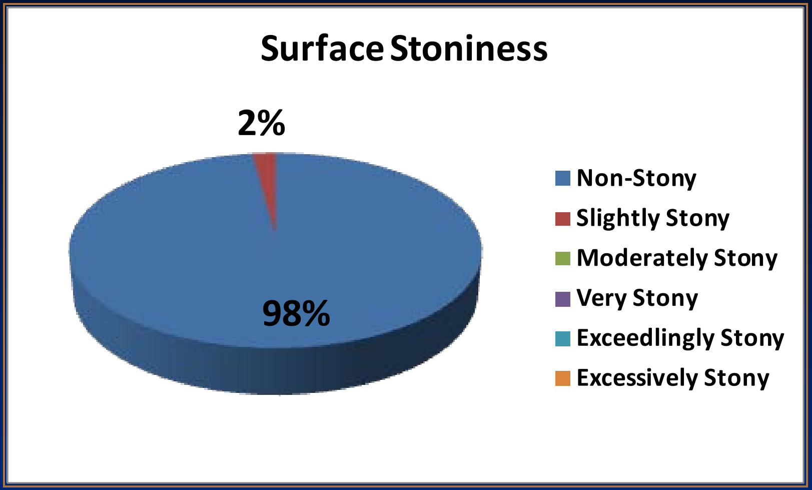
alfalfa, corn, grass, oats,
sod, soybean, sugar beet,
sunflower, tillage radish,
tilled fallow field, & wheat)

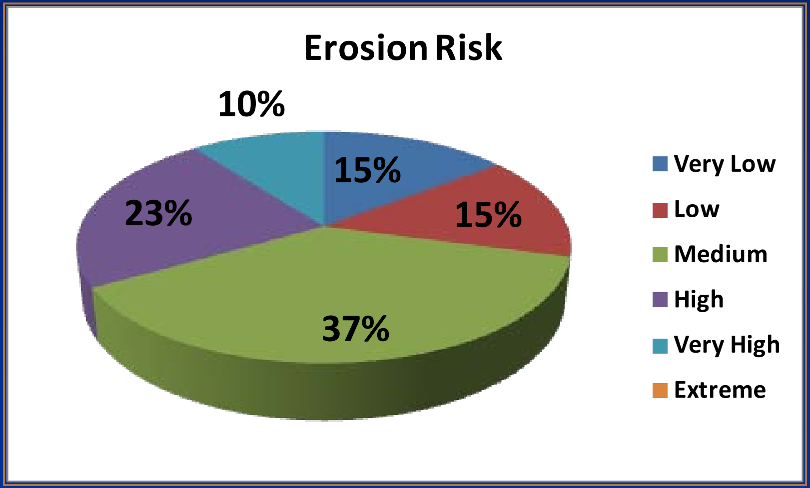
4 cover types = 80%

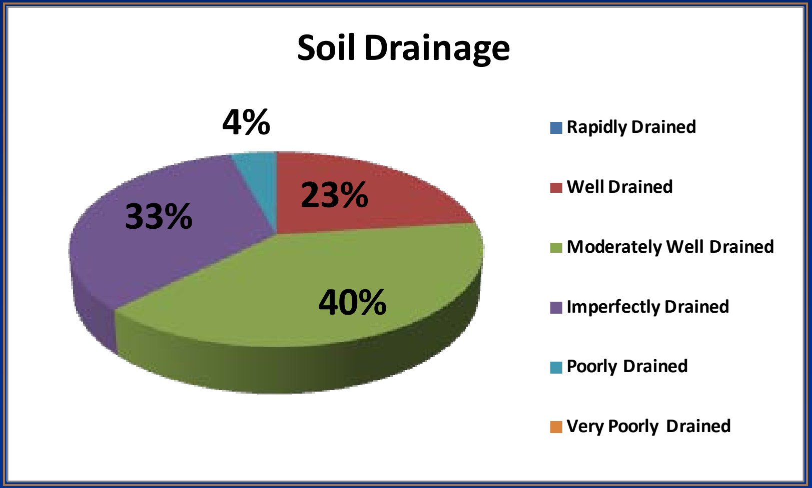
corn (31%)
soybean (23%)
alfalfa (13%)
grass (13%)

Agronomic Site Characterization

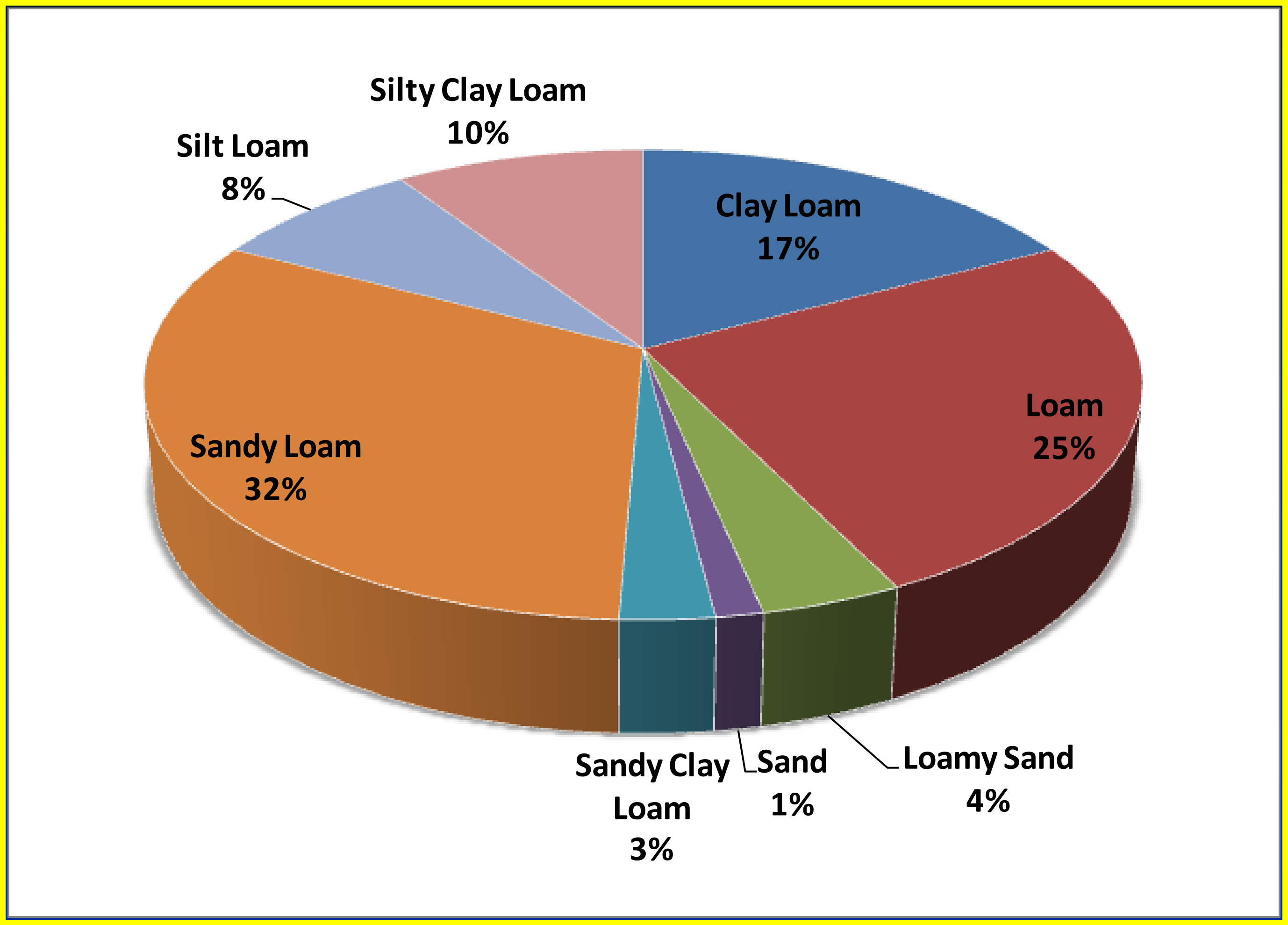






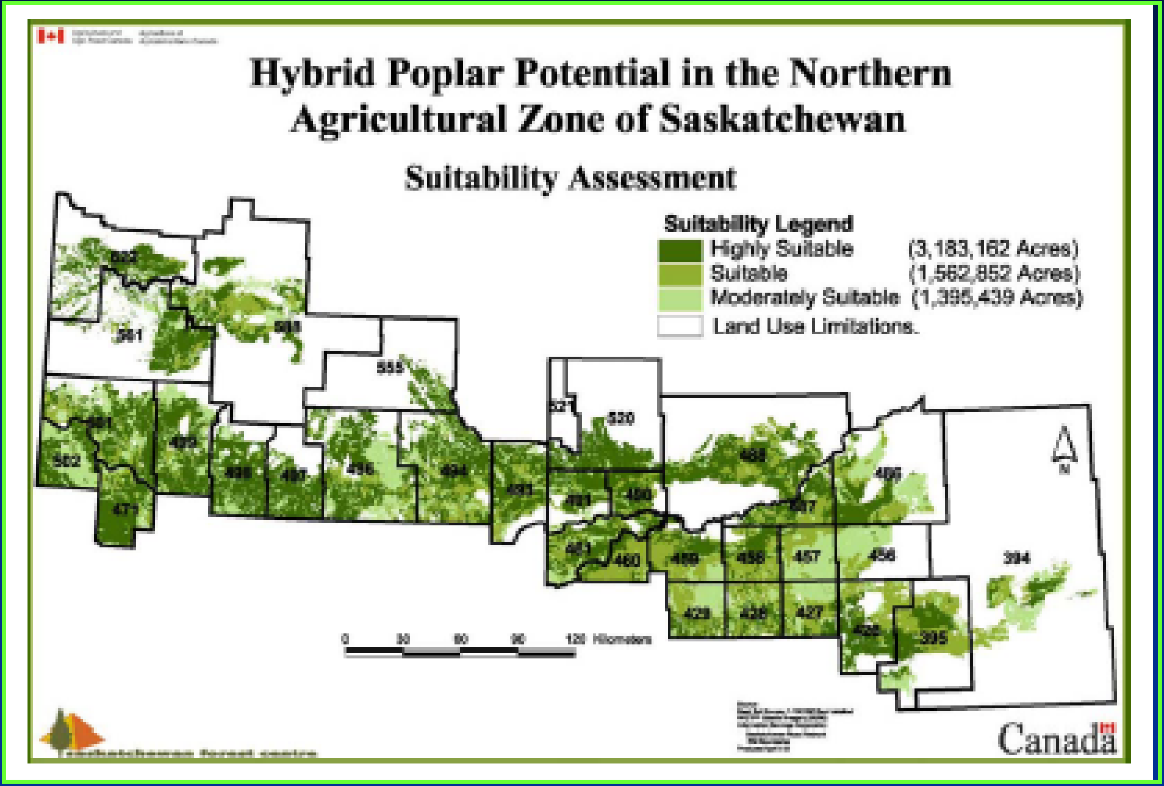


Soil Textures



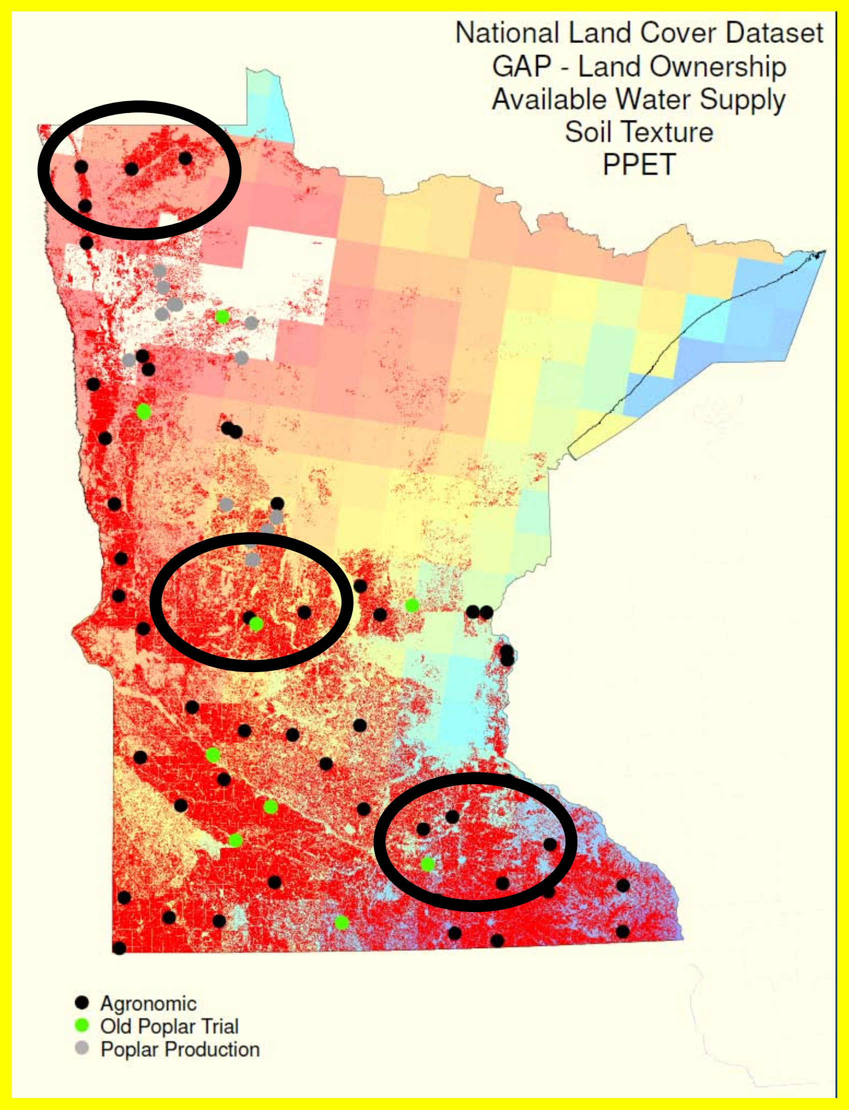
Compare soil from individual sites with GIS data

Poplar Suitability



Predict location of land-use change in addition to estimating quantity of land-use change

Integrated Studies



Enterprise Budgets

Landowner Preferences

Productivity Modeling

Carbon Sequestration

Thank you!

Contact Information

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Acknowledgements
I thank Perdita Spriggs & Stephanie Worley-Firley for hosting me during this seminar.