U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
2017 Project Peer Review

Mapping National Yield Potential for Biomass Crops

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Technology Area Review

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Mapping National Yield Potential for Biomass Crops
Goal, Relevance and Outcome

Resource Assessment Goal

Gain an understanding of the spatial distribution of long-term, potential biomass feedstock resources across the country

Relevance

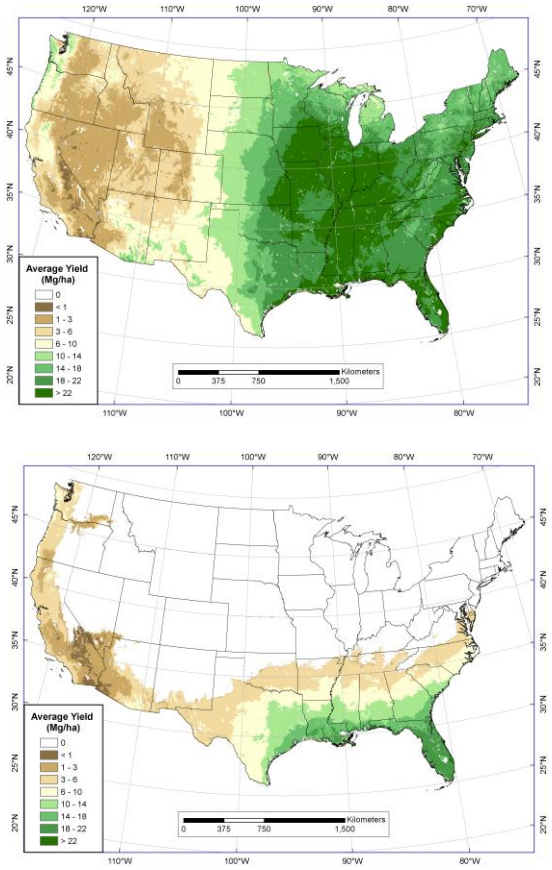
Basic information on the spatial distribution of yield potential for biomass crops is an essential starting point in planning for a bio-economy

Outcome

A series of national geo-referenced grids (maps) that describe potential productivity patterns of biomass crops

Mapping National Yield Potential for Biomass Crops
Overview

- OSU is SGI Western Region GIS Center
- Need for nation-wide biomass mapping, not just regional
- Developed PRISM-ELM for biomass mapping
- Calibrated and validated model with wheat and corn
- Biomass yield data were collected primarily from coordinated Feedstock Partnership trials
- Conducted initial mapping of biomass yields
- Met face-to-face with Parternship agronomists to refine yield data and PRISM-ELM maps
- Produced draft maps for review
- Refined biomass yield maps and delivered to ORNL



Mapping National Yield Potential for Biomass Crops
Challenges

- Need for mapped estimates of long-term production potential for a wide range of biomass crops, prepared in a consistent manner that permits inter-comparison
- Little is known about the environmental tolerances of biomass crops
- Yield histories for biomass crops are limited
- Partnership field trials are coordinated but distributed sparsely and unevenly
- These issues do not lend themselves to a purely statistical approach (insufficient yield data) or a crop modeling approach (many species and varieties, few with detailed information)

Mapping National Yield Potential for Biomass Crops
Approach

- Developed PRISM-ELM, an environmental limitation approach that focuses on basic limits to production presented by climate and soil conditions
- Applied PRISM-ELM to wheat (cool season) and corn (warm season), crops with large amounts of production data, as a calibration and validation tool
- Using wheat and corn as “anchor” species, parameterized PRISM-ELM by ranking biomass crops by perceived temperature optimum and water use efficiency
- Created relative yield maps (0-100%) of biomass crops with PRISM-ELM
- Met with agronomists to determine the most representative yield data and model parameters for each species
- Used statistical relationships between Partnership yield data and relative yield to produce actual yield maps

PRISM-ELM

PRISM Environmental Limitation Model

(PRISM Climate Group at OSU)

- Statistical–process hybrid model that evaluates crop response to environmental constraints
- “Limiting Factor” Approach
- Relative Yield (0 - 100%) =

Lowest production resulting from the following functions:

- Water Balance Model
- Winter Low Temperature Constraint
- Summer High Temperature Constraint
- Soil Properties (pH, salinity, drainage)

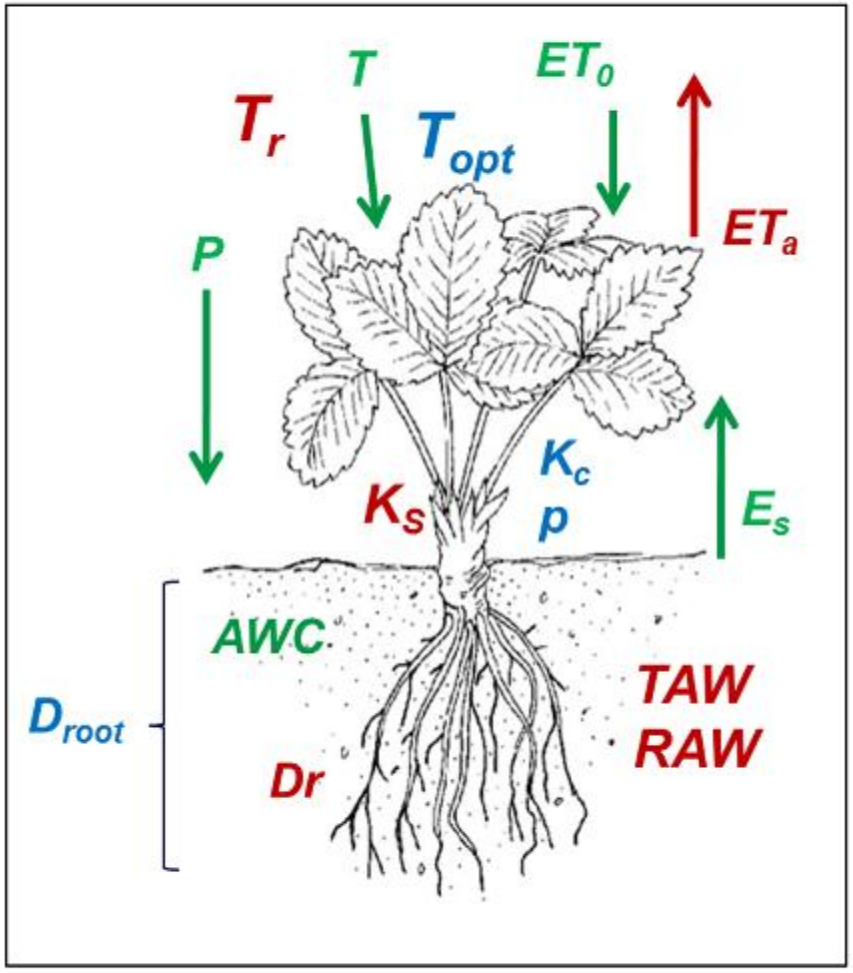
PRISM-ELM Water Balance Model

User Inputs

T_{opt}= Opt temp curve
K_c = Crop ET coef.
p=Stress resp. fac.
D_{root}=Root depth

Grid Inputs

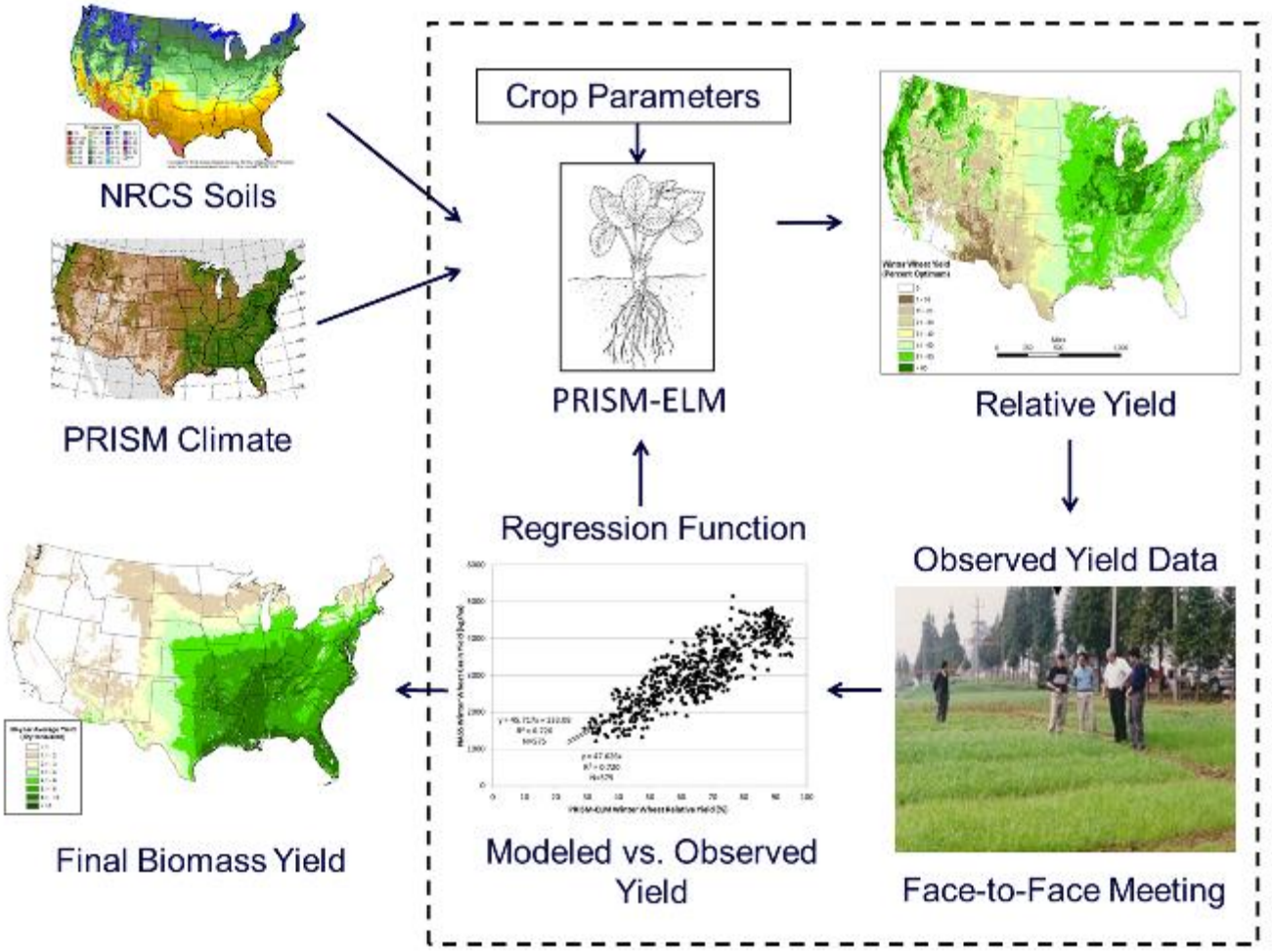
P=Precip
T=Tmean
ET_0=ref ET
ES=Soil evap
AWC=Soil avail water cap.



Internal Variables

Tr=Temp. resp.
Eta=Actual ET
Ks=Stress coef.
Dr=Root water dfct.
TAW=Tot. avail water
RAW=Readily avail. water

PRISM-ELM Modeling Work Flow



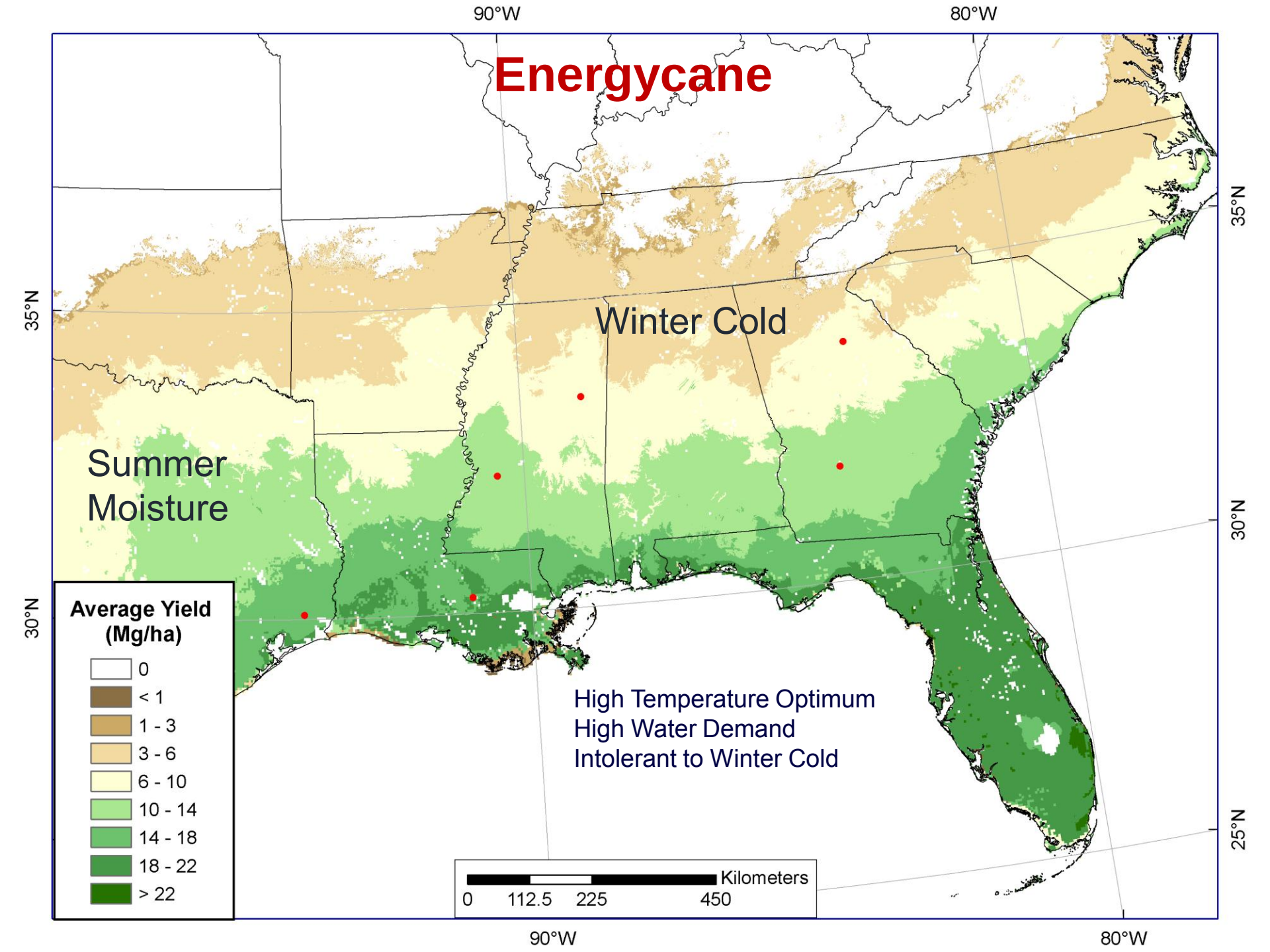
Mapping National Yield Potential for Biomass Crops

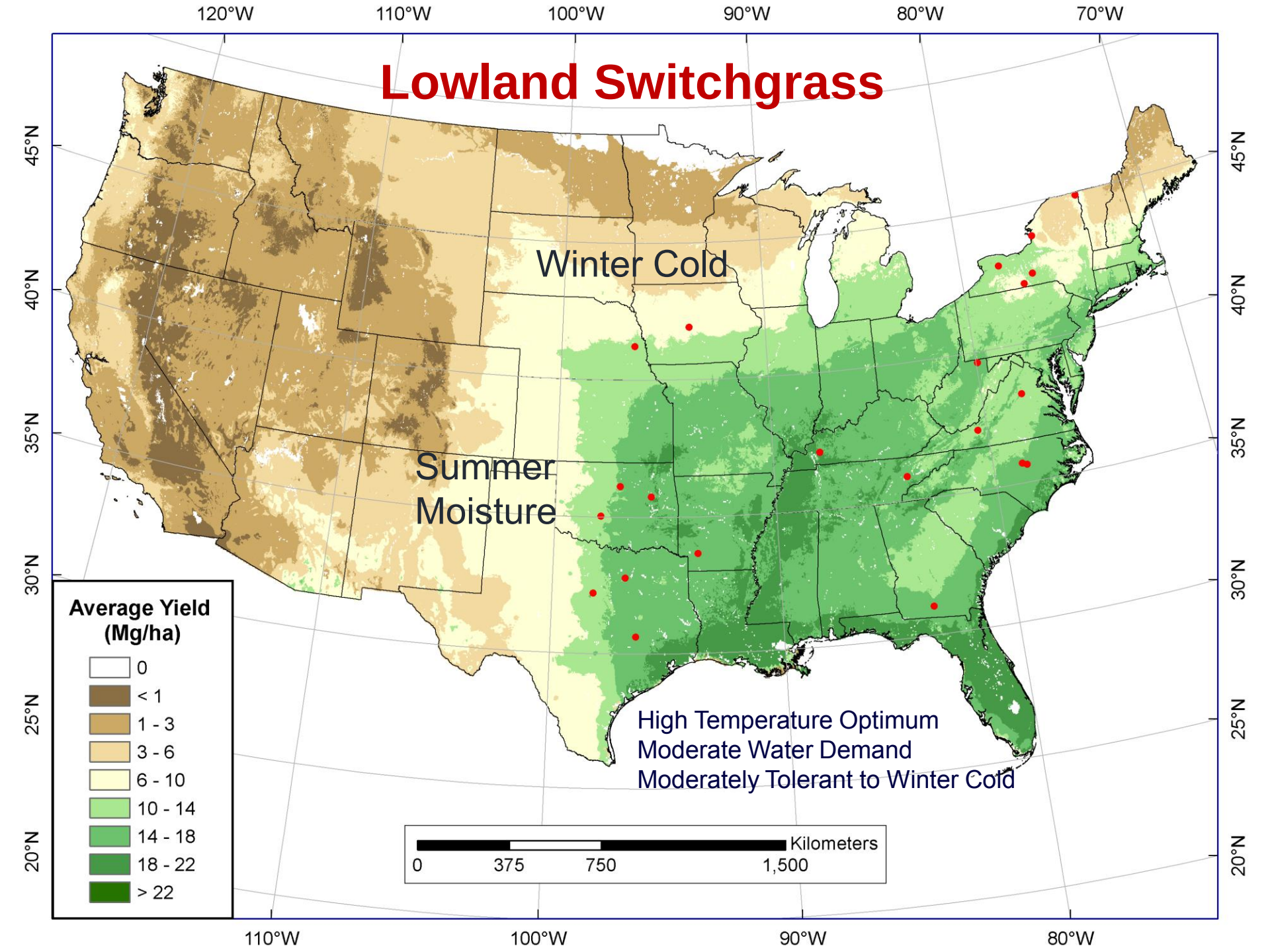
Outcomes

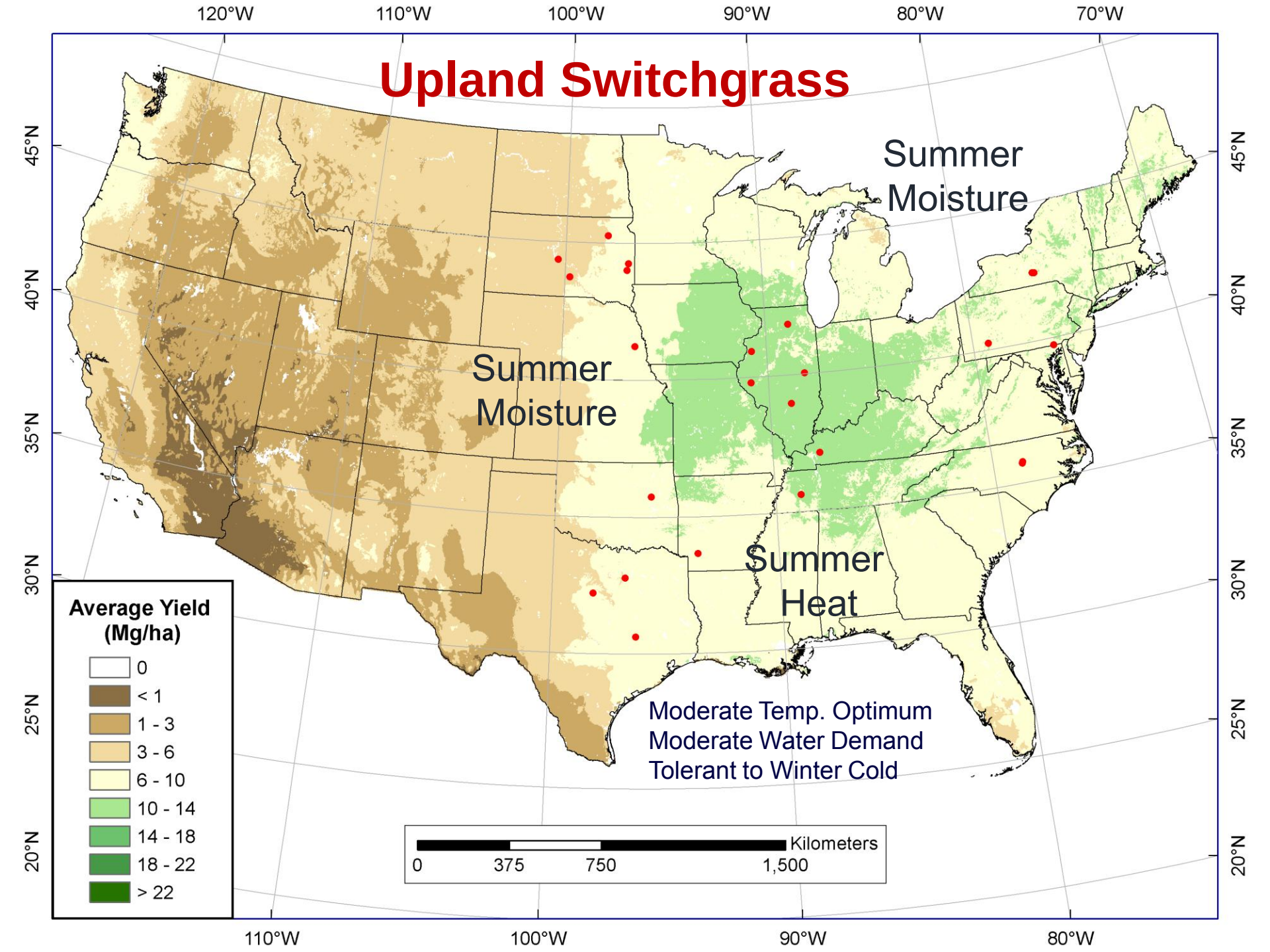
Digital maps of nationwide production potential for the best local cultivars of nine biomass crops, assuming 1981-2010 mean climate conditions, once-per-year harvest, and no irrigation

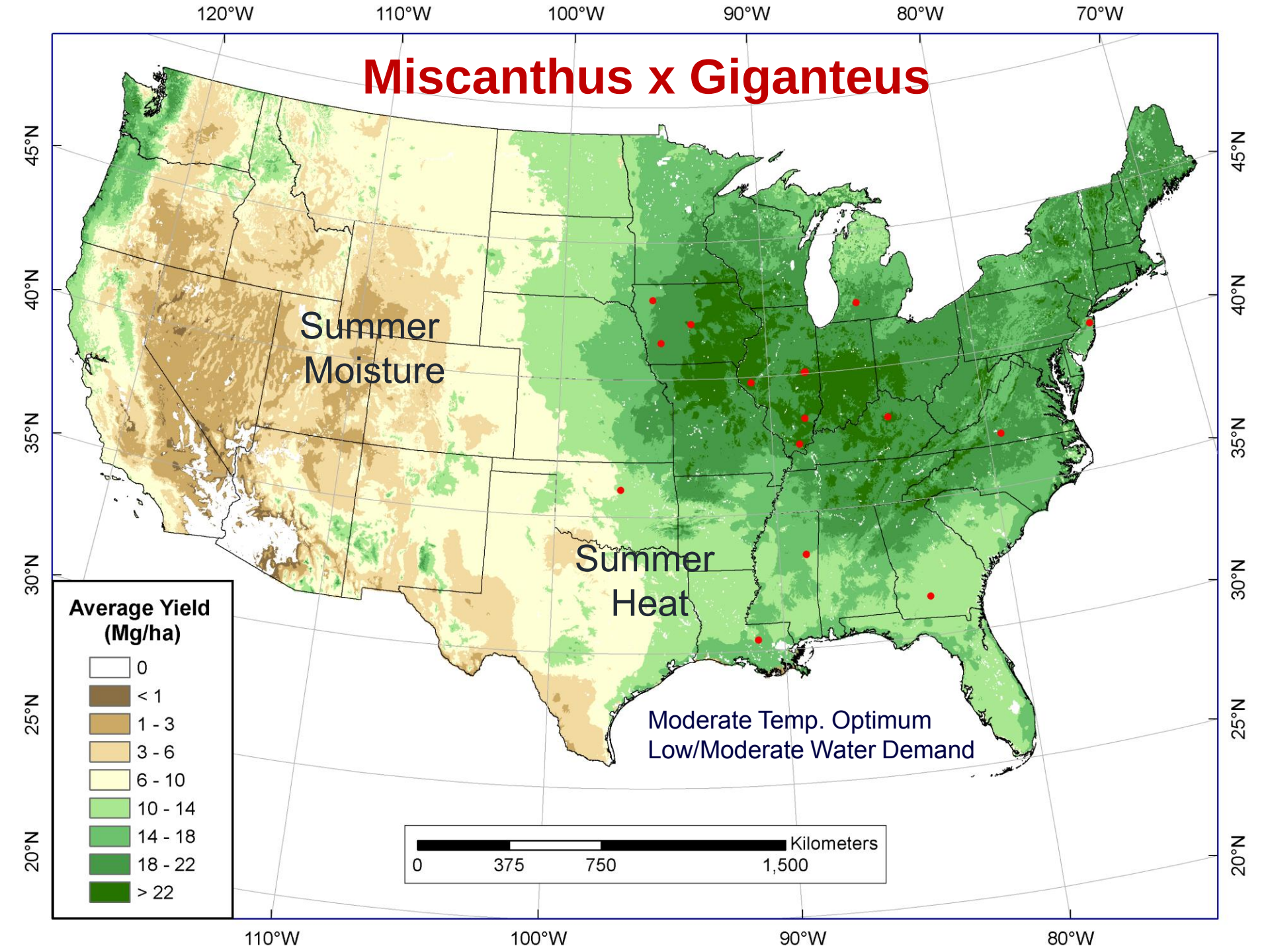
- Energycane
- Upland switchgrass
- Lowland switchgrass
- CRP mixed grasses
- Miscanthus
- Biomass sorghum
- Poplar
- Willow
- Southern pine

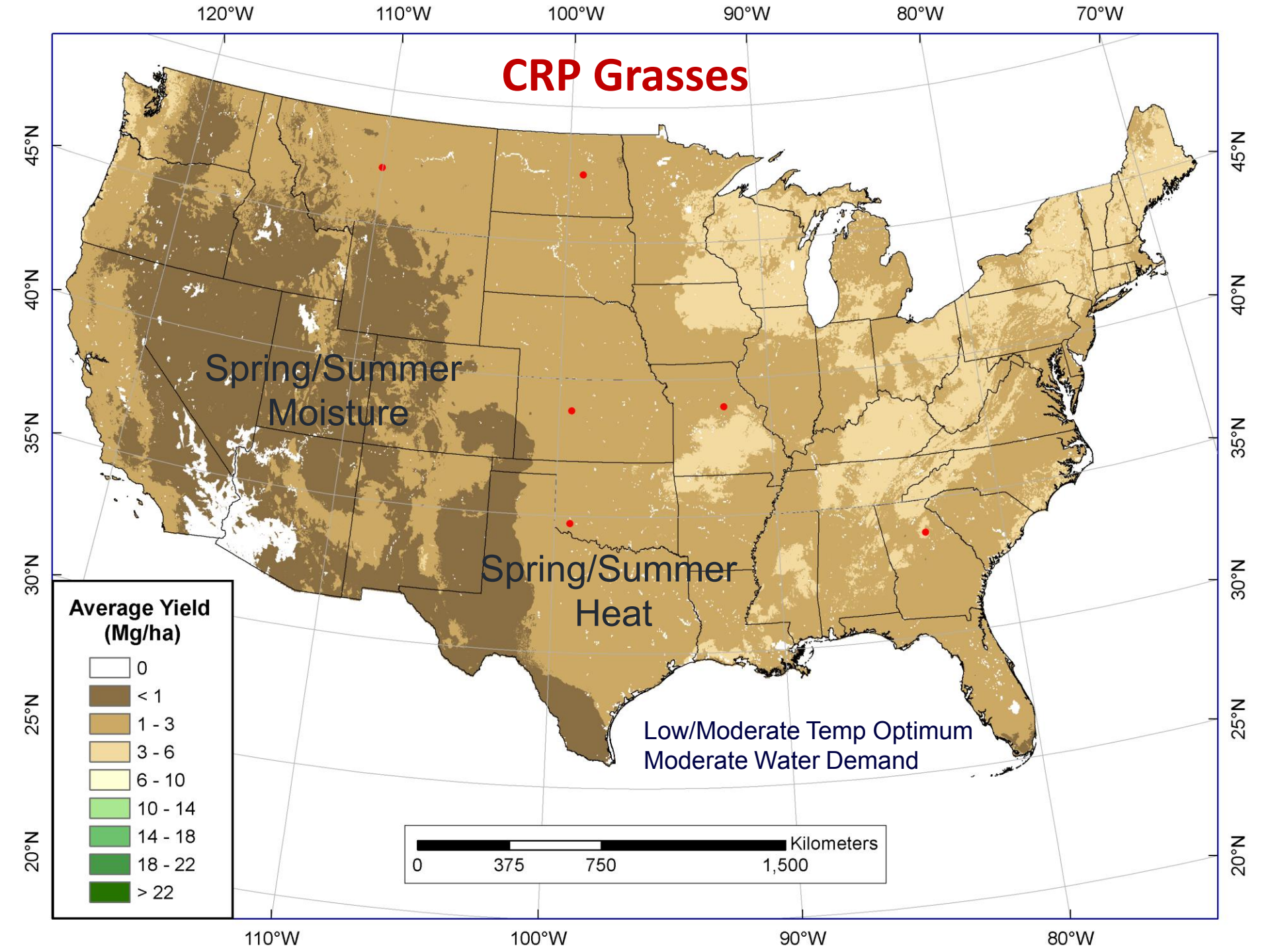
- Manuscript in peer review (GCB-Bioenergy)

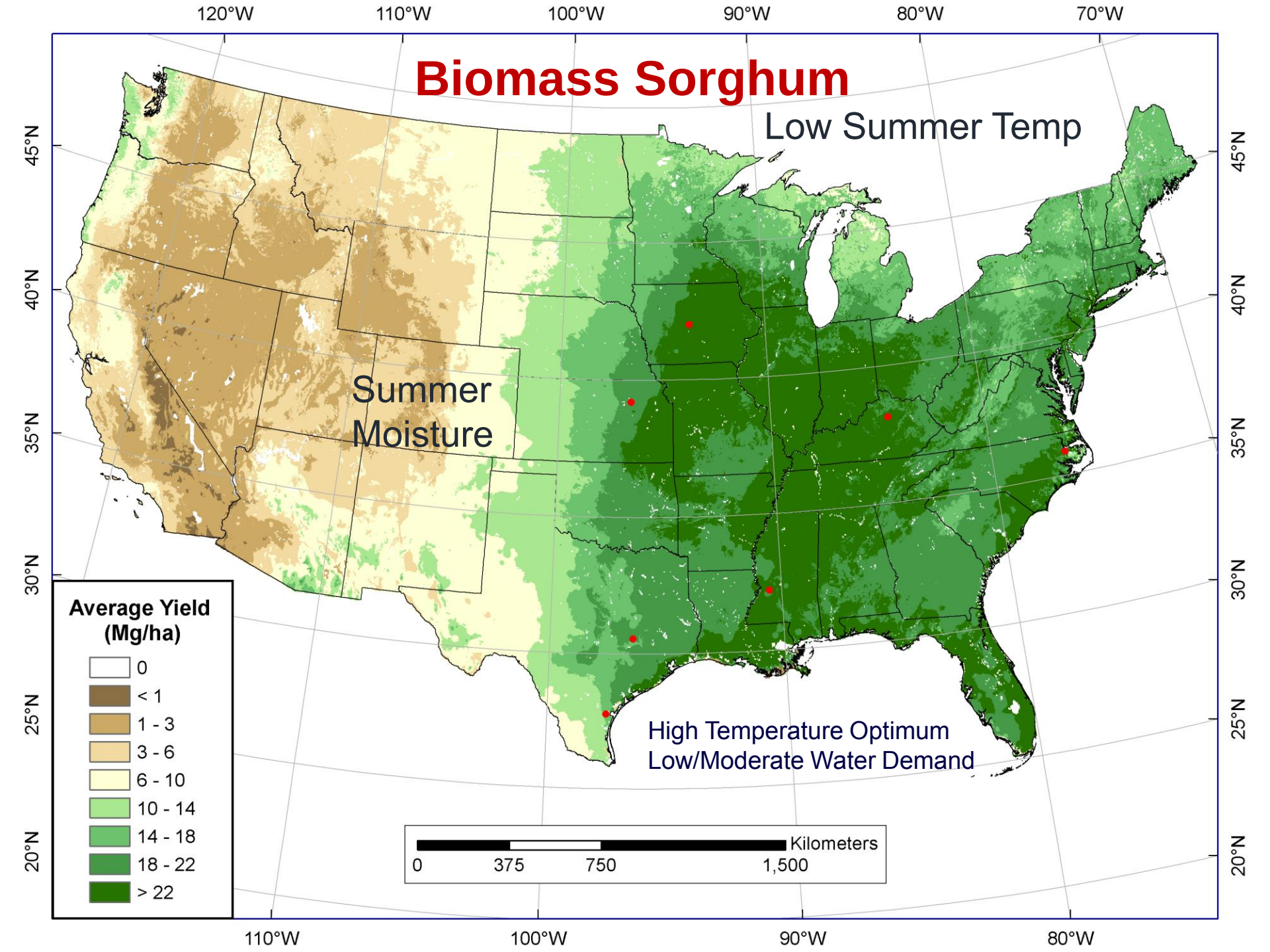

Energycane
Winter Cold
Summer
Moisture
High Temperature Optimum
High Water Demand
Intolerant to Winter Cold
Average Yield
(Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
112.5
225
450
90°W
80°W
35°N
30°N
25°N

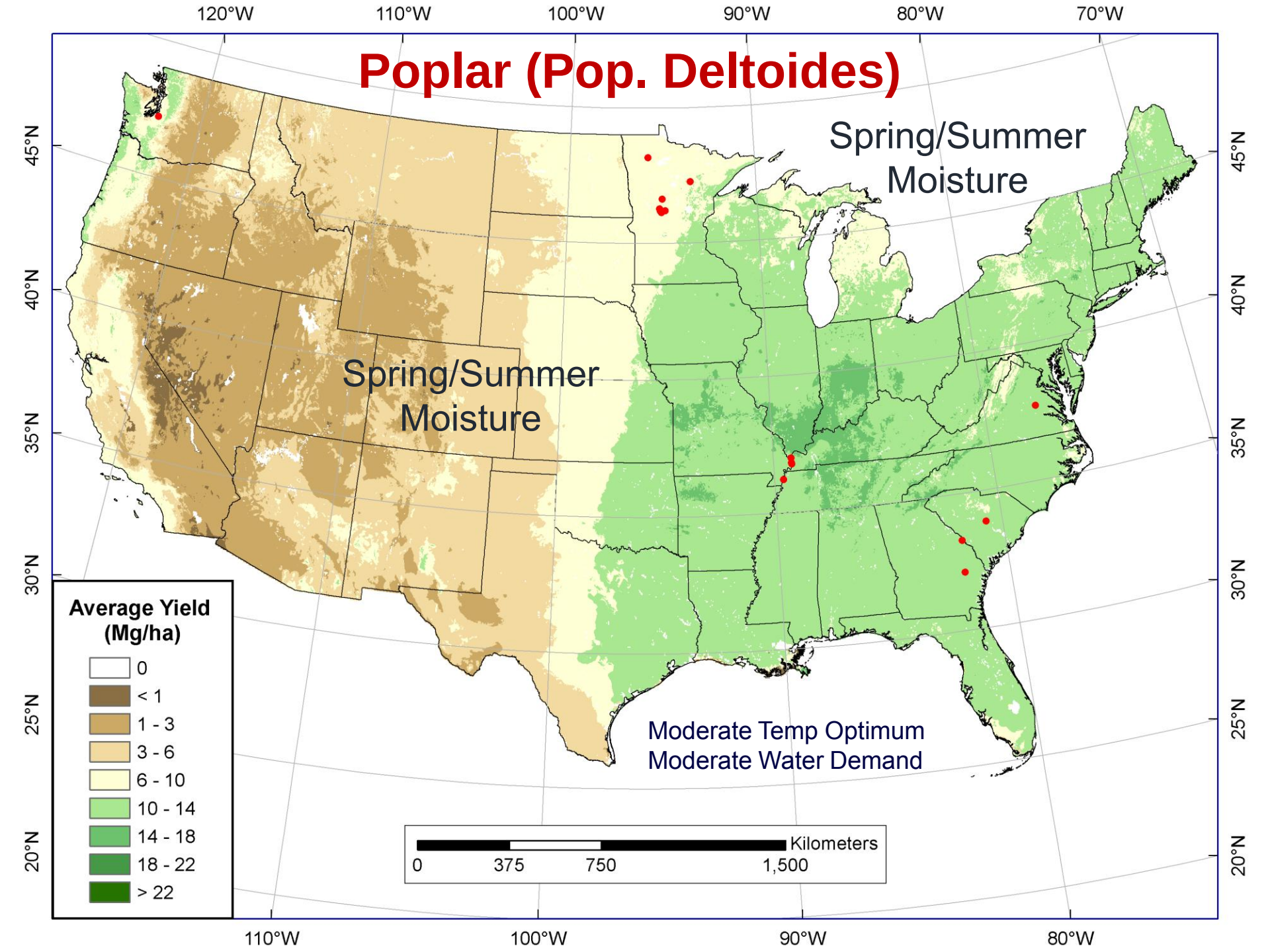

Lowland Switchgrass
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N
Winter Cold
Summer
Moisture
High Temperature Optimum
Moderate Water Demand
Moderately Tolerant to Winter Cold
Average Yield
(Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500

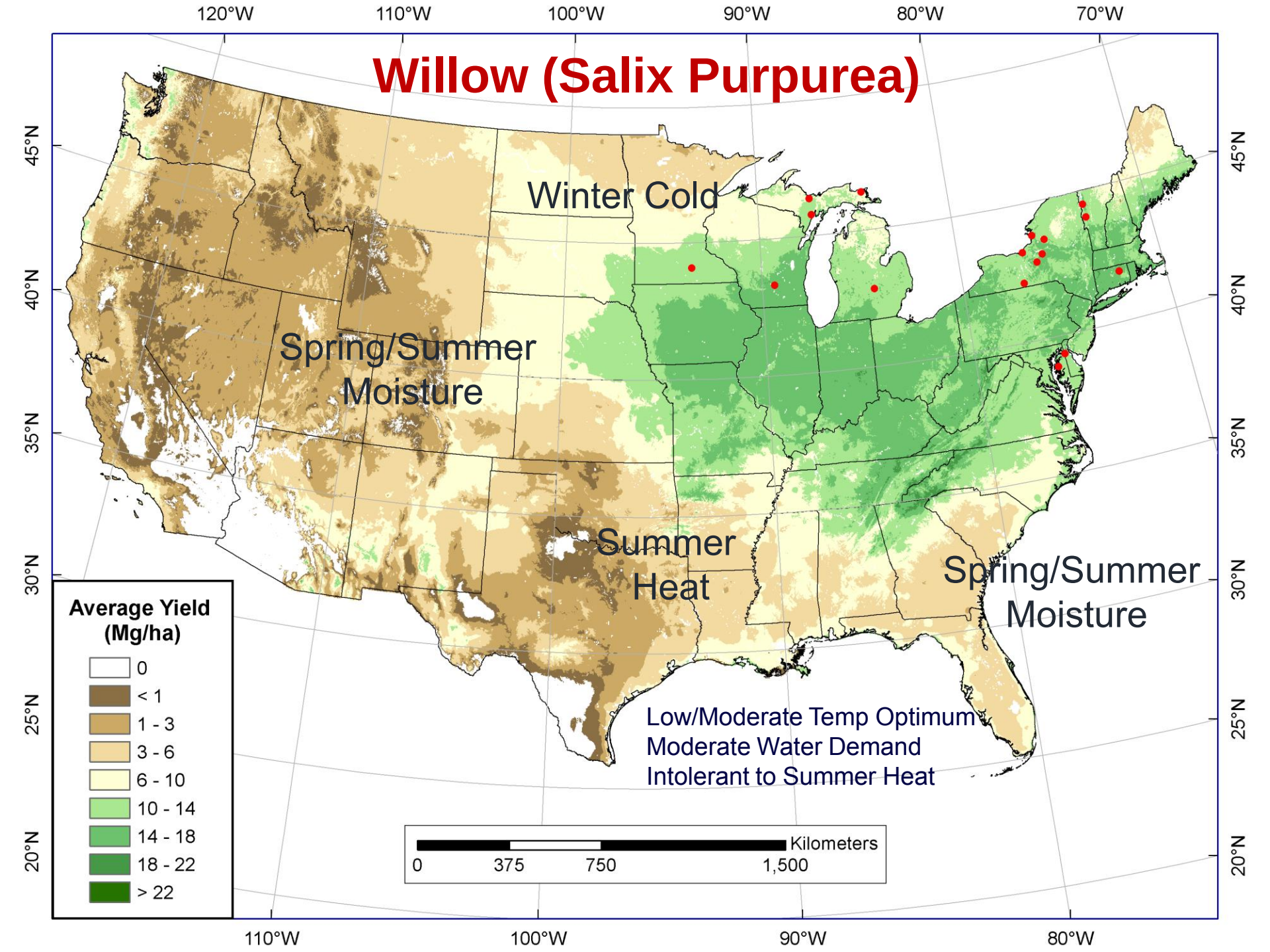

Upland Switchgrass
Summer Moisture
Summer Moisture
Summer Heat
Moderate Temp. Optimum
Moderate Water Demand
Tolerant to Winter Cold
Average Yield (Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N

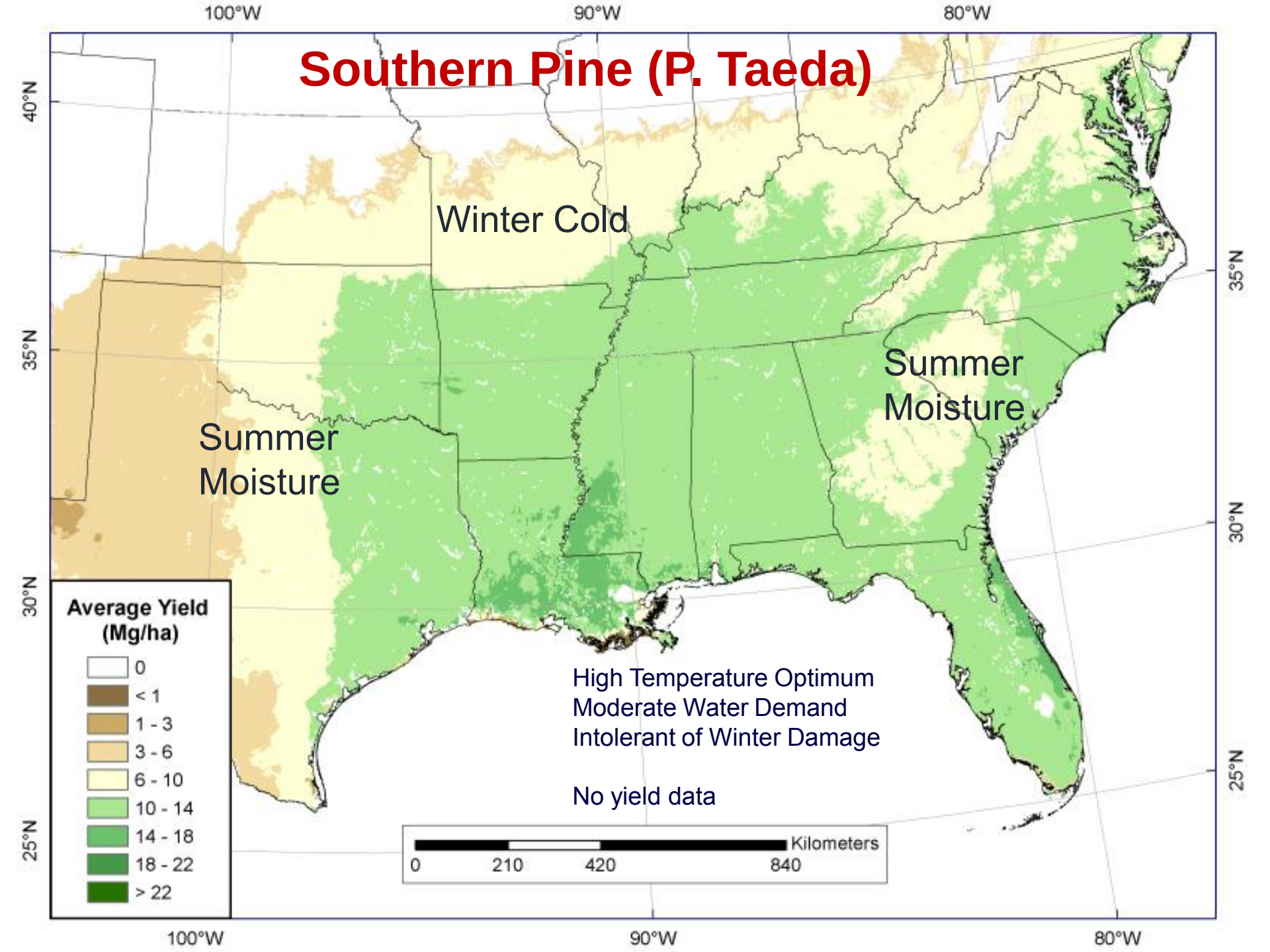

Miscanthus x Giganteus
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N
Summer
Moisture
Summer
Heat
Moderate Temp. Optimum
Low/Moderate Water Demand
Average Yield
(Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500


CRP Grasses
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N
Spring/Summer Moisture
Spring/Summer Heat
Low/Moderate Temp Optimum
Moderate Water Demand
Average Yield (Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500


Biomass Sorghum
Low Summer Temp
Summer Moisture
High Temperature Optimum
Low/Moderate Water Demand
Average Yield (Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N


Poplar (Pop. Deltoides)
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N
Spring/Summer Moisture
Spring/Summer Moisture
Moderate Temp Optimum
Moderate Water Demand
Average Yield (Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500


Willow (Salix Purpurea)
120°W
110°W
100°W
90°W
80°W
70°W
45°N
40°N
35°N
30°N
25°N
20°N
Winter Cold
Spring/Summer Moisture
Summer Heat
Spring/Summer Moisture
Low/Moderate Temp Optimum
Moderate Water Demand
Intolerant to Summer Heat
Average Yield (Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
375
750
1,500


Southern Pine (P. Taeda)
Winter Cold
Summer Moisture
Summer Moisture
High Temperature Optimum
Moderate Water Demand
Intolerant of Winter Damage
No yield data
Average Yield (Mg/ha)
0
< 1
1 - 3
3 - 6
6 - 10
10 - 14
14 - 18
18 - 22
> 22
Kilometers
0
210
420
840
100°W
90°W
80°W
40°N
35°N
30°N
25°N

Mapping National Yield Potential for Biomass Crops
Summary

Resource Assessment Goal

- Gain an understanding of the spatial distribution of long-term, potential biomass feedstock resources across the country

Approach

- Developed PRISM-ELM environmental limitation model
- Used model verification and calibration for wheat and corn as anchor points for biomass crops
- Produced relative yield maps
- Met with agronomists to gain expert opinion, determine the most representative yield data, and develop relationships between relative and actual yield
- Produced actual yield maps

Mapping National Yield Potential for Biomass Crops
Summary (concl.)

Outcomes

- A series of national geo-referenced grids (maps) that describe the long-term production potential of biomass crops
- Manuscript in peer review (GCB-Bioenergy)

Relevance

- Basic information on the spatial distribution of yield potential for biomass crops is an essential starting point in planning for a bio-economy
- Maps allow inter-comparisons of biomass crop selection options
- Maps were used in the BT16 economic analyses

Additional Slides Not For Presentation

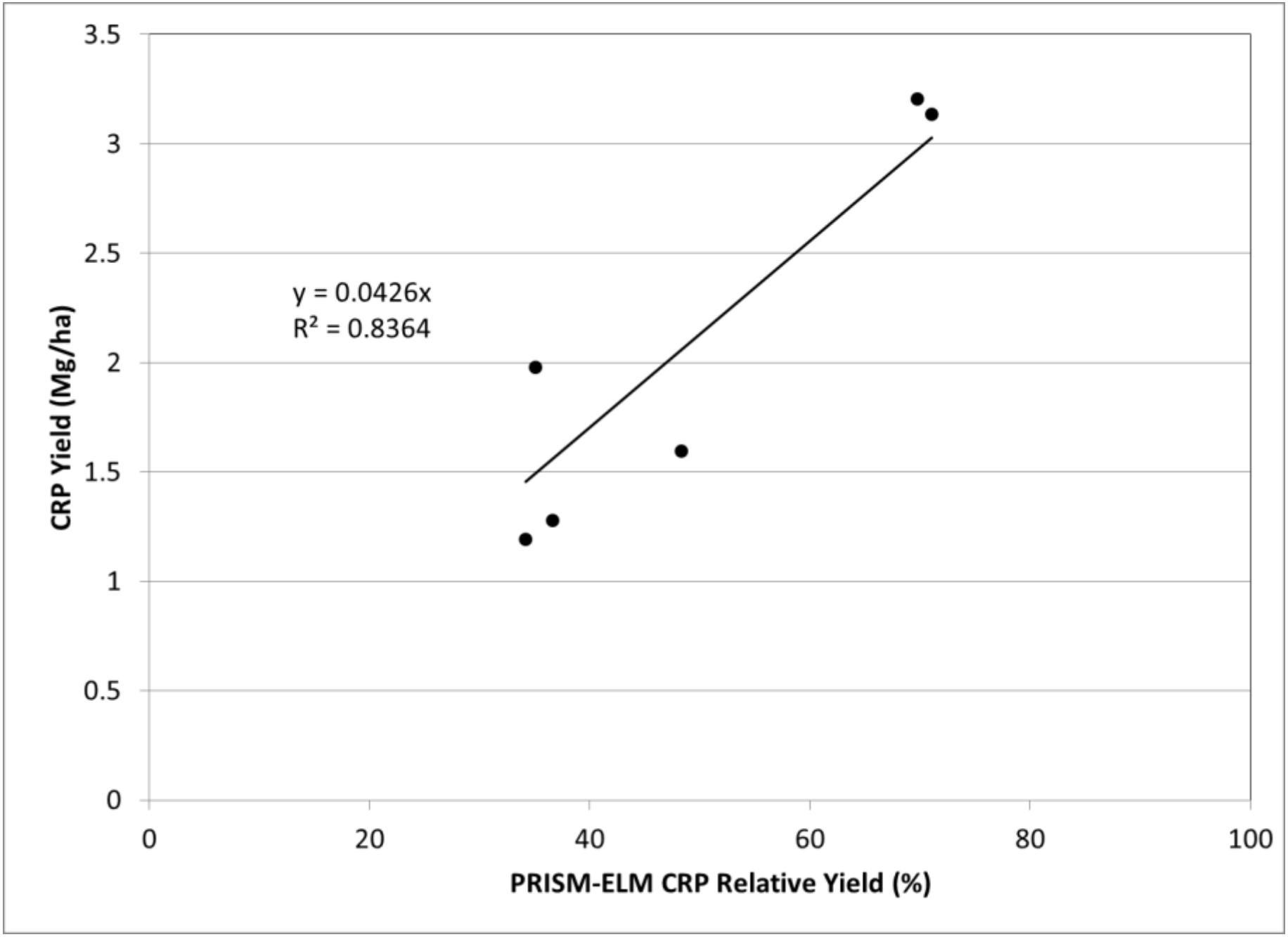
Reviewer Question
Modeling Assumptions

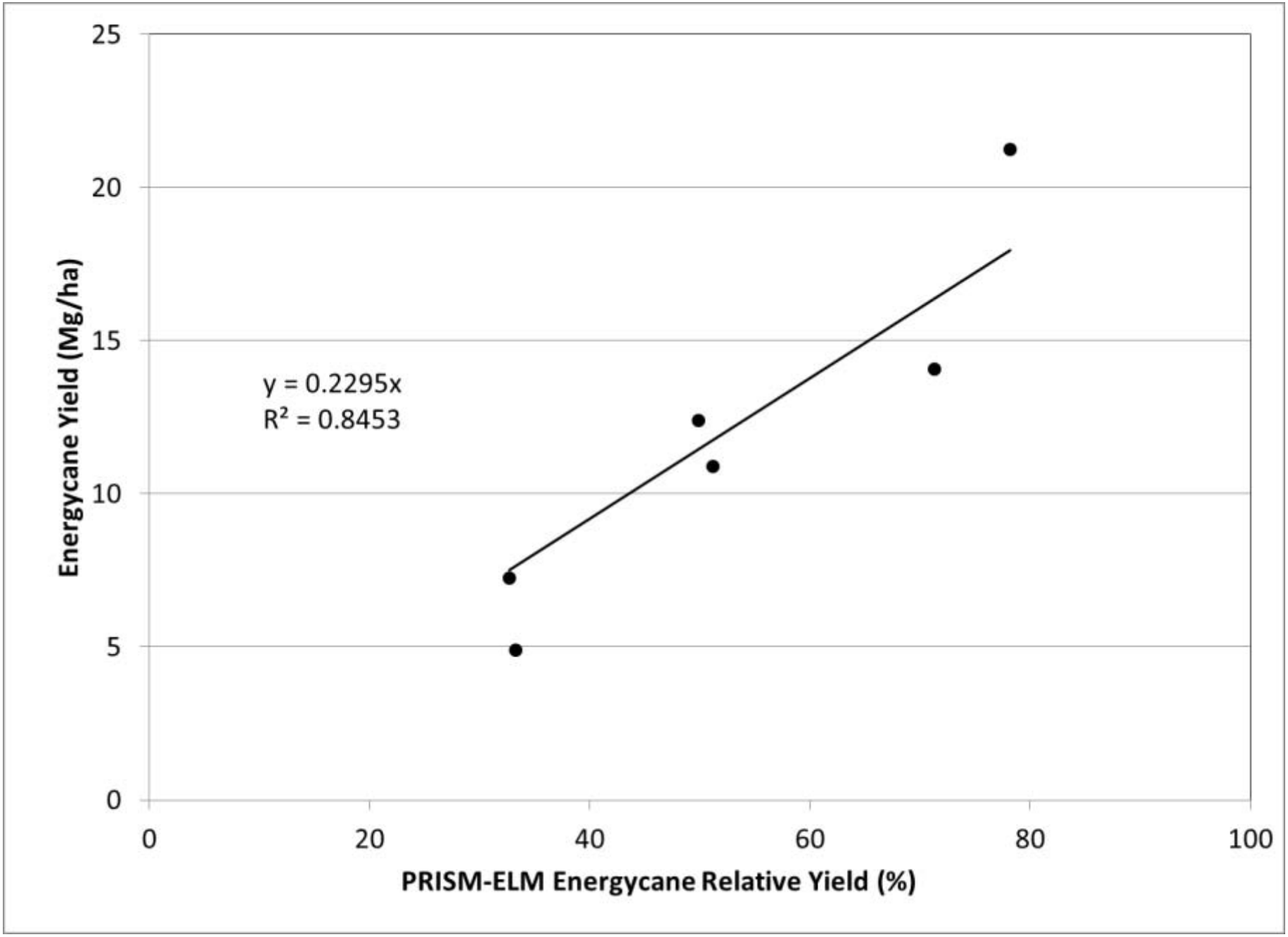
A reviewer asked about what the PRISM-ELM modeling assumptions were. This was something we had to think carefully about early on, because the assumptions defined what the maps actually represented. Below are those assumptions.

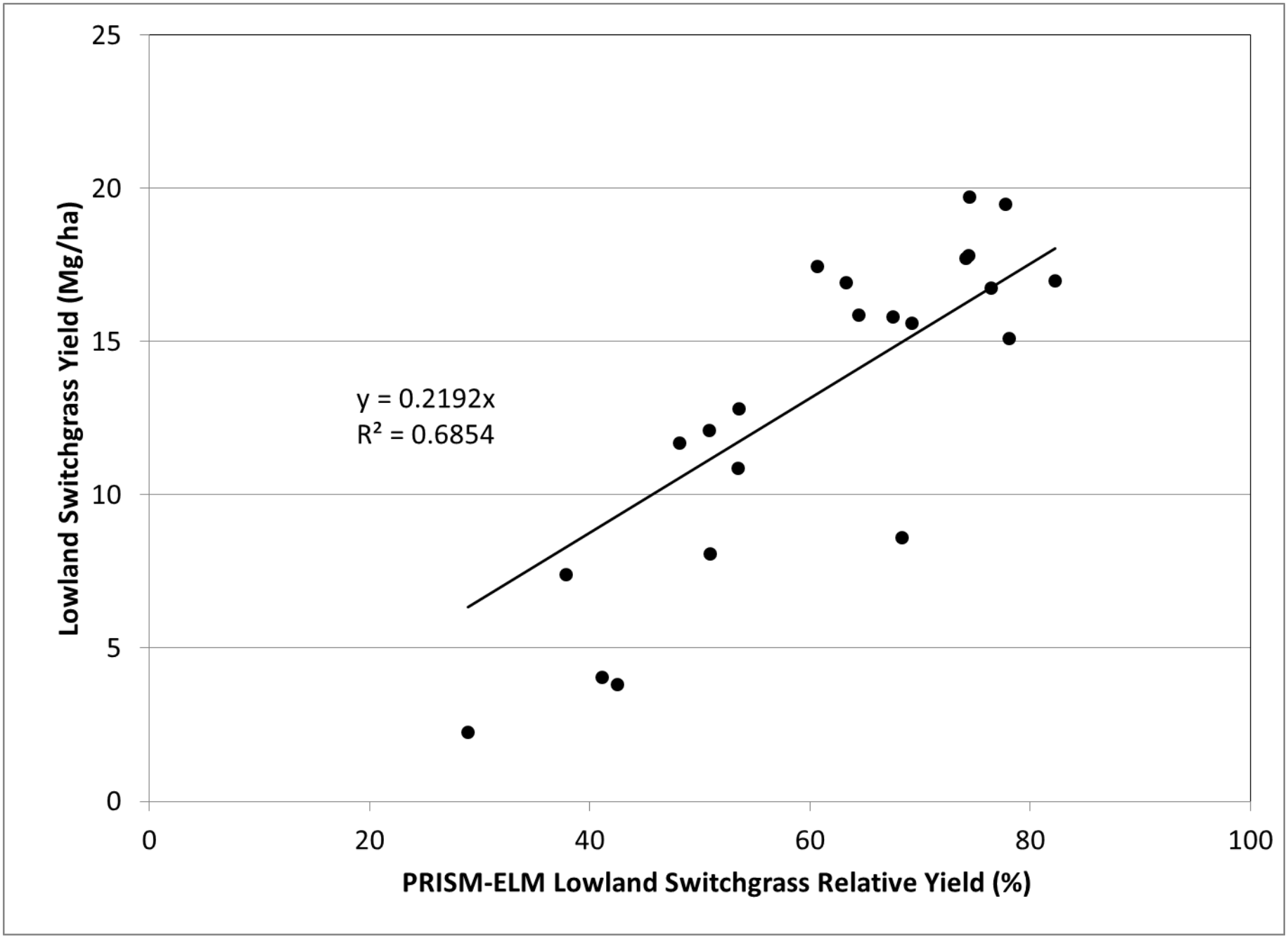
Specifically, the yield potential maps represent:

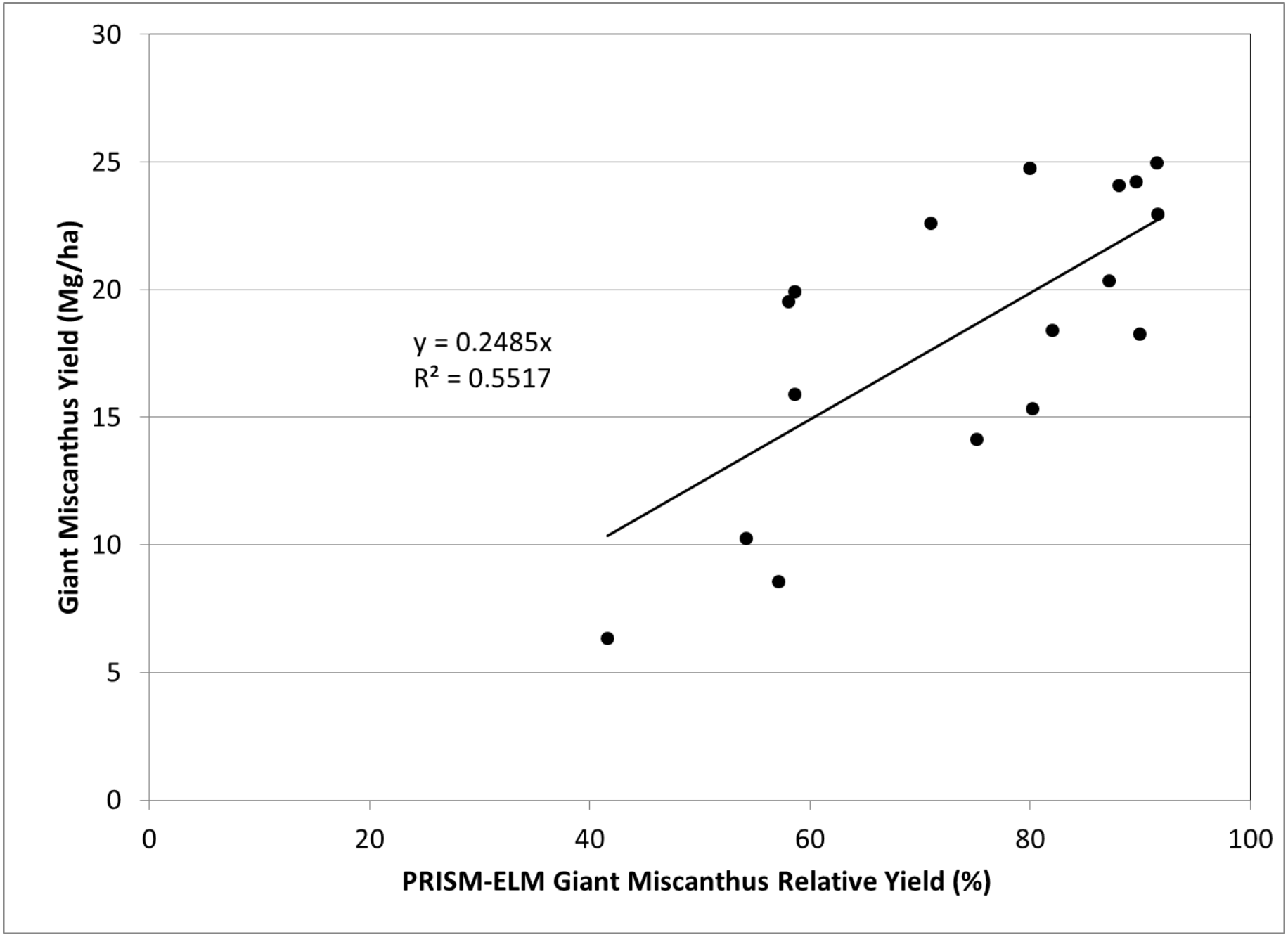
- Long-term average yields based on climatological data for the period 1981-2010, not accounting for occasional damaging events, such as hail, flooding and wind
- Dryland conditions (non-irrigated)
- Yields from the best local cultivar available at the time of the yield trials
- Once-per-year harvest frequency (no summer fallow); estimated mean annual increment at maturity for woody perennials
- Field-scale yields, as opposed to test plot-scale yields
- Yields of fully established crops, if perennials; establishment years not included
- Best-practice fertilizer application using a combination of pre-establishment soil test recommendations and mass balance approach for harvested biomass for local soil type
- Best-practice pesticide application, typically minimal inputs

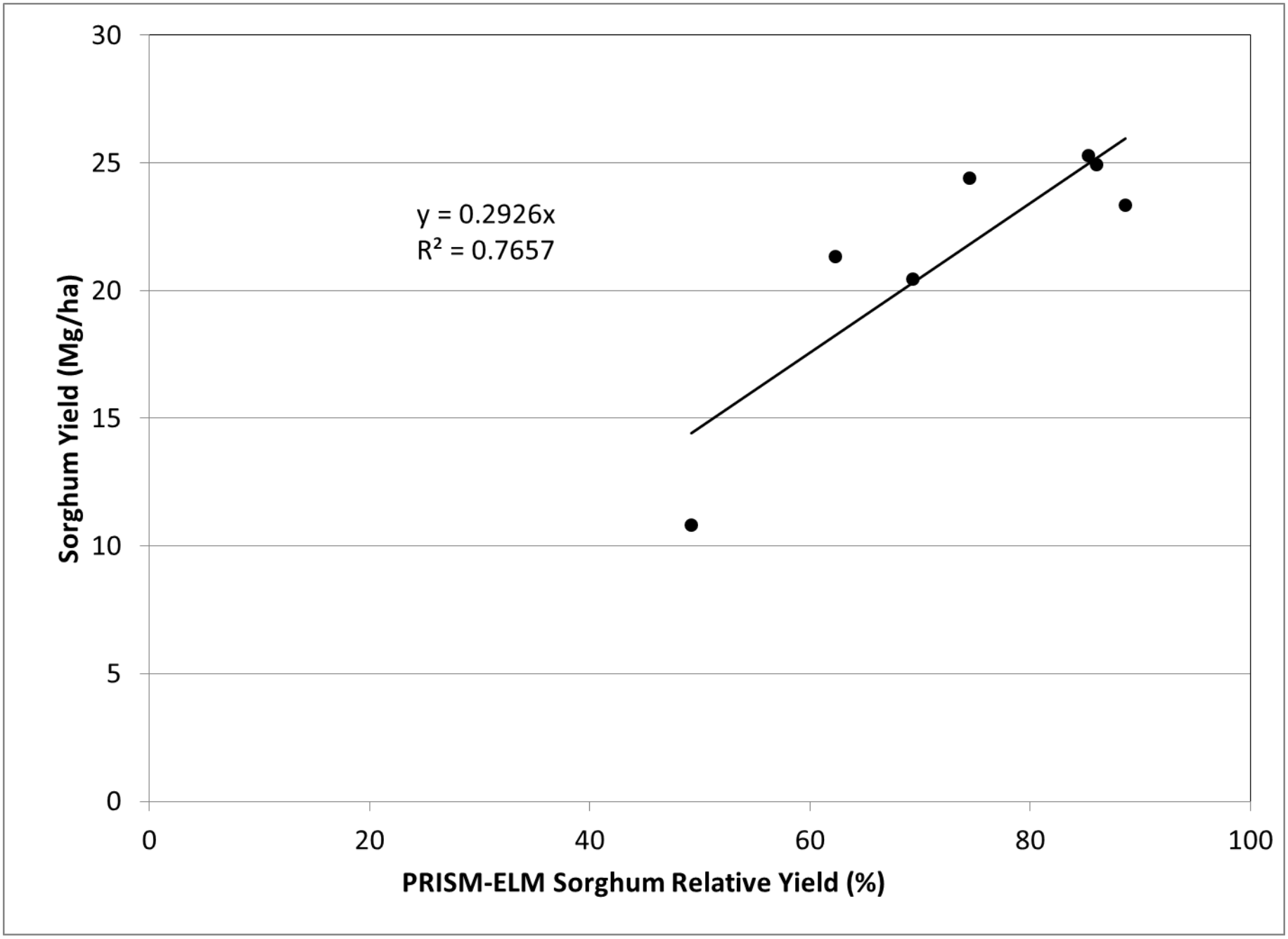
Scatterplots and Regression Functions Used to Convert Relative Yield to Actual Yield

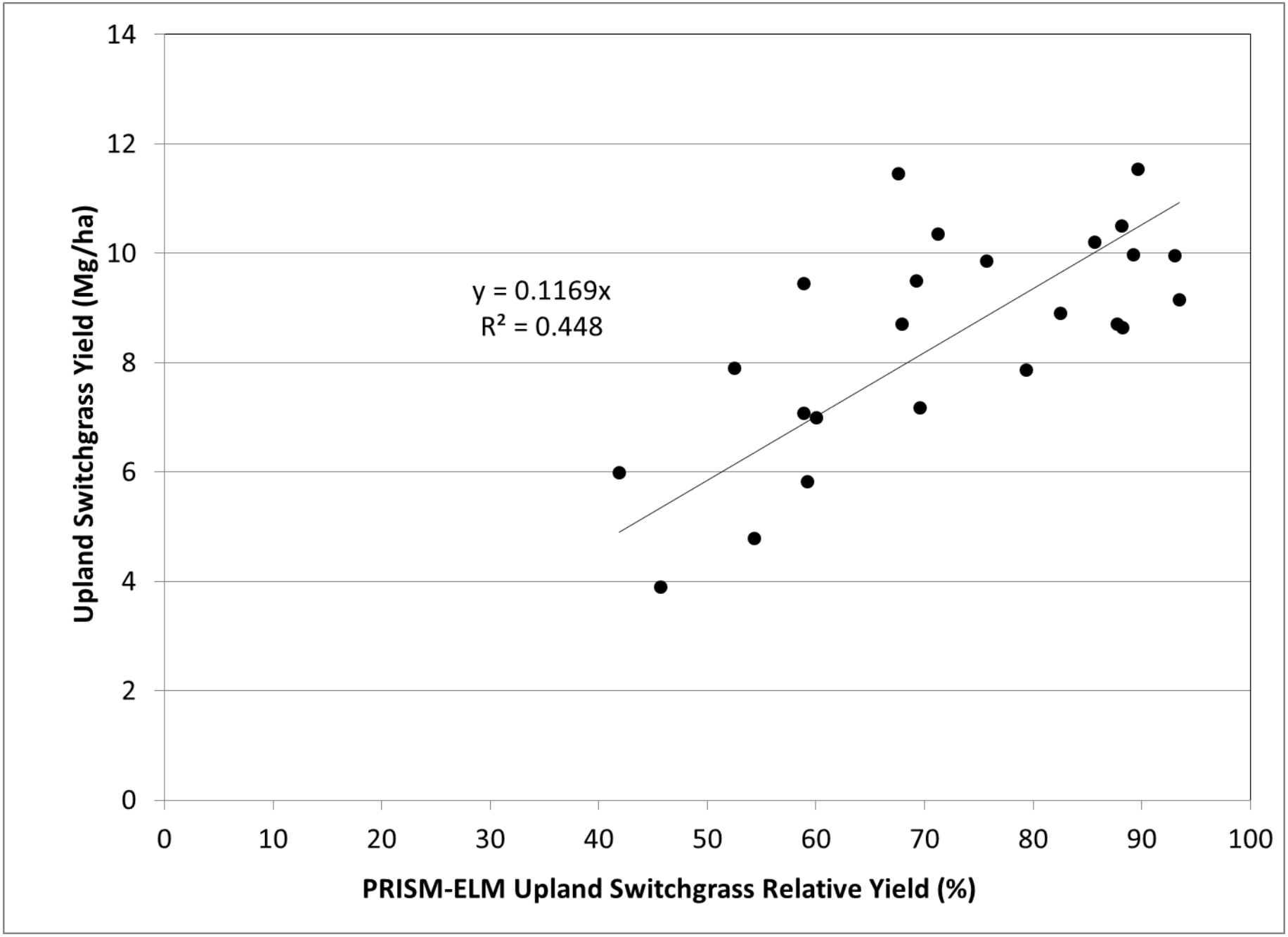

3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
CRP Yield (Mg/ha)
PRISM-ELM CRP Relative Yield (%)
y = 0.0426x
R² = 0.8364

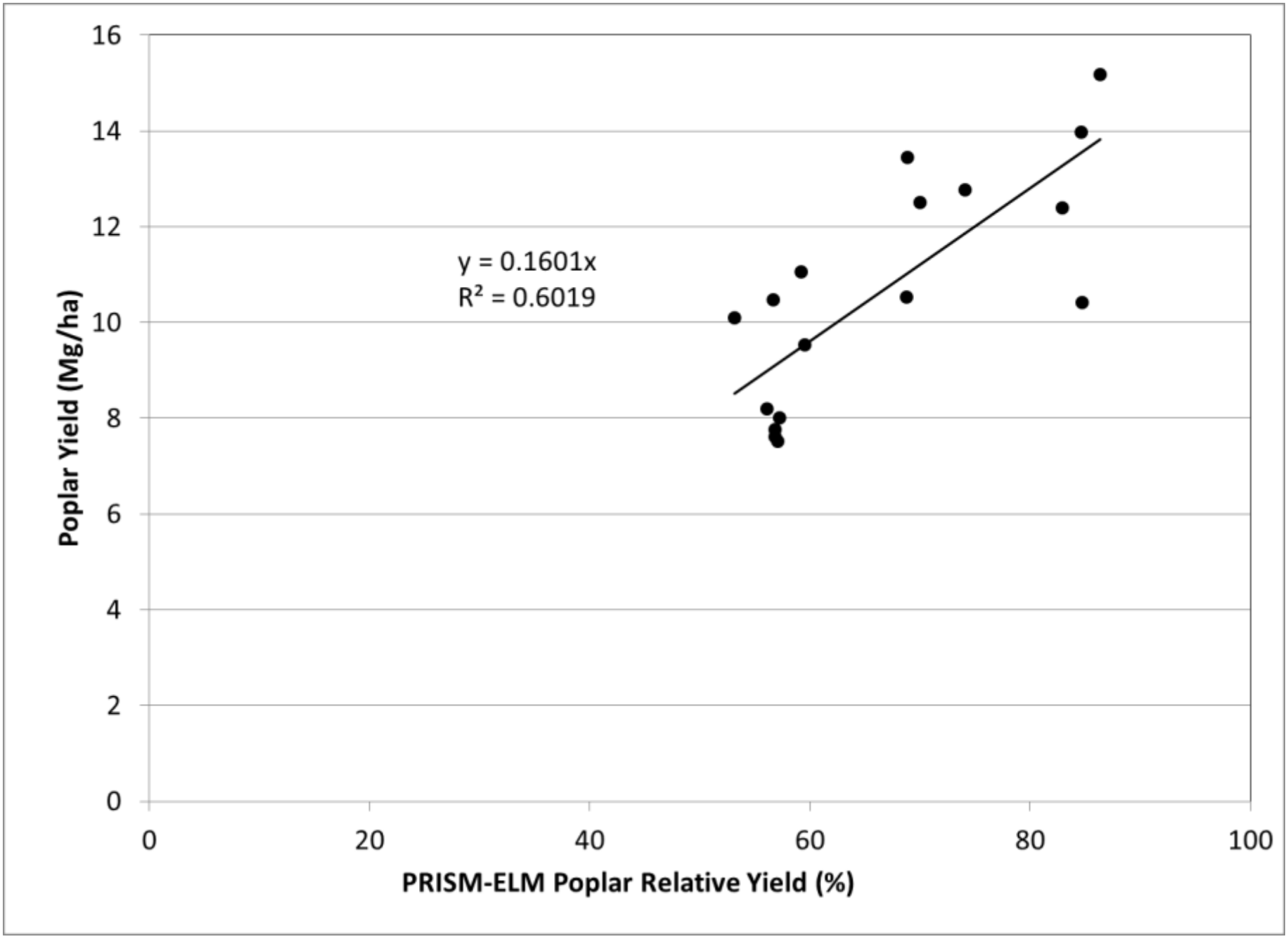

25
20
15
10
5
0
Energycane Yield (Mg/ha)
y = 0.2295x
R² = 0.8453
0
20
40
60
80
100
PRISM-ELM Energycane Relative Yield (%)

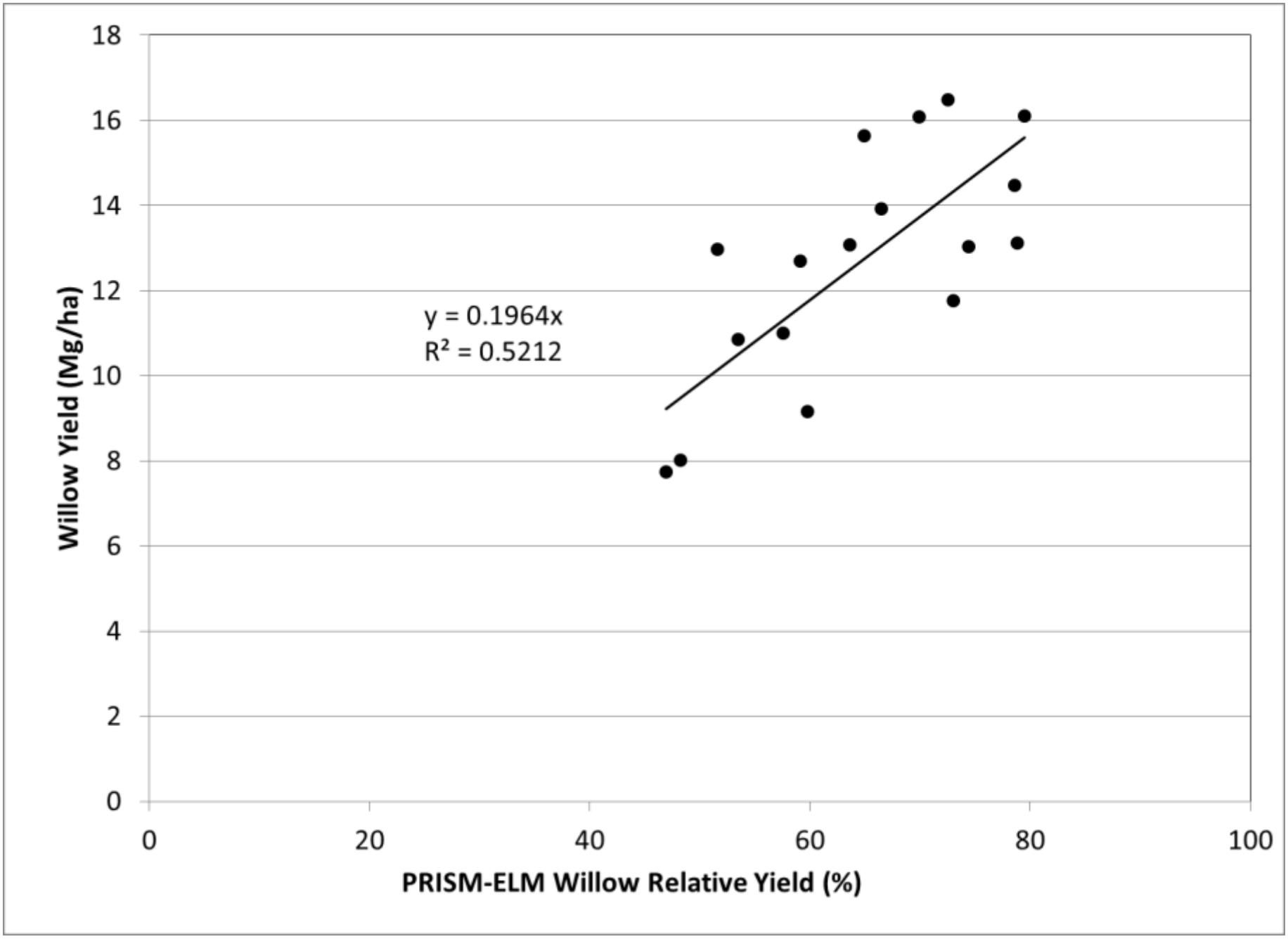

25
20
15
10
5
0
Lowland Switchgrass Yield (Mg/ha)
y = 0.2192x
R² = 0.6854
0
20
40
60
80
100
PRISM-ELM Lowland Switchgrass Relative Yield (%)


30
25
20
15
10
5
0
Giant Miscanthus Yield (Mg/ha)
y = 0.2485x
R² = 0.5517
0
20
40
60
80
100
PRISM-ELM Giant Miscanthus Relative Yield (%)


30
25
20
15
10
5
0
Sorghum Yield (Mg/ha)
y = 0.2926x
R² = 0.7657
0
20
40
60
80
100
PRISM-ELM Sorghum Relative Yield (%)


14
12
10
8
6
4
2
0
Upland Switchgrass Yield (Mg/ha)
y = 0.1169x
R² = 0.448
0
10
20
30
40
50
60
70
80
90
100
PRISM-ELM Upland Switchgrass Relative Yield (%)


16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Poplar Yield (Mg/ha)
PRISM-ELM Poplar Relative Yield (%)
y = 0.1601x
R² = 0.6019


18
16
14
12
10
8
6
4
2
0
Willow Yield (Mg/ha)
y = 0.1964x
R² = 0.5212
0
20
40
60
80
100
PRISM-ELM Willow Relative Yield (%)

Peer reviewed Publications

Daly, C., M.D. Halbleib, and D.B. Hannaway. 2017. Environmental Limitation Mapping of Potential Biomass Resources across the Conterminous United States. GCB Bioenergy. In Review

Conference Proceedings

Halbleib, M., C. Daly, and D. Hannaway. 2012. "Nationwide Crop Suitability Modeling of Biomass Feedstocks." In *Proceedings of the 2012 Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization*, New Orleans, LA, October 2–5. https://ag.tennessee.edu/sungrant/Documents/2012%20National%20Conference/ConferenceProceedings/Volume%202/Vol2.pdf.

Workshops Conducted

Daly, C., M. Halbleib, and L. Eaton. 2013. "Nationwide Bio-Fuel Resource Mapping: Energycane Biomass Feedstocks." Organized and conducted workshop for the U.S. Department of Energy/Department of Agriculture/Department of Transportation Sun Grant Initiative, Jackson, MS, May 7–8.

———. 2013. "Nationwide Bio-Fuel Resource Mapping: Switchgrass Biomass Feedstocks." Organized, conducted, and hosted workshop for the U.S. Department of Energy/Department of Agriculture/Department of Transportation Sun Grant Initiative, Corvallis, OR, May 29–30.

———. 2013. "Nationwide Bio-Fuel Resource Mapping: Sorghum Biomass Feedstocks." Organized and conducted workshop for the U.S. Department of Energy/Department of Agriculture/Department of Transportation Sun Grant Initiative, Oak Ridge National Laboratory, Oak Ridge, TN, June 27–28.

———. 2013. "Nationwide Bio-Fuel Resource Mapping: CRP Grass Biomass Feedstocks." Organized and conducted workshop for the U.S. Department of Energy/Department of Agriculture/Department of Transportation Sun Grant Initiative, Kansas City, MO, July 25–26.

———. 2013. "Nationwide Bio-Fuel Resource Mapping: Woody Biomass Feedstocks." Organized, conducted, and hosted workshop for the U.S. Department of Energy/Department of Agriculture/Department of Transportation Sun Grant Initiative, Corvallis, OR, September 18–19.

———. 2014. "Nationwide Bio-Fuel Resource Mapping: Miscanthus feedstocks." Organized and conducted workshop for the U.S. Department of Energy/Department of Agriculture/Department of Transportation Sun Grant Initiative, Chicago, IL, February 18–19.

Presentations and Panels

Daly, C., and M. Halbleib. 2009a. "Western Region Sun Grant GIS Team Status Report." Presented at the Sun Grant Regional Biomass Feedstock Partnership Workshop, Washington, D.C., March 9.

———.2009b. "Sun Grant Western Region GIS Task Status Report." Presented at the SGI Regional Feedstock Partnership's Annual Working Group Meeting, Washington, D.C., March 9.

———.2009c. "Using Map Server Technology and Environmental Datasets for Feedstock Development and Assessment." Presented at the Sun Grant Initiative Energy Conference, Washington, D.C., March 12.

Daly, C., and M. Halbleib. 2010. "Nationwide Suitability Modeling of Bio-Energy Crops: A Useful Idea?" Presented at the Sun Grant/U.S. Department of Energy Regional Biomass Feedstock Partnership Annual Meeting, San Antonio, TX, February 24. http://www.nacse.org/~daly/sa/Sun_Grant_Western_GIS_24Feb2010.ppt.

Daly, C., M. Halbleib, M. Doggett, and D. Hannaway. 2011. "Nationwide Biomass Modeling of Bio-Energy Feedstocks." Presented at the Sun Grant Feedstock Partnership annual meeting, Knoxville, TN, February 15–16.

Daly, C., M. Halbleib. 2011a. "Biomass Mapping of Bio-Energy Feedstocks." Presented at the U.S. Navy Green Fleet workshop, Honolulu, HI, March 7.

———.2011b. "Nationwide Bio-Fuel Resource Mapping: Estimating the Potential Distribution and Yield of Biomass Crops." Presented at Texas A&M University Biomass Group, June 10.

Halbleib, M., and C. Daly. 2011. "Nationwide Biomass Mapping of Bio-Energy Feedstocks" Presented at Interagency Biofuels Infrastructure Workshop, Washington, DC, June 13-14.

Halbleib, M., C. Daly, M. Doggett, and D. Hannaway. 2012. "Modeling of Bio-Energy Feedstock Biomass in the US." Presented at the Sun Grant Feedstock Partnership Annual Meeting, Indianapolis, IN, March 14–15.

Halbleib, M., C. Daly, M. Doggett, and D. Hannaway. 2013 “Nationwide Bio-Fuel Resource Mapping: Estimating the Potential Distribution and Yield of Biomass Crops” Presented at 2013 DOE Regional Feedstock Partnership Annual Meeting, Tunica, MS, February 14-15.

Daly, C., and M. Halbleib. 2014a. “Potential Yield Mapping of Bioenergy Crops.” Presented at breakout session and panel discussion, “Potential Yield, Composition, and Supply of Dedicated Energy Crops: Results and Outcomes of the Sun Grant Regional Feedstock Partnership,” at the BIO International Bioenergy Congress, Philadelphia, PA, May 12–14.
https://www.bio.org/sites/default/files/WorldCongress/Chris%20Daly.pdf

———.2014b. “Potential Yield Mapping of Dedicated Energy Crops.” Presented at panel session, “Integration of Supply Chains I: Breaking Down Barriers—Addressing Cost, Quality, and Quantity of Feedstocks for Optimizing Bioenergy Production,” at Biomass 2014: Growing the Future Bioeconomy Agenda, Washington, DC, July 29–30.
http://energy.gov/sites/prod/files/2014/11/f19/daly_biomass_2014.pdf

Daly, C. 2014. “An Update on the PRISM-RMA Crop Suitability Mapping, and Weather and Climate Web Portal.” Presented to the U.S. Department of Agriculture’s Risk Management Agency–Davis regional and compliance offices, Davis, CA, December 17.

M. Halbleib., and C. Daly. 2015. “Biomass Feedstock Regional Partnership - Geographic Information System Yield Mapping”. U.S. Department of Energy Bioenergy Technologies Office: Project Peer Review. Alexandria, VA, March 23-27.

Daly, C. 2016 “Biomass Productivity Modeling and National Yield Potential”. U.S. Department of Energy Bioenergy Technologies Office: Project Peer Review. Washington, DC, July 14.