Argonne NATIONAL LABORATORY

2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Biomass Production and Nitrogen Recovery

Date: May 23, 2013
Technology Area Review: Sustainability

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Organization: Argonne National Laboratory

U.S. DEPARTMENT OF ENERGY

Goal Statement

To determine the **feasibility , productivity and sustainability** of a biomass landscape production scenario and BMP that by design **introduce positive land use change and water quality benefits** at the farm and landscape/watershed levels.

- This goal supports:
  - the Feedstock platform goal of developing sustainable technologies to provide a secure, reliable and affordable feedstock supply, and
  - the crosscutting Sustainability goal of understanding and promoting the positive effects, and reducing the potential negative impacts, of bioenergy production.
  - The crosscutting analysis goals by providing field data

A **proactive** approach to couple sustainability with productivity:
- Inventoried impaired/marginal resources
- Provide potential BMP for their use
- Test BMP in the field
- Scale up to watershed scale

Quad Chart Overview

Timeline

- Project start date 04/2010
- Project end date 09/2015
- Percent complete
  - 100% analysis phase
  - 30% field testing, ongoing

Budget

- Funding for FY11($700K / $100K)
- Funding for FY12($350K / $100K)
- Funding for FY13 ($450K / $100K)
- Years the project has been funded / average annual funding: 3/$500K

Barriers Addressed

Feedstocks

Ft –A Feedstock availability and cost

Ft-B: Sustainable production – *“sustainability questions such as water and fertilizer inputs”*

Sustainability

St-E: Best practices for Sustainable bioenergy production

St-F: Systems approach to bioenergy sustainability

St-G: Representation of Innovative landscape designs

Partners

- Interactions/ collaborations
- Project management
  - CTIC
  - SUNY-ESF
  - SWCD
  - USDA-NRCS
  - USEPA-ILEPA
  - Monsanto, Mendel, Ceres

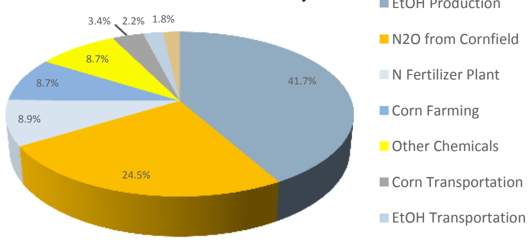
Project Overview

Testing a proactive, synergistic land, water and nitrogen management approach

Integrating concepts from advanced wastewater treatment and phytoremediation into landscape-based biomass production practices: incorporating sustainability by design. "LEED" of biomass production to achieve positive LUC and water quality benefits

Modeling, field trials and GIS analysis provide the basis for a future watershed-scale trial.

Share of GHG Emissions for Corn Ethanol (total of 5,630 g/gal, with co-product credits)



Source: GREET

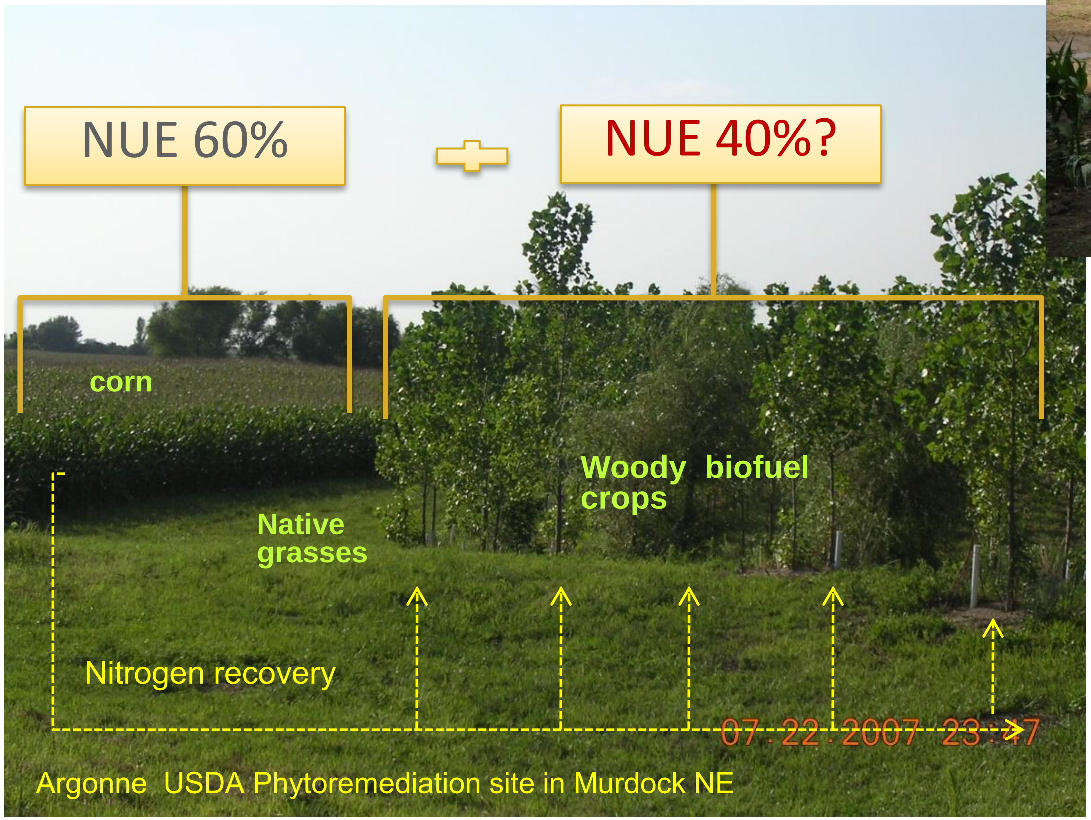
Source: USEPA

Logo credit: International Phytotechnologies Society

Underproductive land for biomass production

engineering landscape-based integrated biomass production models

Productive, diversified, sustainable biomass feedstock



Our hypothesis:

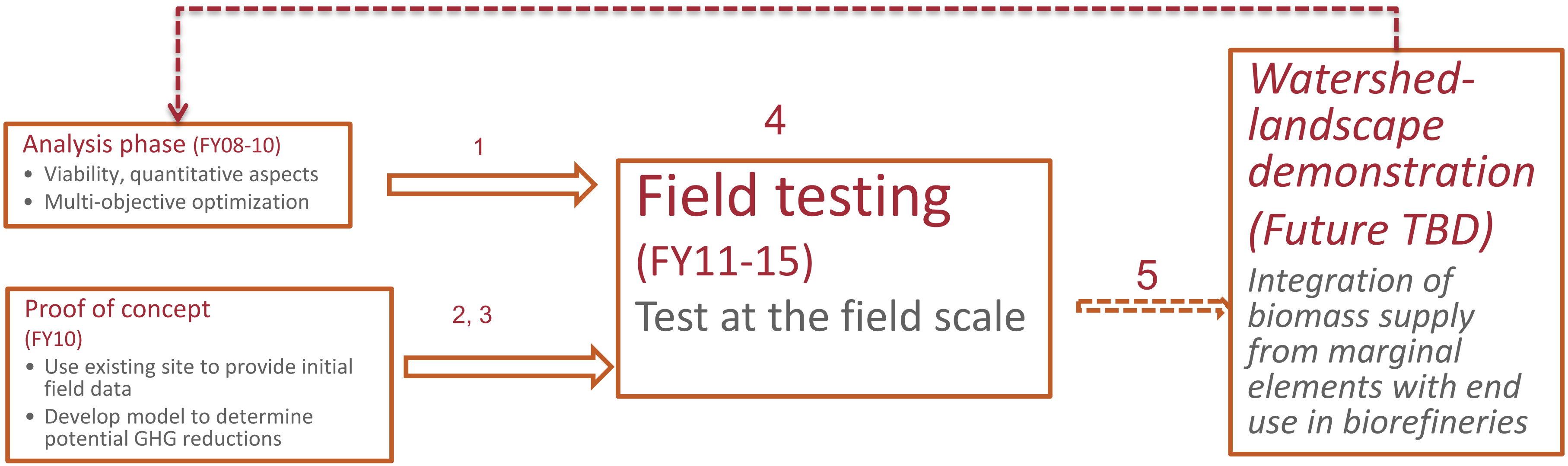
Enhanced biomass productivity and higher sustainability through landscape engineering.

- Can we achieve higher NUE at the farm scale?
- *Can we reduce GHG emission by recycling NO_3 for biomass?*
- *Can we reduce the total N inputs at the farm scale?*

1 - Approach

Metrics and go-no go decision points:

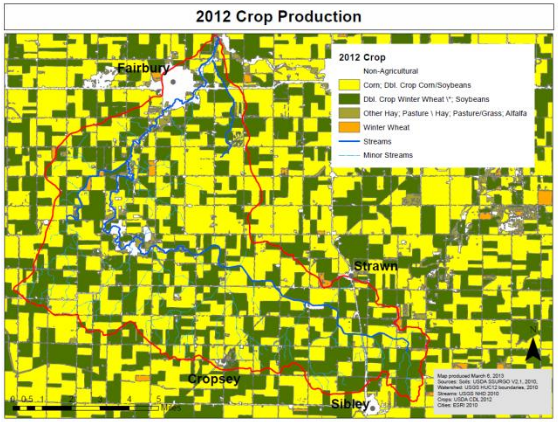
1- Is there sufficient opportunity compared to accepted scenarios (e.g. use of CRP land)?
2- Would existing models support this approach?
3- Do proof of concept data support model results?
4-Field testing results support scenario
5-Watershed scale demonstration if feasible and supported

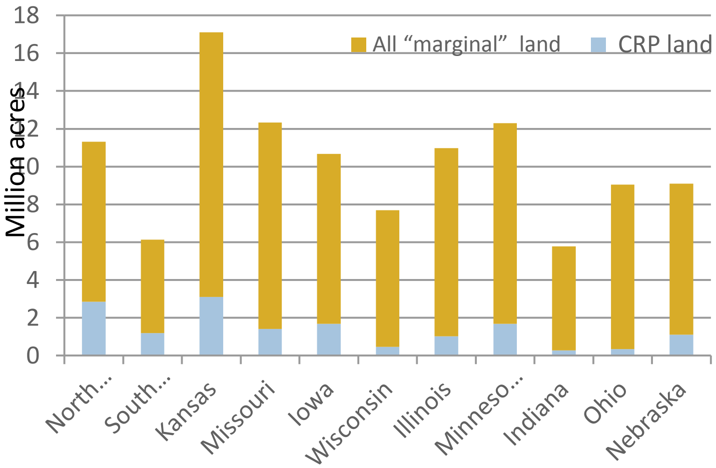


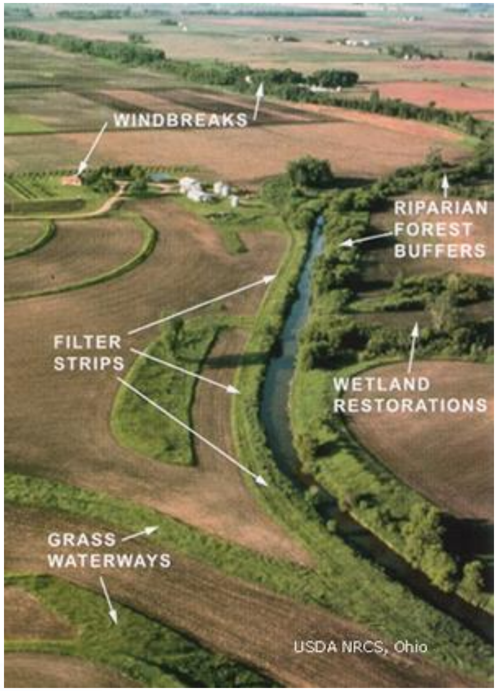
Milestones	FY08-FY10	FY11	FY12	FY13	FY14-15
Resource assessment and proof of concept	X				
Identify field site, address NEPA and other requirements		X			
Install monitoring infrastructure and baseline site conditions		....	X		
Plant Bioenergy crop (willow)			X	X	
Monitor sustainability indicators			X	X	..............X............X
Evaluate scalable sustainability metrics				X	
Questionnaire for farmer involvement developed				X	
Watershed scale demonstration physical plan drafted				X	

A new biomass model - positive land use change and environmental services .... Thinking solutions

- Need a landscape vision to grow bioenergy crops on marginal land and impaired water
- Can we substitute main crops in at-risk or lesser quality land with **diverse biomass crops**?
- Could satisfying multiple benefits address producers AND society's needs?
- BY-DESIGN ecosystems services as part of the optimization – intrinsic sustainability
- Results from 2010 show that the option is viable
- Can we intensify the supply basin?
- *Bioenergy crops could be the opportunity to improve the sustainability of agriculture*
- *Farmers contribute and critique ideas*



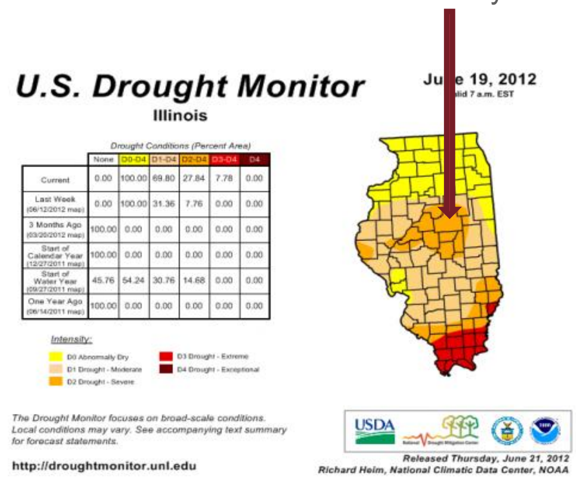




2 - Technical Accomplishments/ Progress/Results

- Identified field test site, completed NEPA, rental agreement and safety reviews
- Installed monitoring infrastructure (monitoring wells, permanent and temporary, rhizons for unsaturated soil)
- Defined metrics and methods, SOPs, standardized with BETO-wide sustainability indicators
- Characterized site hydrology, yield
- Conducted baseline assessment, site conceptual model and experimental design
- Planted willow crop in buffer and control – to be replanted
- Modeled biogeochemistry of N using DNDC on bioenergy crops, willow
- GIS analysis of Indian Creek watershed for scale-up and demonstration
- Held 1st Workshop with farmers to discuss approach and receive feedback. Many positive ideas received.

Fairbury IL

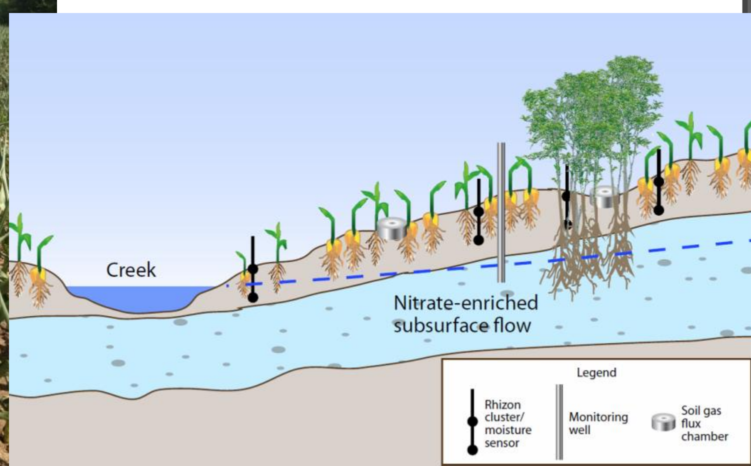


	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	69.80	27.84	7.78	0.00
Last Week (06/12/2012 map)	0.00	100.00	31.36	7.76	0.00	0.00
3 Months Ago (03/20/2012 map)	100.00	0.00	0.00	0.00	0.00	0.00
Start of Calendar Year (12/27/2011 map)	100.00	0.00	0.00	0.00	0.00	0.00
Start of Water Year (09/27/2011 map)	45.76	54.24	30.76	14.68	0.00	0.00
One Year Ago (06/14/2011 map)	100.00	0.00	0.00	0.00	0.00	0.00

2 - Technical Accomplishments/ Progress/Results

(cont'd)

- Since 2011, significant progress in characterizing field site and developing conceptual deployment of the bioenergy buffer trial.
- Performance data during 1st growth year impacted by drought – delayed progress in reaching technical targets (Target: 30% reductions in N leached to subsoil)
- Started developing the base for a watershed scale trial, developed strong local network, preliminary farmer feedback received.



Sustainability metrics tested

Groundwater
- Nitrate-N, C, P

Soil water
- Nitrate-N, C, P

Soil
- N, P, C others

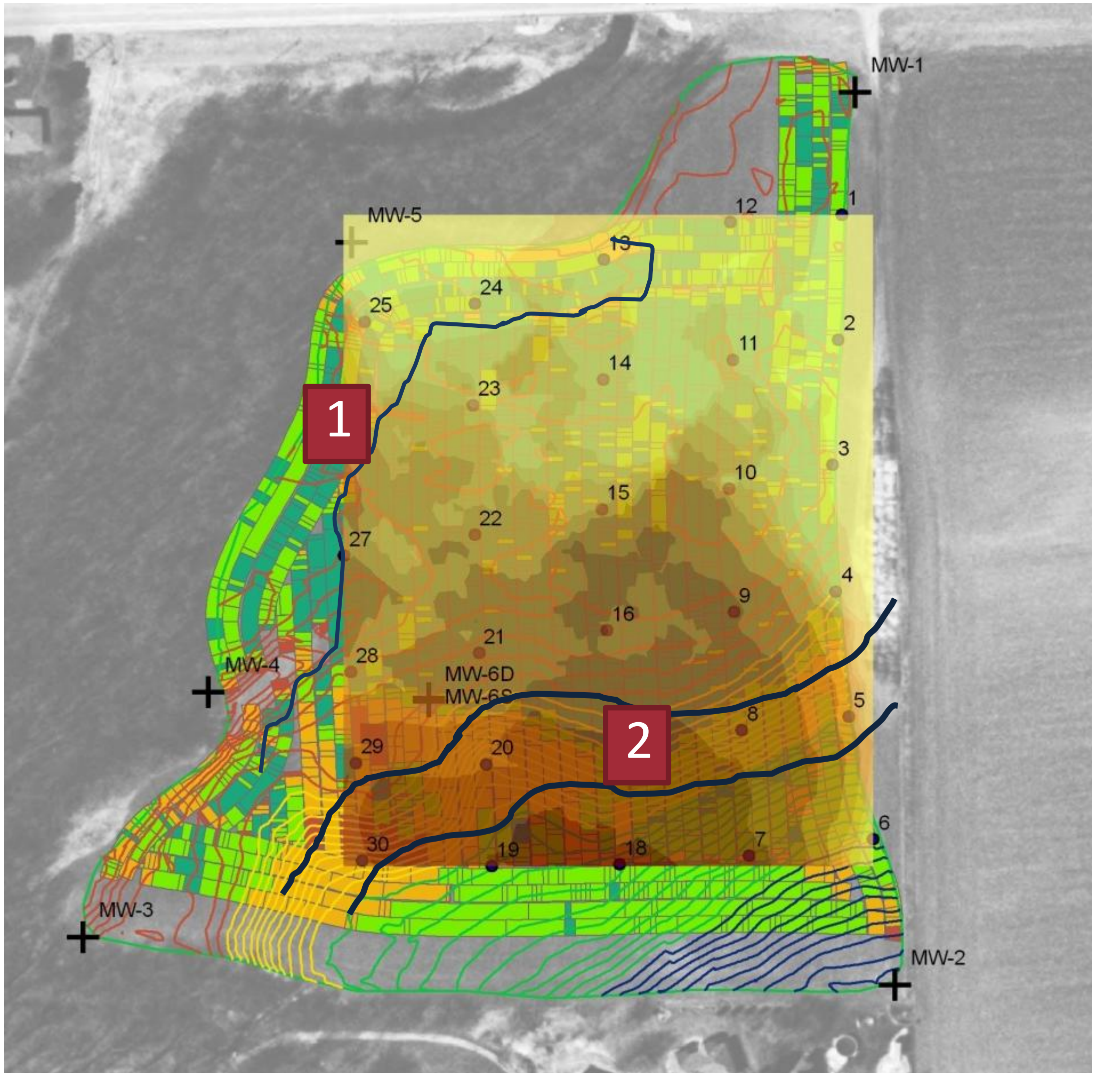
Air
- CO_2, N_2O, CH_4

Biomass (corn, willow by tissue)
- N, P, C, K, consumptive water use

Design: Riparian Buffer (1) vs contour buffer (2)

Consider for design

- Corn productivity and yields
- Nitrate concentrations in subsurface
- Number of sampling points to run geostatistics and determine spatial differences
- Types, location of controls and baseline data



Yield map and topographic map overlaid with Nitrate-N in soil water 4 ft bgs

Surface water modeling for field design- WEPP

Divided the field into 5 approximately equal zones in area based on slope

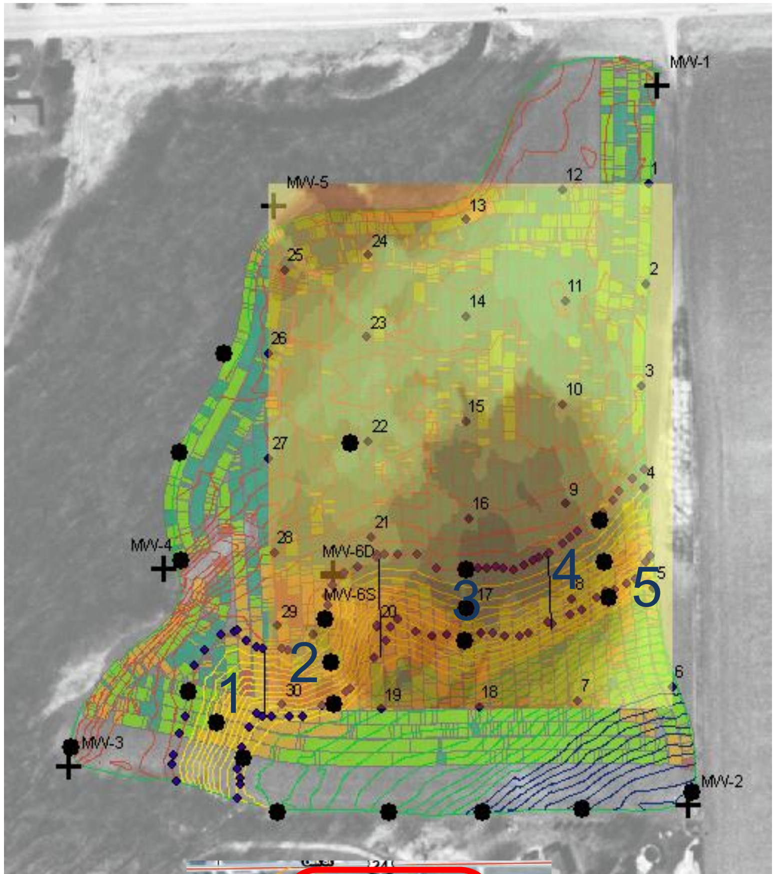


Table 1: Baseline corn production - 30 year simulation time period				
Segment	*Runoff (in/yr)*	*Soil loss (ton/A/yr)*	*Sediment yield (tons/A*	*Runoff (mm/yr)*
1	4	4.8	2.1	101.6
2	3.9	8	8	99.06
3	3.8	8.5	8.5	96.52
4	3.9	4.4	4.4	99.06
5	3.9	4.4	4.4	99.06

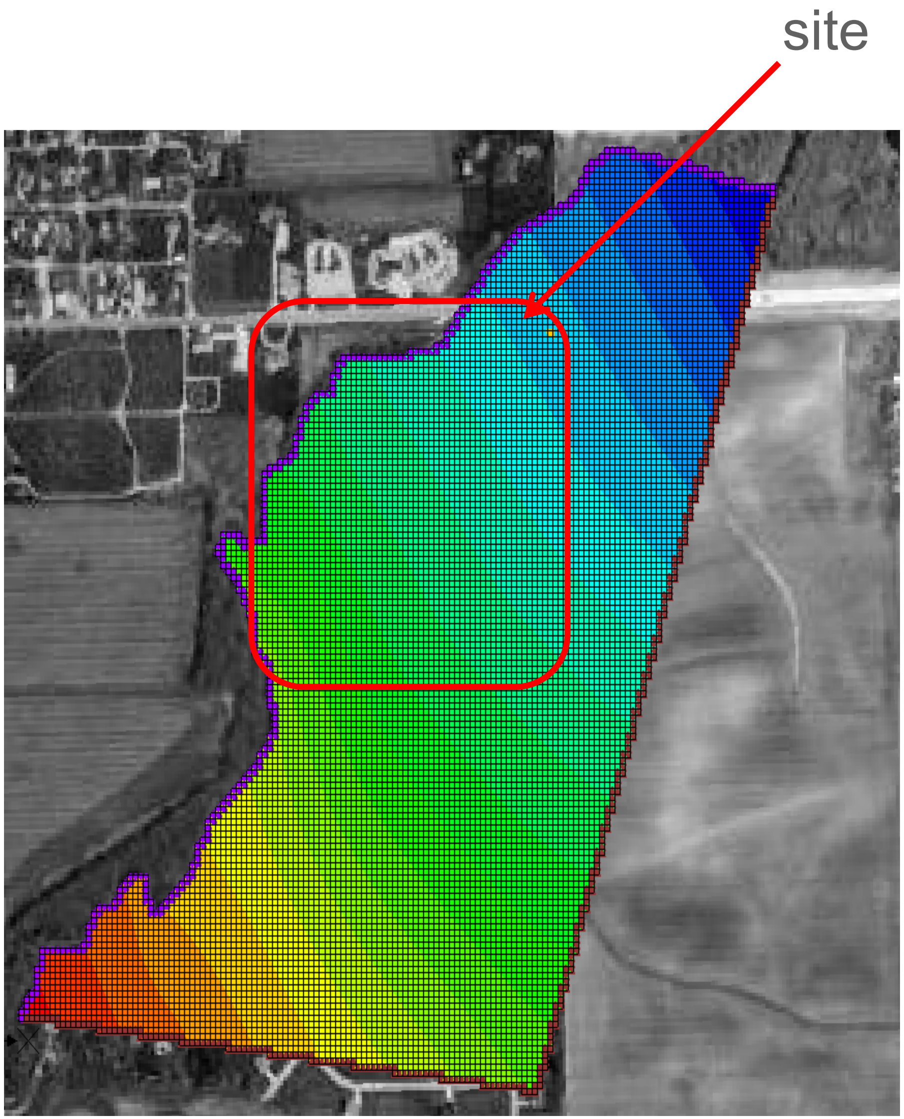
Table 2: Corn and contour buffer - 30 year simulation time period				
Segment	*Runoff (in/yr)*	*Soil loss (ton/A/yr)*	*Sediment yield (tons/A/yr)*	*Runoff (mm/yr)*
1	3.7	4.4	0.1	93.98
2	3.7	6.4	2.9	93.98
3	3.7	5.1	2.3	93.98
4	3.8	5.3	1.6	96.52
5	3.8	5.6	1.7	96.52

Contour buffer vs baseline corn:

- ~6-7% reduction in runoff
- Some reduction in soil and sediment loss

→The majority of losses does not come from runoff - subsurface flow hypothesized

Groundwater modeling for the field - MODFLOW

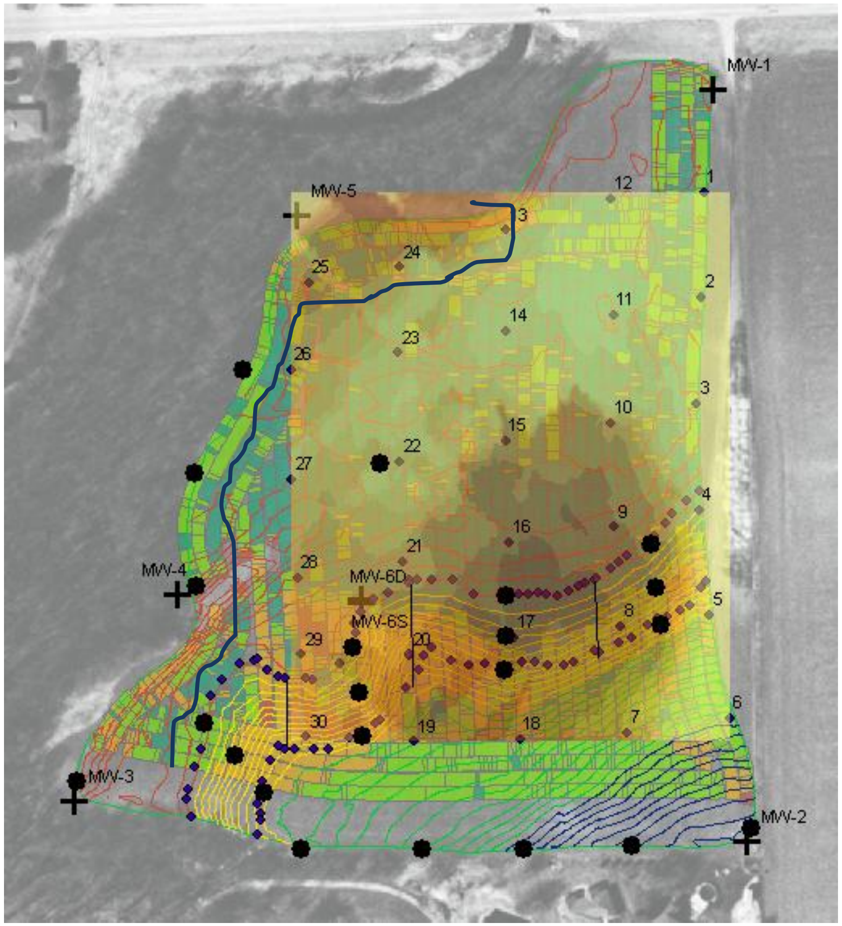


- Single layer MODFLOW model constructed
- Indian Creek as boundary condition
- Calibrated based on groundwater level measurements taken in 2011 at the field
- Model and field baseline data indicate that groundwater flow is from SW to NE – following the stream gradient

Hydrogeo model domain and preliminary head solution
Red: highest, blue: lowest

Model results provided by John Quinn, EVS, Argonne National Laboratory

Biogeochemical modeling for the field – DNDC model



Evaluated Riparian vs Contour buffer designs to understand nitrate leaching, nitrous oxide emissions and yield

		Average		
Crop	**Scenario**	**Yield (tons/ha)**	**NO_3 leached (kg N/ha)**	**N_2O emitted (kg N/ha)**
Corn	Complete field	9.6	94.5	25.6
Switchgrass	Riparian buffer	19.2	15.0	6.5
Miscanthus	Riparian buffer	47.2	16.0	12.4
Corn	Upslope area	8.5	15.6	51.3
Switchgrass	Contour buffer	11.4	9.0	2.3
Miscanthus	Contour buffer	55.7	8.1	9.1

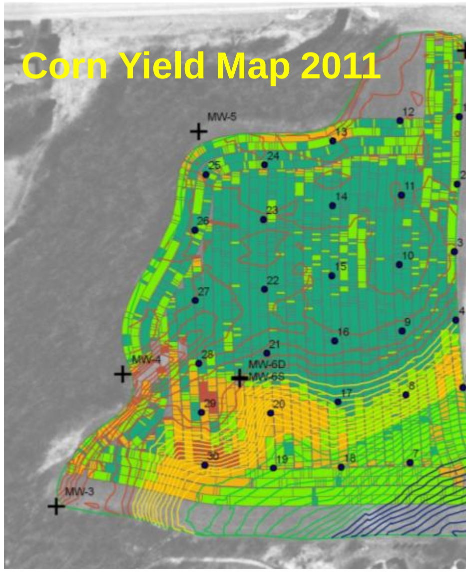
~42-85% reduction in nitrate leaching

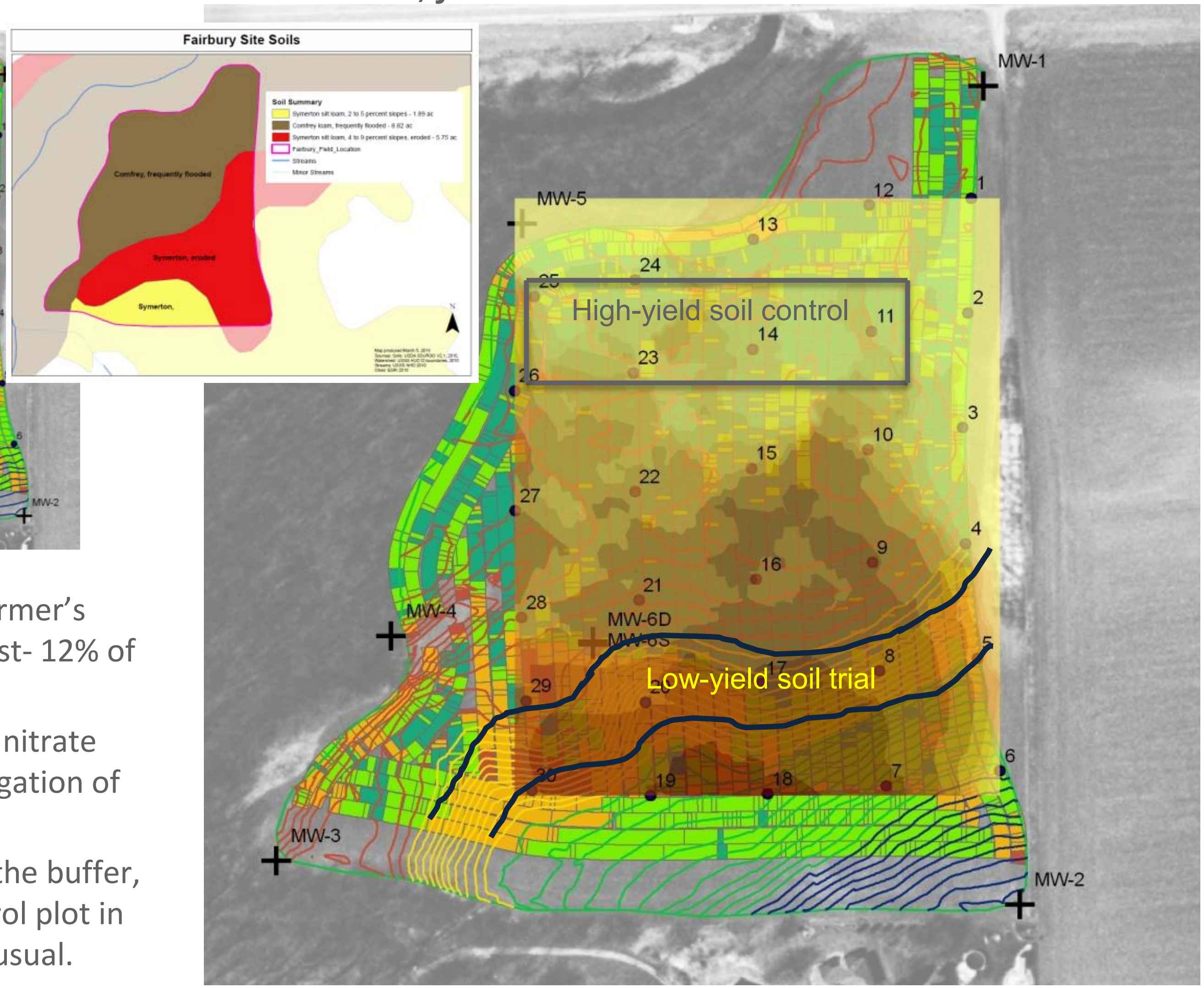
~51-95% reduction in nitrous oxide emissions

Highest reductions with contour buffer

Fairbury IL Field Trial

Corn yield: dark green areas = 175-200 bushels/acre, yellow-red areas = 70-90 bushels/acre

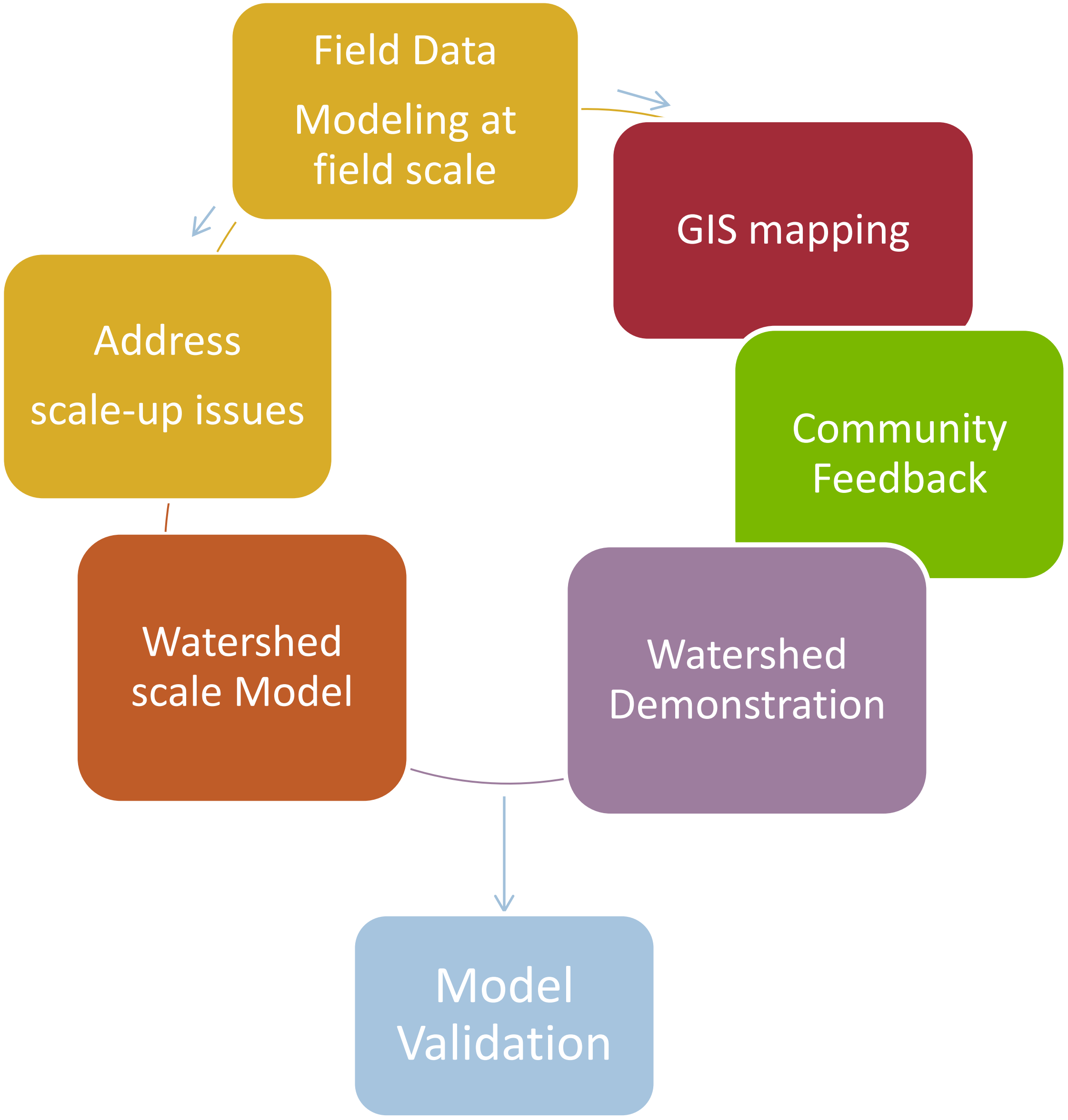


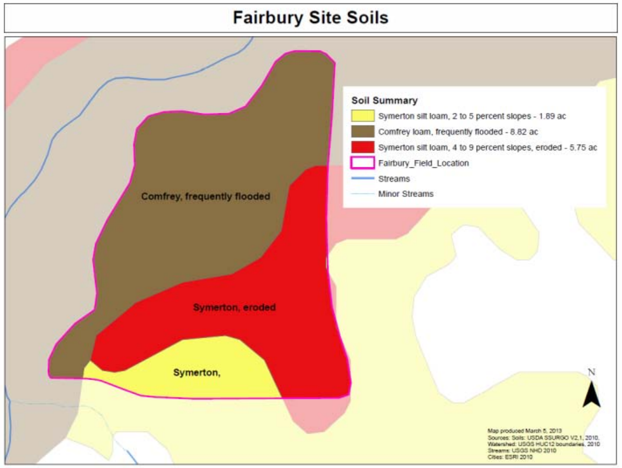


- Marginal land from the farmer's perspective –yield is lowest- 12% of field acreage
- Availability of subsurface nitrate from the corn for ferti-irrigation of the bioenergy crop
- Corn plots as controls on the buffer, and willow and corn control plot in floodplain soil treated as usual.

Yield map and topographic map overlaid with Nitrate-N in soil water 4 ft bgs

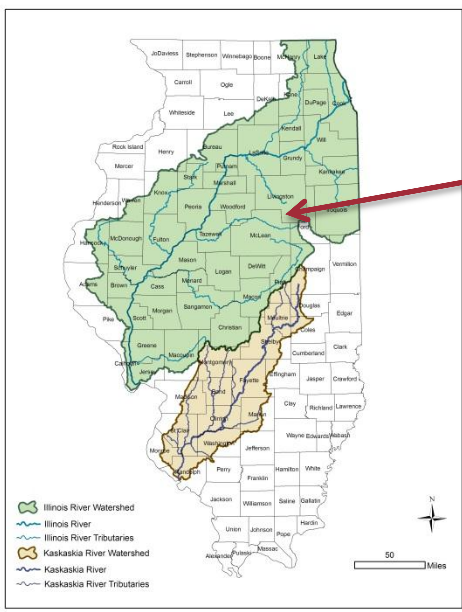
Scaling up to watershed - steps

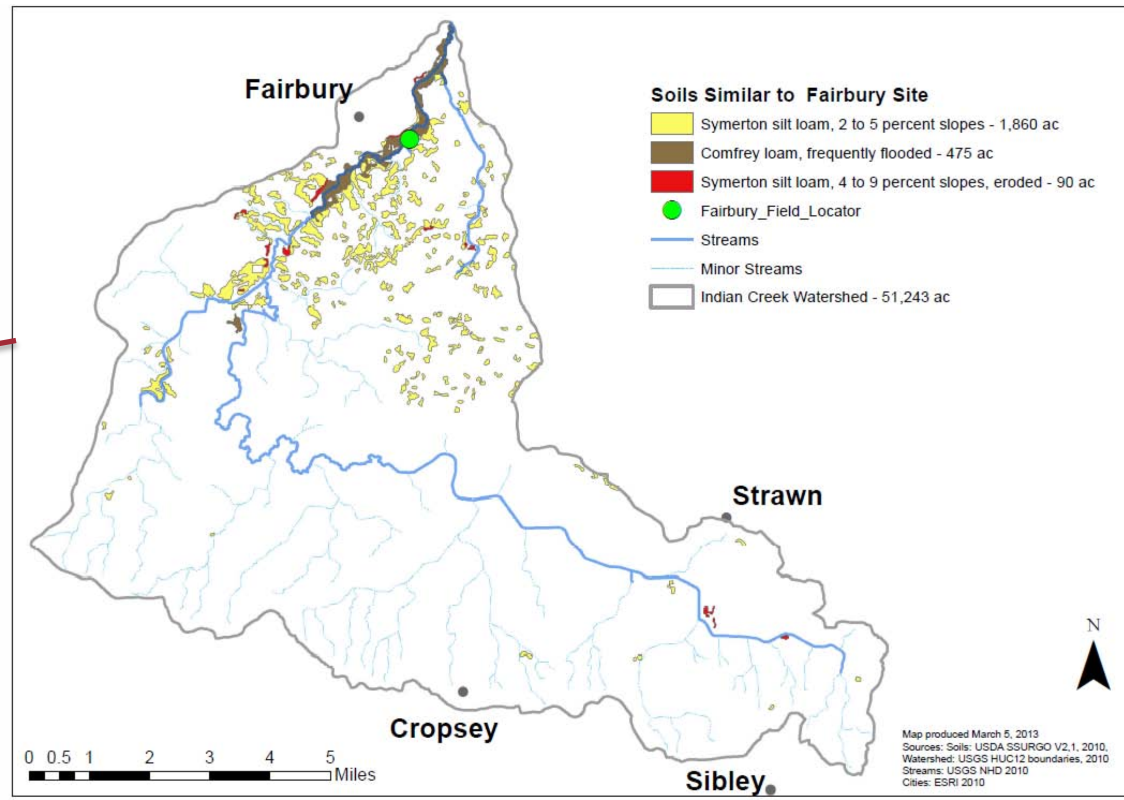




GIS mapping – How common are soils like our field trial in the watershed?

Soil	Productivity Index
Comfrey Loam	138
Symerton silt loam	131

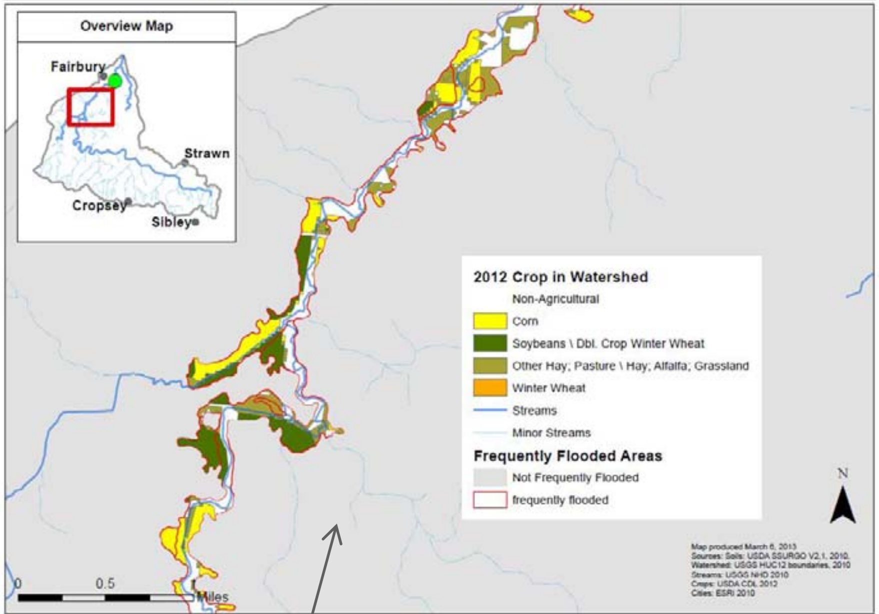




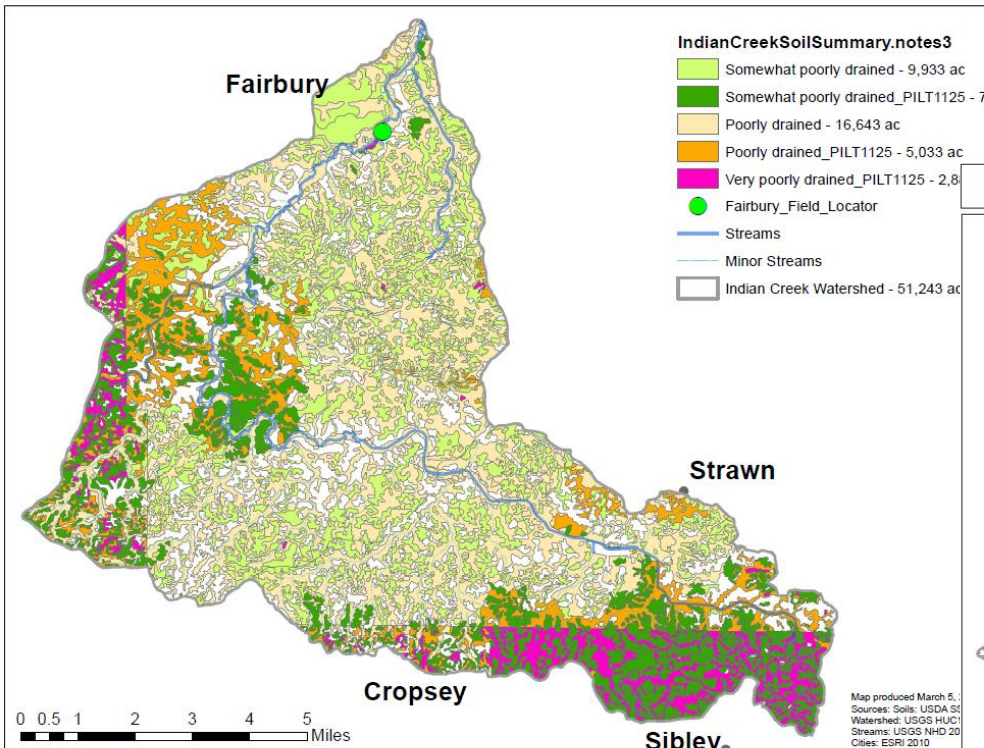
Frequently flooded (all PI>112.5),

Poorly drained soils

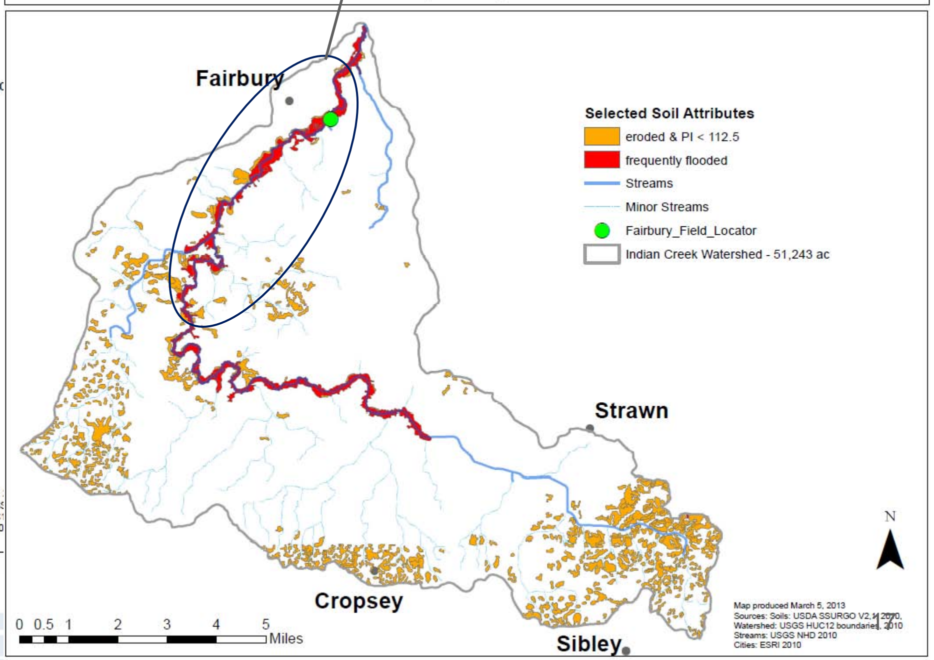
Crop Production in Frequently Flooded Areas



Poorly Drained Soils & Productivity Indexes



Eroded or Frequently Flooded Soils



Fairbury Partnership - Enabling the present and future work, Outreach and sounding board

Partnering with:

- CTIC
- The Soil and Water Conservation District of Livingston County
- State University of New York (SUNY)- ESF Sun Grant knowledge in willow
- USEPA Region V, ILEPA
- USDA RCS in Livingston County
- 160 farmers in watershed

- Monsanto
- Ceres/Blade Energy

3 - Relevance

Feedstocks

Ft-A: Feedstock availability and cost – identifying alternative inputs (land, water nutrients) with minimal tradeoffs

Ft-B: : Sustainable production – *"sustainability questions such as water and fertilizer inputs", Environmental effects of feedstock production*

Sustainability

St-E: Best practices for Sustainable bioenergy production – developing and testing an alternative best practice

St-F: Systems approach to bioenergy sustainability

St-G: Representation of Land use and Innovative Landscape Design

BMP Solution

- This project aligns to MYPP goals by proactively proposing landscapes to minimize negative land use change impacts and maximize environmental benefits.
- We have shown that this approach has the potential for substantial GHG emissions and water quality benefits while maintaining high levels of productivity of both biomass and commodity agriculture

- Relevance to conversion industry needs : proposes ways to intensify biomass supply from defined radius, decreasing transportation costs and improving supply diversification and reliability. Hence it also supports Conversion platforms' needs.
- Through our developing partnership, the project will have a substantial opportunity to link suppliers and end users of biomass for integrated deployment at the landscape scale.

4 - Critical Success Factors

- **This project will advance the state of technology and positively impact environmental performance:**
  - By providing **field data** on sustainability metrics, yields and environmental impacts of landscape-placed bioenergy crops
  - By defining and **testing best practices** for sustainable bioenergy production
  - By accommodating needs to **satisfy different goals** (energy security, environmental protection, low-cost commodities) and different bioenergy scenarios.

- **It connects with existing watershed conservation efforts in Illinois, builds the network to secure implementation and demonstration in the longer term, provide visibility, access, feedback from multiple stakeholders: provides path forward beyond and parallel to field testing stage**
  - Demonstrating recovery of nutrients and sustained yields (best practice) will allow rural producers to identify economic opportunity
  - Demonstrating water quality and GHG benefits will aide regulators and policy development, as well as OBP analysis efforts and support goal of EISA and RFSII
  - Farmer acceptance and feedback will be critical to adoption of the approach: project builds the R&D and farmer connections in parallel

- **Challenges:**
  - Establishing research-grade conditions at the field scale and attaining robust statistical design is the immediate challenge which requires blending of different approaches.
  - Scaling up to watershed research will require significant effort to ensure participation and the collection of sufficiently detailed land use data such as individual yield maps.

5. Future Work

- Continue field monitoring of sustainability and performance metrics
- Develop a conceptual plan for a watershed demonstration
- Keep involving local stakeholders and build interest

- Upcoming Milestones:
  - Willows replanted
  - Evaluate scalable sustainability metrics
  - Questionnaire results complete
  - Conceptual physical plan for watershed demonstration

Summary

- A converging combination of a field trial, modeling and spatial analysis provides **support for an alternative sustainable biomass production scenario or BMP.** Spatial analysis conducted in previous years showed that the **opportunity is viable**
- Proposed scenario to deploy bioenergy crops in landscape design has potential for substantial **benefits in production and sustainability**
- **Aids in market transformation** by demonstrating economically sustainable BMPs to integrate production with environmental sustainability. Open channel for producers to contribute ideas
- Scenario **provides flexibility** in protecting fragile land - **benefits extend to corn as well**
- Currently in **field validation phase**, we are building a strong support basis and network for future watershed/landscape scale-up and comparison with other BMPs.

Additional Slides

Responses to Previous Reviewers' Comments

- **Connect with agroforesty and buffer expertise**
  - In addition to previous access to literature, asked review from National Agroforestry Center experts
- **Need to better understand seasonality of nitrogen recovery**
  - DNDC model incorporates nitrogen fate in plant biomass and emissions from decay. Added additional sampling times to better capture seasonal nitrogen uptake/loss in vegetation and litter
- **Would like to see local scale learnings reapplied to the landscape level**
  - Started to gather data and develop plan for a conceptual design of watershed demonstration.

Publications, Presentations, and Commercialization

- Negri M. C., G. Gopalakrishnan, T. Bachtold, S. John, F. W. Iutzi^, X. Liu^, *Bioenergy crops for resilient landscapes: a design case study and field experiences. Abstract submitted to Soil and Water Conservation Society Annual Meeting Reno, NV July 2013.*
- Gopalakrishnan G. Negri M.C. A novel framework for incorporating sustainability into biomass feedstock design . Presented at the American Geophysical Union Fall Conference, San Francisco, USA December 2012
- Negri M. C. , G. Gopalakrishnan, M. Urgun Demirtas and J. Quinn *Designing a multi-functional sustainable agricultural system at the farm scale using energy crops* Paper presented at the 10th International Phytotechnologies Conference, Hasselt, Belgium, September 2012
- Gopalakrishnan G. M. C. Negri, P..Benda, M. Urgun-Demirtas, J. Quinn *Spatial and temporal variability of nitrate and nitrous oxide concentrations in the unsaturated zone at a corn field in the US Midwest* Presented at the American Geophysical Union Fall Conference, San Francisco, USA December 2011
- Negri M.C. and G. Gopalakrishnan (2012). *Changing the bioenergy equation: turning environmental challenges into sustainable resources*. Argonne OutLoud Public Lecture Series, April 12, 2012, Argonne National Laboratory.
- Biomass 2011
- Gopalakrishnan G.; M.C. Negri, W.A. Salas, (2012) "*Modeling biogeochemical impacts of bioenergy buffers with perennial grasses for a row-crop field in Illinois*", Global Change Biology Bioenergy, DOI: 10.1111/j.1757-1707.2011.01145.
- Gopalakrishnan G., M. C. Negri and S. W. Snyder (2011) . *A novel framework to classify marginal Land for Sustainable Biomass Feedstock Production*. J. Environ. Qual. 40:1593–1600.
- Gopalakrishnan G., M. C. Negri and S. W. Snyder (2011). *Redesigning agricultural landscapes for sustainability using bioenergy crops: quantifying the tradeoffs between agriculture, energy and the environment.* Aspects of Applied Biology 112, 2011-Biomass and Energy Crops IV.
- Gopalakrishnan G., M.C. Negri, "Designing bioenergy crop buffers to mitigate greenhouse gas emissions and improve water quality for agriculture", American Geophysical Union Fall Conference, San Francisco, USA December 2010.
- Negri, M.C., G. Gopalakrishnan, P. Benda and L. LaFreniere, 2009, "A systems approach to Grow Sustainable Biofuel Feedstock" , presented at the 6th Annual Bioenergy Feedstock Symposium, Urbana-Champaign January 13-14, 2009.
- Gopalakrishnan, G., M.C. Negri, M. Wang, M. Wu, S. Snyder, and L. LaFreniere (2009). *Biofuels, land and water: a systems approach to sustainability*. Environ. Sci. Technol. 2009, 43; 6094-6100.
- Wu, M, M. Wang, G. Gopalakrishnan, M. C. Negri, M. Mintz, and S. Arora. "Water Use and GHG Emissions for Sustainable Biofuel Development" . AIChE Spring conference, April 26-30, 2009, Tampa FL.
- M.C. Negri, Gopalakrishnan G., Benda P, "Biofuels sustainaibility: From managing a problem to designing a solution", Sixth International Phytotechnologies Conference, St. Louis, U.S.A., 2009
- Negri M.C. and G. Gopalakrishnan. "*New Approaches to Energy Crops Sustainability".* Council for Chemical Research 30th Anniversary Annual Meeting: The Business of Water. April 20, 2009, Salt Lake City, UT
- Gopalakrishnan G., M. C. Negri (presenter), May Wu, Michael Wang and Seth Snyder. 2009. "A systems approach to biomass sustainability" Biomass 2009: Fueling Our Future March 17-18, 2009, National Harbor, MD.
- Gopalakrishnan, G., M. C. Negri, M. Wang, M. Wu, S. Snyder, 2008, "Use of marginal land and water to maximize biofuel production", *Proceedings of the Short Rotation Crops International Conference: Biofuels, Bioenergy and Bioproducts from sustainable agricultural and forest crops*, Minneapolis, MN, ed: Robert Mitchell and Ronald Zalesny.