April 4, 2023

4.2.2.12 CONTINUATION

Argonne NATIONAL LABORATORY

SCALING UP THE ECOSYSTEM SERVICES OF BIOENERGY LANDSCAPES (FY20-22) AND SCALING UP DECARBONIZATION AND SUSTAINABILITY (SUDS) (FY23-25)

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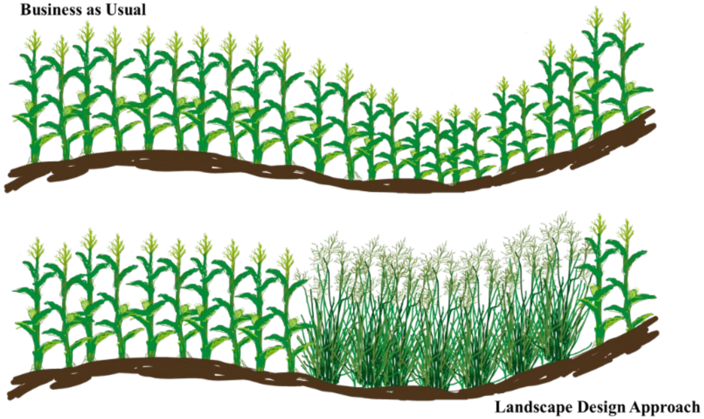
DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review
Denver, Colorado

PROJECT OVERVIEW



Modeling ~ Tool Development ~ Technologies ~ Economic Analyses ~ Field and Lab

- The prior and current projects both focus on how to promote the generation of biomass from perennial bioenergy crops. Economic and environmental aspects are key to a sustainable bioeconomy and reducing the $/gge of biofuel production.
- A key component of these projects is the development of an online geospatial tool to assist in decision-making regarding the conversion of row crops to perennials.
- Adoption of perennial bioenergy crops can be win-win-win for farmers, the environment, and the bioeconomy.

OUTLINE

1. Progress and Outcomes – Scaling up the Ecosystem Services of Bioenergy Landscapes (FY20-22)
2. Approach – Scaling Up Decarbonization and Sustainability (SUDS) (FY23-25)
    - Initial funding received in late January 2023
3. Impact

SCALING UP PERENNIAL BIOENERGY ECONOMICS AND ECOSYSTEM SERVICES TOOL (SUPERBEEST)

SUPERBEEST:

– A free, online geospatial tool
– To assist in decision-making regarding the adoption of perennial bioenergy crops to grow the bioeconomy
– Focus on current row crop land use in a Midwest 12-state region

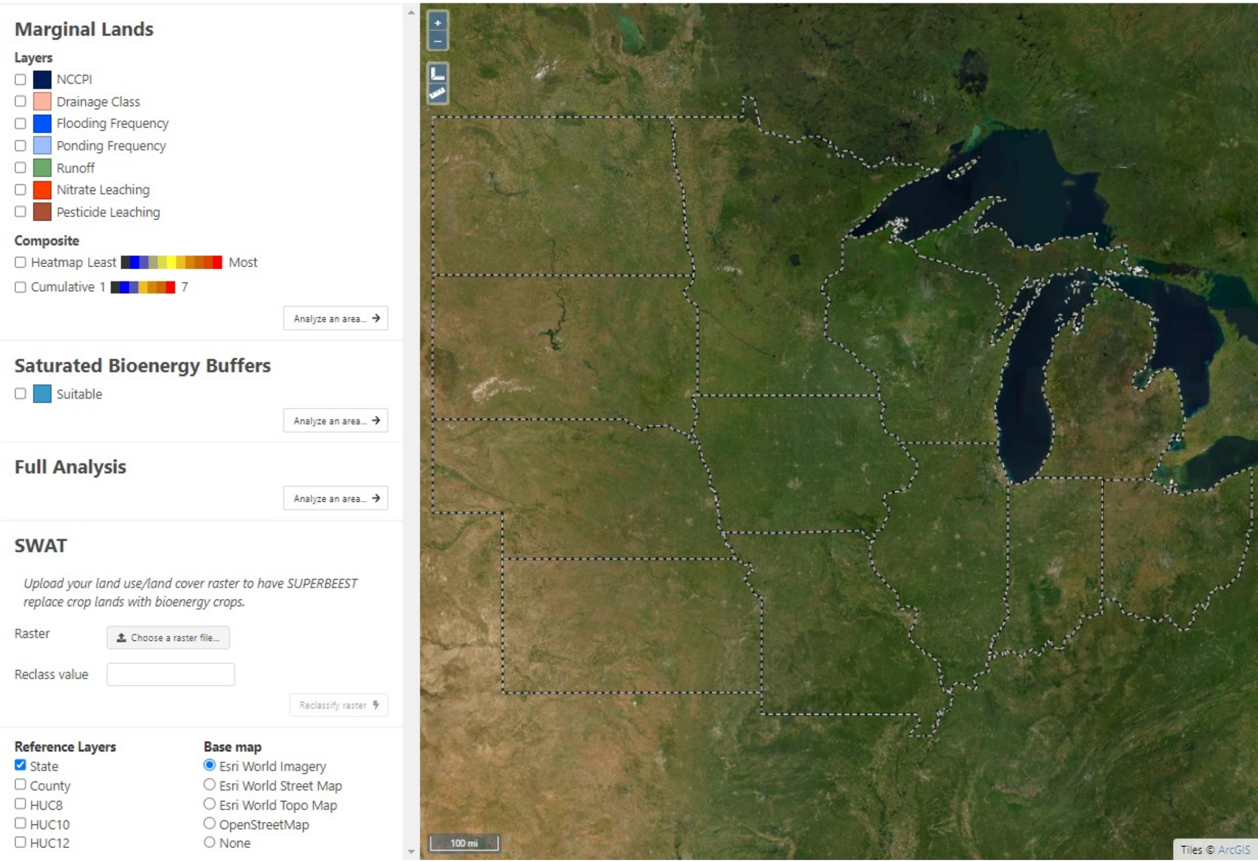
Progress and Outcomes

SUPERBEEST PURPOSE: 3 CAPABILITIES

- Identification of marginal land (any scale) ideal for conversion from corn/soybean to perennial bioenergy crops
  - Marginality by economic and/or environmental measures
  - Identification of good candidate Saturated Bioenergy Buffer locations (for enhanced biomass production and reducing nitrate lost to surface water)
  - No land use change – productive farmland remain in row crop rotation
- Determination of ecosystem services to be realized from the crop change
  - Water quality (nitrate, sediment, water-based recreation) - SWAT model link
  - Carbon sequestration
  - Greenhouse gas
  - Biodiversity, hunting, pollinators, wildlife viewing
- Estimation of the net economic value of the change

Progress and Outcomes SUPERBEEST

- Marginalities
  - National Commodity Crop Productivity Index (NCCPI)
    - Economic
  - Soil Survey Geographic Database (SSURGO)
    - Drainage
    - Flooding
    - Ponding
    - Runoff
  - U.S. Geological Survey
    - Nitrate leaching
    - Pesticide leaching

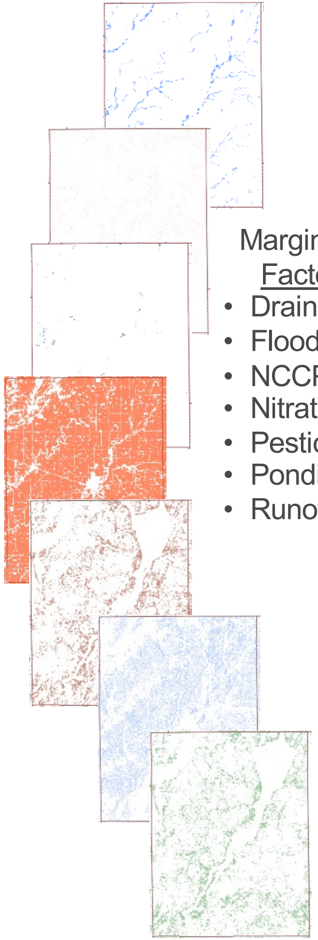


Progress and Outcomes

A COUNTY-SCALE EXAMPLE

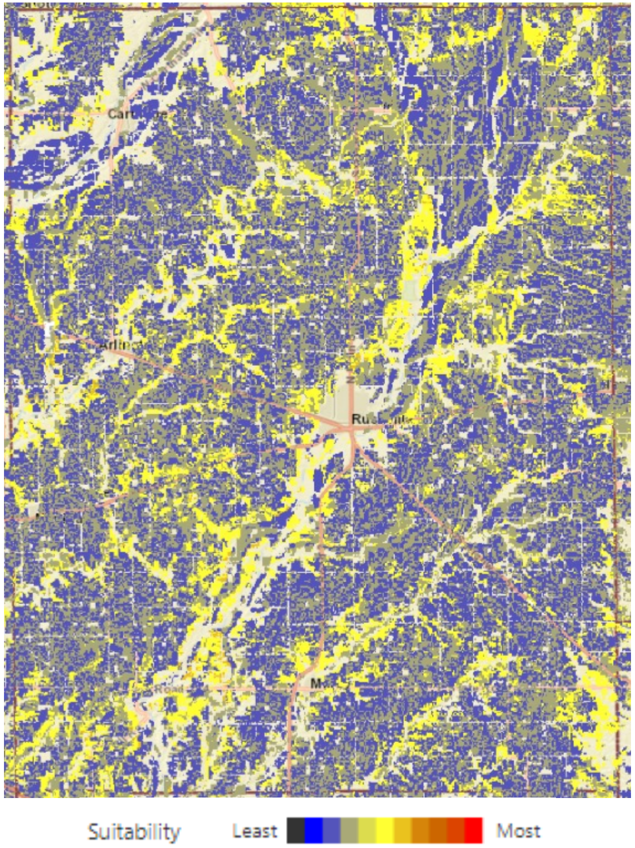
SUPERBEEST

Examples show an Indiana county's environmentally and economically marginal farmland and a combination of marginality factors to identify optimal locations for conversion to perennial bioenergy crops with environmental and economic benefits



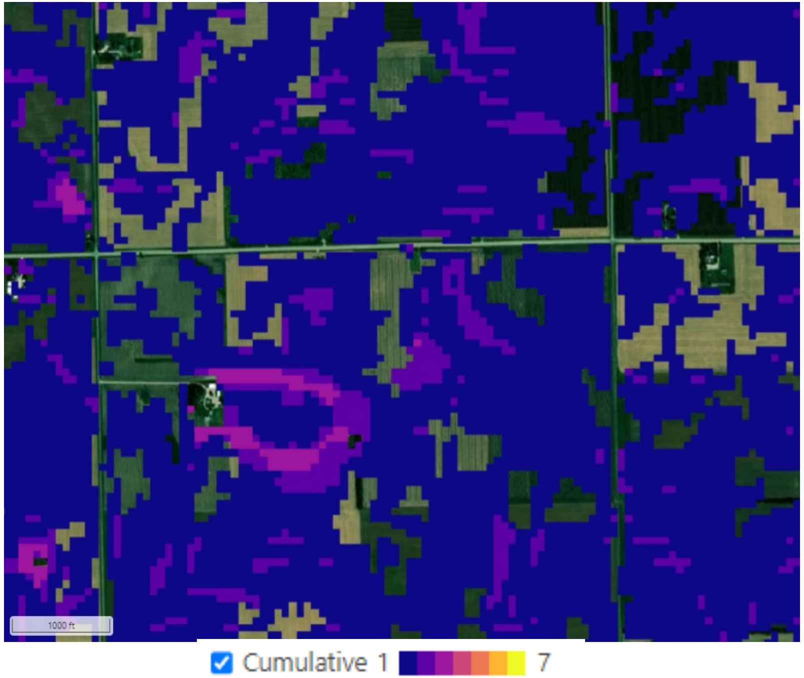
Marginality Factors
- Drainage
- Flooding
- NCCPI
- Nitrate
- Pesticide
- Ponding
- Runoff

Combined marginalities



Example: an Indiana county

Progress and Outcomes



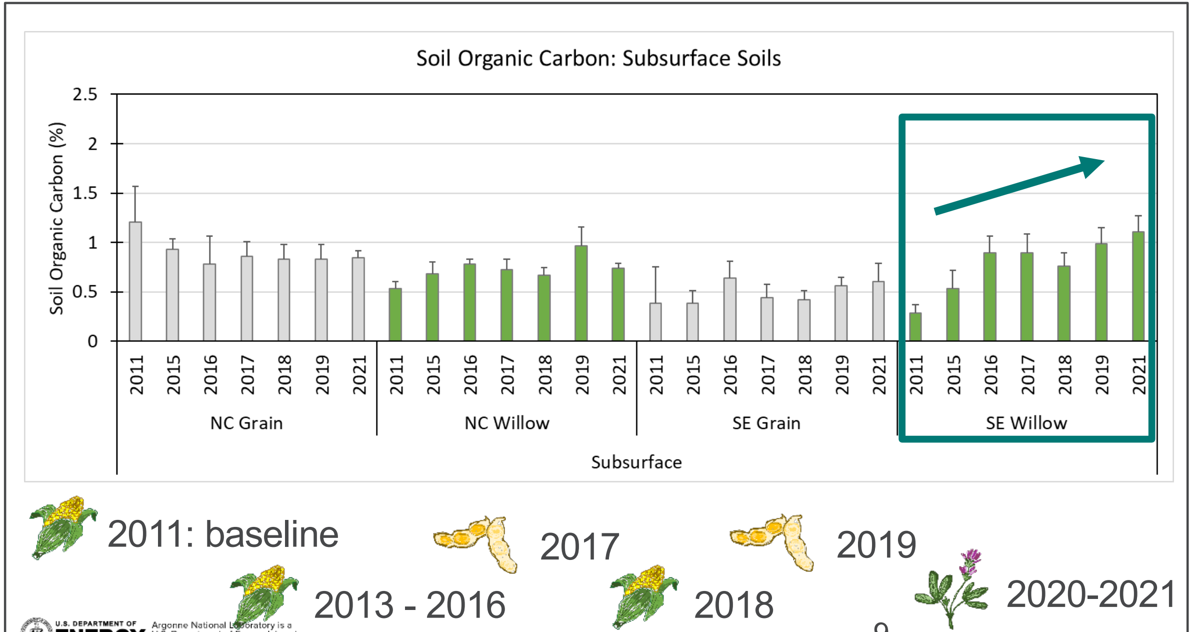
Example of farm level analysis (cumulative marginalities shown over aerial photo)

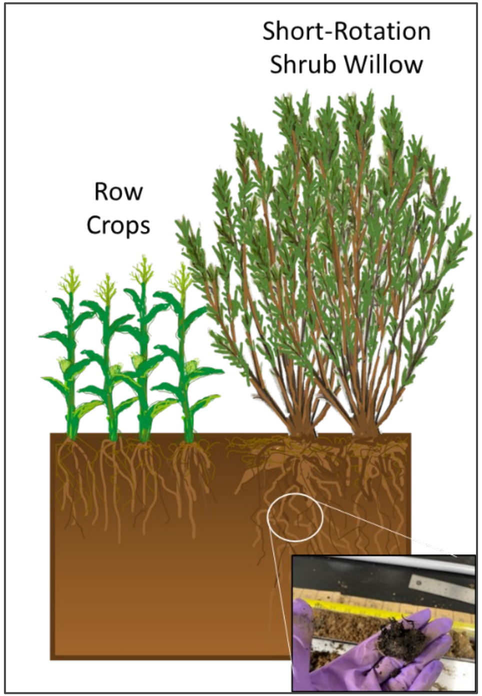
- For multiple scales
  - a manual delineation of landowner's farmland
  - a county or group of counties
  - a watershed or group of watersheds (HUC-8 to HUC-12)
- Target users
  - Farmers and landowners
  - Agencies and regulators
  - Researchers
  - Biorefinery planners

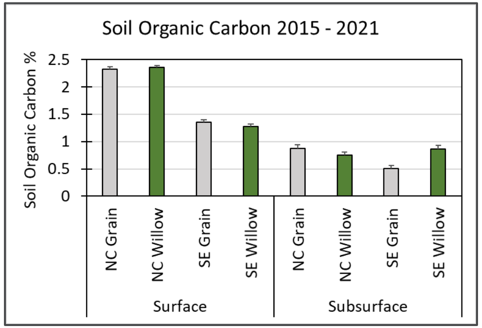
Progress and Outcomes

SUBSOIL CARBON SEQUESTRATION

- A general increase in subsurface carbon was observed across production years under willow grown on marginal soils
- Willows planted on marginal soils had significantly higher subsurface soil organic carbon post-establishment compared to row crops grown on the same soil



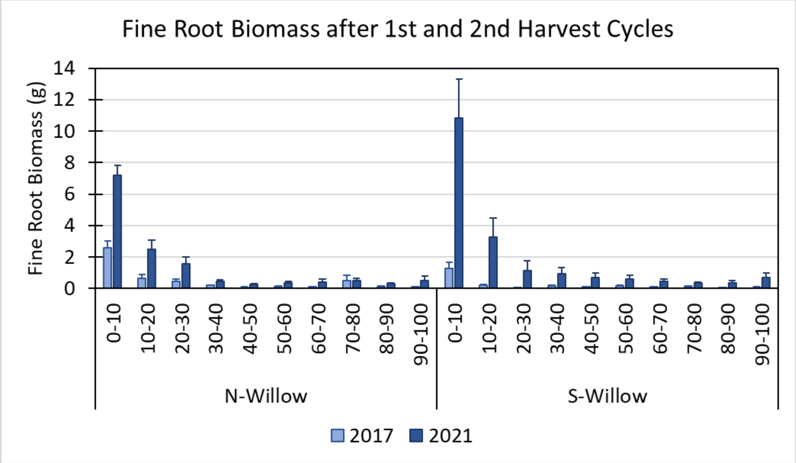


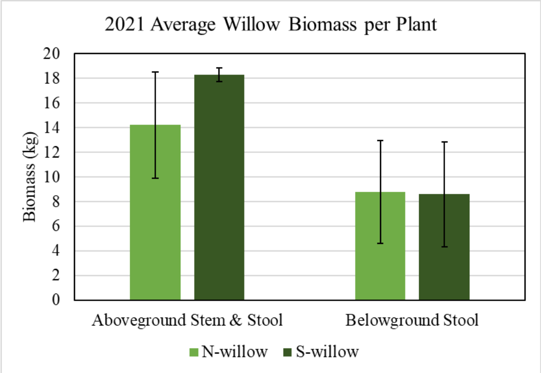


Progress and Outcomes

WILLOW BELOWGROUND BIOMASS

- **Fine roots using 3-in soils cores to a depth of 120-cm were collected after harvest in 2017 and 2021**
  - Top 30 cm contained 71 – 76% of fine roots in 2017 & 2021, respectively
  - There was a large increase in fine root biomass from 2017 (1st harvest) and 2021 (2nd harvest)
- **Full plants were harvested after the 2nd harvest cycle to assess above and belowground productivity**
  - No significant differences between landscape positions of aboveground stem + stool, belowground ground stool, coarse roots from trenches, or fine roots were observed





Progress and Outcomes

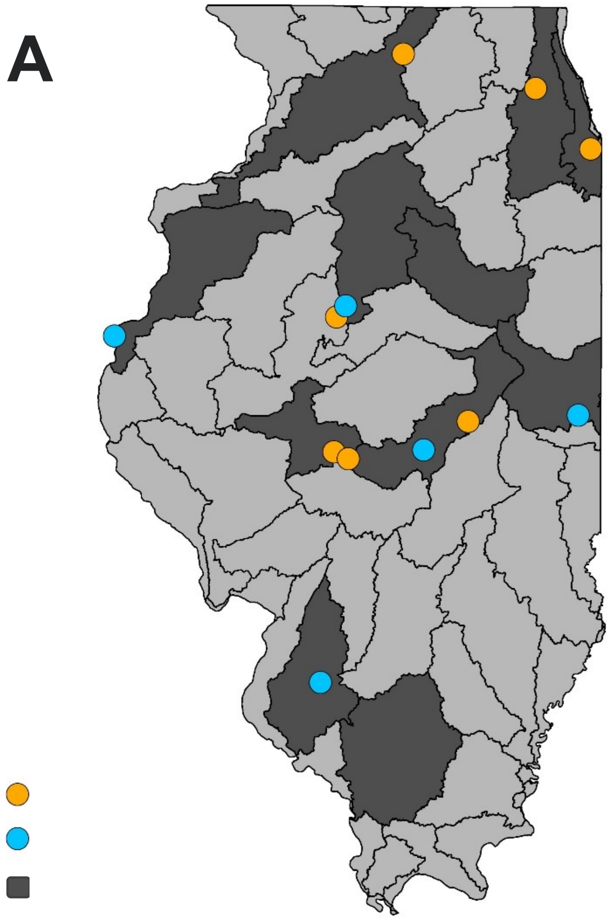
BIOENERGY CROP ADOPTION AS A MEANS FOR A NUTRIENT REDUCTION CREDIT TRADING SCHEME: A DEMAND ANALYSIS

This study compared nitrogen reduction costs ($/kg) in Illinois between:

A. Waste & Drinking Water Treatment Plant (TPs)
   - Water quality standards require taking nitrogen out of water

B. On-farm reduction through bioenergy crop adoption in marginal land

If on-farm reduction costs are more cost effective than what TPs pay to reduce nitrogen, it may be advantageous for TPs to pay farmers a credit to grow bioenergy crops. This can provide an additional market incentive to transition to bioenergy crops.



Progress and Outcomes

Nutrient Reduction Costs

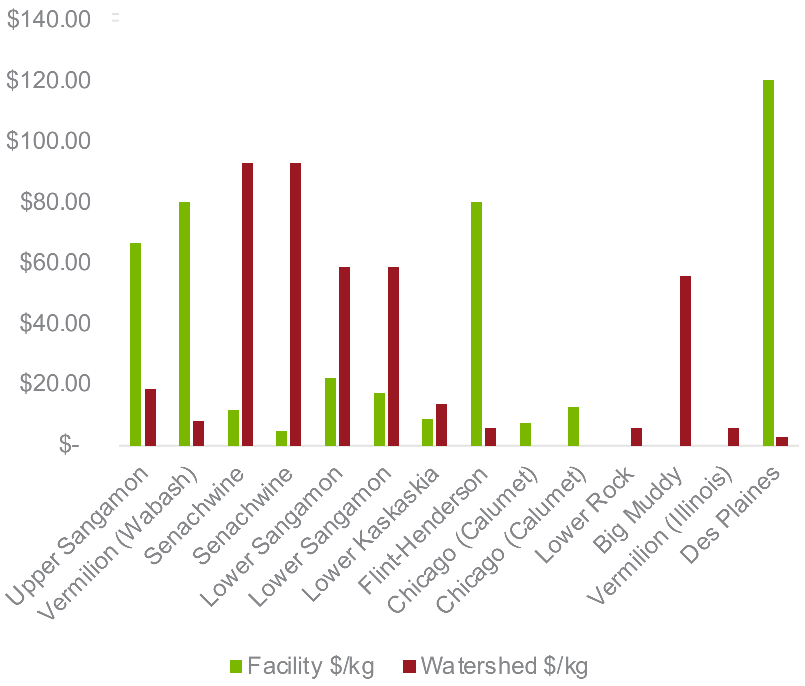
Watershed	Facility ($/kg)	Watershed ($/kg)	Watershed Credit ($/ha)
Upper Sangamon	$66.64	$18.62	$181.57
Vermilion (Wabash)	$80.36	$8.23	$154.99
Senachwine	$11.44	$92.97	$3.06
Senachwine	$4.70	$92.97	$3.06
Lower Sangamon	$22.25	$58.69	$214.62
Lower Sangamon	$17.16	$58.69	$214.68
Lower Kaskaskia	$8.73	$13.60	$64.10
Flint-Henderson	$26.23	$5.86	$100.95
Chicago (Calumet)	$7.56	n/a	n/a
Chicago (Calumet)	$12.65	n/a	n/a
Lower Rock	-	$5.78	$129.16
Big Muddy	-	$55.85	$67.96
Vermilion (Illinois)	-	$5.62	$105.06
Des Plaines	$120.23	$2.97	$110.78

- Treatment Plant variables:
  - Size of facility (million gallons/day)
  - Amount of nitrogen removed (kg/gal)
  - Frequency of nitrogen removal (# days)
  - Labor/O&M costs
- Bioenergy Crop variables:
  - Costs of land ($/ha)
  - Nitrogen reduction potential (high export watersheds vs. low export watersheds) (kg/ha)
  - Yield, revenue ($/ha)
  - Amount of available marginal land (ha)
- Monte Carlo simulation estimated a range of yields, revenues, and nitrogen reduction for bioenergy crop production.

Progress and Outcomes

DEMAND ANALYSIS SUMMARY

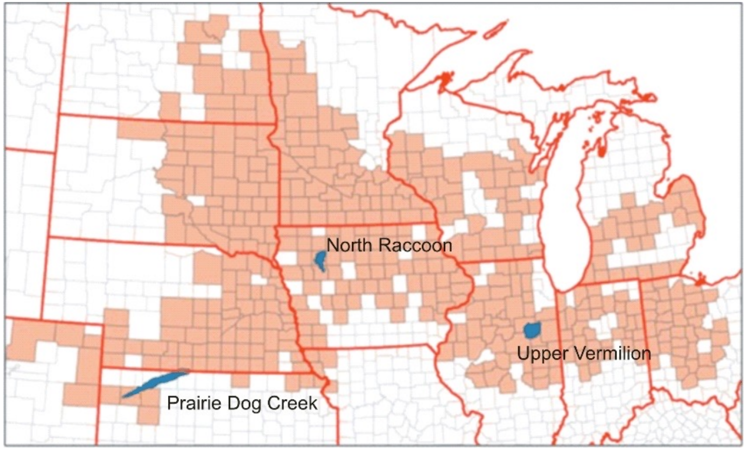
- 4 of 11 watersheds have lower $/kg reduction than facilities, suggesting an opportunity exists for in-watershed credit generation through this scheme.
- This does not explore credit purchasing outside the boundaries of a watershed, i.e. upstate facilities purchasing credits downstate.



Progress and Outcomes

TECHNO-ECONOMIC ANALYSIS (TEA)

- Watershed-specific Soil and Water Assessment Tool (SWAT) modeling and the benefit transfer method to estimate the monetary value of a range of ecosystem services
- Due to methods and data availability, dollar values are approximate and merely reflect a non-zero societal value of ecosystem services
- Three examined watersheds: Upper Vermilion (IL), Raccoon River (IA), and Prairie Dog Creek (KS/NE)

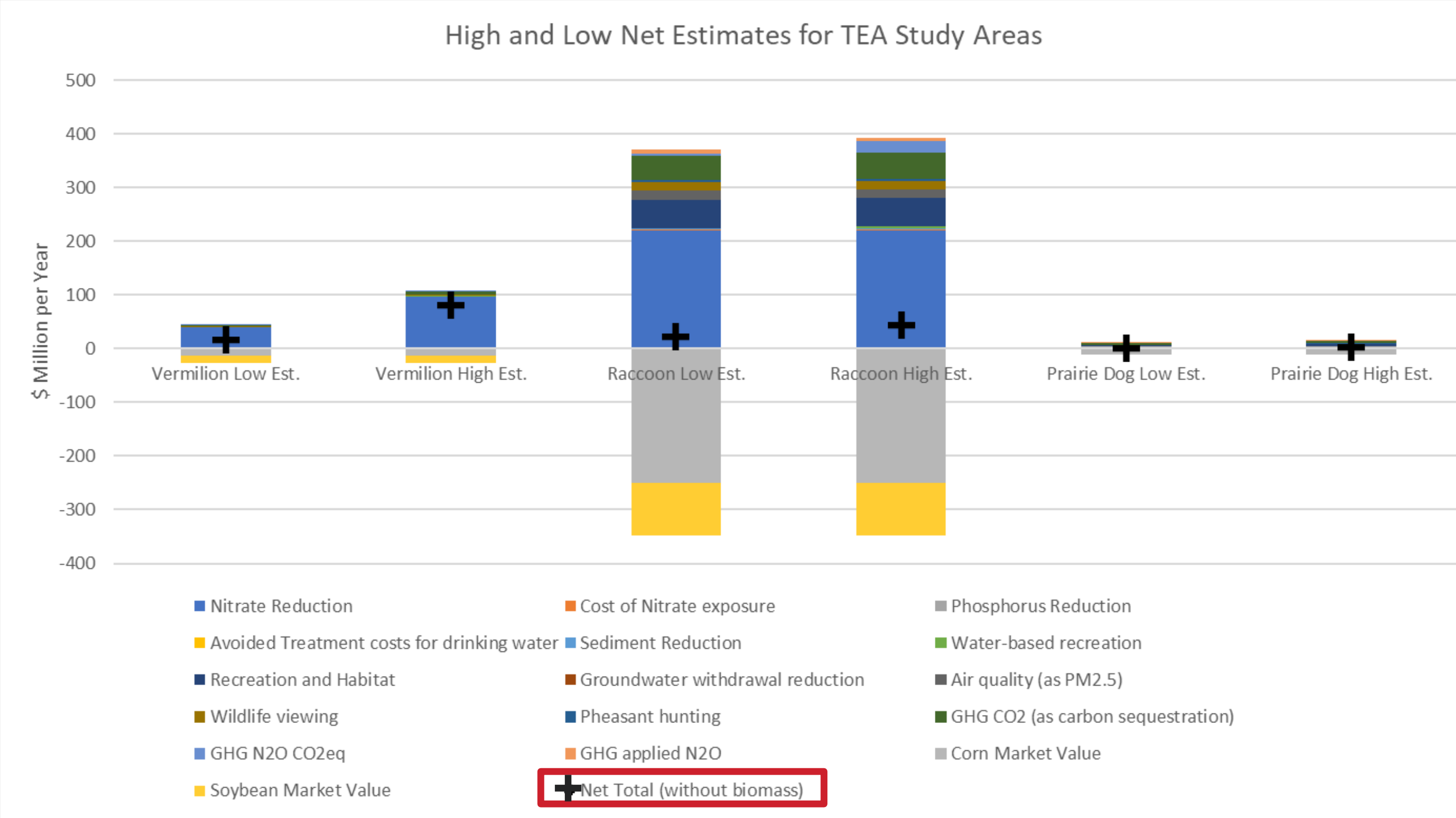


- Ecosystem services include:
  - Nitrate reduction
  - Sediment reduction
  - Phosphorus reduction
  - GHG emission reduction (CO_2 carbon sequestration and N_2O)
  - Local air quality improvements ($PM_{2.5}$)
  - Water-based recreation improvements
  - Wildlife viewing/pheasant hunting
- Revenue from crop production

Progress and Outcomes

TEA

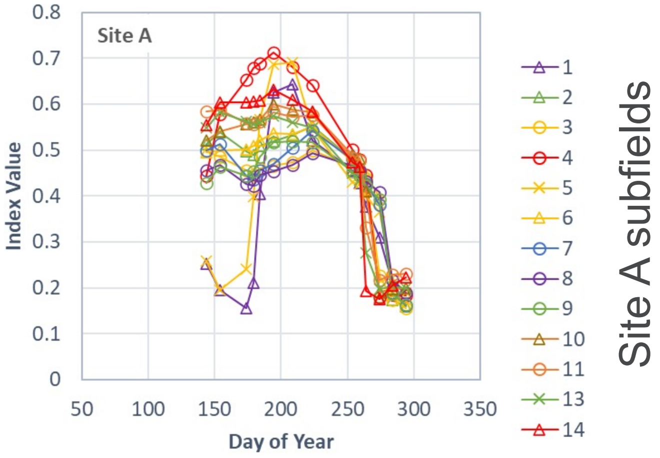
- Results indicate the values of ecosystem services are greater than the loss of corn/soybean revenue on the marginal lands

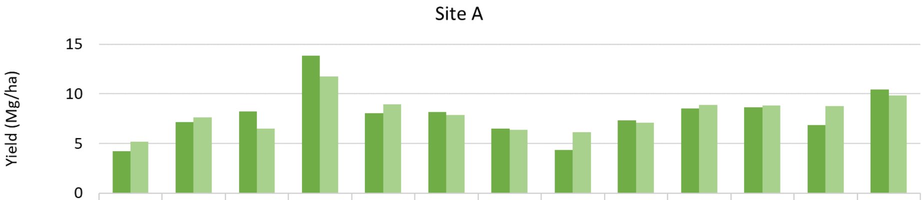


Progress and Outcomes

REMOTE SENSING FOR PREDICTION OF YIELD

- Study area
  - 4 mature switchgrass sites in Virginia, each with subfields
  - Baling data for calibration (Antares)
- Approach
  - Analysis of 30 spectral vegetation indices from Sentinel-2 imagery
- Results
  - normalized difference red-edge index utilizing the red-edge band 5 (NDRE5) showed the most robust and consistent correlation with the recorded biomass yields (R^2=0.75 on average)
  - Optimal imagery date for harvest prediction was early July





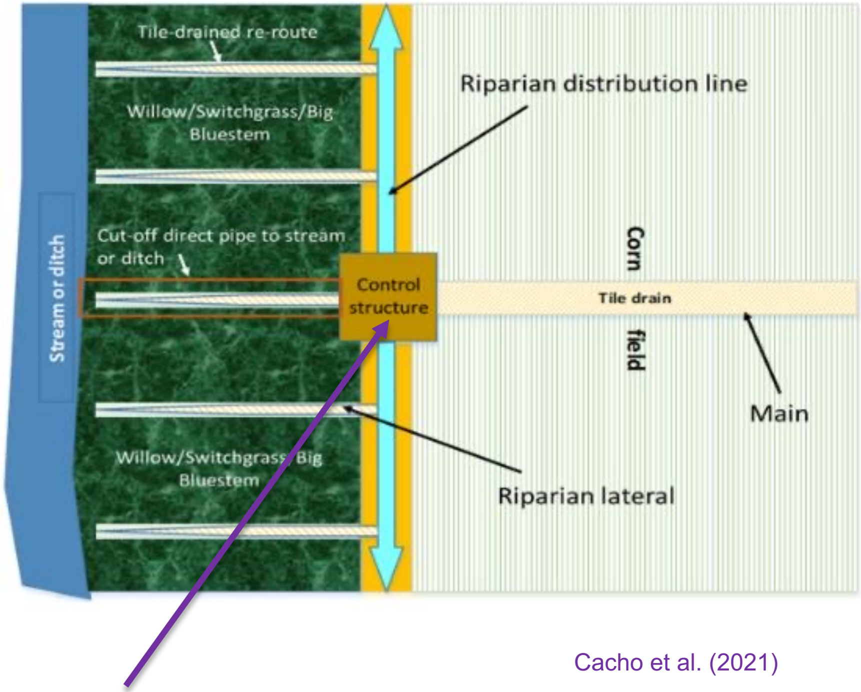
	1	2	3	4	5	6	7	8	9	10	11	13	14
Recorded	4.228	7.124	8.215	13.873	8.037	8.180	6.493	4.335	7.304	8.553	8.648	6.876	10.439
Estimated	5.200	7.616	6.489	11.727	8.932	7.893	6.373	6.151	7.078	8.910	8.845	8.779	9.857

In review: Biomass and Bioenergy

Progress and Outcomes

SUITABLE SATURATED BIOENERGY BUFFER (SBB) SITE CLASSIFICATION

- Drain tiles represent a significant source of nitrate flux to surface water
- Capturing nutrient-rich, drainage water via a flow control structure and utilizing it for growing bioenergy crops can improve farm economics in heavily tile-drained systems, while protecting the environment
- We have completed a site suitability model for determining locations favorable for an SBB



The flow control structure is for diverting/recirculating drainage water

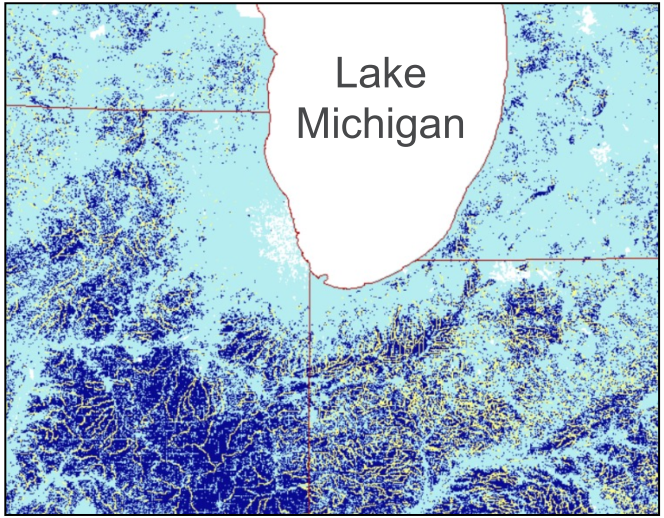
Cacho et al. (2021)

Progress and Outcomes

- For riparian land with width of 20-30 m from ditch/stream edge
- Inputs of soil, topography/slope, LULC, and drainageway locations
- GIS-based multicriteria decision analysis

Example results:

- Dark blue
  - ✓ likely tile-drained
- Yellow
  - ✓ candidate for SBB



Cacho, J.F, Quinn, J.J., Zumpf, C.R., and M.C. Negri, 2021, Saturated Bioenergy Buffers: site suitability classification and estimated areas of candidate sites in the U.S. Midwest under three scenarios: Argonne Technical Report ANL/EVS-21/2.

Environmental Metric	Classification	Suitability
1. Soil drainage	Somewhat poorly drained	1
	Poorly drained	1
	Very poorly drained	1
	Moderately well drained	0
	Well drained	0
	Somewhat excessively drained	0
	Missing data	Null
2. Topography	Very flat (≤1% slope)	1
	Flat (>1% to ≤2% slope)	1
	Moderately flat (>2% to ≤3% slope)	1
	Slightly flat (>3% to <5% slope)	1
	Not flat (≥5% slope)	0
	Missing data	Null
3. Land use land cover	Corn/soybean	1
	Others	0
	Missing data	Null
4. SOC content in the top 76 cm	Low (<1%)	0
	Medium (1-2%)	1
	High (>2%)	1
	Missing data	Null
5. Depth to hydraulically restricting layer	1.2 - 2.5 m	1
	Otherwise	0
	Missing data	Null
6. Soil erodibility factor (whole soil profile)	Low (≤0.44)	1
	High (>0.44)	0
	Missing data	Null

Progress and Outcomes

- SBB suitability criteria and method were integrated into the SUPERBEEST as an additional capability
- A manuscript was submitted for peer review*
- Next step: Assessment of Regional Water Quality Benefits (focused on nitrate losses reduction) as an Edge-of-Field practice as part of the SUDS Project

*Cacho, J.F., Quinn, J.J., Zumpf, C.R., Negri, M.C. (In review). Site suitability classification for saturated bioenergy buffers and area estimates of candidate sites in the U.S. Midwest. (Biomass and Bioenergy Journal).

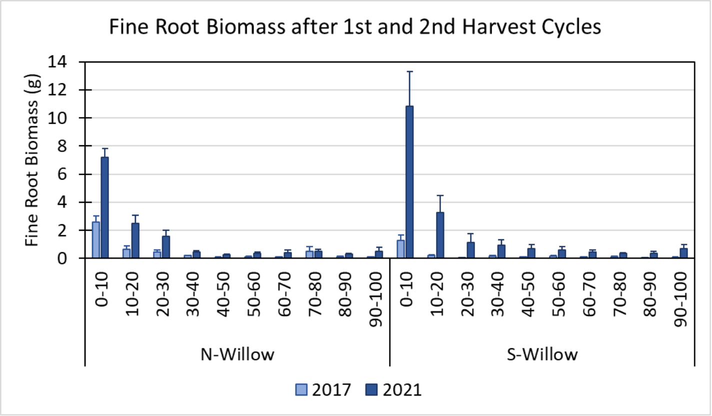
Saturated Bioenergy Buffers

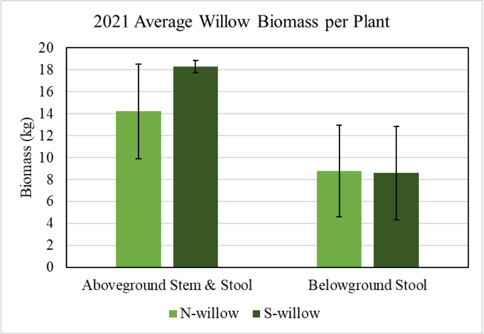
Suitable

Progress and Outcomes

OTHER KEY ACCOMPLISHMENTS SINCE 2021

- Assessed biodiversity (invertebrates and vegetative) at the Fairbury site, published in a journal paper
- Assessed biodiversity (soil microbes) and soil health at the Fairbury site, published in a journal paper
- Published journal paper on emission analysis/LCA related to the scale of deployment of perennial bioenergy crops
- See Extra Slides for details





APPROACH

Task 1. SUPERBEEST

- With marginal land identification completed, focus is on
  - Determining the Ecosystem Services (ES) realized by a conversion from row crops to perennial bioenergy crops in marginal lands
    - Soil and Water Assessment Tool (SWAT model) for nutrients and soil loss
      - » Capability to input SWAT model results
      - » Use of a national-scale SWAT model from USDA where detailed results aren't available
    - Area-based literature values to estimate ES for reduced GHG emissions, carbon sequestration, hunting, recreation

Approach

SUPERBEEST (CONT.)

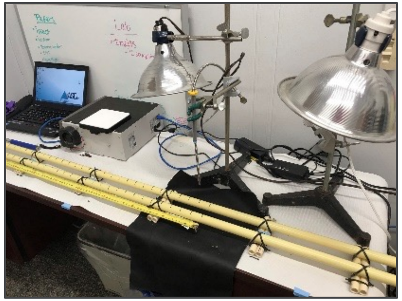
- Economic estimates of the ES based on
  - TEA
  - Demand Analysis
  - Other literature
  - Commodity pricing
  - Biomass value
  - Government programs (carbon sequestration, GHG)
  - Corporate programs (carbon sequestration, GHG)
  - Trading scheme (nutrients)
- Ranges of values qualified in report

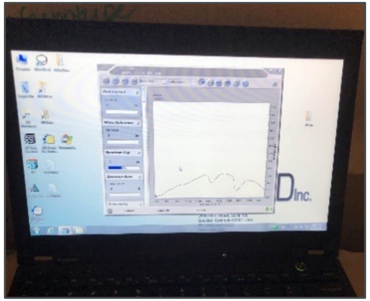
Approach

SUPERBEEST (CONT.)

- User will be able to choose Generate Report
  - For selected study area, images illustrating marginalities
  - Narrative of ecosystem services associated with a change
  - Summary of net valuation of the change
- Will continue to obtain useful feedback on changes and additions to SUPERBEEST from the sister project “Ecosystem Services Entrepreneurship Technical Assistance”
  - To address the needs of various users
  - This relates to suggestions from Peer Review 2021
- Environmental Justice (EJ) to be included
  - Identify where farming income is low (marginal soil influence) and perennials may make more sense
- Submitted SUPERBEEST abstract to national conference (SWCS in August)

Approach





Task 2. Soil Carbon Scanning Technology

- Internal funding (LDRD) to perform initial research prior to BETO proposal
- Carbon sequestration in agricultural soils has been targeted as one potential solution for mitigating CO_2
- Need for less expensive and faster ways to monitor soil carbon (verification)
- Soil color and light reflectance correlates well to soil carbon
- Spectroscopy (hand-held spectroradiometer) to measure light reflectance of sliced cores (minimal prep & disturbance)

Approach

Task 3. Soil Organic Carbon and GHG Field Studies

- Mature shrub willow at our Fairbury, IL research site
  - 2024 – will do final harvest (biomass data), soil coring, and root mass study, then restore site
- New switchgrass plots in Iowa
  - Marginal farmland areas
  - State-funded program administered by Antares
  - Invited by Antares to “do the science” for baseline and future evaluations
    - Contrast soil organic carbon and GHG from converted row crop land to adjacent cornfields

Approach

Task 4. Saturated Bioenergy Buffers

- Identify a willing farmer partner in Illinois with a *saturated buffer* or interest in having one (contacts include American Farmland Trust, Illinois State University, and others)
- Convert it to a *saturated bioenergy buffer* with appropriate plant varieties
- Assess economic (biomass production) and environmental (water quality)

- A project risk (tied to Go/No-Go) is being unable to find a willing partner.
  - In this case, our mitigation would be to make use of the USDA's Measured Annual Nutrient loads from Agricultural Environments (MANAGE) dataset for related analysis, including machine learning techniques

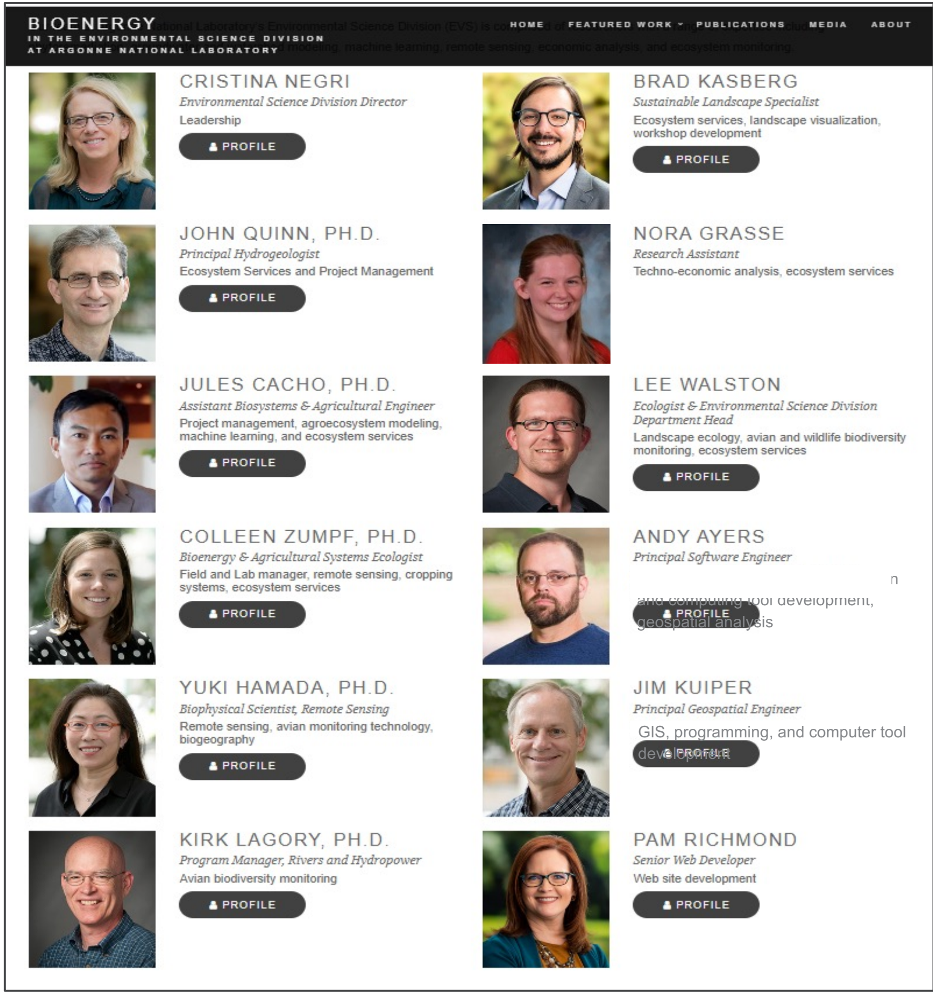
Approach

- **Communication and Collaboration**
  - Antares for coordination with new Iowa switchgrass plots
  - American Farmland Trust, Illinois State University, and others to identify a saturated buffer location in Illinois
  - Comments and suggestions from a wide range of stakeholders learning about perennial bioenergy crops and SUPERBEEST through the sister project “Ecosystem Services and Farm Decarbonization Entrepreneurship Technical Assistance” (4.1.2.11)

American Farmland Trust

Approach

- **Diversity, Equity, and Inclusion**
  - We continue to maintain a diverse team of staff and interns
  - We hired to staff from underrepresented group to work on our BETO portfolio and in particular this project
  - We envision SUPERBEEST and our related tasks as benefitting underserved rural communities socioeconomically while developing the bioeconomy and avoiding environmental degradation.



IMPACT

- **Biomass growth for the Bioeconomy** – increased adoption of perennials, increased biomass, and reduced feedstock production cost
- **The Environment** – improved carbon sequestration, biodiversity, and water quality, and decreased greenhouse gas emissions and topsoil loss
- **Producers** – farmers' need for optimal cropping systems, low input (e.g. fertilizer) cost, and a resilient and stable rural economy

SUPERBEEST contributes toward all these needs:

- Identifying marginal land, ecosystem services and net economics of a conversion to perennials
- A free, online tool, undergoing refinement through outreach efforts.

- **Our other tasks** provide supporting data on various ecosystem services, and the scanning device can provide rapid verification data needed for payments for carbon sequestration

SUMMARY

- Technology development (remote sensing applications, development of soil core carbon scanner) support the BETO mission
  - Payments for carbon sequestration would depend on "how much carbon?", and the scanning technology could perform this verification rapidly
- The project includes unique, relevant ways to assess the positive impacts of perennials in Iowa (new switchgrass) and Illinois (established shrub willow)
- Support for saturated bioenergy buffers could sharply reduce the nutrient loss due to the short-circuiting of fertilizer from field to surface water, therefore increasing biomass while improving water quality both locally and in the Gulf of Mexico
- SUPERBEEST continues to evolve, with planned capabilities and new ideas from outreach and comments generated by the sister project 4.1.2.11.
  - It is expected to assist in decision-making for a wide audience interested in learning how perennials integrated into the agricultural landscape may provide both economic and environmental benefits.

QUAD CHART OVERVIEW

Timeline (for Scaling Up Decarbonization and Sustainability)

- *FY23 (initial funding late January 2023)*
- *FY25 conclusion*

	FY22 Costed	Total Award
DOE Funding	(10/01/2021 – 9/30/2022) $650K for Scaling Up the Ecosystem Services of Bioenergy Landscapes	$545K per year for Scaling Up Decarbonization and Sustainability
Project Cost Share	N/A	N/A

TRL at Project Start: 3

TRL at Project End: 3

Project Goal

The goal of this project is to promote the adoption of perennial bioenergy crops to support the bioeconomy while providing carbon sequestration and other ecosystem services (ES). Specifically, we will accomplish this through tool development (both a geospatial tool for decision-making and a scanning device for verification of soil organic carbon), and through data collection on carbon and other ES at large-scale startups of switchgrass in Iowa, a long-term shrub willow site in Illinois, and a saturated bioenergy buffer.

End of Project Milestones

1. An online tool to identify marginal land, explore the ES associated with a conversion of ML to perennial bioenergy crops, estimate the most accurate current economic aspects of that conversion, address cover crop influence, and relate to regional EJ factors.

2. Demonstration of soil carbon scanning technology.

Funding Mechanism

DE-LC-0000015: FY23 BETO Lab Call

Project Partners

- Antares (sharing biomass harvest data, connecting us to new Iowa-sponsored switchgrass program)
- Fairbury, IL landowner

ADDITIONAL SLIDES

RESPONSES TO PREVIOUS REVIEWERS' COMMENTS

The 2021 Peer Review netted us many positive or informative comments. Here are key comments along with responses:

- "…work with agricultural community to identify barriers to implementation", "future plans to test and solicit feedback"
  - We are accomplishing this very actively in a separate project, 4.1.2.11
- "…inclusion of actual payment programs into the modeling (SUPERBEEST) would help with the realism of the revenue potential"
  - Agreed, understood at the time, and a focus for the new project. We look forward to incorporating the ever-changing government or corporate payment programs.
- "some additional thought should be given to user needs"
  - Agreed. We are learning these needs through the outreach in the sister project and implementing them (e.g. mapping biorefinery locations in SUPERBEEST).

PUBLICATIONS SINCE PEER REVIEW 2021 (1/2)

- Hamada, Y., C. Zumpf, and J. Quinn, in review, Remote Sensing Estimation of Field-Level Perennial Grass Biomass Yields Using Spectral Vegetation Indices: submitted to Biomass and Bioenergy.
- Kasberg, B.C., J.J. Quinn, M.C. Negri, N.F. Grasse, C.R. Zumpf, and J.F. Cacho, in review, Demand Analysis of Nutrient Credit Trading between the Agricultural and Water Treatment Industries in Illinois: submitted to Energy Nexus.
- Quinn, J.J., J.F. Cacho, A.J. Ayers, M.C. Negri, B.C. Kasberg, N.F. Grasse, C.R. Zumpf, in prep., Scaling Up Perennial Bioenergy Economics and Ecosystems Tool (SUPERBEEST) Part 1. Marginal Land Identification: Argonne Technical Report.
- Grasse, N., J. Quinn, J. Cacho, C. Zumpf, B. Kasberg, L. Walston, M.C. Negri, 2023, Ecosystem Service Valuation of Hypothetical Transition from Marginal Lands to Perennial Bioenergy Crop in Three Midwestern U.S. Watersheds: Argonne Technical Report.
- Cacho, J.F., J.J. Quinn, C.R. Zumpf, and M.C. Negri, in review, Site suitability classification for saturated bioenergy buffers and area estimates of candidate sites in the U.S. Midwest: submitted to Biomass and Bioenergy Journal
- Vera, I., B. Wicke, P. Lamers, A. Cowie, A. Repo, B. Heukels, C. Zumpf, D. Styles, E. Parish, F. Cherubini, G. Berndes, H. Jager, L. Schiesari, M. Junginger, M. Brandao, N.S. Bentsen, V. Daioglou, Z. Harris, and F. van der Hilst, 2022, Land use for bioenergy: Synergies and trade-offs between sustainable development goals: Renewable and Sustainable Energy Reviews (161) 112409. https://doi.org/10.1016/j.rser.2022.112409

PUBLICATIONS SINCE PEER REVIEW 2021 (2/2)

- Canter, C.E., K. Zolton, J.F. Cacho, M.C. Negri, C.R. Zumpf, and J.J. Quinn, 2022, Impact of landscape design on the greenhouse gas emissions of shrub willow bioenergy buffers in a U.S. Midwest corn production landscape: Biofuels, Bioproducts, and Biorefining. https://doi.org/10.1002/bbb.2345
- Zumpf, C., J. Quinn, J. Cacho, N. Grasse, M.C. Negri, and D. Lee, 2021, Invertebrate and Plant Community Diversity of an Illinois Corn–Soybean Field with Integrated Shrub Willow Bioenergy Buffers: Sustainability (13)12280. https://doi.org/10.3390/su132112280
- Zumpf, C., J. Cacho, N. Grasse, J. Quinn, J. Marcel-Hamilton, A. Armstrong, P. Campbell, M.C. Negri, and D.K. Lee, 2021, Influence of Shrub Willow Buffers Strategically Integrated in an Illinois Corn-Soybean Field on Soil Health and Microbial Community Composition: Science of the Total Environment, volume 772. https://doi.org/10.1016/j.scitotenv.2021.145674

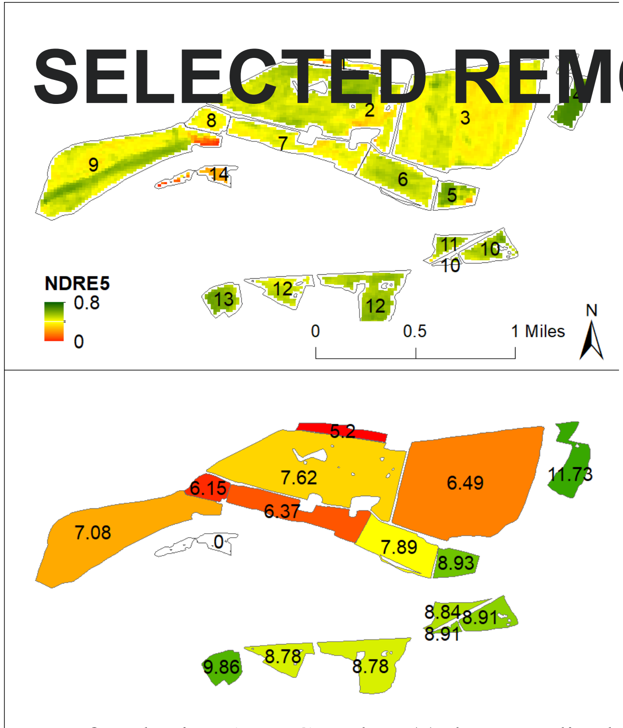
PRESENTATIONS SINCE PEER REVIEW 2021

- Quinn, J., J. Cacho, A. Ayers, M.C. Negri, B. Kasberg, J. Kuiper, C. Zumpf, N. Grasse, 2023, A Geospatial Tool for Identifying Marginal Land and Assessing the Ecosystem Services of Perennial Bioenergy Crops: 78th Soil and Water Conservation Society (SWCS) International Annual Conference, August 6-9, 2023, Des Moines, Iowa.
- Grasse, Nora, Colleen Zumpf, Jules Cacho, John Quinn, Jarrad Marcel-Hamilton, Patty Campbell, M. Cristina Negri, and D.K. Lee, 2023, Microbial Communities across an Agricultural Phytoremediation Site: International Phytotechnologies Conference, May 23-26, 2023, Argonne, IL.
- Zumpf, C., J. Quinn, N. Grasse, J. Cacho, and M.C. Negri, 2023, Application of Shrub Willow Buffers for Nutrient Reduction in Agricultural Fields: International Phytotechnologies Conference, May 23-26, 2023, Argonne, IL.
- Zumpf, C., J. Quinn, J. Cacho, B. Kasberg, N. Grasse, M.C. Negri, 2022. Additional Positive Impacts that Could Be Transferred to Buyers; Ecosystem Services = Additional Claims? Roundtable on Sustainable Biotechnologies (RSB) Innovations Meeting, October 4-6, 2022, Boston, Massachusetts.
- Zumpf, C., J. Cacho, Y. Hamada, and J. Quinn, 2022, Impacts of Long-term Shrub Willow Production for Bioenergy on Soil Carbon in a Midwest Agricultural Field: 77th Soil and Water Conservation Society (SWCS) International Annual Conference, July 31-August 3, 2022, Denver, Colorado.
- Zumpf, C., Y. Hamada, J. Quinn, J. Cacho, M.C. Negri, and B. Drewniak, 2021, Soil Carbon in a Strategically Designed Midwest Agricultural Landscape with Shrub Willow Buffers: ASA, CSSA and SSSA International Meeting, Salt Lake City, UT, November 7-10 (virtual).
- Negri, M.C., J. Quinn, and M. MacDonell, 2021, Responsible Innovation for a Healthy Planet: Council of Scientific Society Presidents, 2021 Spring Leadership Workshop, May 1 (virtual).
- Zumpf, C., J. Cacho, J. Quinn, C. Negri, N. Grasse, Cheng-hsien Lin, D.K. Lee, and N. Namoi, 2021, Water Use and Greenhouse Gas Emissions of Bioenergy Switchgrass Production Systems in the U.S. Midwest: International Association for Landscape Ecology IALE-North America 2021 Annual Meeting, April 12-16 (virtual).

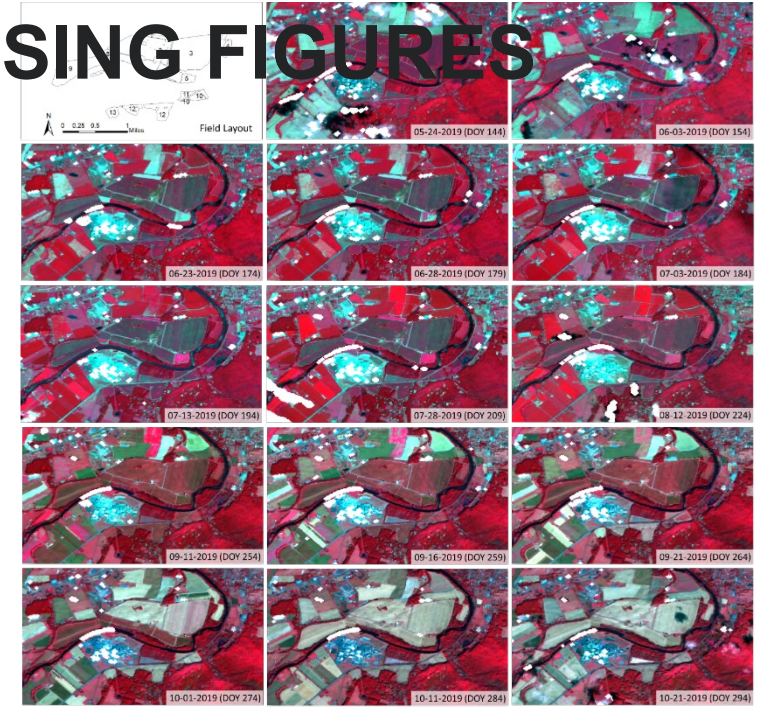
ELECTRONIC POSTER

- Bioenergy and Ecosystem Services
  – a website serving as a living resource and compilation of our research group efforts for BETO projects
  – https://web.evs.anl.gov/bioenergy/

SELECTED REMOTE SENSING FIGURES



Maps of study sites A, B, C, and D: (a) the normalized difference red-edge index calculated using the red-edge band 5 ($NDRE_5$) with field IDs and (b) estimated perennial grass biomass yields in Mg ha^{-1} using the $NDRE_5$ linear regression model having the median R^2. Fields indicating no yields were those excluded from estimation due to limited data availability or no recorded yields. Polygon color indicates relative yields (i.e., green=high yield, red=low yield).



Selected Sentinel-2 images of Site A from May 14 to July 28, 2019 (DOY 144–294). Mowing began on September 18 (DOY 261) with mowing and baling complete across all fields by October 7 (DOY 280). Blue, green, and red in the display correspond to the green, red and, near infrared bands, respectively.

Past Go/No-Go Decision

Milestone

- **Milestone** – Aquifer Susceptibility
  - **Criteria** - Complete the assessment of available Midwest soil and hydrogeologic data for suitability and consistency across all states. Quantify appropriately the susceptibility of aquifers to leaching of agrichemicals. Determine if this quantification can be done to a resolution consistent with that of Keefer (1995) for Illinois, in order to address a key aspect of environmental marginality.
  - **Response** - Wrote a document identifying the method, which focuses on use of a large U.S. Geological Survey database covering most of the 12-state area of interest. The method consistently identifies areas having an aquifer susceptible to nitrate contamination on the basis of the hydrogeologic framework (surficial sandy aquifers or karst areas), and factors in surficial soil organic matter for addressing susceptibility of the aquifer to pesticide contamination.

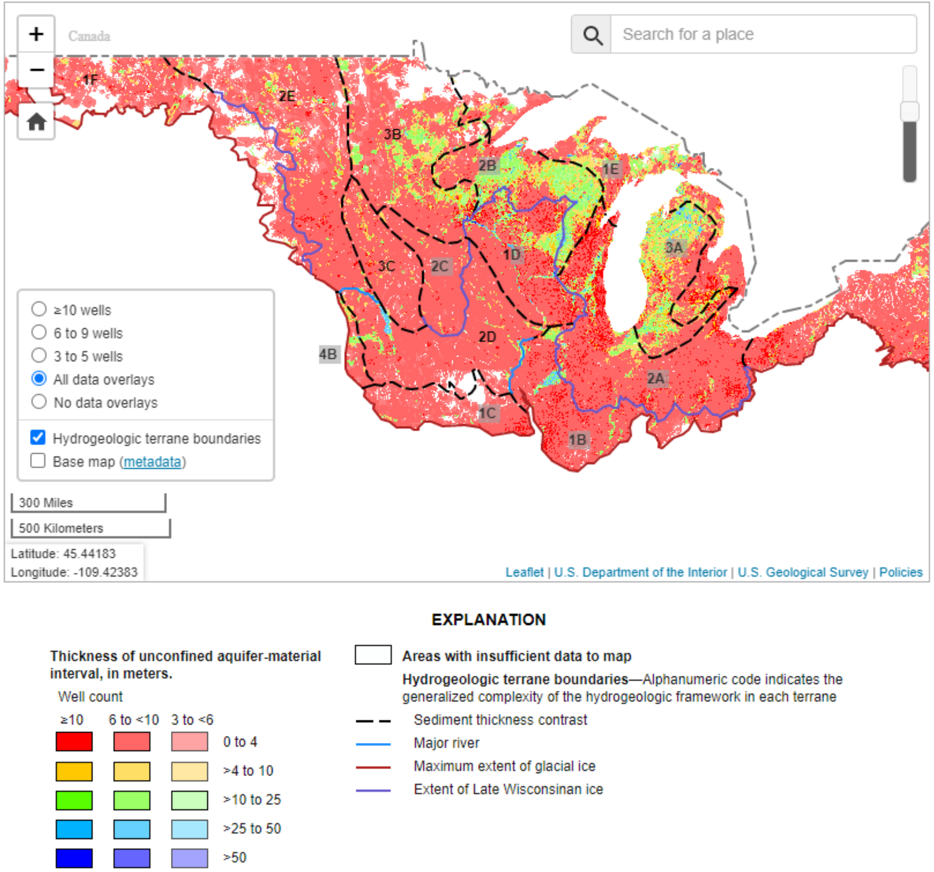
Go/No-Go Decision

- Is sufficient information at a required scale (analogous to Keefer (1995) for Illinois – state what scale that is)) available for Midwest states to determine the spatial distribution of the potential for leaching of nitrate and pesticide to groundwater, based on soil and hydrogeologic information.
- **Description** - Evaluate available Midwest maps and data for suitability and consistency across all states to evaluate appropriately the susceptibility of aquifers to leaching of agrichemicals at the subfield scale as illustrated by Keefer (1995).
- **Criteria** - Aquifer vulnerability/ susceptibility mapping (including published paper versions or GIS) are available and at a resolution comparable to Keefer (1995) in Illinois. Otherwise, basic geologic, hydrogeology, and soil mapping along with raw data from subsurface drilling databases will be analyzed for the evaluation of leaching potential to the effect of recreating datasets similar to what Keefer (1995) has done for the State of Illinois.
- **Response** - Satisfied a Go/No-Go decision point pertaining to a path forward for the identification of aquifers susceptible to the leaching of nitrate and pesticide. The approach relies on an extensive U.S. Geological Survey database of well drilling logs throughout the Midwest. The available data can be used to delineate – at a sufficient resolution – where aquifers are most vulnerable to surface activities, and thereby adds another environmental marginality factor to the analysis capability of our developing geospatial tool, SUPERBEEST.

Past Go/No-Go Decision

SUPERBEEST DOMAIN

Main watersheds of the midcontinent.
(source: USEPA)

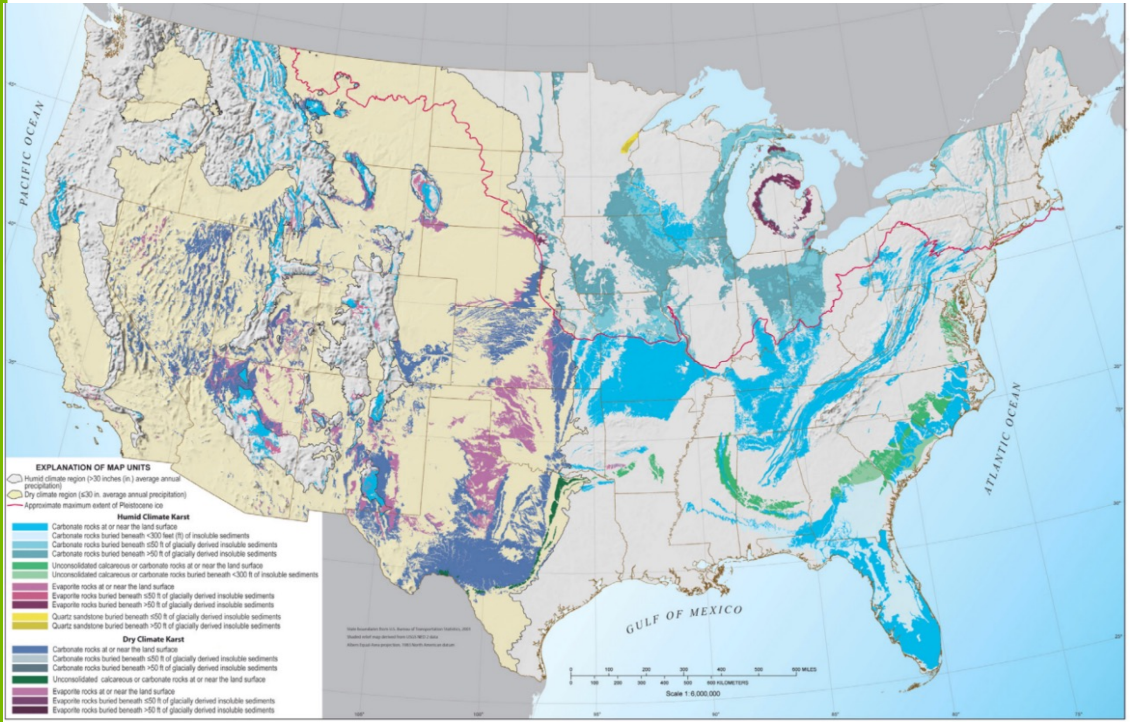


Thickness of unconfined (surficial) Quaternary aquifers in the Midwest (source: modified from Yager et al. 2020).

Past Go/No-Go Decision

Karst

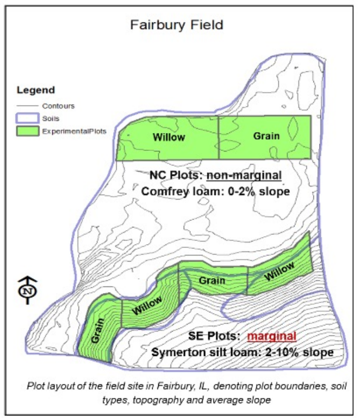
- Karst and potential karst areas in soluble rocks in the U.S. (source: Weary and Doctor 2014)
- Key susceptible areas are "carbonate rocks at or near the land surface"



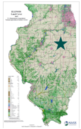
- **Summary of the Approach:**
  - Where unconfined (surficial) aquifer >4 m thick and/or where carbonate rock is at or near surface, the uppermost aquifer is considered susceptible to nitrate contamination and therefore marginal.
  - In those areas, surficial soil will be evaluated with SSURGO for organic matter to determine susceptibility to pesticide contamination and associated marginality.
  - Other areas will not be considered marginal for aquifer susceptibility.
  - Minor fringe areas not included in USGS analysis will not be assessed for marginality from aquifer susceptibility (but will be addressed by other environmental or economic marginality factors).

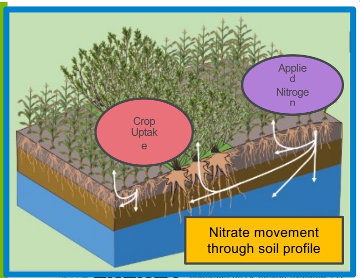
Fairbury, IL Shrub Willow Buffer Observatory

Objective: Evaluate the environmental impacts and productivity of strategically placed short-rotation shrub willow buffers in an intensively managed agricultural landscape in the U.S. Midwest



Plot layout of the field site in Fairbury, IL, denoting plot boundaries, soil types, topography and average slope





Biodiversity
Plants Invertebrates

Greenhouse Gas Emissions
N_2O CH_4 CO_2

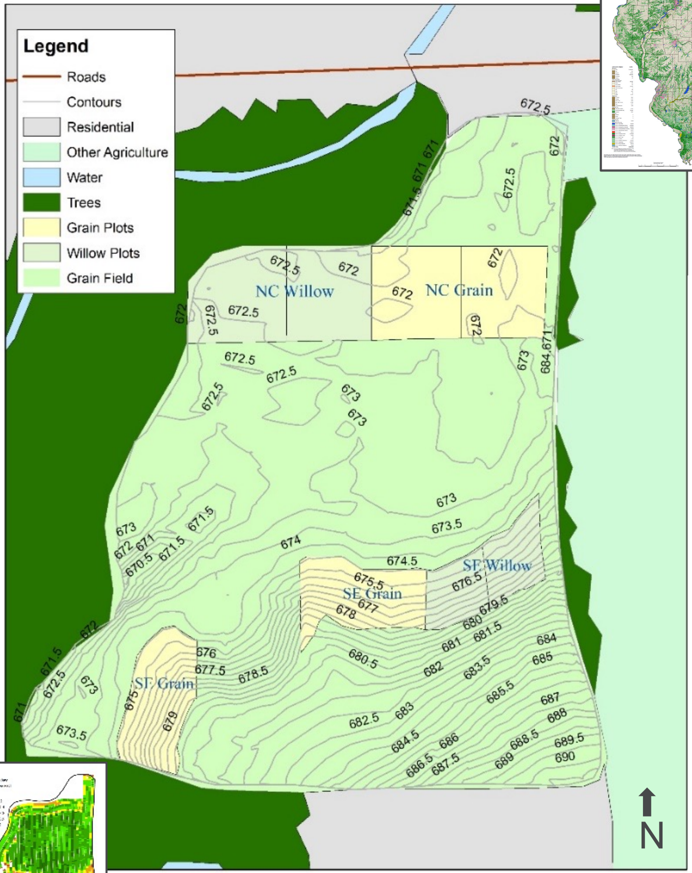
Soil Health
Soil Chemistry Microbes

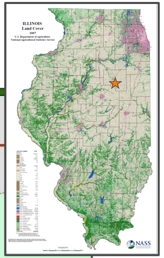
Water Quality
Nitrate Phosphate Total Carbon

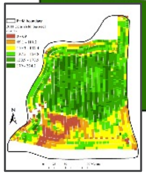
Biomass
Aboveground Belowground

Water Quantity
Groundwater Soil Moisture Evapotranspiration

Plot Layout and Contours







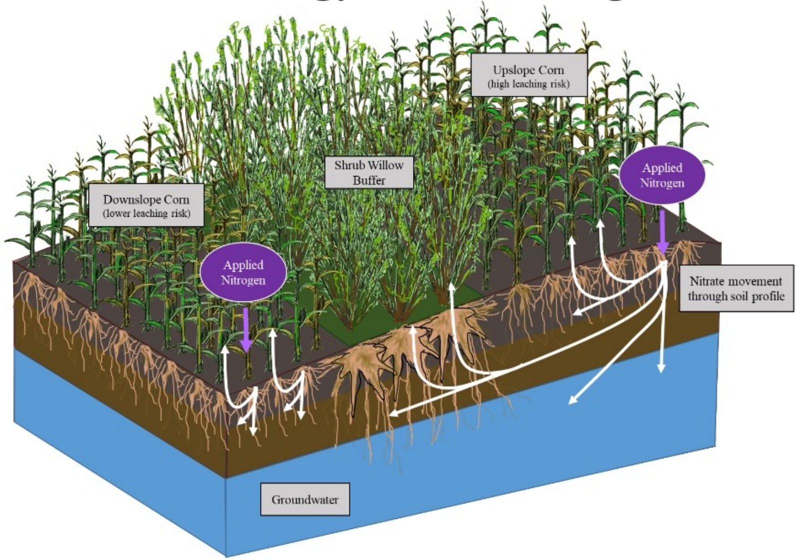
Fairbury, Illinois USA

DESIGN & OBJECTIVES

Targeted placement of bioenergy crops:

- Low yielding areas
- Have increased potential to provide ES

Bioenergy Buffer Design



Objectives

Biomass Production Using leached nutrients as nutrient source

Provision of Ecosystem services
Water Quality
GHGs
Biodiversity
Soil Health

Argonne NATIONAL LABORATORY

BIODIVERSITY & SOIL HEALTH

Objective: Assess impacts of willow buffer placement (marginal & non-marginal) within a row crop system on ecosystem services (ES: nutrient loss and emissions) and processes (changes in soil health)

Landscape Placement: plays a large role in

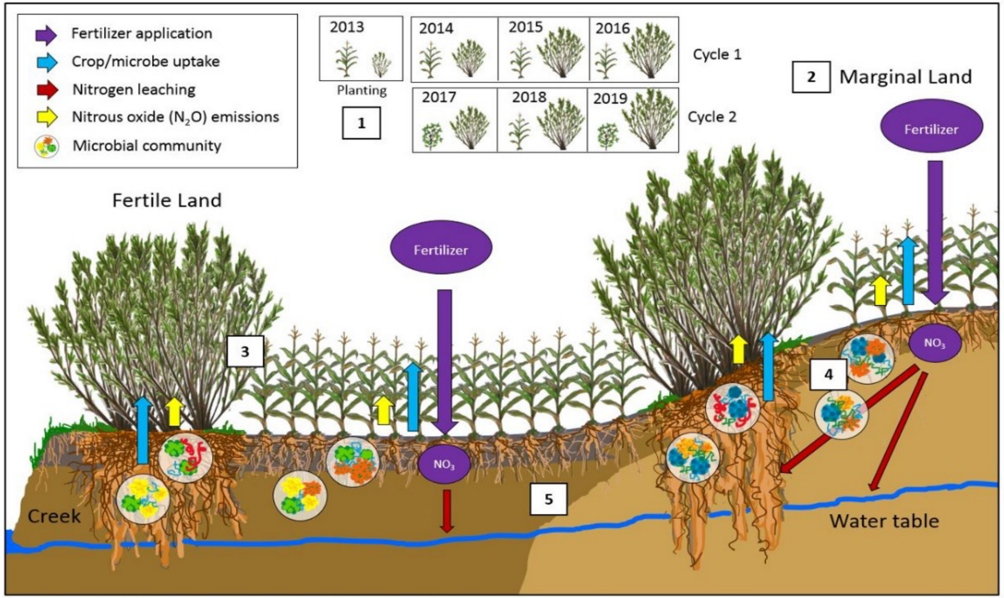
1. Dynamics of soil chemistry
2. Willow productivity and influence on surrounding soil
3. ES – nitrous oxide emissions and nitrogen leaching

Landscape Placement + Crop Type

- Influenced soil microbial community resulting in unique and identifiable communities
- Nitrate leaching was reduced by 70 and 95% respectively under marginal and non-marginal willow

Crop Type

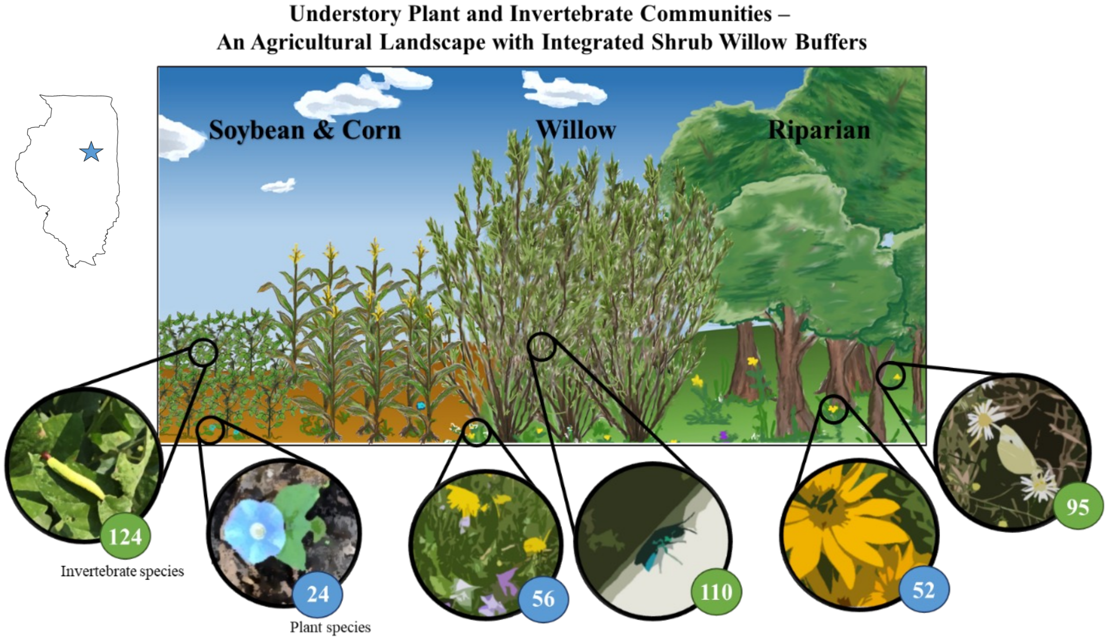
- Willow plots had lower soil bulk density than row crops
- Nitrous oxide emissions were lower under willow



Graphical Abstract: Factors that influence soil microbial community composition and ecosystem services

Published: Zumpf, C., Cacho, J., Grasse, N., Quinn, J., Hampton-Marcell, J., Armstrong, A., Campbell, P., Negri, M.C. and Lee, D.K., 2021. Influence of shrub willow buffers strategically integrated in an Illinois corn-soybean field on soil health and microbial community composition. *Science of the Total Environment*, *772*, p.145674.

BIODIVERSITY – PLANTS AND INVERTEBRATES



Graphical Abstract : number of understory plant and invertebrate species observed during the growing season from the 2017 to 2019 growing seasons.

Published: Zumpf, C., Quinn, J., Cacho, J., Grasse, N., Negri, M. C., & Lee, D. (2021). Invertebrate and Plant Community Diversity of an Illinois Corn–Soybean Field with Integrated Shrub Willow Bioenergy Buffers. *Sustainability*, *13*(21), 12280.

Objective: Does biodiversity differ among row crops, willow and adjacent riparian landcover within a integrated bioenergy production system

Plants:
- Willow plots had higher richness and diversity than row crop plots
- Willows had greater number of perennial native plants in the understory

Invertebrates:
- Similar communities were observed between willow and row crop plots
- Timing of sampling had larger influence on species presence

Conclusions:
- Unique plant and invertebrate species observed in each landcover type highlights the importance of habitat heterogeneity to support biodiversity

LIFE CYCLE ANALYSIS

Objective: Assess whether distributed production of willow on targeted marginal land could reduce greenhouse gas emissions (GHGs) compared to plantation-style production (business-as-usual)

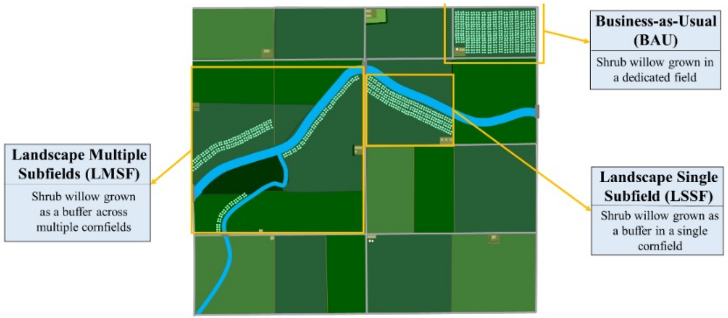
GREET Model Design: Shrub willow grown for 21 years

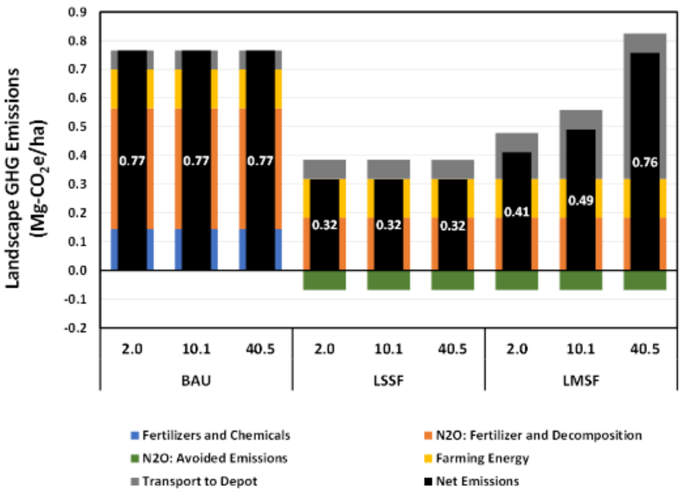
- Three production designs (BAU, LSSF, LMSF)
- Three production scales (2.0, 10.1, 40.5-ha)
- Boundary: willow production to transport to a depot

Results:

- GHG ranged from 0.32 – 0.77 Mg CO_2e ha^{-1}
- Emissions were lowest for LSSF and highest for BAU
- Under LMSF only emissions increased with increasing field size due to increased transportation distances
- Emission results were most sensitive to willow yield followed by fertilizer rate (BAU), fuel consumption during harvest, and transportation distance

Conclusions: landscape design needs to be considered at both the field-level (where buffer is placed to address nutrient loss), but also at the watershed/fuel-shed scale to optimize production and minimize transportation





Published: Canter, C.E., Zolton, K., Cacho, J.F., Negri, M.C., Zumpf, C.R. and Quinn, J.J., 2022. Impact of landscape design on the greenhouse gas emissions of shrub willow bioenergy buffers in a US Midwest corn-production landscape. *Biofuels, Bioproducts and Biorefining*, *16*(3), pp.629-639.

WILLOW HARVESTABLE BIOMASS

- **Aboveground biomass was harvested in the winter**
  - 1st cycle: 3 years of growth
    - Yield was comparable between landscape positions
  - 2nd cycle: 4 years of growth
    - **South willow yielded above 12 dry Mg/ha/yr; which was marginally greater than North Willow (p=0.09)**
- **Yield gradient along buffer slope**
  - Soil trench work for belowground biomass showed notable soil profile differences between upslope and downslope positons of South Willow plots (more organic soils in downslope position)
  - Both harvest cycles showed trend in biomass yield along this gradient
  - In North Willow where there is little slope, willow closer to neighboring crop field showed higher yields

Gradient effect will need to be taken into account in landscape planning