DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

Next-Generation Feedstocks for the Emerging Bioeconomy

60% of Completion (2019-2024)

Date: April 4, 2023
Feedstock Technologies Program

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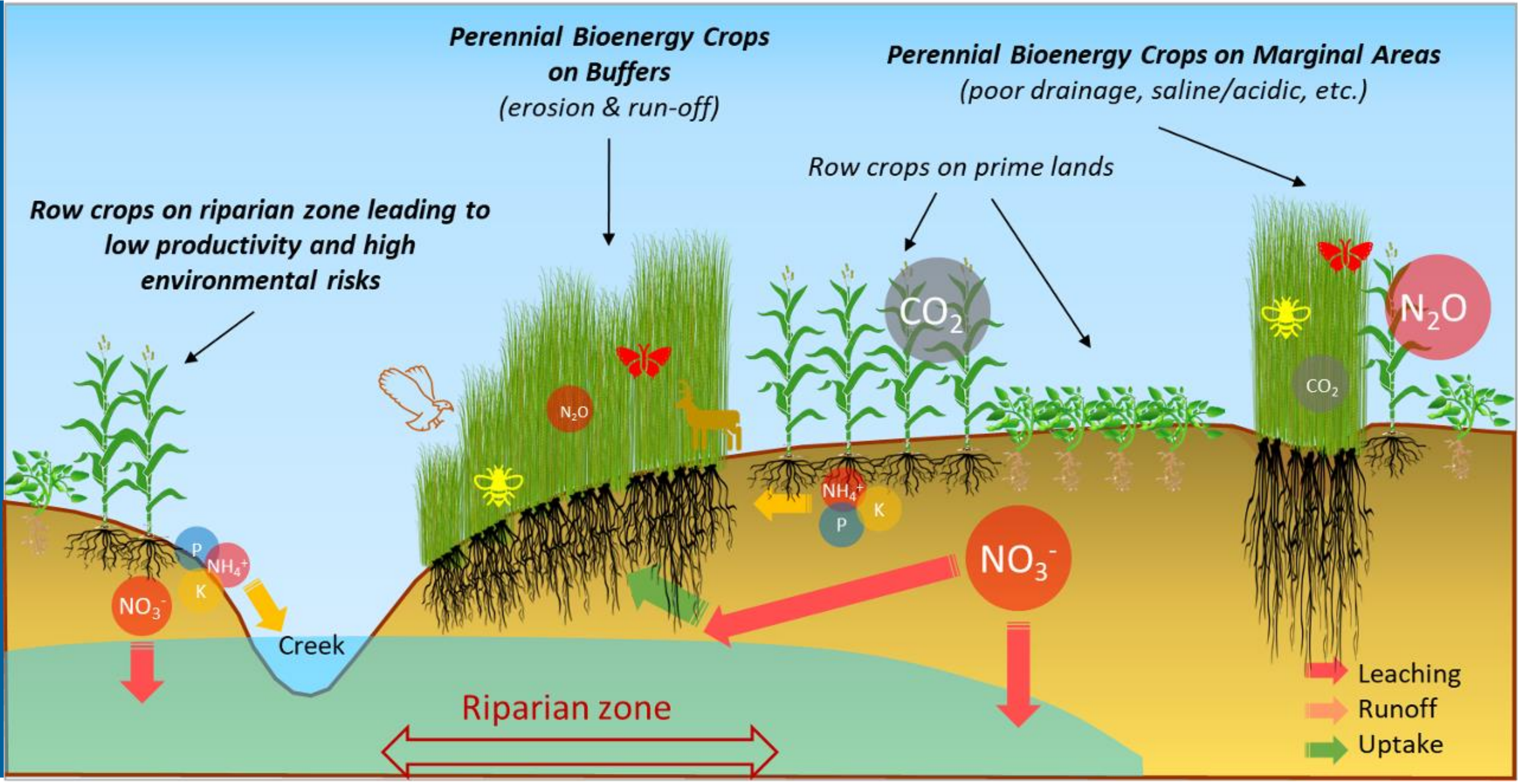
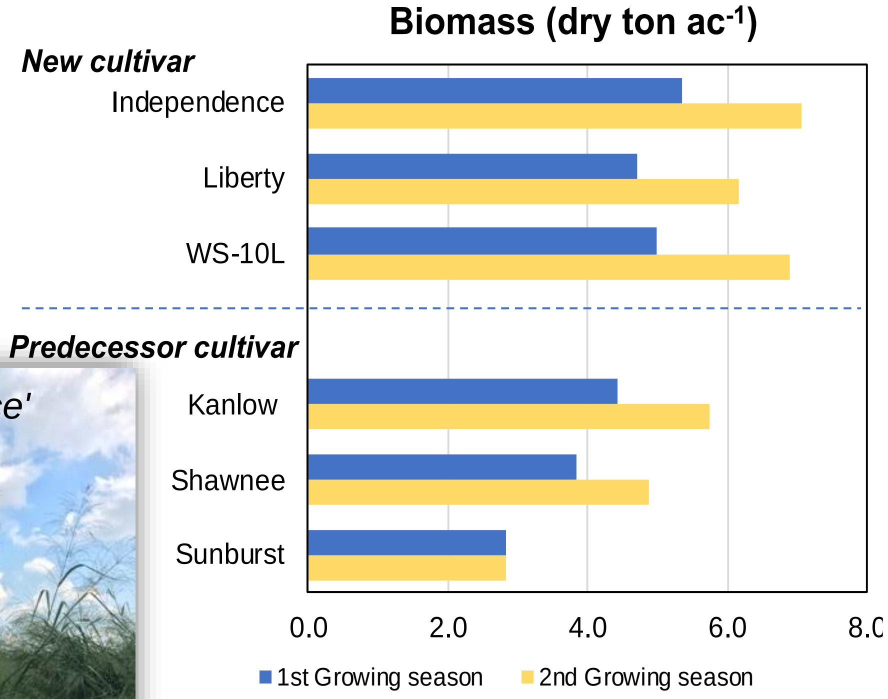


High-level Project Goal

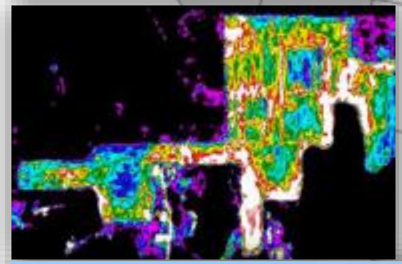
Develop productive, cost-effective, and sustainable warm-season perennial bioenergy feedstock production systems on marginal croplands across geographic locations in the Midwest

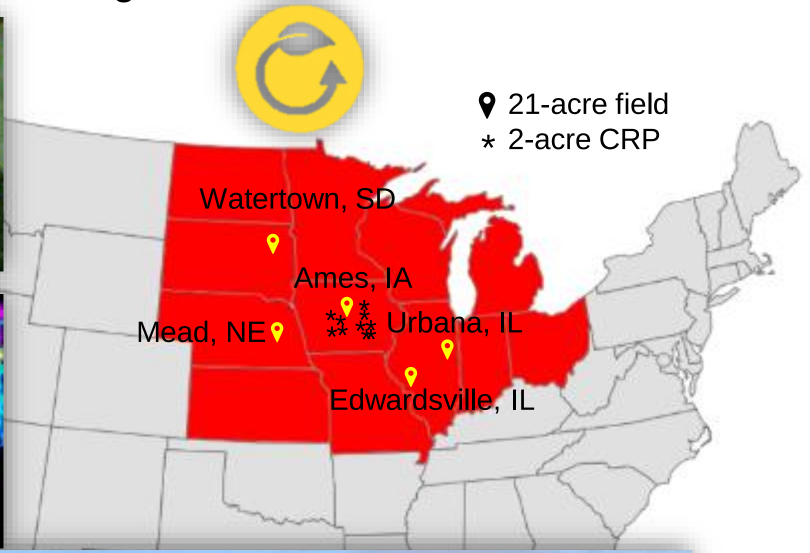
High-yielding bioenergy switchgrass



On-farm field scale production on marginal Land

Sustainable feedstock Production across geographic regions in Midwest





Context and project history:

- Limited data availability on field-scale research with high-yielding switchgrass cultivars
- Need to demonstrate ecosystem service benefits of energy-type switchgrass on marginal lands

Project Framework

Feedstock

Objective 1&2

- Potentials of high-yielding switchgrass at field scale
- Best Management Practices
- Harvest logistics
- Feedstock quality

Sustainability

Objective 4

Ecosystem services (ES)

- CO_2, N_2O, CH_4 emissions
- Nutrient leaching (N&P)
- Water quantity (ET)
- Biodiversity
- Soil quality (SOC, WAS, etc.)

Bioeconomy

Objective 5

- Develop a regional feedstock cost-rate model for delivering switchgrass to biorefinery locations

Plot-scale (100 ft^2) to field-scale (1 acre)

Harvest logistics

Objective 3

Machine learning (ML)

Input

- Soil data
- Weather data
- Field management
- Growth and development
- Phenotypical data
- ES measurements
- GPS coordinates

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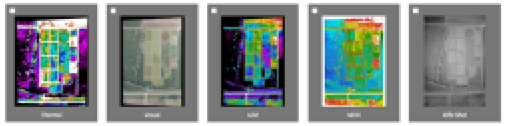


Prediction
Yield&ES

Technoeconomic analysis

2 – Approach (Technical Metrics)

Proof of concept (FY19)

Identify marginal lands

Field study (FY19-23)

Field-scale validation

Harvest logistics
BMPs
Ecosystem services

ML modeling (FY20-24)

Ground-truth data
Aerial imagery
Precision data science

- Compile field-based data (agronomic, logistical, environmental, etc.) to be used as input criteria for the techno-economic analysis
- Generate geospatially resolved techno-economic analysis to quantify opportunities to meet BETO's cost goal of less than $3/gge with > 6-ton dry matter per acre yield and feedstock delivery cost of less than $84/dry ton (final goal)

Develop a regional feedstock cost-rate model for delivering switchgrass to biorefinery locations

(FY23-24)

Metrics:

✓ **6 ton/ac biomass yield**

✓ **Better ecosystem services than row crops**

Go/No-go Decision Points:

✓ **Achieved minimum yields of 3.0 ton/ac in SD and 4.5 ton/ac in NE, IA and IL**

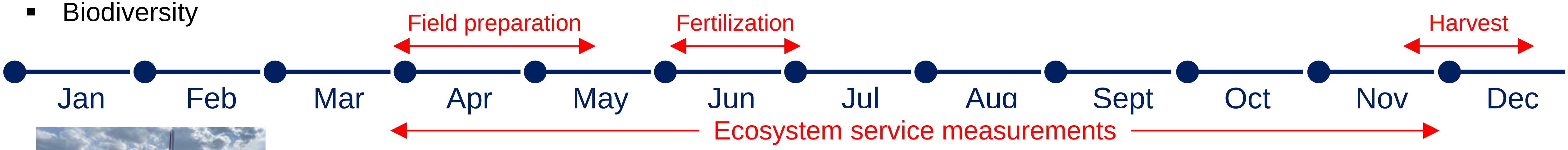
2 – Approach (Technical metrics)

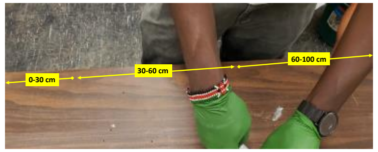
Establishment
- Seed bed preparation/Planting
- Weed control

Maintenance and harvest
- Fertilization/Weed control
- Sustainable biomass harvest

Ecosystem service
- Water quality/quantity
- Soil health/C sequestration/GHG
- Biodiversity

Vegetative growth

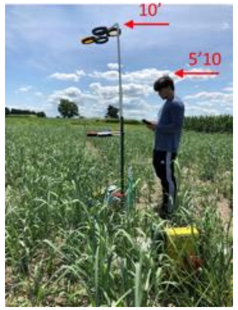


Soil sampling & processing


- GHGs (CO_2/N_2O/CH_4) measurement (Left)
- Water quality/nutrient leaching (Right)


Soil sensors with 3 depths for evapotranspiration (ET)

Biodiversity measurements
- Avian acoustic monitoring (Left)
- Insects & pollinators (Middle, Right)

2 – Approach (potential challenges)

Challenge 1:

- Establishment challenges on marginal lands (spring flooding) during the first year, delay weed control and fertilization

Challenge 2:

- Cold winter in South Dakota during the third growing year causing stand damage, winter kill

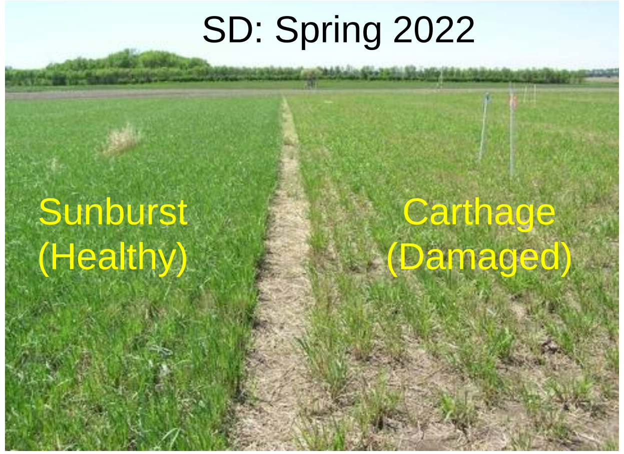
Challenge 3:

- Drought challenge in the third growing year in IL and NE impacted on productivity

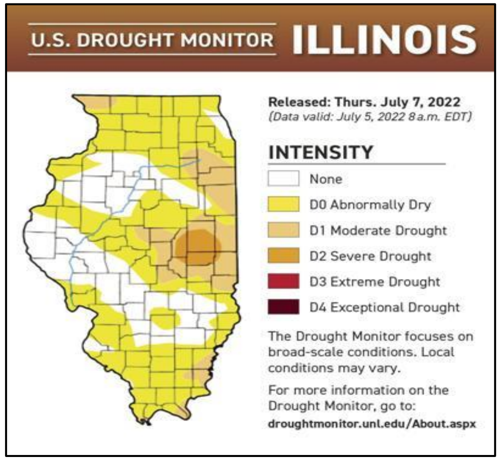
Challenge 3:

- Machine breakdown limits timely operations such as seeding, spraying, harvesting, and ultimately limits data collection points

Spring flooding



Winter damage



Drought

Machine breakdown

4 – Progress and Outcomes (Field-scale, FY 21-22)

Task 1: Management of field-scale switchgrass production system

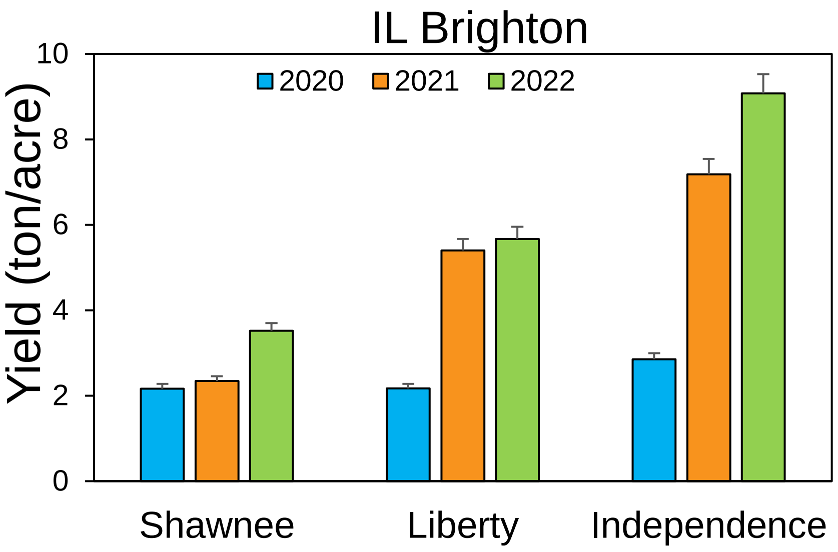
- Comparing switchgrass and corn production system: Productivity, ecosystem services and biodiversity benefits
- Annual nitrogen application rates
  - Switchgrass: 25 and 50 lbs N /acre
  - Corn: 180 lbs N /acre

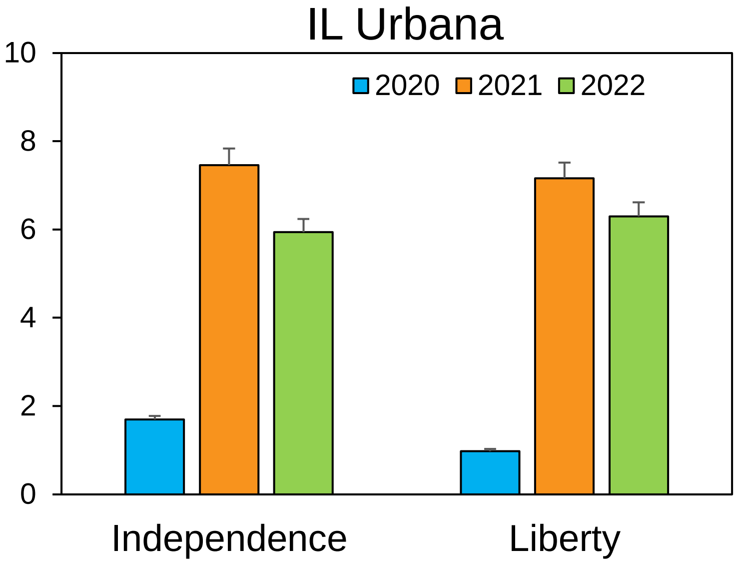
Grain and Biomass yield of corn in 2022

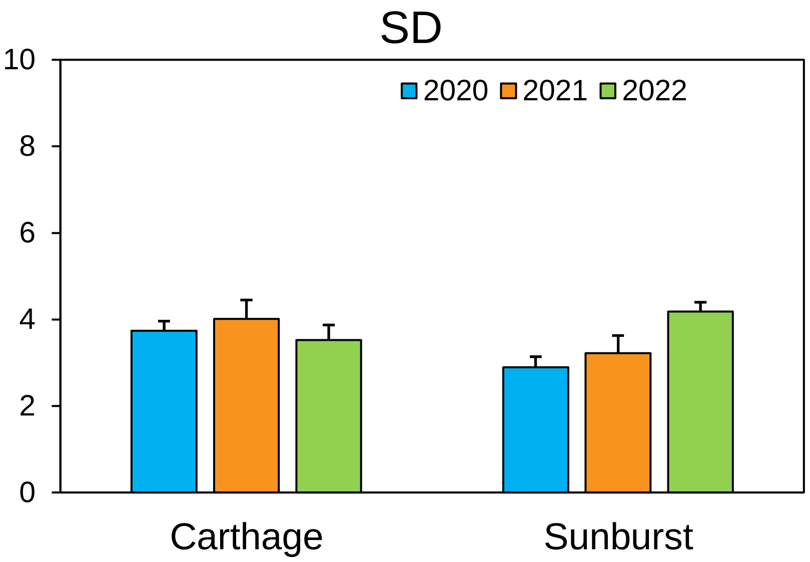
Site	Grain yield (ton/acre)	Total Biomass (ton/acre)
IL Urbana	2.5	5.0
Nebraska	2.3	4.6
South Dakota	2.8	5.5

4 – Progress and Outcomes (Field-scale, FY 21-22)

Task 1: Field-scale (1 acre) biomass yields under 50 lbs N/ac

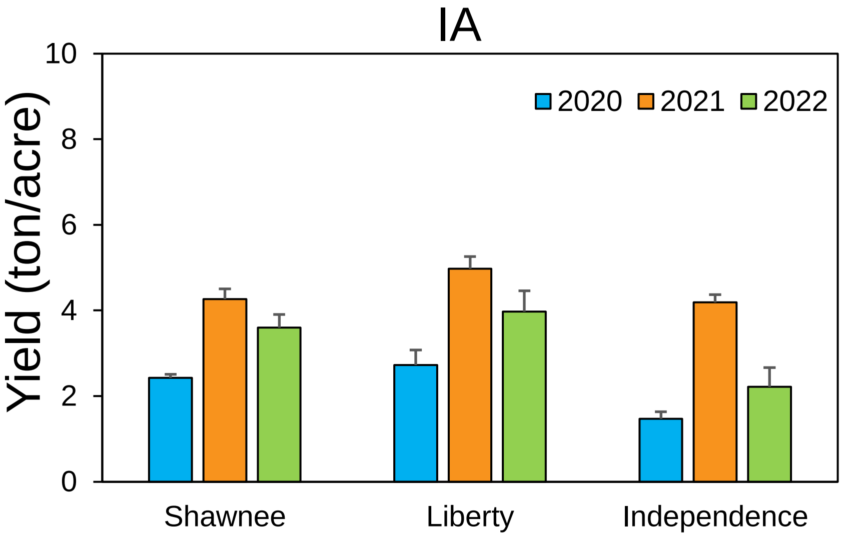


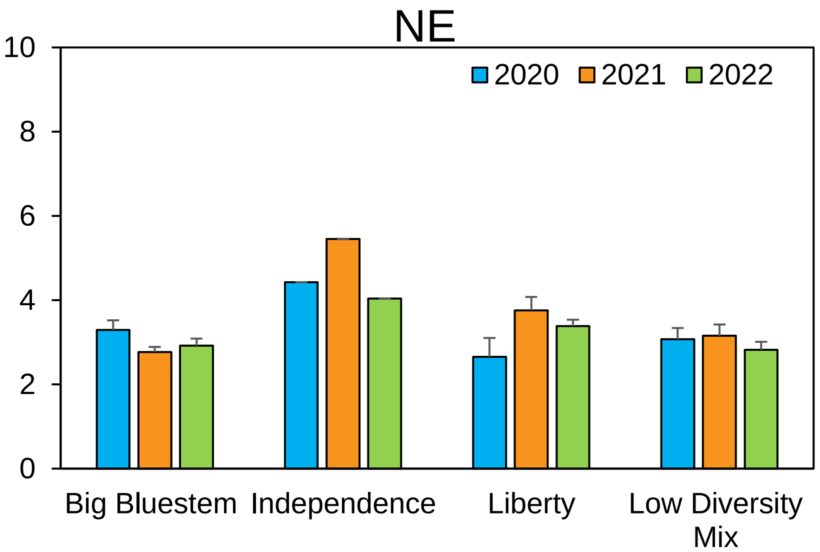




Takeaway

- ‘Liberty’ and ‘Independence’ produced higher biomass on average when compared to ‘Shawnee’
- N fertilization with 50 lbs N/ac increased 10-15% of biomass yield

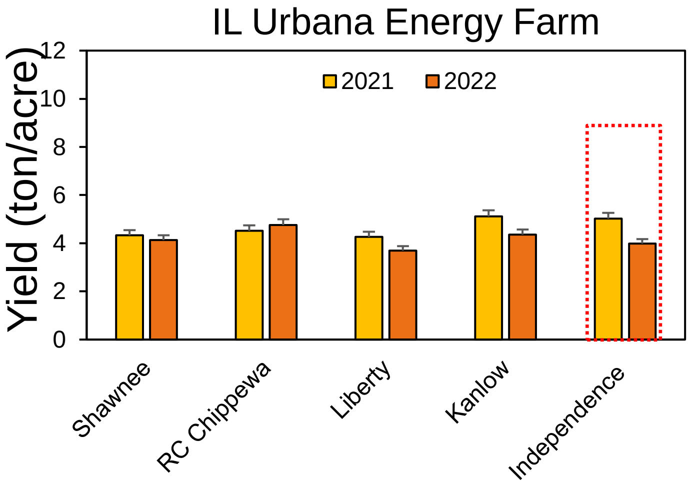


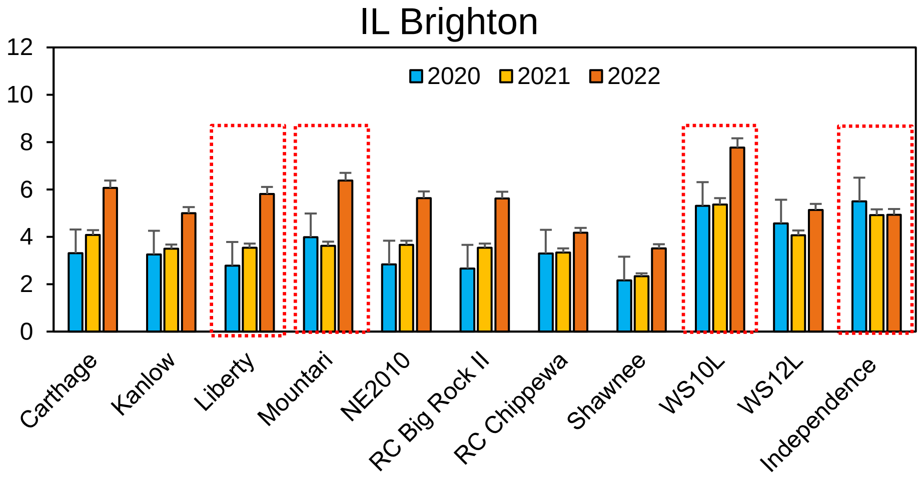


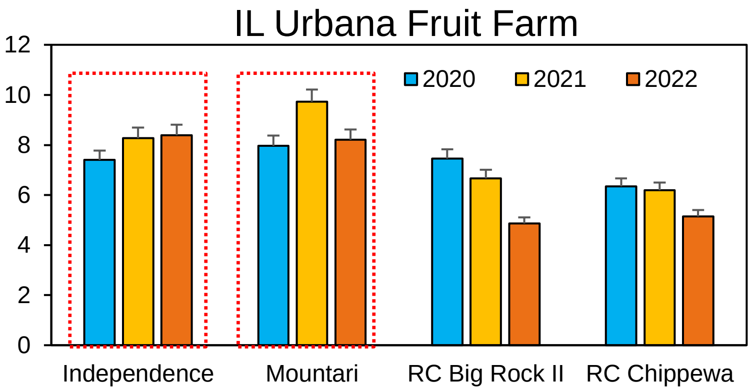
4 – Progress and Outcomes (Small-scale, FY 21-22)

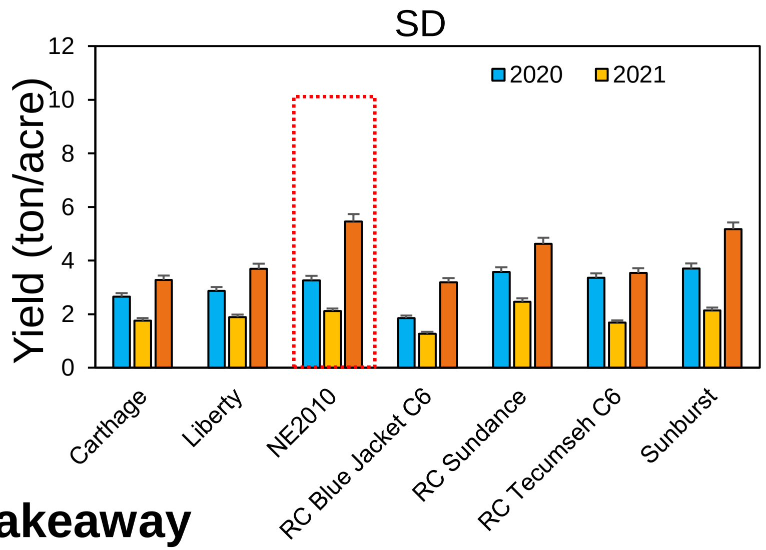
Task 2: Small-scale plot (100 ft^2) evaluation on marginal croplands

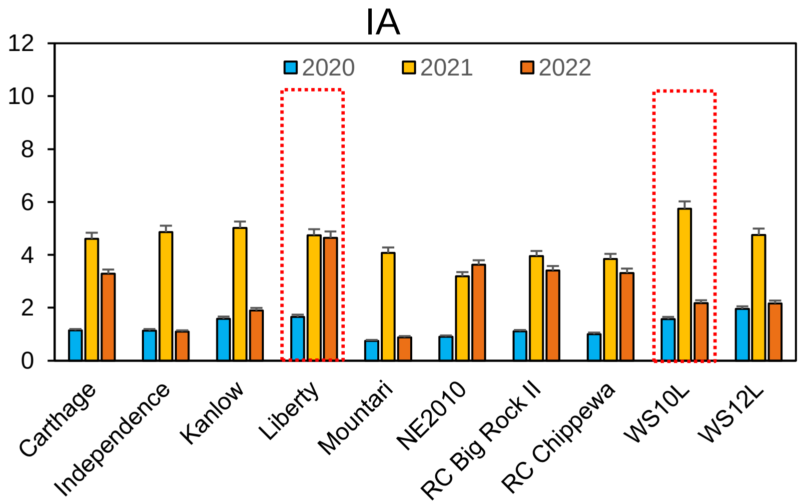
50 lbs N/ac

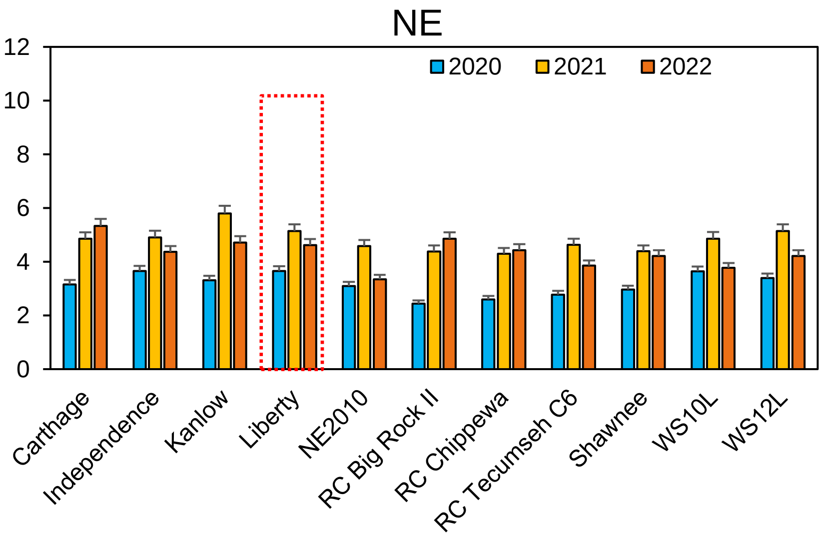












Takeaway

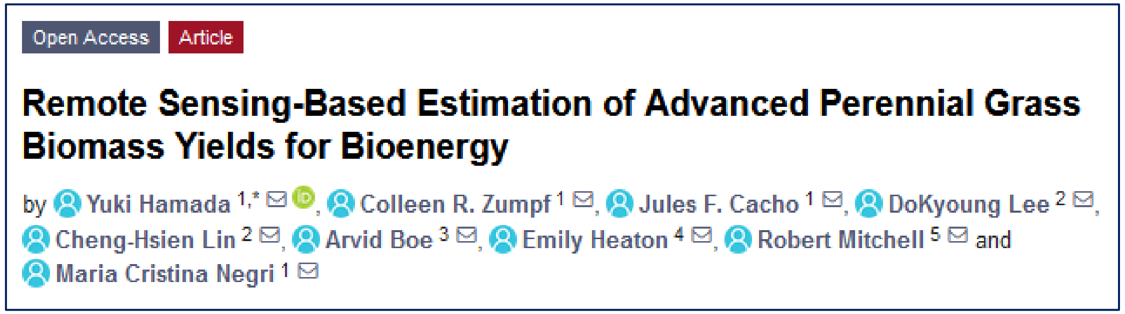
- Many newer bioenergy type switchgrass yielded more biomass than existing variety, Shawnee

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

4 – Progress and Outcomes (Machine learning (ML) FY 21-22)

Task 3: Machine learning (ML) and model development

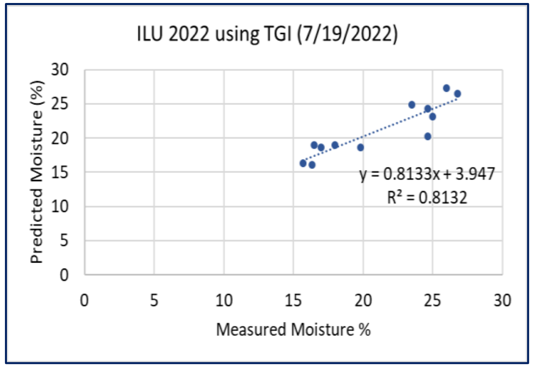
- Developed, validated, and published a remote sensing model to estimate biomass yield at harvest

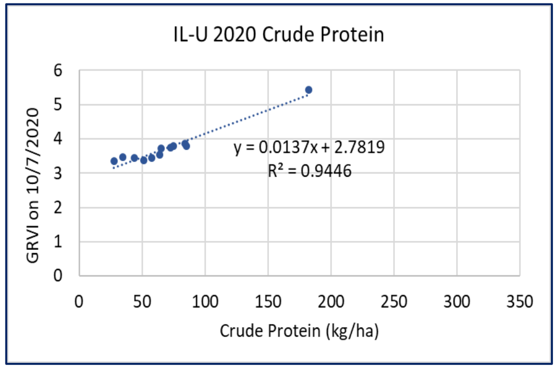

Open Access Article

Remote Sensing-Based Estimation of Advanced Perennial Grass Biomass Yields for Bioenergy

by Yuki Hamada [1,*], Colleen R. Zumpf [1], Jules F. Cacho [1], DoKyoung Lee [2], Cheng-Hsien Lin [2], Arvid Boe [3], Emily Heaton [4], Robert Mitchell [5] and Maria Cristina Negri [1]

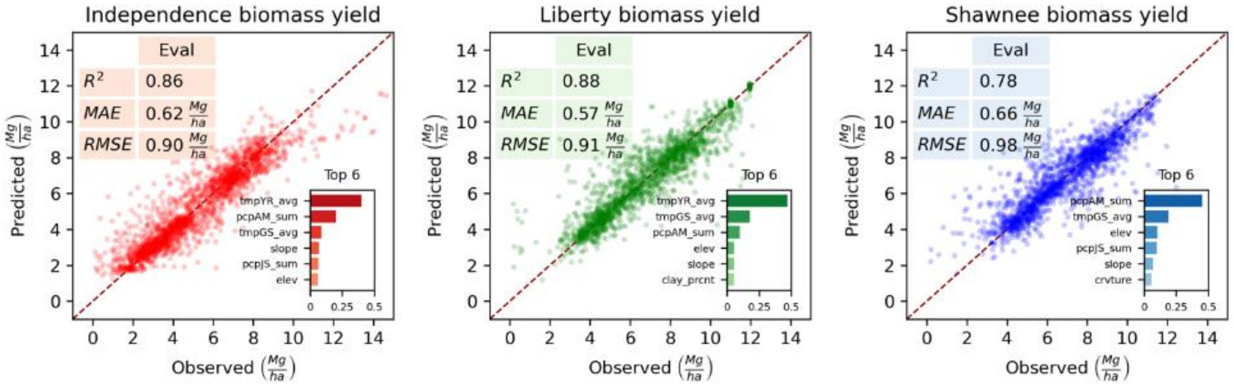
- Developed and validated remote sensing models to estimate biomass moisture and crude protein contents





TGI = Triangular Greenness Index; **GRVI** = Green Red Vegetation Index; **ILU** = Illinois (Urbana) Study Site

- Trained and tested ML model for predicting biomass yield at harvest time using 3-yr. (2020-2022) dataset

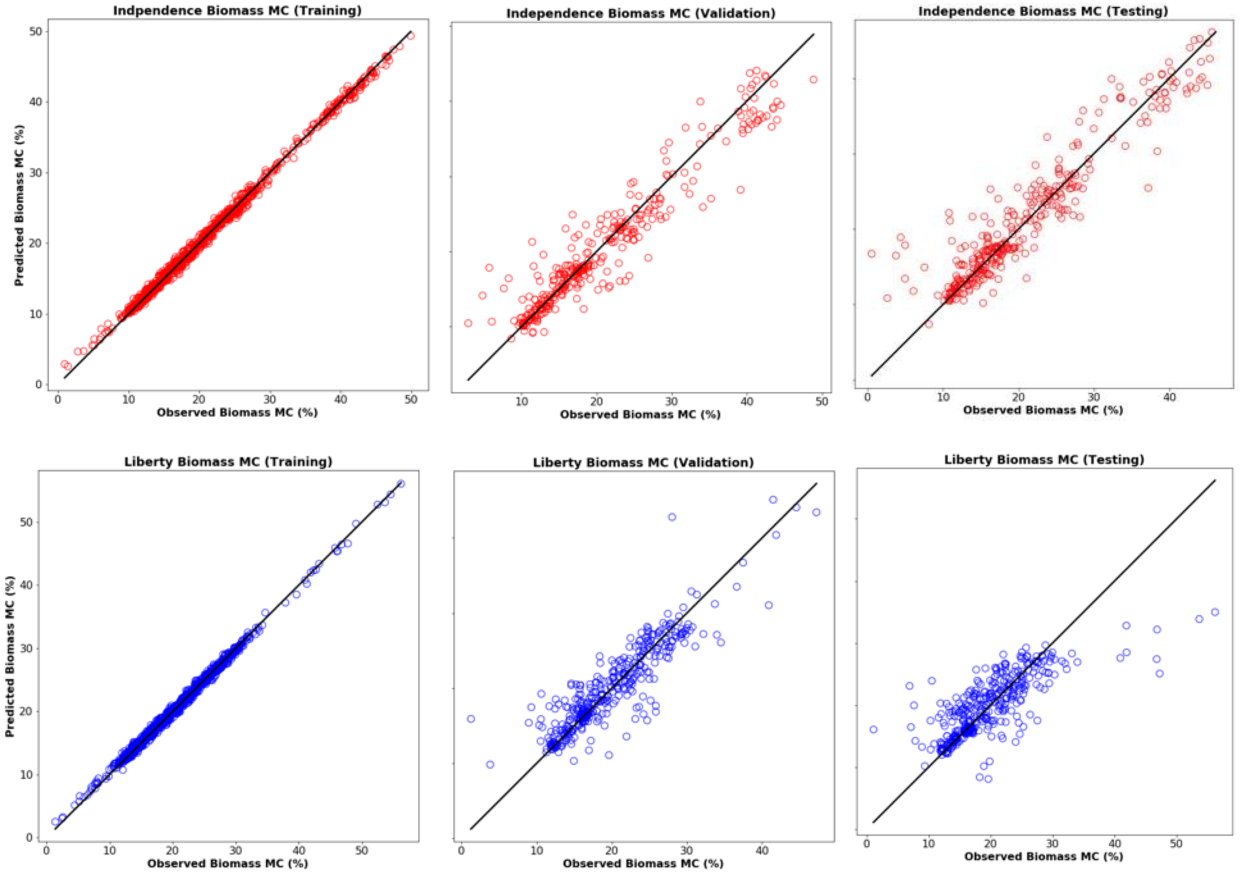


- Submitted a manuscript for peer-review in the Energies journal: “Predicting biomass yields of switchgrass cultivars for bioenergy and ecosystem services using machine learning”

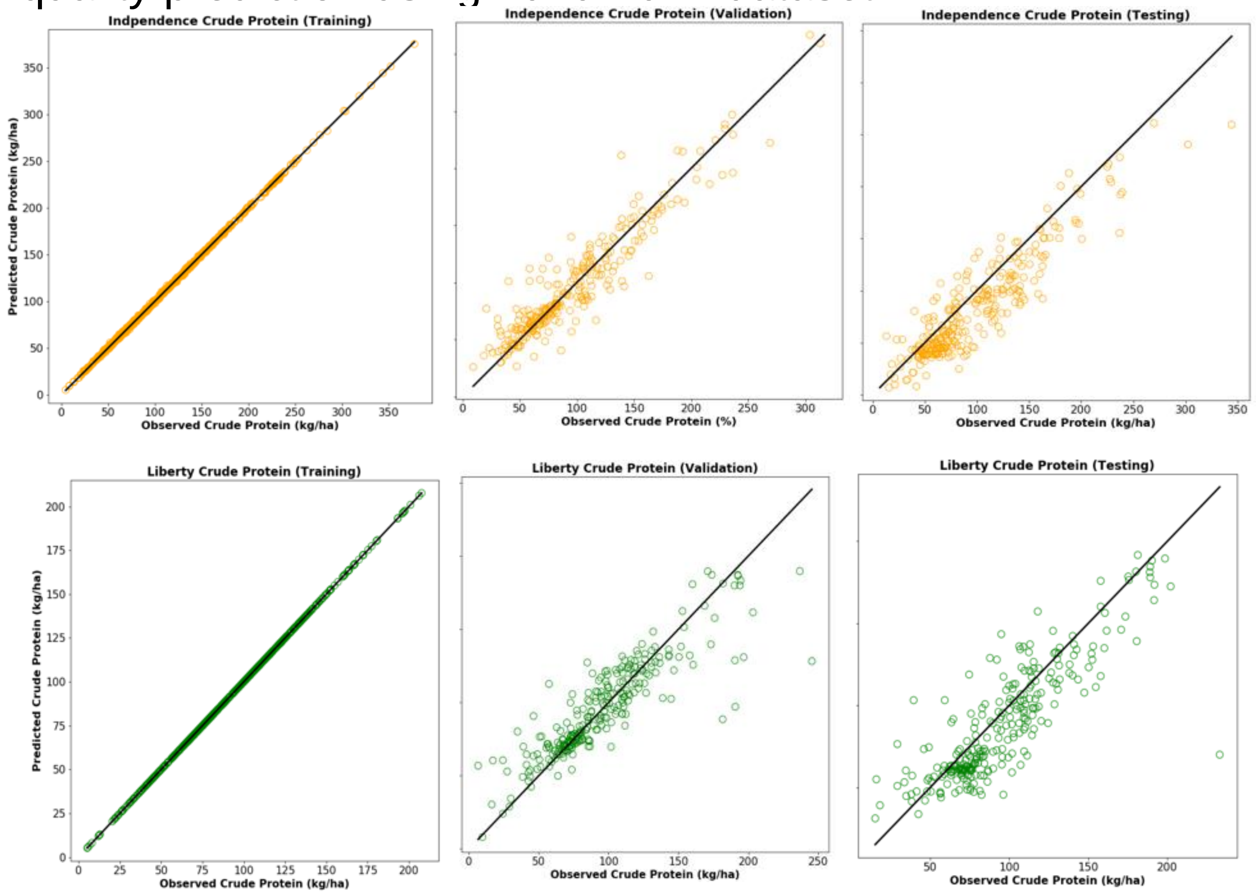
4 – Progress and Outcomes (Machine learning (ML) FY 21-22)

Task 3: Machine learning (ML) and model development

- Trained, validated, and tested the ML model for biomass quality prediction using 2020-2021 dataset



(Preliminary results for predicting **Biomass Moisture Content** of Independence (Red) and Liberty (Blue) using datasets from Illinois [Brighton and Urbana] and Iowa [Madrid] from 2020-2022)

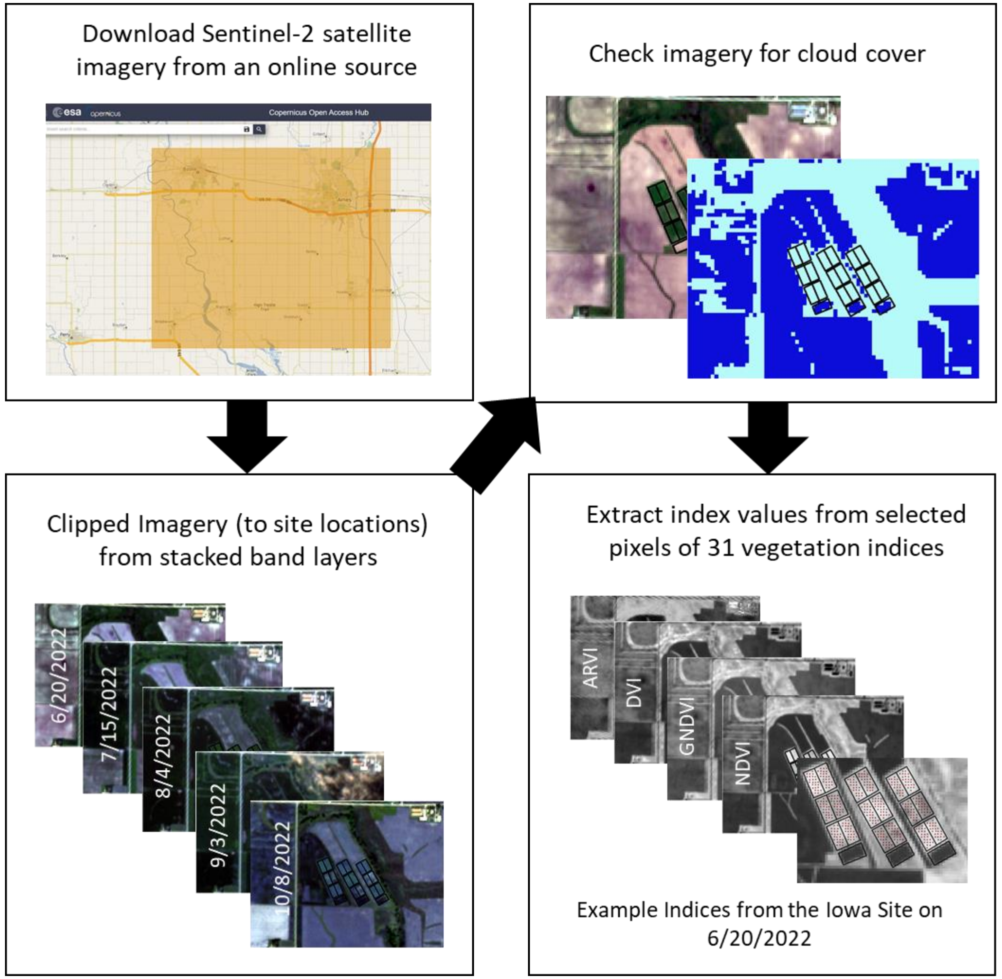


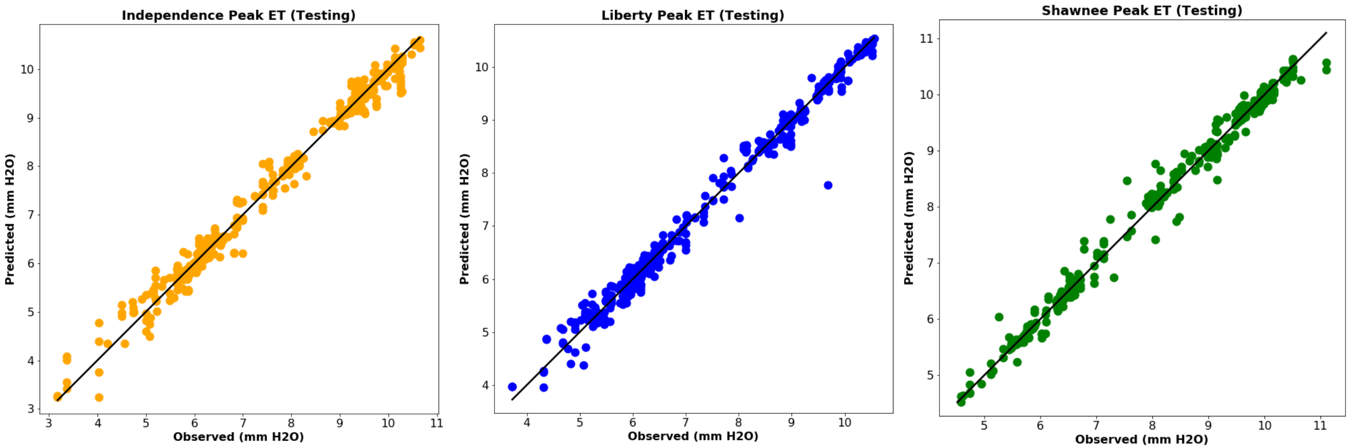
(Preliminary results for predicting **Biomass Crude Protein** Content of Independence (Orange) and Liberty (Green) using datasets from Illinois [Brighton and Urbana] and Iowa [Madrid] from 2020 to 2021

4 – Progress and Outcomes (Machine learning (ML) FY 21-22)

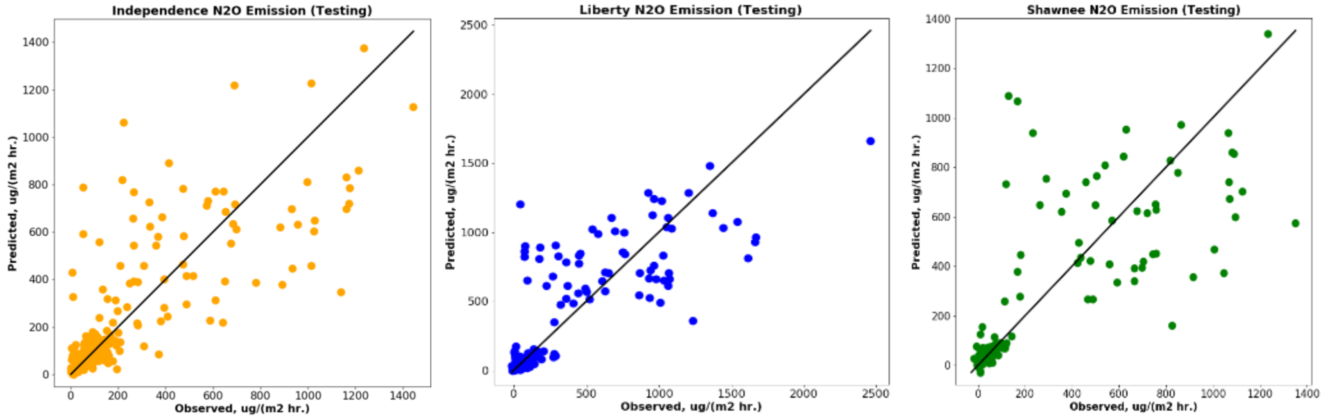
Task 3: ML model development, ES Impacts focused (Progress)

- Processed 2022 satellite imagery for generating gridded biomass dataset outside of the IL study sites (e.g., IA, NE, and SD sites)
- Trained and tested ML model for predicting ET (peak) and N_2O (seasonal average) with 2-year (2020-2021) dataset.





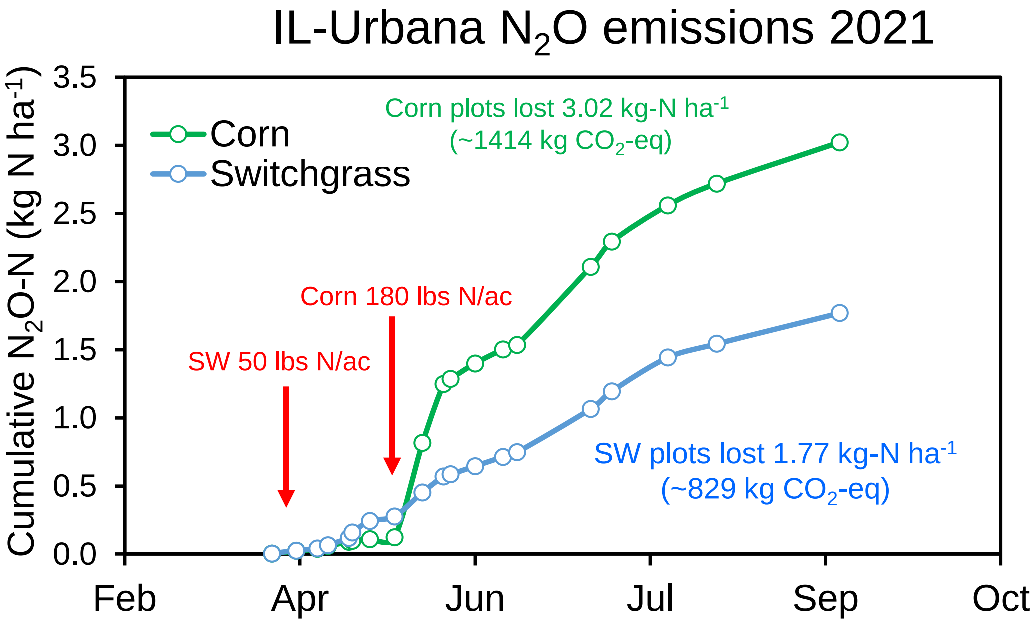
Preliminary testing results of ML model predictions on peak ET using 2020-2021 dataset. Independence (orange) and Liberty (Blue) datasets were from three sites [Illinois (Urbana and Brighton) and Iowa (Madrid)]; Shawnee (green) dataset was from two sites (Brighton, IL and Madrid, IA).

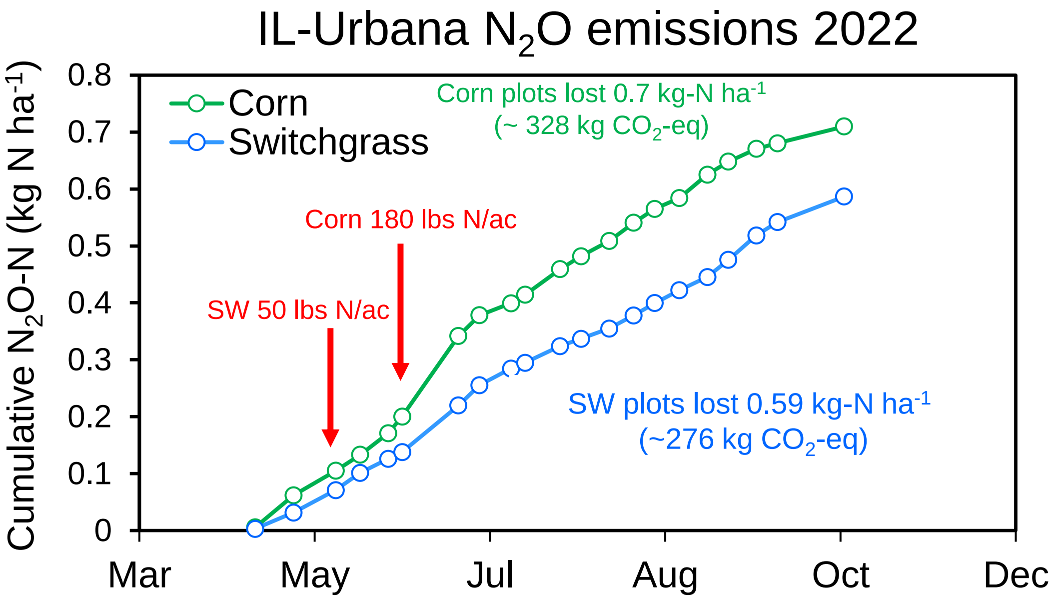


Preliminary testing results of ML model predictions on N_2O (ave) using 2020-2021 dataset. Independence (orange), Liberty (Blue), and Shawnee (Green). Datasets used were from three sites [Illinois (Urbana and Brighton) and Iowa (Madrid)].

4 – Progress and Outcomes (Ecosystem Services – Soil N_2O emissions)

Task 4: Ecosystem service measurement





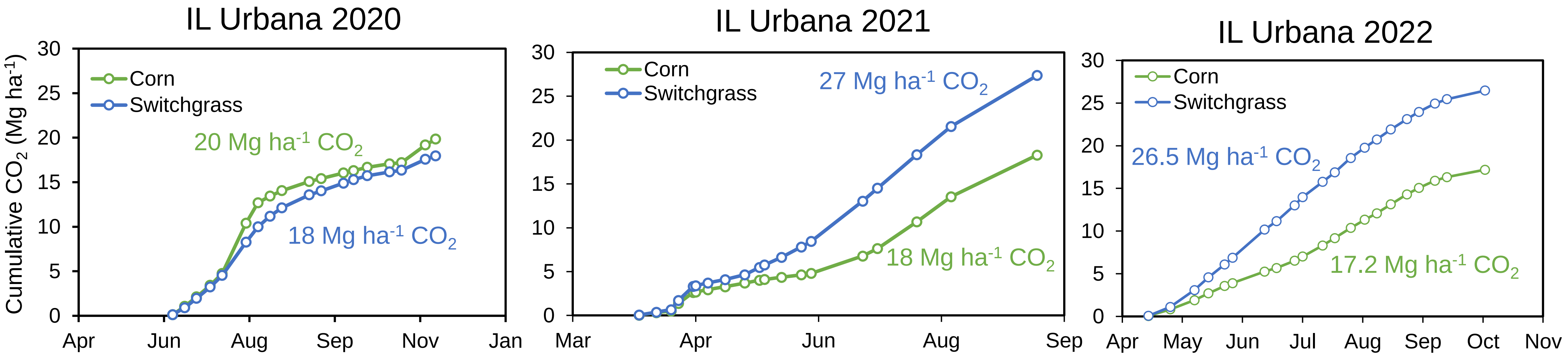
Takeaway

- Increased N losses via N_2O emissions after N application for both corn and switchgrass systems
- Soil N_2O emissions in switchgrass was lower by 15 -70% compared to corn field
- Detected seasonal variation in N loss, 65% lower in 2022 relative to 2021

4 – Progress and Outcomes (ES – Soil CO_2 emissions)

Task 4: Ecosystem service measurement

Corn: 180 lbs N/ac
Switchgrass: 50 lbs N/ac

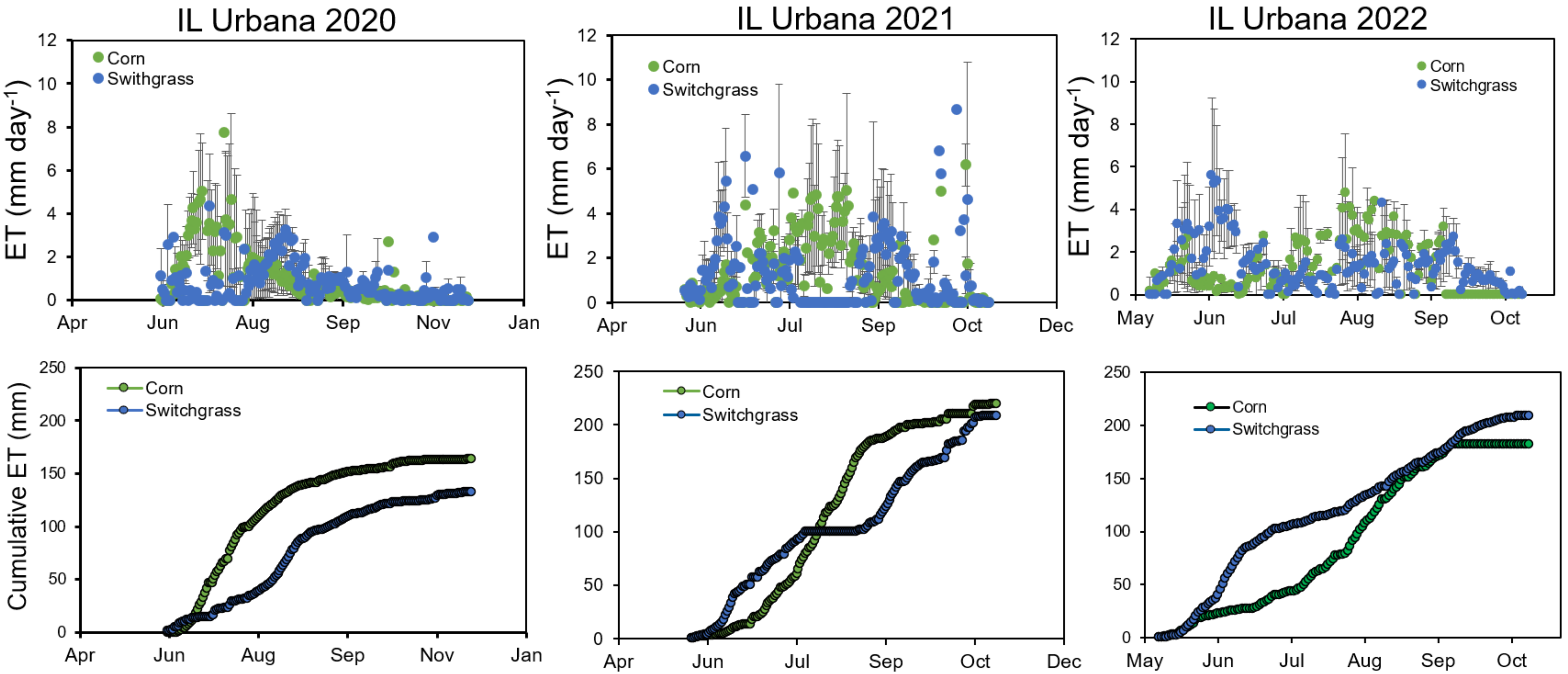


Takeaway

- During the establishment year, soil CO_2 flux was slightly lower in the switchgrass field. However, as switchgrass established and produced more biomass in 2nd and 3rd year, soil CO_2 flux was higher in the switchgrass field than the cord field
- Soil CO_2 emissions were on average ~26% higher in the switchgrass field than in the corn field

4 – Progress and Outcomes (ES – Evapotranspiration, ET)

Task 4: Ecosystem service measurement



Takeaway

- Switchgrass field had lower ET than the corn field with seasonal variation

Next-Generation Feedstocks for the Emerging Bioeconomy Support (FY20-FY22)

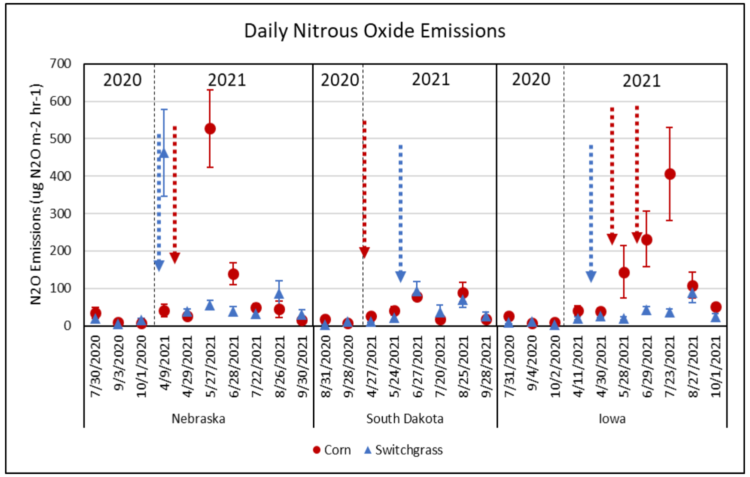
Project Overview

- Supplemental AOP (WBS 1.1.1.1051) aimed at complementing the “Next-Generation Feedstocks for the Emerging Bioeconomy” (WBS 1.1.1.1053).
- Extend the ecosystem services (ES) impact assessment under WBS 1.1.1.1053 to a wider geographical range (Nebraska, Iowa, and South Dakota sites).
- Support the generation of dataset needed for the machine learning (ML) model development.
- Expand the predictive capabilities of the proposed ML model under WBS 1.1.1.1053 (focused on dry biomass yield and quality only) to ES impacts (focused on ET and GHG emissions).

Task 1 – ES Impact Assessment (IA, NE, SD sites) (Progress)

– Completed the 3-year field data collection in November 2022.
– Switchgrass biomass production ET impacts were not consistent across site and were largely affected by production year with variations in precipitation and temperature as the likely driving factors (plots in extra slides section).
– Manuscript on the results of the 3-year ET impact assessment was recently submitted for peer-review: “*Zumpf et al. (In review). Evapotranspiration of Advanced Perennial Bioenergy Grasses Produced on Marginal Land in the U.S. Midwest.*” (Biomass and Bioenergy Journal)
– On-going activities: analyses of GHG emissions and switchgrass allometric characteristics

Soil N_2O Emissions (2020-2021)

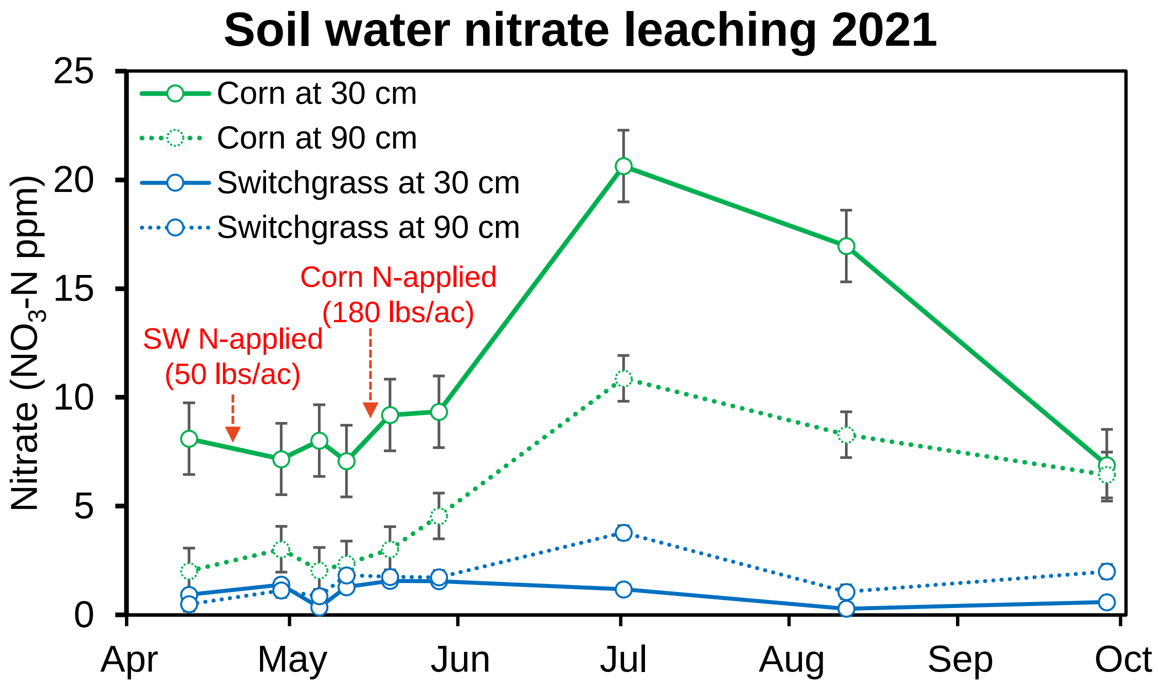


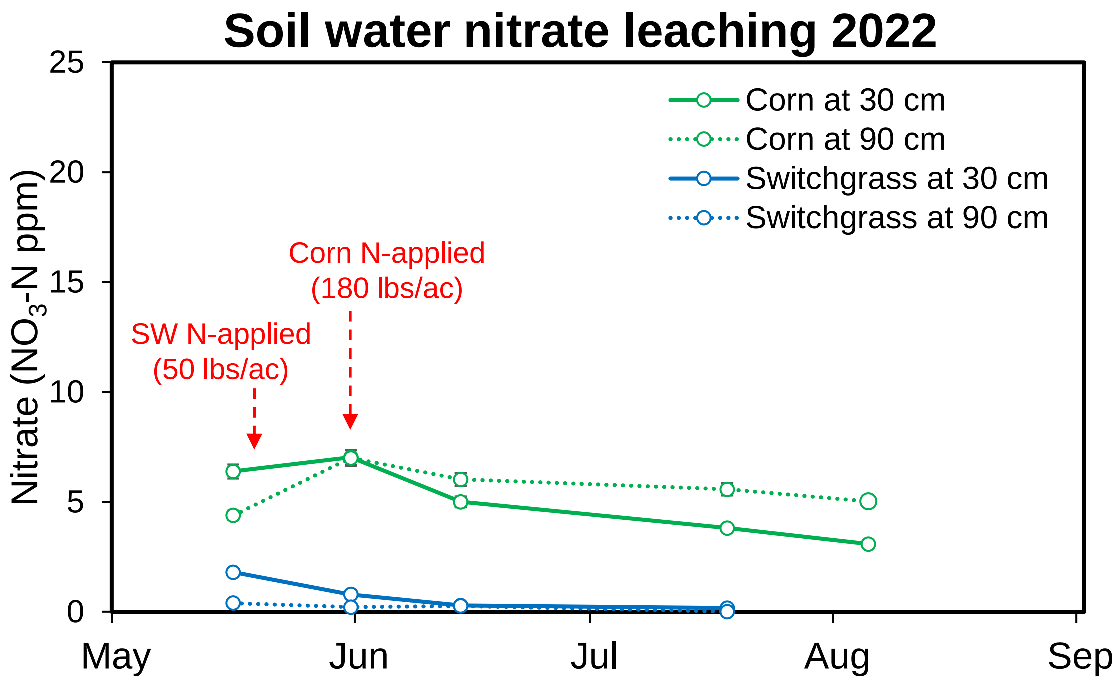
Arrows: Fertilizer dates color-coded by crop type

- Observed little differences in 2020 due to late sampling
- **Nebraska**: no crop differences annually, but in 2021 significant differences were observed after fertilizer application
- **Iowa**: Liberty had lower N_2O emissions than corn in 2021 ($p=0.01$)
- **South Dakota**: Carthage switchgrass had marginally lower N_2O emissions than corn in 2021 ($p=0.07$)

4 – Progress and Outcomes (ES – Water quality, NO_3-N leaching)

Task 4: Ecosystem service measurement





Takeaway

- Average soil water nitrate (NO_3-N) concentrations for corn were 4-10x greater than switchgrass
- Nitrate concentrations were low at both depths for switchgrass
- Low nitrate leaching (2x lower) in 2022 when compared to 2021

4 – Progress and Outcomes (ES – Biodiversity)

Task 4: Ecosystem service measurement

- ❖ Monitored the diversity and population of insects and birds
- ❖ Higher insect diversity in corn than switchgrass
- ❖ Higher bird diversity in corn than switchgrass but the total number of birds was higher in switchgrass as plots matured

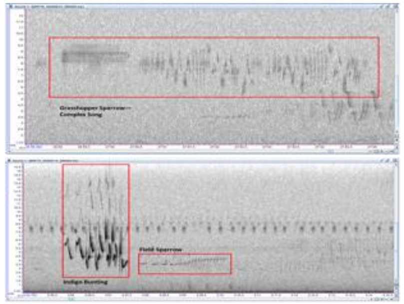
Bird counts in plots during 2020, 2021, and 2022

IL	2020		2021		2022	
	Corn	SW	Corn	SW	Corn	SW
No. of species	8	2	11	7	13	10
Total no. of birds	66	20	87	63	52	59
No. of birds per point count	2.4	0.7	3.2	2.3	1.9	2.2

Number of insect species recorded in plots during 2020 and 2021

		IL-Urbana	
Crop	**Insect species**	**2020**	**2021**
Corn	Ground Beetles	101	12
	Other Coleoptera	168	3
	Spiders	46	11
	Millipede/Centipede	0	1
	Lepidoptera	1	5
	Hemiptera	5	11
Switchgrass	Ground Beetles	93	15
	Other Coleoptera	51	4
	Spiders	77	2
	Millipede/Centipede	1	0
	Lepidoptera	7	0
	Hemiptera	29	4


Adult Male Indigo Bunting in Switchgrass plot, June 2021 (left); Red-winged Blackbird on UIUC Prairie

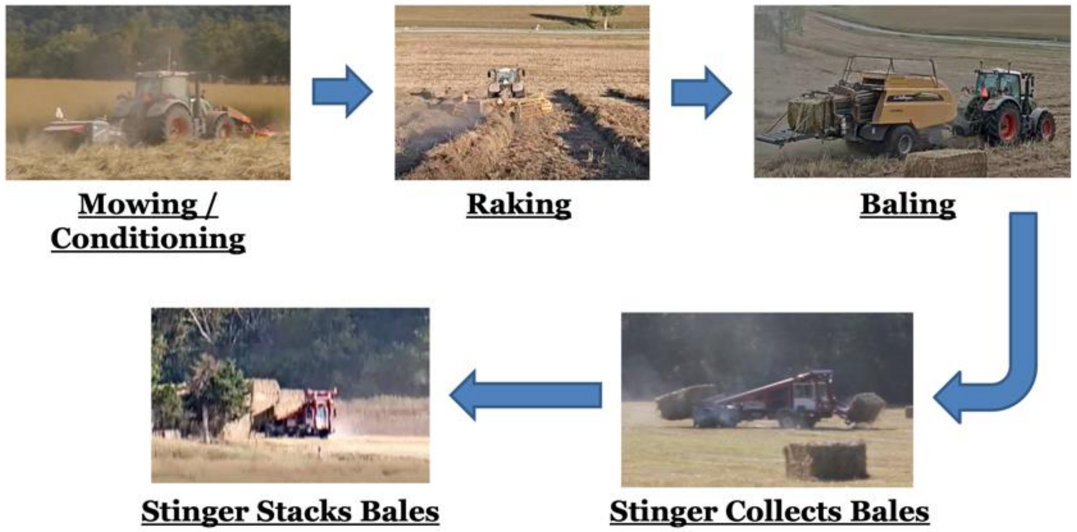



Acoustic Monitor at UIUC Prairie (left); Spectrograms of Bird vocalizations recorded in IL Brighton site

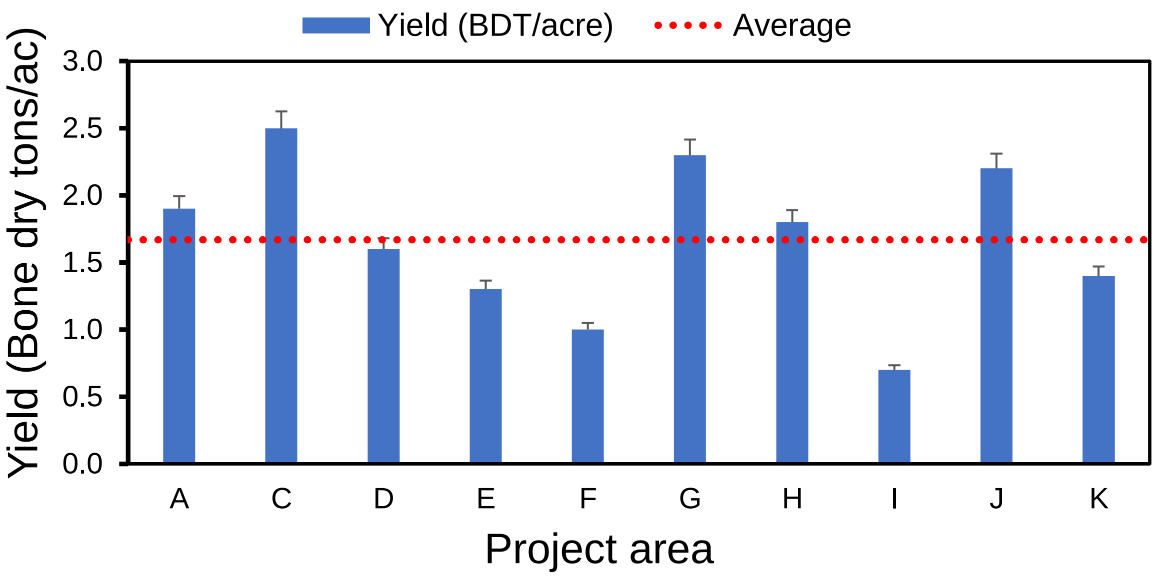
4 – Progress and Outcomes (Feedstock harvest & logistics, FY 21-22)

Task 5: Feedstock harvest and logistics

Overall order of Harvesting operations



Project area Switchgrass yield 2021



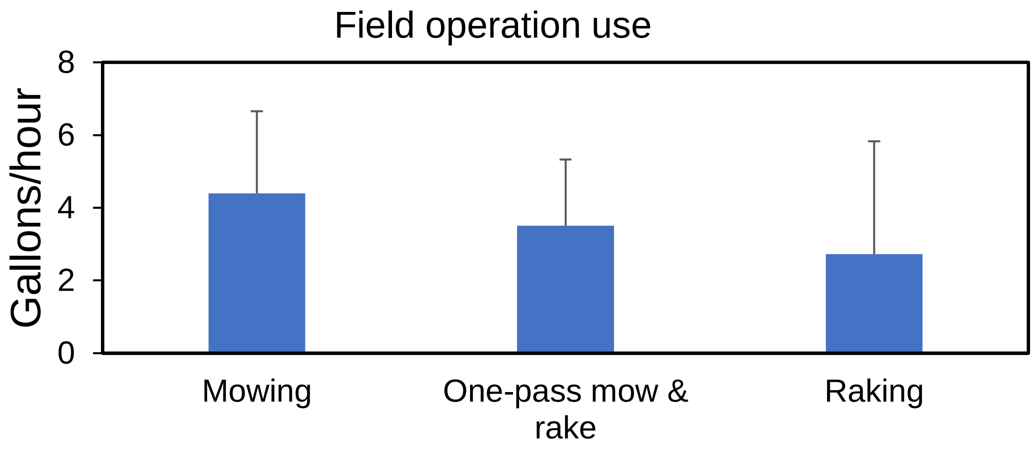
Takeaway

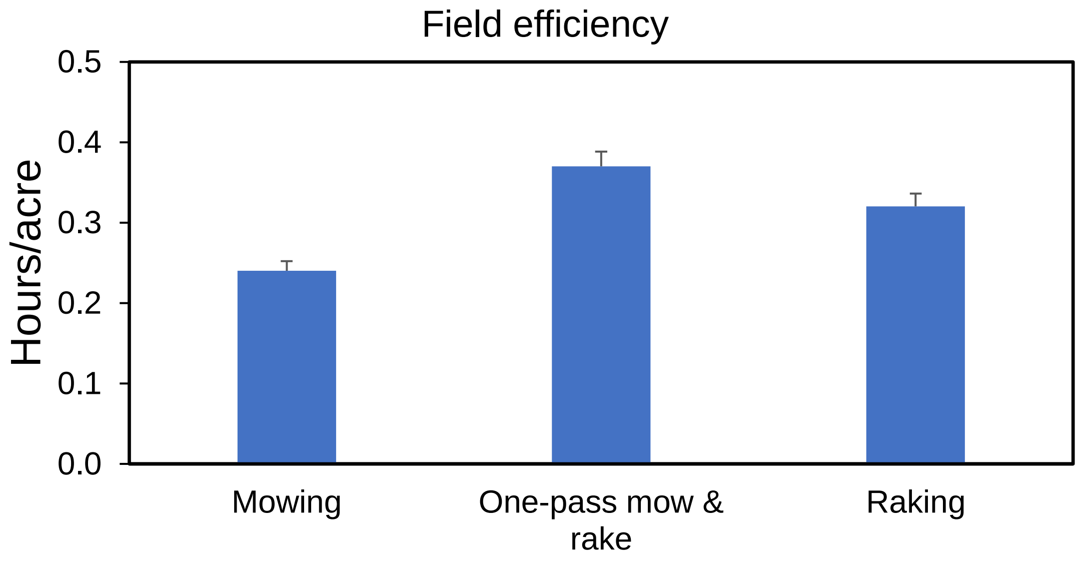
- Harvest operations, data collection methods, and database have been established for measuring performance and cost parameters

4 – Progress and Outcomes (Feedstock harvest & logistics, FY 21-22)

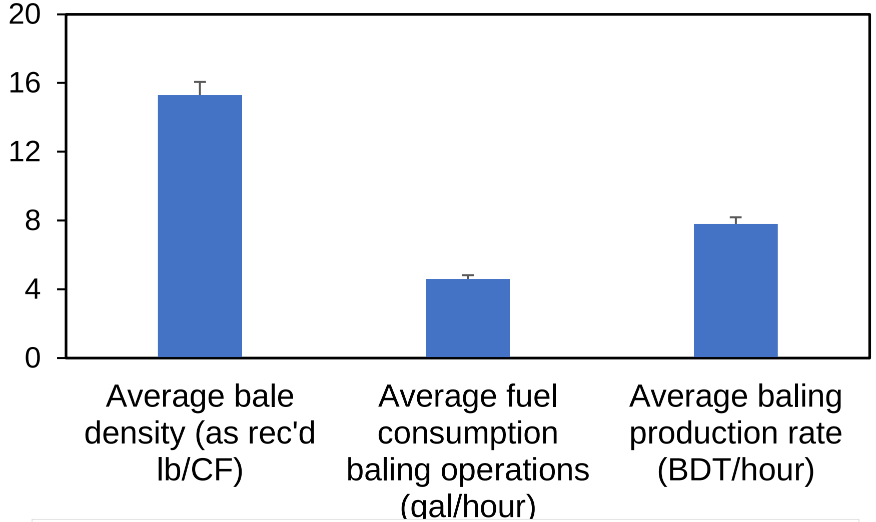
Task 5: Feedstock harvest and logistics

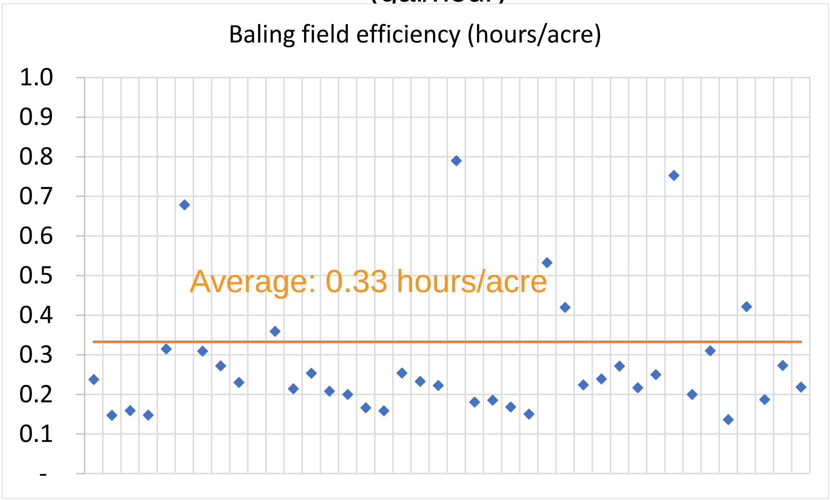
Other Field Operation Performance





Baling performance





4 – Progress and Outcomes (Feedstock harvest & logistics, FY 21-22)

Task 5: Feedstock harvest and logistics


Mowing/ Conditioning


Raking


Forage Chopping


Storing Chopped SWG in Silage Bags


Baling Chopped SWG


Load Bales for Transport

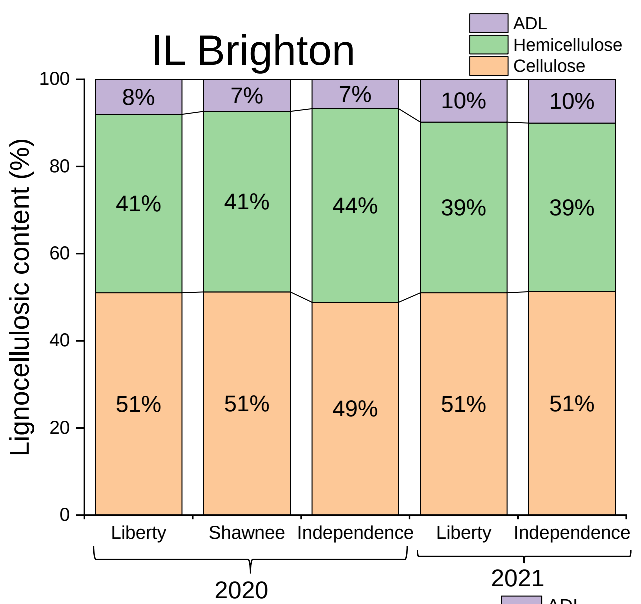
- **Harvest Method Changed to Forage Chopping and Bagging Operation in year 2022**

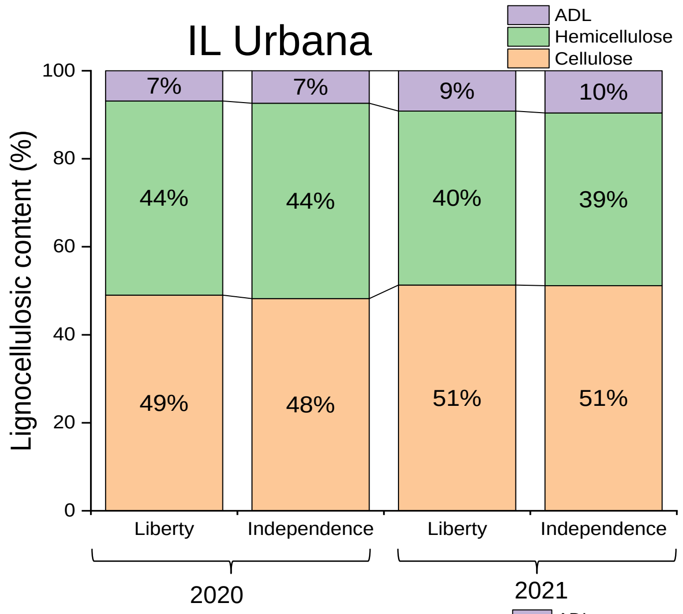
4 – Progress and Outcomes (Feedstock chemical composition, FY 21-22)

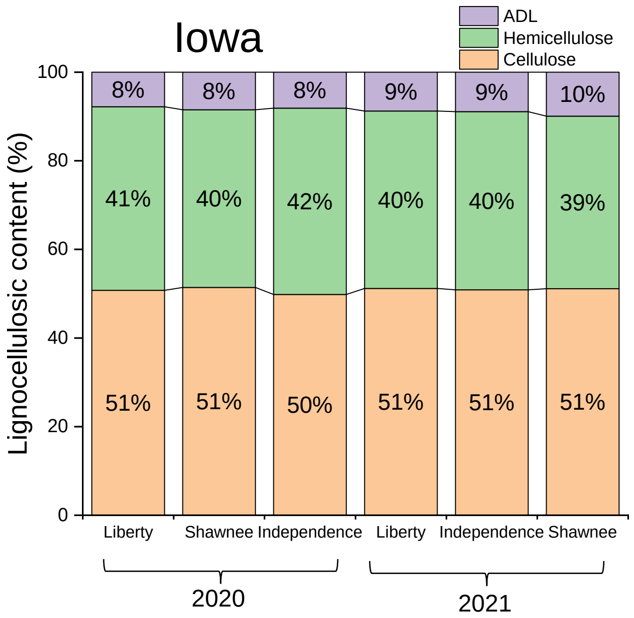
Task 6: Feedstock chemical composition

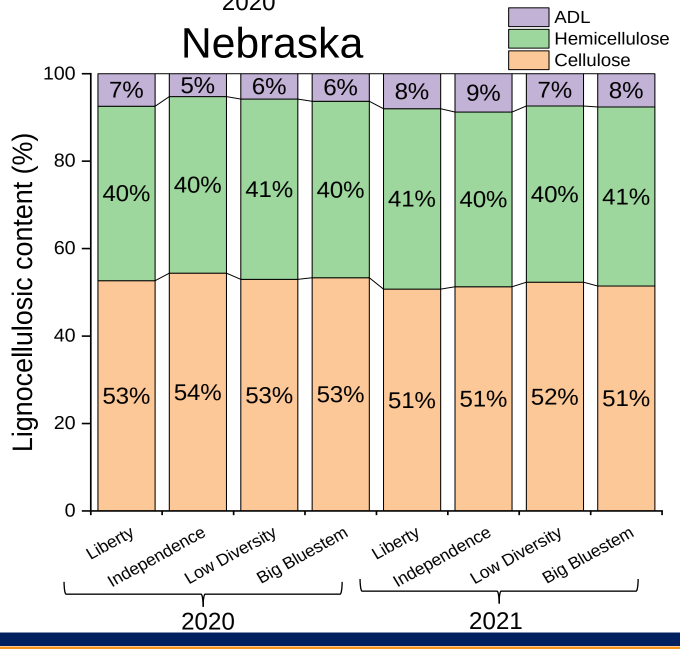
Takeaway

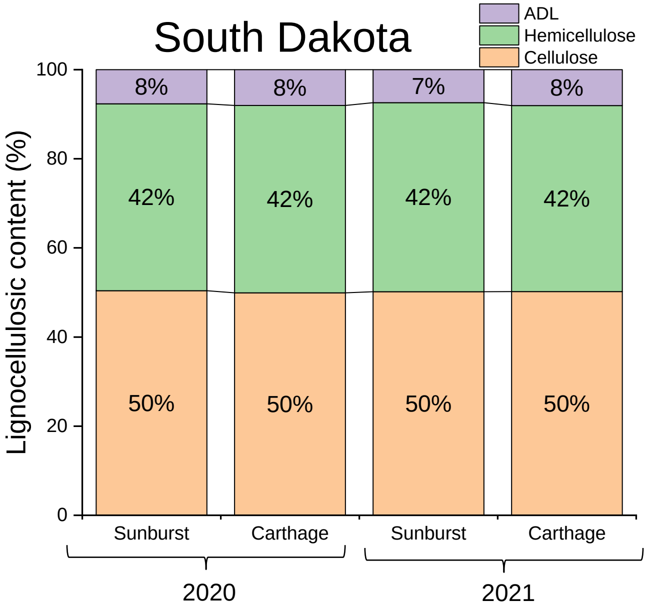
- The chemical compositions of feedstocks were not significantly different across cultivars and environmental conditions.
- However, non-statistical differences in chemical composition were detected among the years and locations.







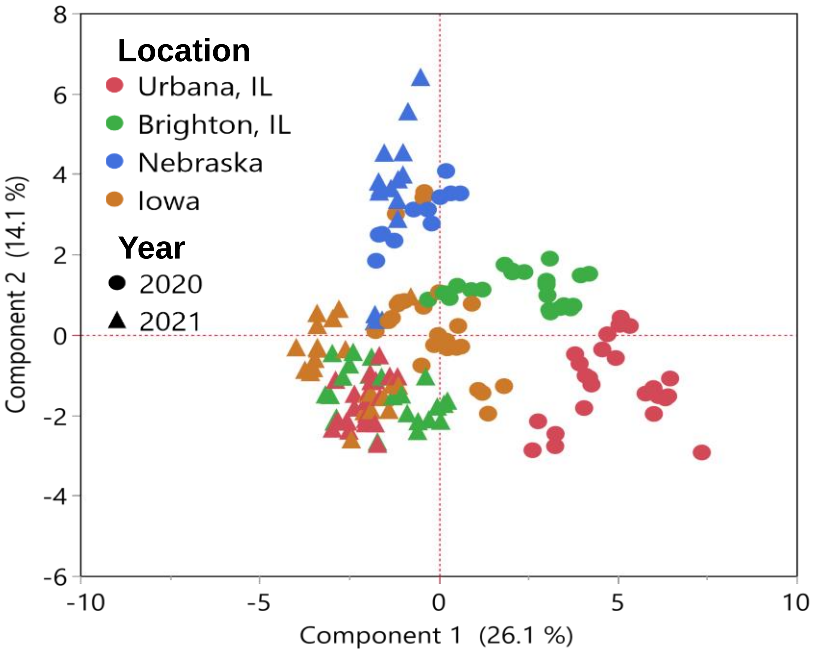




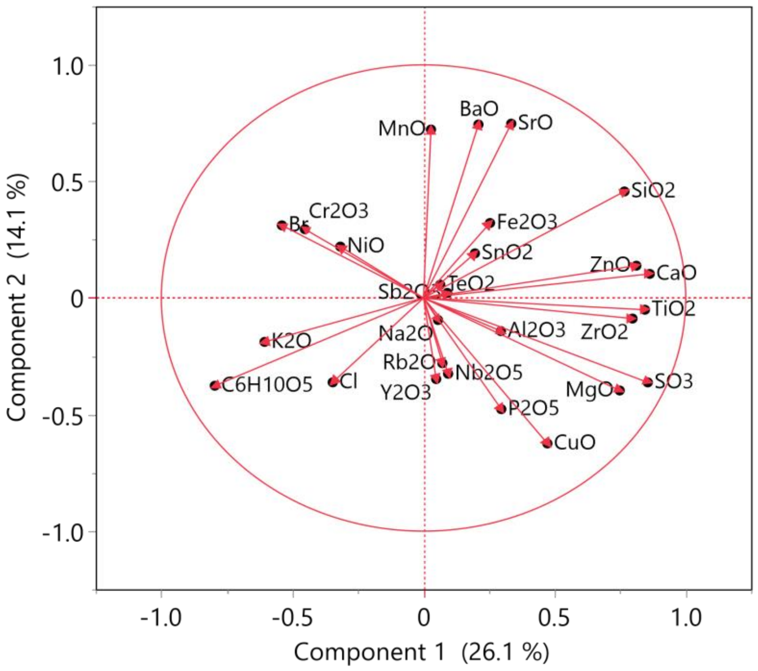
4 – Progress and Outcomes (Feedstock chemical composition, FY 21-22)

Task 6: Feedstock chemical composition

Principal Component Analysis Scores



Principal Component Analysis Loadings



X-Ray Fluorescence

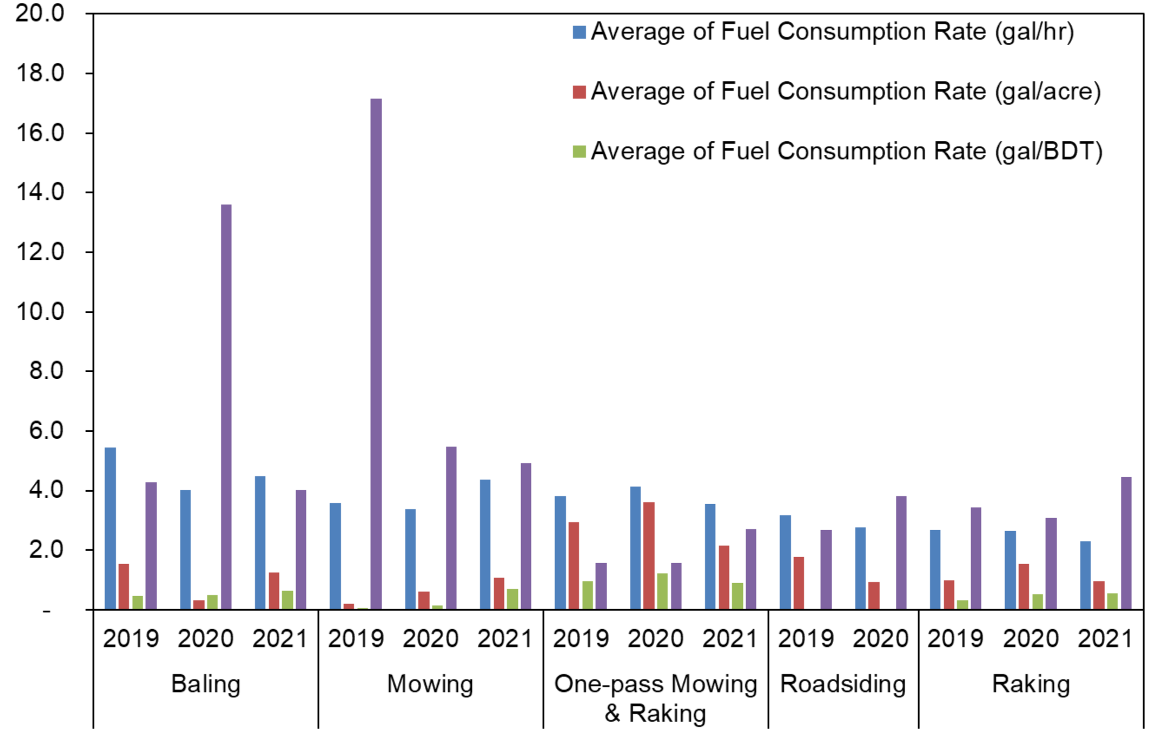
Takeaway

- X-Ray Fluorescence analysis completed for switchgrass samples from harvest years 2020 and 2021
- Analysis of plots with 50 lbs N/ac and Liberty/Independence cultivars indicate differences in soil and intrinsic inorganics due to location and harvest year

4 – Progress and Outcomes (Techno-economic analysis, FY 21-22)

Task 7: Techno-economic analysis

- Enterprise Budget for IL, SD, NE and IA sites on progress
- Utilizing detailed yield, harvest logistics, fuel use, and field capacity data received from Antares to develop Logistics Model



No	Item	Description	Total plot size (ha)	Input name	Year 2020 unit	Year 2020 quantity	Year 2020 cost/unit (USD)	Year 2020 Amount (USD)	Year 2021 unit	Year 2021 quantity	Year 2021 cost/unit (USD)	Year 2021 Amount (USD)
1	**Seedbed preparation**											
	Burndown herbicide/pre-emergence herbicide	cost per gal	3.254	Roundup	gal	1.72	149	256.10	gal		149	0
	Herbicide spraying	cost per pass	3.254	Boom sprayer	pass		7.55	0.00	pass		7.55	
	Brush mowing	cost per ha	3.254	Mower	ha			0.00	ha			0
	Labour seedbed preparation	cost per hr	3.254	Man hours	hr		9.75	0.00	hr		9.75	0
	Subtotal Seedbed preparation							256.10				0
2	**Planting /Seeding**											
	Seed	cost of PLS/ lb		Liberty	lb		24.71	0.00	lb		24.71	0
		cost of PLS/ lb		Independence	lb							
		cost of PLS/ lb			lb							
		cost of PLS/ lb										
	Seed drilling	cost per ha	3.254	No-till Drill	ha	3.254	39.66	129.05	ha		39.66	0
	Labour planting	cost per hr	3.254	Man hours	hr		9.75	0.00	hr		9.75	0
	Subtotal Planting							129.05				0
3	**Re-seeding**											
	Seed	10% re-seeding	3.254	Cultivars: liberty, Independence	lb	-	-	0.00	lb	0.3254	24.71	8.04
	Seed drilling	cost per ha	3.254	No-till Drill	ha	-	-	0.00	ha		39.66	0.00
	Labour re-seeding	cost per hr	3.254	Man hours	hr	-	-	0.00	hr		9.75	0.00
	Subtotal Re-Seeding							0.00				8.04
4	**Management I (25 lb N/ac)**											
	Post emergence herbicide	cost per gal	3.254	2, 4-D	gal		17.6	0.00	gal		17.6	0.00
	Herbicide spraying	cost per pass	3.254	Boom sprayer	pass		7.55	0.00	pass		7.55	0.00
	Fertilizer	cost per lb	1.627	Urea, 25 lb N/ac	lb	0	1.04	0.00	lb	218.5	1.04	227.22
	Fertilizer spreading	cost per pass	3.254	Fertilizer spreader	pass	0	5.00	0.00	pass		5.00	0.00
	Labour Management		3.254	Man hours	hr		9.75	0.00			9.75	0.00
	Subtotal Management							0.00				227.22
5	**Management II (50 lb N/ac)**											
	Post emergence herbicide	cost per gal	3.254	2, 4-D	gal		17.6	0.00	gal		17.6	0.00
	Herbicide spraying	cost per pass	3.254	Boom sprayer	pass		7.55	0.00	pass		7.55	0.00
	Fertilizer	cost per lb	1.627	Urea, 50 lb N/ac	lb	0	1.04	0.00	lb	437.0	1.04	454.43
	Fertilizer spreading	cost per pass	3.254	Fertilizer spreader	pass	0	5.00	0.00	pass		5.00	0.00
	Labour Management		3.254	Man hours	hr		9.75	0.00			9.75	0.00
	Subtotal Management							0.00				454.43
6	**Harvesting I (25 lb N/ac)**											
	Mowing/conditioning/windrowing/Swathing	cost per ha	3.254	SP swather	ha	1.627	35.08	57.08	ha	1.63	35.08	57.08
	Baling	cost per bale	3.254	Square baler	bale#		12.60	0.00	bale#	58.87	12.60	741.76
	Transport to storage	cost per bale	3.254	Bale mover/tractor	bale#		3.30	0.00	bale#	58.87	3.30	194.27
	Labour harvesting	cost per hr	3.254	Man hours	hr		9.75	0.00	hr		9.75	0.00
	Subtotal Harvesting							57.08				
7	**Harvesting II (50 lb N/ac)**											
	Mowing/conditioning/windrowing/Swathing	cost per ha	3.254	SP swather	ha	1.627	35.08	57.08	ha	1.63	35.08	57.08
	Baling	cost per bale	3.254	Square baler	bale#		12.60	0.00	bale#	58.87	12.60	741.76
	Transport to storage	cost per bale	3.254	Bale mover/tractor	bale#		3.30	0.00	bale#	58.87	3.30	194.27
	Labour harvesting	cost per hr	3.254	Man hours	hr		9.75	0.00	hr		9.75	0.00
	Subtotal Harvesting							57.08				
8	**Other costs**											
	Machinery and repair	cost per ha			ha		19.94	0.00	ha			
	Total costs							442.22				235.26

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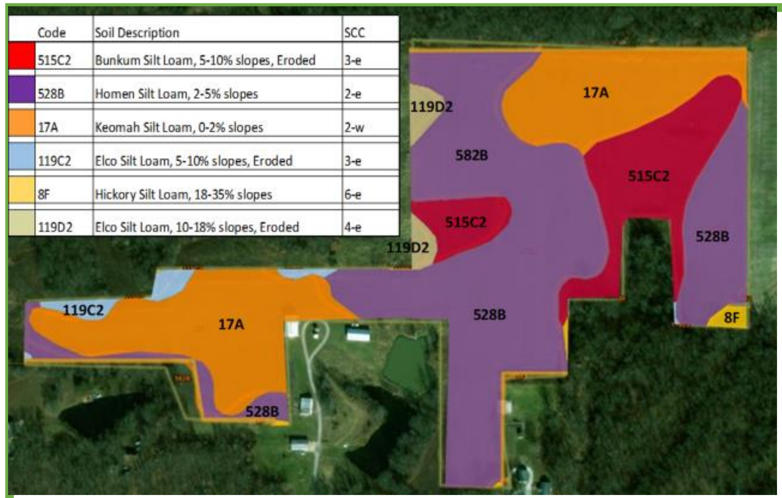
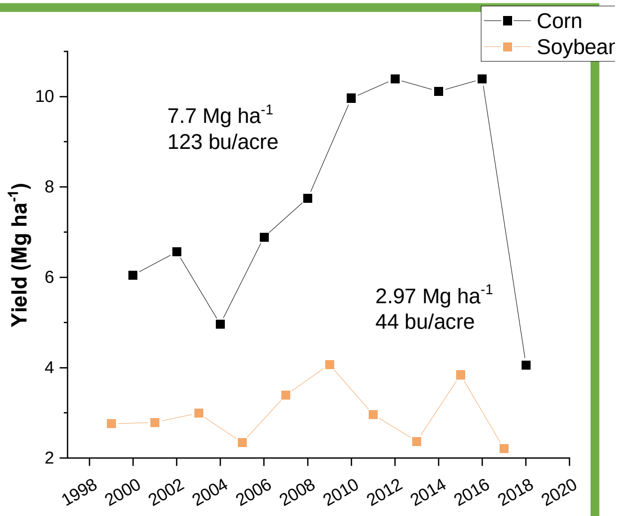
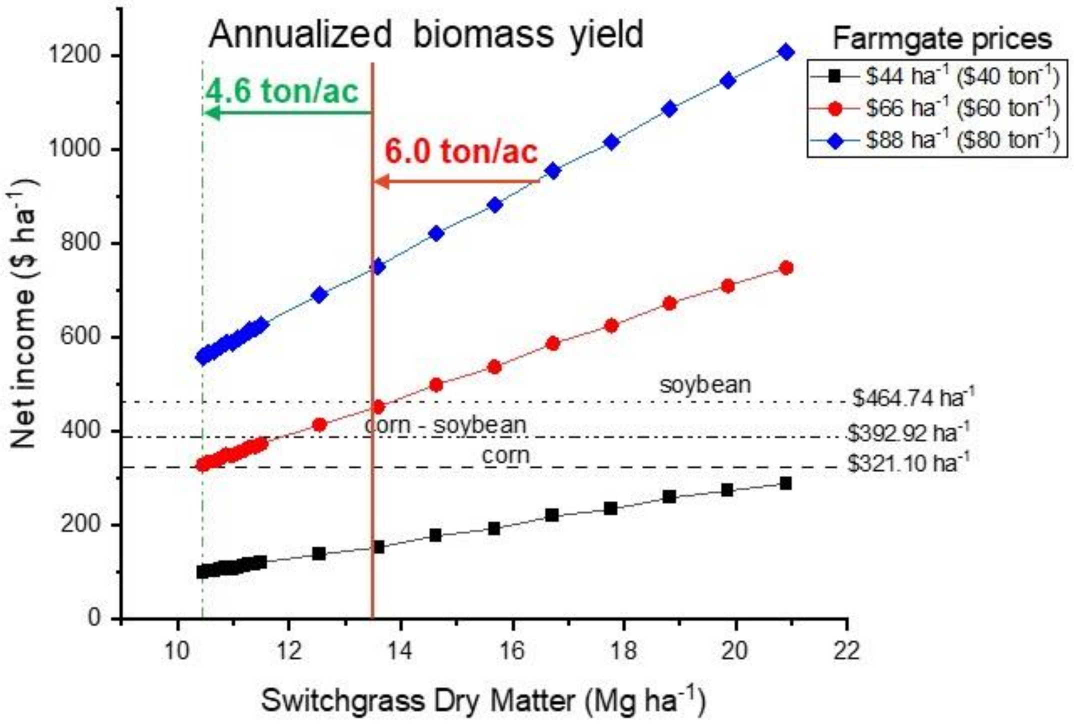
3 – Impact (Significance of outcomes)







MARGINAL LAND

This project will

- Contribute to BETO's goal of producing >4 dry tons/acre annually at a cost of $84/dry ton or less with high-yielding bioenergy switchgrass on marginal lands (Namoi et al., 2022)
- Encourage producers to integrate switchgrass on their farms by 1) demonstrating the economic benefits of feedstock production and the potentially monetizable ecosystem service benefits of switchgrass; 2) providing new decision-making tools to expand sustainable production systems using high-performance computing, data science, and precision farming technology.
- Collaborate with biorefineries to provide critical access to conversion technology insights with feedstock produced by farm practices

3 – Impact (Significance of outcomes)

- Annual on-site field day with local stakeholders to showcase production systems and local specific best management guides for switchgrass
- Over 7 peer-reviewed publications
- Presentations at various national and international conferences
- Two public data repositories
  - The Bioenergy Knowledge Discovery Framework (KDF) for biomass yield and composition
  - The Bioenergy Feedstock Library for biomass samples and data
  - GitHub for the ML-model source code
- Project webpage (UIUC, iSEE) to disseminate our findings
- Promote bioenergy switchgrass cultivars, ”Liberty” and “Independence” through our commercial partners, seed producers and seed companies

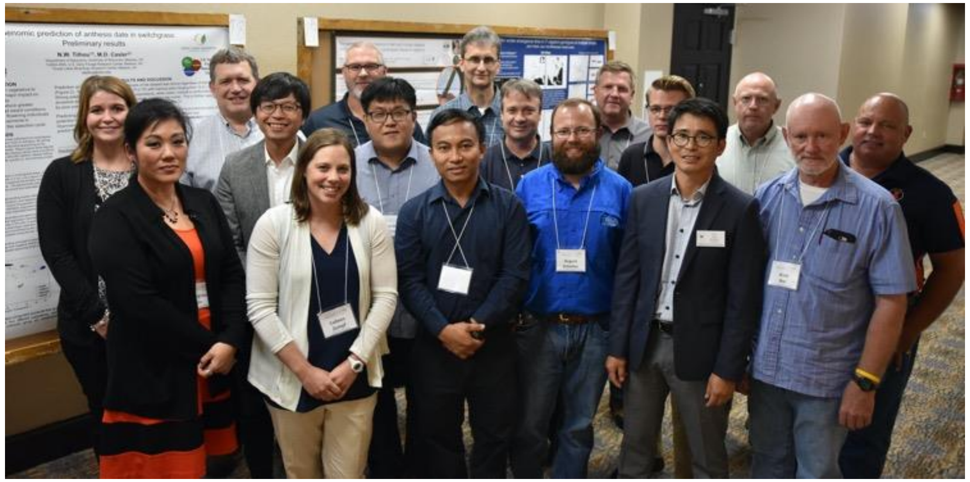

Switchgrass V International Conference
July 2019, Urbana, IL


Brighton IL open House, Sept 16, 2021


CABBI Open House June 28, 2022

Summary (FY 20-22)

- **Bioenergy switchgrass was successfully harvested on marginally productive crop lands in SD, NE, IA, and IL.**
  - Best management practices resulted in high biomass yield
  - Year 2 and 3 harvest demonstrated promising biomass yield (>4 ton/ac)
  - Promising species and cultivars for future applications were identified
- **Bioenergy switchgrass feedstock production systems demonstrated the potential benefits of ecosystem services on the marginal croplands compared to the row cropping system (i.e., corn)**
  - Lower N_2O emissions by approximately 15 to 70%.
  - High CO_2 emissions in SW due to large root biomass and root respiration
  - Improved water quality with low soil N leaching
  - More efficient water use (low evapotranspiration)
  - High insect and bird diversity in corn but number of birds was higher in switchgrass as plots matured
  - Trained and tested ML model for predicting biomass yield at harvest time, and developed and validated RS models to estimate biomass moisture and crude protein



DOE-ASEC Switchgrass Team

Quad Chart Overview (Competitive Project)

Timeline
- Start: 10/01/2018
- End: 09/30/2024

	FY22 Costed	Total Award
DOE Funding	(10/01/2021 – 9/30/2022) *$1,008,412*	*$5,000,000*
Project Cost Share	*$251,200*	*$1,251,000*

Project Partners*
- University of Illinois at Urbana-Champaign
- Iowa State university
- South Dakota State University
- Antares Group
- USDA-ARS, Lincoln, NE and Mandan, ND
- Argonne National Lab
- Idaho National Lab

Project Goal
The goal of the project is to research and develop productive, cost-effective, and sustainable warm-season perennial bioenergy feedstock production systems on marginally productive croplands across geographic locations in the Midwest.

End of Project Milestone
- Develop BMP for sustainable feedstock production of switchgrass on marginal lands in Midwestern regions to meet BETO's goal of >4 dry tons/ac at the cost of delivered feedstock to less than $84/dry ton
- Demonstrate ecosystem service benefits of switchgrass feedstock production systems
- Develop a fully functional ML-based predictive model and a publicly available regional feedstock cost-rate model for delivering switchgrass to the biorefinery

Funding Mechanism
FOA: DE-FOA-0001917,
Affordable and Sustainable Energy Crops (ASEC), 2018

Additional Slides

Responses to Previous Reviewers' Comments

Comment 1: Can switchgrass at 6-ton/acre yield be dried sufficiently (<20%) to bale into large bales and stored in a stack? Does this require delayed harvest with a partial dry-down before harvest? This project is well positioned to answer these questions if it falls within the scope of work.

Response: Switchgrass biomass harvested after killing frost is dry enough to be stored. The average moisture in the biomass across all switchgrass cultivars harvested was about 15%, which should be appropriate for storage.

Comment 2: BMP development is being used as a major success factor. It is not clear what BMPs will be developed. It may be planned in BP 4 and 5. I think BMPs can be developed earlier and the BMPs application and effectiveness can be accessed in BP4 and 5.

Response: BMPs will be developed based on evaluated biomass yield, ecosystem services, and the overall costs, and values of implementing the new switchgrass varieties when compared with the predecessor varieties. The agronomic BMP often focus on herbicide, N application, and harvest practices. In the project, we apply minimal chemical inputs (herbicide and fertilizers) to prevent further environmental degradation to the sensitive marginal lands. Moreover, the delayed harvest after killing frost is known to improve feedstock qualities by reducing the moisture and ash content.

Comment 3: This is a very hands-on project, with the need to collect a lot of field data. This type of project requires a great deal of coordination. There is a risk that data does not get collected (failure of measurement devices) etc.

Response: The intensive data collections are focused on the evaluations of biomass yield, ecosystem services, and the ground-truth soil and biomass samples for the ML model development. The consistency of data collection has been successful due to the established uniform data protocols and timelines that are used by all Co-PIs. The heavy communication and coordination between Co-PIs in IL, SD, NE, IA, and Argonne National Laboratory and the periodic quarterly reports from each location further keeps track of the activities. Moreover, some activities such as ML and soil sampling are performed by single individuals across the sites and assures quality.

Publications

- Cooney, D., Namoi, N., Zumpf, C., Villamil, M., Mitchell, R., & Lee, D. K. (2022) Biomass Production Bioenergy. https://doi. and Nutrient Removal from Perennial Energy Grasses on a Wet Marginal Land. Accepted (BioEnergy Research)
- Lin, C. H., Namoi, N., Hoover, A., Emerson, R., Cortez, M., Wolfrum, E., Payne, C., Egenolf, J., Harmoney, K., Kallenbach, R., & Lee, D. K. (2022). Harvest and Nitrogen Effects on Bioenergy Feedstock Quality of Grass-Legume Mixtures on Conservation Reserve Program Grasslands. GCB org/10.1111/gcbb.12980
- Namoi, N., Archer, D., Rosenstock, T. S., Jang, C., Lin, C. H., Boe, A., Lee, D., & Brummer, C. (2022). How profitable is switchgrass in Illinois, USA? An economic definition of marginal land. Grassland Research. https://doi.org/10.1002/glr2.12017
- Zumpf, C., Cacho, J., Grasse, N., Quinn, J., Hampton-Marcell, J., Armstrong, A., ... & 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, 145674.
- Hamada, Y., Zumpf C.R., Cacho J.F., Lee D., Lin C-H., Boe A., Heaton E,. Mitchell R., Negri M.C. 2021. Remote Sensing-Based Estimation of Advanced Perennial Grass Biomass Yields for Bioenergy. Land, 10(11):1221.
- Cacho, J., Feinstein, J., Zumpf, C., Hamada, Y., Lee, D., Namoi, N., Lee, D.K., Boersma, N., Heaton, E., Quinn, J., and Negri, C. (In review). Predicting biomass yields of switchgrass cultivars for bioenergy and ecosystem services using machine learning. Energies Journal.
- Zumpf, C.R., Cacho, J.F., Grasse, N.F., Walsh, C., Lee, D.J., Lee, D., and Negri, M.C. (*In review*). Evapotranspiration of Advanced Perennial Bioenergy Grasses Produced on Marginal Land in the U.S. Midwest. Biomass and Bioenergy Journal.