Final Abstract

Final Report Approved on January 21, 2025

M.L. 2021 Project Abstract

For the Period Ending June 30, 2024

Project Title: Agrivoltaics to Improve the Environment and Farm Resiliency

Project Manager: Bradley Heins

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Website: https://wcroc.cfans.umn.edu/

Funding Source:

Fiscal Year:

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 07c

Appropriation Amount: $646,000

Amount Spent: $646,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

Agrivoltaics research at WCROC improved Minnesota's natural resources by integrating solar energy with livestock farming, reducing greenhouse gas emissions, enhancing land use efficiency, and improving cattle welfare. This project demonstrated sustainable forage growth under solar panels and educated farmers statewide, advancing environmental conservation and farm resiliency.

Overall Project Outcome and Results

The University of Minnesota West Central Research and Outreach Center (WCROC) launched the Agrivoltaics Project to address the growing need for sustainable energy solutions that do not compete with agricultural production. Traditionally, solar farms take up valuable farmland, creating a conflict between renewable energy development and food production. This project explored how solar panels and livestock farming can coexist, providing benefits to both energy production and agriculture. The project designed and tested innovative solar systems that provide shade and shelter for dairy cattle during the summer and act as windbreaks in the winter. Additionally, researchers studied how different forage crops grow under solar panels, combining renewable energy production with livestock feed growth. A portable solar shade power station, powered by solar panels and an electric tractor, was developed and deployed to

support cattle welfare and farm energy needs. The primary outcomes and accomplishments were: 1) Successfully grew perennial forages under solar panels, with grass and legume combinations yielding the highest quality feed, 2) Increased forage biomass at 30kW solar sites (8,730 kg/ha) compared to control sites (8,256 kg/ha), 3) Reduced forage production at 50kW fully shaded sites (4,241 kg/ha), highlighting optimal solar design for balance between shade and forage growth, 4) Demonstrated that solar arrays improved cattle welfare by providing shade in summer and wind protection in winter, reducing heat stress and exposure to cold, 5) Showcased the solar shade system and electric tractor to over 2,500 farmers, industry representatives, and policymakers at events such as FarmFest and the Midwest Farm Energy Conference, and 6) Disseminated research findings through presentations at national and international conferences (see Attachments), reaching global audiences and policymakers.

Project Results Use and Dissemination

The Agrivoltaics Project's findings were shared widely through workshops, conferences, and public demonstrations. Over 2,500 farmers, industry professionals, and policymakers engaged with the project at events like FarmFest and the Midwest Farm Energy Conference. Presentations at national and international conferences expanded outreach globally. Educational materials, research reports, and best practices were made available through WCROC's website and University of Minnesota Extension. These resources provide practical guidance for integrating solar energy and agriculture. See Attachments for Research Reports and Publications, Photos of Solar Shade Power Station and Electric Tractor, Conference Presentations and Outreach Materials.

Environment and Natural Resources Trust Fund

M.L. 2021 Approved Final Report

General Information

Date: January 21, 2025

ID Number: 2021-191

Staff Lead: Mike Campana

Project Title: Agrivoltaics to Improve the Environment and Farm Resiliency

Project Budget: $646,000

Project Manager Information

Name: Bradley Heins

Organization: U of MN - WCROC

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Project Reporting

Final Report Approved: January 21, 2025

Reporting Status: Project Completed

Date of Last Action: January 21, 2025

Project Completion: June 30, 2024

Legal Information

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 07c

Appropriation Language: $646,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, West Central Research and Outreach Center, Morris, to model and evaluate alternative solar energy system designs to maximize energy production while providing other benefits to cattle and farmers.

Appropriation End Date: June 30, 2024

Narrative

Project Summary: The project team at the WCROC will model and evaluate alternative solar system designs that will maximize energy production as well as provide maximal benefits to cattle and farmers .

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Livestock production is based on capturing energy from the sun through photosynthesis by crops that are fed to livestock. Solar power is based on capturing energy from the sun by photovoltaic conversion to electricity. The proposed project will determine resilient strategies to integrate solar technology and livestock production systems in the United States. Through past investments and institutional experience in renewable energy and dairy production research, the University of Minnesota West Central Research and Outreach Center (WCROC) has a globally unique opportunity to lead a new green revolution - a revolution that greens energy currently consumed within agricultural industries. The WCROC has a 10-year strategic plan to reduce fossil energy consumption and the carbon footprint within dairy production systems. This collaborative project will build on renewable energy and solar technology activities of the project investigators. This proposal will leverage current efforts by further integrating solar technology and livestock production strategies for agricultural producers.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

Agrivoltaics (co-location of solar and agriculture) is a relatively new idea in which agricultural systems are combined with use of solar systems to maximize land use. Some potential concurrent land uses include pollinator habitats, gardens, and cropping systems using the same land as a solar array. The proposed project will determine resilient strategies to integrate solar technology and livestock productions systems in the United States. Specifically, this project will provide new frameworks that will develop and model innovative structural designs for a combination solar shade for pastured livestock during the summer and windbreaks/ snow fence for cattle during winter. We will also evaluate potential for solar arrays to produce electricity and serve as field windbreaks on lands that are marginal for livestock production. We will model and test novel use of tracking systems to optimize solar energy potential. The team will utilize a solar array in a pasture to evaluate its potential to shade and cool cows during summer and serve as a wind break during cold winter months to protect cattle housed outdoors all with the objective of improving welfare of cattle. The project will involve testing these new strategies to assess results and make recommendations to farmers.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

The team will leverage current research by testing agrivoltaic systems and provide consumers with an evaluation of solar technologies. By providing information on solar technologies to the public, we will help improve the image of solar technologies to protect and preserve the state's natural resources that will enable Minnesota to meet greenhouse gas emissions and other current and future environmental regulatory requirements. Furthermore, demonstrating concurrent use of land for solar and livestock production, farmers and consumers will not view solar production as a competitor with food production for use of limited land.

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Activities and Milestones

Activity 1: Design solar systems for co-location of livestock and agriculture

Activity Budget: $391,000

Activity Description:
A solar photovoltaic system will be designed that will be moved around the pasture. The system will not be stationary. The system will be built with an innovative design that will include a portable solar system that will be pulled by an electric tractor charged from the solar panels. The solar system will also include battery storage for charging of equipment and for power usage for irrigation and cow cooling methods. The system would allow for battery storage to be powered from solar panels for the use of irrigation of pastures, cow cooling, and water pumping for farms. The system will allow longer term studies during the winter and summer and allow for more diverse solar technologies that will allow for cow cooling in the summer and for windbreaks during the winter. The portable solar system will be installed in a pasture or field or along marginal land at the WCROC. This project will provide new frameworks that will develop and model innovative structural designs for a combination solar shade for pastured livestock during the summer and windbreaks/ snow fences for cattle during winter. A pre-design analysis will describe novel use of tracking systems to optimize solar energy potential.

Activity Milestones:

Description	Approximate Completion Date
Install energy meters and record energy consumption data	June 30, 2022
Install tracking photovoltaic solar in pasture and field with electric tractor	June 30, 2022
Model and test novel use of tracking systems to optimize solar energy potential	June 30, 2023

Activity 2: We will evaluate the potential of solar systems for agronomic conditions and cattle housed outdoors

Activity Budget: $242,000

Activity Description:
Solar arrays in pasture or on farmland represents an area to integrate energy production with feed production for livestock, as well as ecological restoration and the sustained conservation of valuable farmland. Our project will address plant growth potential under the same solar panels for feed production that will eventually be consumed by livestock. We will investigate and research forages and crops for use as feed for livestock (12 species) that can be grown under solar arrays. Modeling will determine land needed for solar arrays while allowing for continued crop and forage production and characterize the photosynthetic potential of crops grown under solar arrays. We will investigate various agronomic crops to include in a solar system. Spectral analysis, soil moisture, water usage, and biomass productivity will be determined for the solar system designs that will be evaluated. The direct and indirect effects of solar systems on micro-climatic factors and plant-soil interactions will also be modeled and tested. The team will utilize a solar array in a pasture to evaluate its potential to shade and cool cows thus improving their welfare and serve as a wind break during cold winter months to protect cattle housed outdoors.

Activity Milestones:

Description	Approximate Completion Date
Evaluate forages and crops for use as feed for livestock under solar panels	June 30, 2022
Complete designs of clean energy systems for field testing at the WCROC	June 30, 2022
Investigate various agronomic crops to include in a solar system	June 30, 2023
Utilize the solar production system to evaluate long-term shade potential of cows	June 30, 2023

Evaluate economic and ecological benefits of co-locating solar installations and agriculture	June 30, 2023

Activity 3: Educate consumers, industry representatives, farmers and the general public about solar energy technologies.

Activity Budget: $13,000

Activity Description:

The most effective way to educate farmers and consumers to adopt new technologies is to demonstrate improved solar systems. The results from all activities will be used to demonstrate the potential of the co-location of the agrivoltaic system. The knowledge and information generated will be disseminated to agricultural producers, energy professionals, students, government officials, and other stakeholders through Extension websites, social media, and field days hosted at the WCROC. The WCROC also hosts a Midwest Farm Energy Conference every 2 years in Morris, Minnesota where strategic information is presented to farmers and industry representatives. Through this project we will develop a "Best Management Practices for Integrating Solar and Agriculture on Farms" and disseminate through a dedicated web portal and University Extension. This will provide information to farmers and the solar industry well beyond the period of the grant funding.

Activity Milestones:

Description	Approximate Completion Date
Conduct energy workshops and webinars and present results at conferences	June 30, 2023
Host a tour and demonstration of the site during our Midwest Farm Energy Conference	June 30, 2023
Submit semi-annual reports and a comprehensive final report	June 30, 2024

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Researcher 3 - Technician - TBD	University of Minnesota WCROC	Data collection, system testing, data collection and management	Yes
PhD Graduate Research Assistant - TBD	University of Minnesota WCROC	Assist with all aspects of the project in data collection, monitoring and analysis.	Yes
Lee Johnston	University of Minnesota WCROC	Dr. Lee Johnston, U of MN Swine Scientist, will be co-investigator and manage the activities and outreach within his respected specialty. Dr. Johnston has previous experience with on-farm monitoring of energy use funded by LCCMR.	No
Eric Buchanan	University of Minnesota WCROC	Eric Buchanan, WCROC Renewable Energy Scientist, will be assist in the design, installation, testing, and control strategies of the solar technologies. He will also assist with the outreach and dissemination of results.	Yes

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
The most effective way to educate and motivate livestock producers to adopt new technologies is to demonstrate improved profitability with the incorporation of solar energy into Minnesota dairy farms. The results from Activity 1 ,2, and 3 will be used to demonstrate the potential of the Solar PV system for Minnesota farms. The research and outreach center will be used as the demonstration site to showcase the opportunities for solar energy for farms, as well as generate new opportunities for the 5,000+ Minnesota dairy producers to utilize a solar energy to reduce the environmental footprint of their farm. These activities are well within the capabilities of the WRCOC and the University of Minnesota. The Environment and Natural Resources Trust Fund will be acknowledged with the trust fund logo on all presentations at conferences and workshops. In any printed material or electronic media we will utilize the logo and will acknowledge the ENTRF per the Acknowledgment Guidelines posted on the LCCMR website.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
The WCROC has a 10-year strategic plan to reduce fossil energy consumption and the carbon footprint within dairy production systems. This collaborative project will build on renewable energy and solar technology activities of the project investigators. Previous funding has been received through the ENRTF fund to measure energy consumption within the WCROC dairy and test clean thermal energy systems. This proposed project will facilitate and demonstrate the need for co-location of solar photovoltaic and agriculture. Additional long-term funding will be sought to conduct research with alternatives to fossil energy within all agricultural crop and livestock enterprises.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Utilization of Dairy Farm Wastewater for Sustainable Production	M.L. 2016, Chp. 186, Sec. 2, Subd. 07d	$475,000
Generation, Storage, and Utilization of Solar Energy	M.L. 2017, Chp. 96, Sec. 2, Subd. 07c	$500,000

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Farm Animal Attendant		Farm management to assist with labor of project, i.e. fencing, moving cattle			31.8%	0.3		$5,000	-	-
Researcher 5		Engineering Technician to help with system design and placement and management			31.8%	0.4		$20,000	-	-
Researcher 3		Technician for data collection, system testing, data collection and management			31.8%	2		$108,000	-	-
PhD Graduate Research Assistant		Data collection, monitoring and analysis			19.9%	2.5		$125,000	-	-
Visiting Scholar		The Scholar will collect data, evaluate solar shade of dairy cattle, and evaluate technolgies for solar grazing of cattle.			0%	0.3		$12,000	-	-
							Sub Total	**$270,000**	**$270,000**	**-**
Contracts and Services										
AKF Engineering (or equivalent firm)	Professional or Technical Service Contract	Modeling, Pre-design, Design, Commissioning, and Control Optimization Engineering Professional Services Working with C Lock Inc for design and solar pasture systems.				0.2		$5,000	$5,000	-
Utility Engineering Study	Professional or Technical Service Contract	To evaluate the engineering designs of alternative and tracking solar systems for livestock and forages co-location. Working with C Lock Inc for design and solar pasture systems.				0.2		$5,000	$5,000	-
C Lock Inc	Professional or Technical Service Contract	Installation of solar and Agrivoltaic Solar Trailer and component system				0.2		$15,000	$15,000	-
Forage Sample and Analysis	Professional or Technical	Analysis of forage and crop quality for crops and forages growing under photovoltaic systems.				0.6		$12,000	$12,000	-

	Service Contract									
WCROC Agronomy	Internal services or fees (uncommon)	Support for forage and crop testing with solar installation. This is for WCROC agronomy for services that include planting forages and crops, and harvesting of plants and crops, as well as some seeds. This is internal to the U of MN WCROC.				0.3		$7,000	$7,000	-
							Sub Total	**$44,000**	**$44,000**	**-**
Equipment, Tools, and Supplies										
	Equipment	Tracking Systems	Supplies for Evaluating Tracking Systems for Solar installations					$50,000	$50,000	-
	Tools and Supplies	Fencing Supplies	This will require purchasing fiberglass fence posts, insulators, poly wire and additional fence energizers.					$4,000	$4,000	-
	Tools and Supplies	Energy Meters	Meters for Dairy Facilities to Monitor Solar Installation and Agrivoltaic Voltage Systems					$5,000	$5,000	-
	Tools and Supplies	Field, Lab, and Feed Supplies	All objectives will require supplies that include: plot markers, sample bags, laboratory reagents, assays, and other supplies. The sampling supplies include milk sample tubes, gloves, protective clothing and a freezer. Seeds for cropping system objectives will also be needed for studies.					$10,000	$10,000	-
							Sub Total	**$69,000**	**$69,000**	**-**
Capital Expenditures										
		Solar System with Tracking System and Battery and Electric Tractor	Solar System and Foundation for Solar for Crops and Cows	X				$250,000	$250,000	-

			and Tracking System and Electric Tractor							
							Sub Total	**$250,000**	**$250,000**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Conference Registration Miles/ Meals/ Lodging	Travel	Travel, Lodging and meals for WCROC project team at Minnesota Workshops These expenses will be to participate in formal presentation of project findings at workshops and seminars within Minnesota.	X				$5,000	$5,000	-
							Sub Total	**$5,000**	**$5,000**	**-**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										
	Printing	Extension Supplies and Printing	Printing for Extension Workshops, Field Days, and Printing					$5,000	$5,000	-
	Publication	Peer Reviewed Publications	Publication of research in Open Access Journals					$3,000	$3,000	-
							Sub Total	**$8,000**	**$8,000**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$646,000**	**$646,000**	**-**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		Solar System with Tracking System and Battery and Electric Tractor	Captial Expenditure **Additional Explanation :** The system will be a permanent system at the WCROC and will be used throughout the life of the project and well beyond. We will continue to research novel solar systems with the project and will provide a demonstration site for educating farmers, legislators, and consumers about the benefits of solar technologies. The system would be used as leverage for other projects at the WCROC as well. The system would charge an electric tractor as part of the budget and would include battery storage for the tracking systems. Agrivoltaics pasture solar system and tracking from C Lock Inc. for use in pasture that is powered by soalr powered systems for collecting data from Dairy Cattle.
Travel In Minnesota	Conference Registration Miles/Meals/Lodging	Travel	These expenses will be to participate in formal presentation of project findings at workshops and seminars within Minnesota. These will be for either the Project investigator or the graduate student to present on the project. We feel it is very important to attend in state conferences and workshops to disseminate the project findings throughout the project.

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
In-Kind	In-Kind services from the University of Minnesota	The foregone federally negotiated ICR funding constitutes the University of Minnesota's cost share to the project. Additionally, PI and Co-I unpaid effort. ICR is 55%	Pending	$355,300	-	$355,300
			State Sub Total	**$355,300**	**-**	**$355,300**
Non-State						
			Non State Sub Total	**-**	**-**	**-**
			Funds Total	**$355,300**	**-**	**$355,300**

Attachments

Required Attachments

Visual Component

File: 171ea860-2ee.docx

Alternate Text for Visual Component

Our concept is to evaluate the applicability, implementation, and integration of solar systems for livestock and cropping production systems. We will develop and model innovative structural designs for a combination of livestock windbreaks and shading as well as field windbreaks and use of solar on marginal lands for livestock production. Novel use of tracking systems will also be modeled and tested to optimize solar energy potential. We will investigate forages and crops for use as feed ...

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
UMN Authorization of Proposal	877b08bb-1c3.pdf
Financial audit for UMN for Proposal	b8385822-72d.pdf
Solar Plans	2607834d-178.pdf
Research Addendum - Brad Heins	bd8324ce-dc2.docx
Background Check Certification Form	95a3e69b-73f.pdf
Midwest Farm Energy Conference Brochure	1b0740e4-292.pdf
Field Plots Planted under Solar Panels	0dd484a6-8ba.docx
Pictures of Planting under Solar Panels	c6ed4107-4f2.pdf
Pictures of Plots under Solar Panels	634709c4-074.docx
Throwing Shade is Solar Energy's New Superpower - Washington Post	b66bd30b-2a5.pdf
Sabrina Portner MS Thesis	9c5d86be-0d0.pdf
Agrivoltaics Conference 2023 Paper	e682935c-e83.pdf
Progressive Dairy Article Agrivoltaics	cbf14d5a-271.pdf
Agrivoltaics Conferen Paper for 2024	ca8171d9-cb7.pdf
Agrivoltaics - Dairy Star	c70345ae-848.pdf
ASGA Presentation June 2024	ba9b8e12-df5.pdf
ASGA Presentation June 2024	15e47c62-79e.pdf
ASGA Presentation June 2024	e05d90c4-ea6.pdf
Heins - Rutgers presentation March 2024	2d53ecfa-83c.pdf
Heins - Solar Farm Summit July 2024	d8d5b894-415.pdf
Heins - World Agrivoltaics Presentation June 2024	383d9cff-8cc.pdf
Solar Shade Photos	d6539110-9e9.pptx
Solar Shade Power Station Photos	31a3c385-d49.pptx
Evaluation of solar photovoltaic systems to shade cows in a pasture-based dairy herd	b3480fd5-1c6.pdf

Media Links

Title	Link
Midwest Farm Energy Conference	https://wcroc.cfans.umn.edu/events/mfec-2022
Could solar panels be integrated into farms instead of taking acreage out of commission?	https://wcroc.cfans.umn.edu/news/integrating-solar-farms
MPR News article	https://www.mprnews.org/story/2023/11/07/farming-and-solar-landsharing-could-be-key-to-clean-energy-future

Bloomberg and Washington Post	https://www.bloomberg.com/opinion/articles/2022-10-02/solar-energy-s-new-superpower-is-throwing-shade
AgriVoltaics Conference Proceedings	https://www.tib-op.org/ojs/index.php/agripv/article/view/979
WCROC Agrivoltaics	https://wcroc.cfans.umn.edu/research/dairy/agrivoltaics
Raising livestock and crops under solar panels	https://extension.umn.edu/livestock-operations/what-are-agrivoltaics

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

We have reduced the budget and reduced scope of the project. The main main objectives of the project are still in place, we have removed some of the detailed information that we were planning on doing to reduce the scope because of the budget reduction. Thank you for the comments on the budget and narrative. Also, thank you for helping with the research addendum. We have updated the workplan based on suggestions and have uploaded the documents in the attachment section. We have also changed the budget and clarified as suggested.
On 2/23/22. Acitivty 1 description, Milestones,and more detail on budget expenses for Activity 1 was Amended per request.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

Yes

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Amendment Request	• Budget - Personnel	I have moved money from undergraduate workers to an undergraduate visiting scholar from the Netherlands. The student will will evaluate solar shading and grazing technolgies for the summer of 2023 at the the WCROC. The project will not change in scope and this is part of their thesis requirements to work on projects and write a thesis.	March 27, 2023	Yes	April 11, 2023
2	Amendment Request	• Budget - Professional / Technical Contracts • Budget - Capital, Equipment, Tools, and Supplies	We have added more details on the agrivoltaics pasture system that will be used as well as adding that we will be working with C-Lock Inc. Engineering for design and install of Agrivoltaic Pasture systems for collecting data on dairy cattle with a portable Agrivoltaics system in the pasture.	August 29, 2023	Yes	September 12, 2023

Status Update Reporting

Final Status Update August 14, 2024

Date Submitted: January 12, 2025

Date Approved: January 13, 2025

Overall Update

We have completed the project with growing forages under solar panels, as well as deploying our solar shade power station for grazing dairy cattle. We have monitored performance usage of the electric tractor that is used for the solar shade system. Periennial forages have proven to grow very well under solar panels and combinations of grasses and legumes produce the most forage biomass with the highest quality for grazing dairy cattle under solar panels. Our research has been shared with farmers and industry professionals across Minnesota and other states in the Upper Midwest. We have showcased our research to others all over the United States as well and the world. Many people are contacting our research center for guidance and more information on Agrivoltaics because of this project. This project has thrust our research center into the premiere Agrivoltaics research center with dairy cattle. All activies have been completed.

Activity 1

We have completed the Solar Shade Power Station with portable solar shade technology and battery storage. We also also monitoring the energy usage from this system, as well as the electric tractor. We have deployed the solar shade system and have showcased this at Midwest Farm Energy Conference and FarmFest where many legislators and the public were very interested in seeing our portable shade system and electric tractor. Pictures are uploaded to Attachments. We completed modeling with PV Watts and the System Advisor Model from NREL on designing our solar shade power station. We designed a tracking system as well as a fixed tilt system in designing. Based on the modeling results of the alternative systems, we designed the system to have a flat top panel. However, the system can also be modified to be at 35 degrees to track the sun. The modeling suggested that a flat topped system would not lose any energy efficiency and would produce similar electricity for storage as a fixed tilt system.
(This activity marked as complete as of this status update)

Activity 2

We completed the analysis of forages under solar panels. We analyzed over 450 forage and crop samples for the 2 years of the study. The results indicated that forages grown under solar panels produced more overall total biomass at the 30kW (8730 kg/ha) solar sites compared to a control site (8256 kg/ha). The 50 KW site with 100% shade produced the least amount of forage biomass (4,241 kg/ha). Forage biomass and nutrient values varied based on the solar array design and amount of sun exposure. The highest quality forages were the mixes of meadow fescue, orgachardgrass and red clover or alafalfa. The sorghum sudangrass had the highest biomass total. Our study indicates that agrivoltaics may provide an acceptable method of heat abatement to pastured dairy cows, as well as generating electrical energy for farmers, thus reducing the carbon footprint of the dairy operation. Futhermore, numerous forages can be grown under solar panels without sacraficing forage quality and forage biomass production, except for those crops in full shade.
(This activity marked as complete as of this status update)

Activity 3

We have hosted many people at the WCROC that have wanted to learn more about our agrivoltaics work. We spoke at the Solar Farm Summit and the World Agrivoltaics Conference and exhibiited at FarmFest in August 2024 and the Midwest Farm Energy Conference. We have had over 2,500 farmers and industry representatives enquire about our Agrivoltaics project. We also had may tour groups here in Morris to view our Agrivoltaics systems and people were able to observe the growing of crops under solar systems and learn about the new designs for solar systems. Legislators have also inquired about our Agrivoltaics work and he have informed and educated them about Agrivoltaics in Minnesota.

Presentations that were presented at conference and seminars are in the attachments and are from ASGA, Rutgers, World Agrivoltaics Conference, Solar Farm Summit 2024. Numerous articles were printer for The Dairy Star as well as Progressive Dairy. Sabrina Portner has published her MS Thesis and defended in 2023 with the University of Minnesota. Lastly, Photos of the Solar Shade Power Station and Electric Tractor are uploaded to attachments.
(This activity marked as complete as of this status update)

Dissemination
We have disseminated results of this Agrivoltaics project to many stakeholders over Minnesota as well as the United States. This project is know all over the world and many come to the University of Minnesota for answers on grazing cattle with solar, as well as growing forages under solar panels. We have presesented this research all over the USA in the last 6 months. We have presented at the World Agrivoltaics Conference in Denver, the Solar Farm Summit in Chicago, as well as have presented this work to many farmers and industry representatives across Minnesota. Within Minnesota, we hosted an exhibit at Farmfest 2024 in Redwood Falls in June 2024 where we showcased our project and solar work at the WCROC Midwest Farm Energy Conference. We continue to develp materials to disseminate the results of our research to the public. We have published work in Agrivoltaics conference proceedings. https://www.tib-op.org/ojs/index.php/agripv/article/view/979 and https://pubs.aip.org/aip/acp/article/2635/1/060001/2830634/Agrivoltaics-to-shade-cows-in-a-pasture-based. Our published work on shading of dairy cattle under solar panels can be found at https://doi.org/10.3168/jds.2020-18821

Status Update Reporting

Status Update December 1, 2023

Date Submitted: February 8, 2024

Date Approved: February 12, 2024

Overall Update

We have finished the second year of planting and harvesting forages underneath different solar arrays at the WCROC dairy and pastures. Overall, we have found that Agrivoltaics site prevent evaporation of moisture during droughts and grass and forage growth is much better under solar panels compared to open pasture. Orchardgrass and Meadow Fescure grasses tend to have the best grass growth under solar arrays. We have designed and are contructing the portable agrivoltaic system and are working with companies on deployment of Agrivoltaics systems in pasture at the WCROC. The electric tractor will be available to us in December 2023. We have presented our research to farmers and industry professions in Minnesota and other states in the Upper Midwest. We are planning for our Midwest Farm Energy Conference in June 2024 to showcase our Agrivoltaics project. All project activities will be completed by June 2024.

Activity 1

We have developed concept design of our Portable Solar Shade system within the pasture. We have begun manufacturing the solar shade system and it will be deployed during the spring of 2024 for use with cows. This system will revolutionize agrivoltaics that might not have to be connected the the grid for power. The electric tractor and GPS guidance system arrived December 20, 2023. We have been working with 2 companies in design with our agrivoltaic system and electric tractor. We will be tested and gathering data over the winter time on performance before deployment. There were some delays in the initial stages with manufacturing of the portable solar system. As of February 1, 2024, the solar system is almost completed and will be ready for deployment early this spring on pasture for the dairy. The portable system will deployed and we will be able to complete all of the activies by June 2024.

Activity 2

We have completed a second growing year of forages under solar panels. The growing season was from May 2023 to October 2023. We are currently analyzing forage quality and biomass of over 300 forage samples collected. Early results indicate, forages grown under solar panels produced less biomass at the 30kW (564 kg/ha) and 50kW (446 kg/ha) solar sites compared to a control site (1,100 kg/ha). Forage biomass and nutrient values varied based on the solar array design and amount of sun exposure. Although less biomass was produced in the agrivoltaic sites compared to the control, forages were of high quality based on similar or higher crude protein, fiber content and digestibility, and mineral levels of the forages in the 30kW and 50kW sites.

Based on the results of this study, cows may have sacrificed grazing time to stand in the protection of the shade. Our study indicates that agrivoltaics may provide an acceptable method of heat abatement to pastured dairy cows, as well as generating electrical energy for farmers, thus reducing the carbon footprint of the dairy operation.

Activity 3

We have had some field days at the WCROC that have showcased our agrivoltaics work. We spoke at the Minnesota Organic Conference and exhibiited some display and booths at FarmFest in August 2023 that showcased our Agrivoltaics work. We have had over 500 farmers and industry representatives enquire about our Agrivoltaics project. We presented at the AgriVoltaics Conference in 2023 virtually to South Korea to researchers all around the world. We also had tours of our Agrivoltaics systems were people were able to observe the growing of crops under solar systems and learn about the new designs for solar systems. Legislators have also inquired about our Agrivoltaics work and he have informed and educated them about Agrivoltaics in Minnesota.

Dissemination

We have been able to disseminate results of the Agrivoltaics project to industry stakeholders, farmers, to people all over Minnesota as well as the United States. We have presented at Agrivoltaics conference in Minnesota and around the world. Many people around the world know of our Agrivoltaics work. We have also worked with undergraduates from Harvard University on Agrivoltaics and how to develop agrivoltaics in the United States and Europe. We presented to the Agrivoltaics 2023 conference in South Korea. Within Minnesota, we hosted an exhibit at Farmfest 2023 in Redwood Falls in August 2023 where we showcased our project and solar work. We have also been showcased in MPR News and the StarTribune in Minnesota. We continue to develp materials to disseminate the results of our research to the public. A graduate student defended her MS Thesis on Agrivoltaics in May 2023 and has started with University of Minnesota Extension working on solar energy.

Status Update Reporting

Status Update June 1, 2023

Date Submitted: June 8, 2023

Date Approved: June 14, 2023

Overall Update

We have developed concept designs for agrivoltaics that will focus on solar energy and livestockhose o systems. We will manufacutre those and finish them in June 2023 and deploy them during the summer of 2023. We have completed 1 year of growing forage and crops under solar panels and we have planted a second year of crops during May 2023. We have also presented at the Minnesota Organic Confernce and the International Agrivoltaics 2023 confernece and other online venues aorund the USA on our research with Agrivoltaics. A graduate student successfully defended her Master's thesis in May 2023 and has been employed with Minnesota Farmers Union and will work with farmers and be involved in Agrivoltaics with that farmer organizion.

Activity 1

We have developed concept design of our Portable Solar Shade system within the pasture, and are currently in the manufacturing stage and it will be complete in June 2023.The system will have solar panels that will track with the sun and will be able to fold and follow the sun. This system will be deployed for testing at the WCROC in the summer of 2023. We will be showcasing the portable solar shade system at FarmFest in Redwood Falls, MN in August 2023. The Electric Tractor should arrive in September 2023.

Activity 2

Forage crops grown underneath ground-mounted photovoltaic systems (PV) may provide a feed source for livestock production. The objective was to evaluate forage biomass and nutritive value of grasses and legumes grown under different PV conditions. Forages were planted underneath a 30-kilowatt PV site (30kW), a 50-kilowatt PV site (50kW) and one control site without PV (CON) in May 2022 with four replicates per site. Forages included alfalfa (Medicago sativa L.), field peas (Pisum sativum L.), meadow fescue (Festuca pratensis), orchardgrass (Dactylis glomerata L.), red clover (Trifolium pratense L.), brown midrib sorghumsudan grass (Sorghum bicolor [L.] Moench subsp. drummondii [Steud.]), white clover (Trifolium repens L.), and three mixtures (that included meadow fescue and orchardgrass) planted with either alfalfa, red clover, or white clover. Forages produced less biomass at the 30kW (563.7 kg/ha) and 50kW (446.4 kg/ha) solar sites compared to CON (1099.7 kg/ha). The forages at the 50kW site had greater crude protein n a dry matter basis (25.8%) than the forages at the 30kW (21.4%) and CON (20.9%) sites.This research suggests that forage biomass and nutritive values varied based on the solar array design due to the amount of sun.

Activity 3

We presented to farmers at the Minnesota Organic Conference in 2023, as well as at the International Agrivoltaics 2023 conference. We had over 500 people attend the conferences and attendees were farmers, solar industry representatives, policy makers, NGOs, and Legislators from Minnesota. At the International conference, there were researchers from all over the world and presented on our growing of forage crops under the solar panels. We have also had many tours of our Agrivoltaics systems were farmers and industry representatives were able to observe the growing of crops under solar systems and learn about the new designs for solar systems.

Dissemination

We have been able to disseminate results of the Agrivoltaics project to industry stakeholders, farmers, to people all over Minnesota as well as the United States. We have presented on our Project at the Minnesota Organic Conference in January 2023. We have presented our research to researchers and farmers at Universities in Germany and Sweden, as well as to agricultural law students at the University of North Dakota. We presented to the AgriVoltaics2023 - the

Fourth World Conference on Agrivoltaics that took place from April 12 to April 14 in Daegu, South Korea & online. We continue to develp materials to disseminate the results of our research to the public. We are planning on showcasing our portable Agrivoltaics solar system at FarmFest in August 2023.

Status Update Reporting

Status Update December 1, 2022

Date Submitted: December 7, 2022

Date Approved: December 20, 2022

Overall Update

We have developed concept designs for agrivoltaics that will focus on solar energy and livestock systems. We will manufacutre those over the next few months and will be deploying them on pasture in spring 2023. Our solar powered tractor will arrive in Spring 2023 as well for developing the agrivoltaics system. We have completed 1 year of growing forage and crops under solar panels and we have a second year of data in 2023. We had a Midwest Farm Energy Conference in June 2022 and had over 100 people attend the conference where we had an emphasis on Agrivoltaics. We have also presented to other online venues aorund the USA on our research with Agrivoltaics. This research was showcased in the Washington Post in September of 2022.

Activity 1

We have developed concept design of our Portable Solar Shade system within the pasture. We are designing the system that would add solar panels to an irrigation system as the base. This makes the system portable for a pasture system. The system will have solar panels that will track with the sun and will be able to fold and follow the sun. This system will be portable and will have a battery system. This system will revolutionize agrivoltaics that might not have to be connected the the grid for power. This system will be deployed for testing at the WCROC in the summer of 2023.

Activity 2

We have completed a first year of growing crops under solar systems and have evaluated them for their biomass and nutritional value potential when grown under varying levels of shade. We will completed a second year in 2023. During May of 2022, 7 forage species 3 mixes of grass and legume species, as well as 4 grain crops were planted underneath 2 different solar sites and 1 control site without shade. Forage crops included alfalfa, field peas, meadow fescue, orchard grass, red clover, BMR sorghum-sudan grass, white clover and 3 meadow fescue, orchard grass, and legume mixes with either alfalfa, red clover, or white clover. Grain crops included corn, oats, soybeans, and wheat. Sorghum-sudan grass had greater biomass ($P < 0.05$) than the other forage crops grown at the 30kW site. The 30kW solar array received greater sunlight than the 50kW solar array. For the 50kW solar array, sorghum-sudan grass had similar biomass compared to other forages. At the 30kw array, the grass and legume mixes had numerically greater biomass compared to forages grown in monoculture. Crop biomass varied based on the solar array design and amount of sun exposure.

Activity 3

We had the 2022 Midwest Farm Energy Conference at the WCROC in June 2022 where we had one day devoted to Agrivoltaics. We had over 100 people attend the conference and attendees were farmers, solar industry representatives, policy makers, NGOs, and Legislators from Minnesota. The day focused on the Agrivoltaics systems at the WCROC and introducing the Agrivoltaics project. We also had tours of our Agrivoltaics systems were people were able to observe the growing of crops under solar systems and learn about the new designs for solar systems.

Dissemination

We have been able to disseminate results of the Agrivoltaics project to industry stakeholders, farmers, to people all over Minnesota as well as the United States. We have presented our research at farmer meetings in Minnesota and have presented virtually to other grazing farmers interested in Agrivoltaics around the United States. We presented to the Amerian Solar Grazing Associations Teatime online event on our research of growing crops and forages under solar panels. We had a Bloomberg news reportor to the WCROC in September and they reported on our project in Bloomberg

News and the Washington Post. We have also been in the StarTribune in Minnesota. We continue to develp materials to disseminate the results of our research to the public.

Status Update Reporting

Status Update June 1, 2022

Date Submitted: June 1, 2022

Date Approved: July 6, 2022

Overall Update
We have started the pre-design drawings and concept of the solar systems for co-location of livestock and solar panels. We are been working with Monarch Tractor company to assist with design of system and tractor for solar panels. We have planted all crops underneath 4 solar systems used at the WCROC and crops are growing. We will continue to monitor during the summer of 2022. We are hosting the Midwest Farm Energy Conference in June 2022 where we will have tours of our solar installations and crops growing, as well as have seminars on agrivoltaics for livestock and will present the progress of the project as part of dissemination of the project.

Activity 1
We have started a pre-design fot he solar system and are acquiring the equipement to assemble the solar grazing system in the pasture. We are working with Monarch electric tractor company to design system and to implement the co-location of solar and livestock. We will be working alot of this during the next 6 months with implementation in early 2023.

Activity 2
We have planted agronomic crops under 4 solar systems utilized at the West Central Research and Outreach Center in Morris. Crops seeded include corn, soybeans, wheat, oats, alfalfa, field peas, meadow fescue, orchardgrass, red clover, white clover, sorghym sudangrass, and combination of periennial grass species. All crops will be monitored for grown, yield, and qualtiy during the summer of 2022. We are also workign with a farm near Olivia, MN that is growing corn and soybeans under solar panels and are working with them to set up a monitoring system and to record information on yield and growth of the crops.

Activity 3
We are hosting the Midwest Farm Energy Conference at the West Central Research and Outreach Center in June 2022. The conference will be June 15 and 16. We have devoted a full day, June 16, on sessions on the use of solar arrays for farms, also known as agrivoltaics. Sessions included will be "Exciting New World of Agrivoltaics: Combining Solar Energy with Agricultural Production", "Benefits of Agrivoltaics Across the Food-Energy-Water Nexus", "Solar Shading of Cows", and "Resources to Support the Growth of Co-located Solar and Sustainable Agriculture".

Dissemination
We are having tours and workshop demonstrations of Co-Location of Solary and Energy with our Midwest Farm Energy Conference. We will disseminate information to farmers, industry representatives, NGOs, and goverment personell at the conference.