Scalable Minimally Invasive Agrivoltaics

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FOUNDATIONAL AGRIVOLTAIC RESEARCH FOR MEGAWATT SCALE (FARMS)

Research Focus:
Integrated agriculture-energy impact studies

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Agrivoltaic Farming Group	Olivia, MN

Abstract

Corn and soybean farming use about two-thirds of the agricultural land in the US. To accelerate large scale adoption of agrivoltaics, best practices need to be developed that are compatible with traditional farming operations for corn and soybean. However, federally funded research has so far largely neglected agrivoltaics for commodity crops. This project will focus on photovoltaic (PV) system concepts that are "minimally invasive" to corn-soybean farming, thus laying the ground for large-scale adoption. Different from most other agrivoltaic projects that are conceived by academic researchers and located at specialized research farms, the proposed concept is "farmer-designed" by landowners with decades of farming experience. It will be located on an actual corn-soybean production farm in Olivia, MN, also known as the "Corn Capital", about two hours west of Minneapolis. The project will focus on sparse arrays of solar panels arranged on corn-soybean farming land in a manner that is compatible with current farming practices and does not negatively impact crop yield. This research will develop approaches that are broadly acceptable from a farmer's perspective. Studies will focus on the agronomic impact of combining PVs and crop growth on the same land including crop and soil health, electricity production, and the impact on traditional farming operations. Research will also engage with the local utility cooperative to identify business models that enable the scaling to megawatt levels. Furthermore, the project will engage diverse and underrepresented communities, and will explore how the scaling of this technology to megawatt levels broadly benefits and advances underserved groups and rural communities.

Proposed Technology

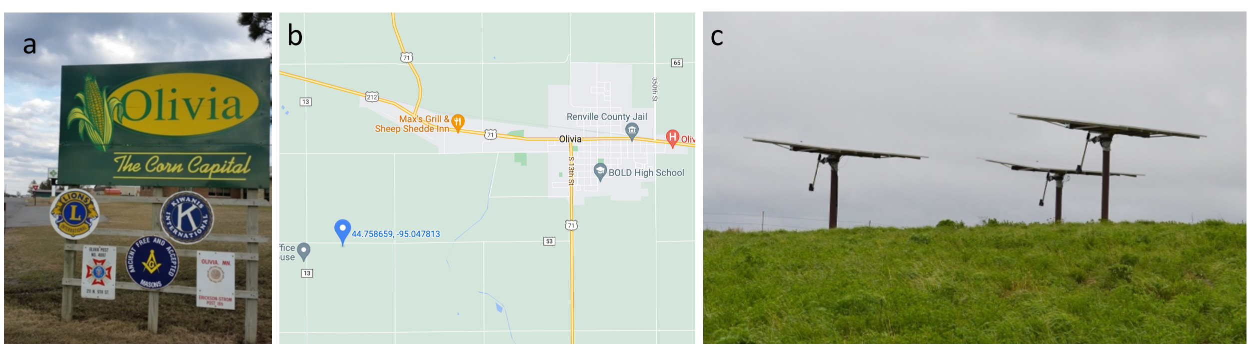

Figure 1: a) Sign greeting visitors of Olivia, MN, the Corn Capital; b) location of the Rauenhorst farm, the site of the proposed research; c) Solar arrays mounted on posts and trackers, similar to the arrays that will be used in this study. (Photo by the US Fish and Wildlife Service).

The proposed PV technology is based on an original concept developed by a group of farmers in Olivia, MN (Figure 1a)– Larry Rauenhorst, Roland Rauenhorst, John Baumgartner, and Parker Revier – who jointly have more than 120 years of experience in farming. The main principles of the proposed technology are to:

- install solar arrays on production farmed land (the Rauenhorst farm, Figure 1b) with corn-soybean crop growing underneath. This approach is unique compared to other agrivoltaic projects that have been developed at a research plot scale;
- install arrays on 12'-14' posts (similar to the example in Figure 1c) that will track the sun and allow for arrays to be oriented horizontally for farming equipment to pass underneath as required for regular farm operations;

- limit the overall shading of the arrays to 7.5%-20% to explore the amount of shading that is acceptable to maintain a good crop yield.

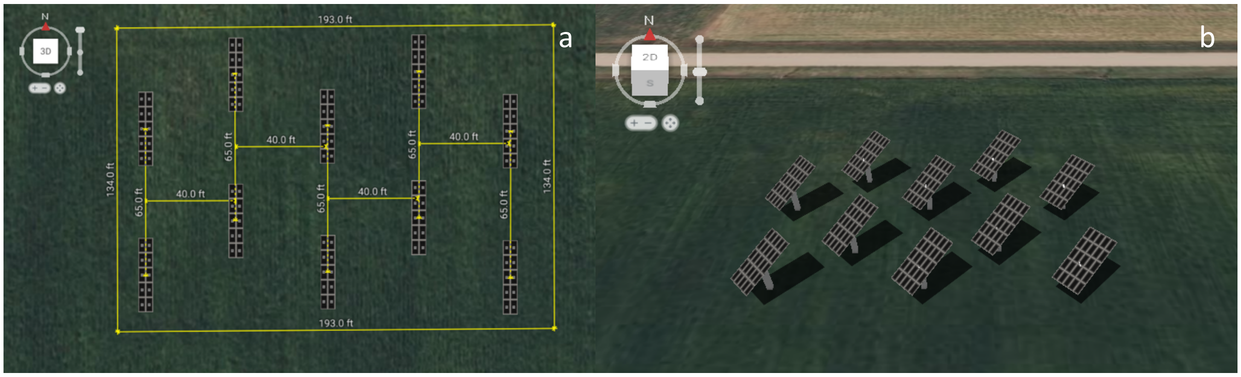

Figure 2: Preliminary layouts of sparse solar arrays on the Rauenhorst farm (layout in Aurora Solar). a) Top view of array with ~7.5% ground shading; b) Array with ~20% ground shading in the afternoon. The solar modules shown are generic modules with 400 W peak power and dimensions of 2m x 1m.

The project team comprises expertise in monitoring and analyzing the solar array performance, agronomic evaluation of the impact of the solar array on crop growth and yield, and techno-economic analysis of the integration of the array into the local power grid operated by Renville-Sibley Co-op Power.

Four solar arrays, each consisting of ten subarrays placed on 12'-14' poles and trackers, will be constructed at the North-East corner of the Rauenhorst farm, as shown in Figure 2. This location was chosen because of its high and uniform soil quality and its proximity to an electric utility substation. Each array will measure 193 ft in E-W direction and 134 ft in N-S direction and occupy a total area of 0.6 acres. Sufficient space between the arrays and the North end of the field will be reserved to allow space for farming equipment to turn and pass through the arrays in the N-S direction. Unshaded space between the arrays will serve as control for the experiments.

Each array will be equipped with meteorological and performance monitoring systems according to applicable codes and standards (National Electric Code, IEC 61724 "Photovoltaic System Performance Monitoring – Guidelines for Measurement, Data Exchange and Analysis", ASTM E1036 "Standard Test Methods for Electrical for Electrical Performance of Nonconcentrating Photovoltaic Modules and Arrays Using Reference cells"). Measurements will include AC and DC power generation, inverter status and error, global horizontal and plane-of-array irradiance, ambient and module backsheet temperatures, as well as wind speed.

An important question that this project will address is whether and to what degree the PV panels will affect the growth and yield of corn and soybean crops. To answer this question, we will measure the above- and below-canopy photosynthetically active radiation (PAR), and plant maximum growth, phenology, and yield. Soil moisture will be monitored at 6- and 12-inch depths, and weather conditions will be monitored under and outside of the PV panel shaded area. The experimental results of corn and soybean productivity for each of the arrays will be used as input to simulate corn and soybean productivity at other sites in the State of Minnesota.

The economics of the agrivoltaics in corn-soybean farming is multi-dimensional with principal dimensions being: (i) PV electricity generation, (ii) agricultural crop yield, (iii) project installation costs including grid interconnection, and, (iv) operation and maintenance costs. This intricate dependency will be studied by cost-benefit analysis based on data collected in this project using the projected costs and benefits of the system. PV electricity generation will be valued based on its retail economic value to the landowner and its modeled future economic and environmental value to the utility system using the National Renewable Energy Laboratory's Cambium Model. Project installation costs, and operation and maintenance costs will be based on observations collected from this project. Agricultural crop yields will be valued at market rates. Over the course of the project, different PV control strategies will be implemented, which will allow for assessment of the optimal control strategies to maximize the net benefits of the system under different decision criteria and pricing assumptions.

Data collected and analyzed from this project will result in a blueprint for integration of agrivoltaics with traditional corn-soybean farming. It will open up new pathways of how to quickly increase adoption of agrivoltaics on more than half of the agricultural cropland used in the U.S.

The proposed technology's target level of performance

The proposed project is based on four sets of solar arrays each creating a different amount of shading (7.5%, 11.4%, 15.2%, and 19%). Each of the four sets of arrays will consist of ten individual arrays placed on 12'-14' posts, covering an area of 0.6 acres each. As such, the project is estimated to establish a total power generation of ~280 kW. Work with the Renville-Sibley Power cooperative will examine scaling this project to the MW level.

The overall potential of the technology is immense. If solar arrays with 7.5% shading were built on ~60% of corn-soybean farming land (~166,000,000 acres in 2019[1]) the power generation capacity would be ~16,000 TWh/year, which is more than four times the annual electricity production of the US from all energy sources (~3,900 TWh/year) or about one half of the entire primary energy use of the US in 2021 (97.3 quadrillion BTUs or 30,000 TWh). Because of the inefficiencies involved in converting the energy stored in fossil fuels, 16,000 TWh/year of electricity may cover most of the energy needs of the US in a future, fully electrified economy. While this number is unlikely to be achieved soon, it demonstrates the enormous potential of agrivoltaics on corn-soybean fields without significantly reducing the agricultural yield.

Current state-of-the-art, key shortcomings, limitations, and challenges

Multiple studies have suggested that dual-use of agricultural land can lead to diversification and risk reduction for farmers,[2, 3] and to the creation of more than 100,000 jobs in rural communities.[4] However, to fully realize the potential of agrivoltaics, it is imperative to explore agrivoltaic strategies that are compatible with commodity crops such as corn and soybeans. To our knowledge, none of the agrivoltaic projects funded by DOE-EERE and USDA are addressing agrivoltaic installations in a corn-soybean farm environment. Moreover, the vast majority of agrivoltaic projects to date are being conducted on specialized research farms at the campuses of academic institutions. These environments are fundamentally different from real world farms; hence, concepts developed under such conditions often face hurdles with large-scale adoption in actual farming environments.

A potential challenge for agrivoltaics with corn-soybean farming is that corn, known as a shade-intolerant crop, might be negatively affected. A meta-analysis of 10 different experimental studies suggested that the corn crop yield decreases roughly linearly with the degree of shading with 50% shade leading to a ~50% reduction of crop yield.[5] However, the individual studies used in the meta-analysis addressed widely varying experimental approaches and were conducted in very diverse climatic conditions. It should be noted that none of the 10 studies were performed in the US, but rather in China, Japan, Korea, and Germany, where farming practices may be different. There were also notable exceptions that did not follow the general trend of the meta-analysis. Sekiyama and Nagashima studied corn growth under solar arrays that provided 20% and 49% shading.[6] While the arrays were mounted stationarily on stilts and shaded the crop only for part of the day, they reported a 4.9% increase of crop yield for light shading, and only 3.6% decrease of crop yield under heavy shading. Hyon Jo *et al.* found minimal reduction of corn forage yield under an array with 30% shading over a two year period.[7] The significant spread of yields with different amounts of shading reported in the meta-analysis[5] as well as the complete lack of data under US farming practices reinforces the urgent need for our proposed study.

Moreover, there may be some beneficial impacts to partially shading corn plants. Corn plants do not grow when the temperature exceeds 90°F, and the plants need cooler nights late in the growing season (August) to reach desired yields. Minnesota is seeing more days over 90°F and increased nighttime low temperatures in August due to climate change. Some shade may ameliorate these conditions.

Our proposed project will address the lack of agrivoltaics research in corn-soybean farms widely practiced in the US Heartland. While a National Science Foundation (NSF) funded Research Traineeship in Sustainable Food, Energy, and Water Systems at Purdue University nominally has plans that seem similar to our proposal, no data on corn farming have yet been reported. Moreover, our proposed concept of sparse agrivoltaic arrays is based on the insights and designs of practicing farmers with many decades of experience in corn-soybean farming. As such, our concept is likely to broadly appeal to the farming community running similar farm operations.

How the proposed technology will overcome the shortcomings, limitations, and challenges

As discussed previously, we expect our proposed project to yield a solution for agrivoltaics that is compatible with farming of commodity crops and demonstrated at scale in an actual production farm environment. We expect that such a demonstration will be more persuasive to other farmers than projects that are conducted in specialized research farms that use farming methods different from commodity farming.

The potential impact

This project will have several important impacts. The project will:

- demonstrate a farmer-designed minimally invasive approach to agrivoltaics in commodity crop farming, which will be broadly acceptable to farmers across the US,
- develop the scientific foundation of the impacts of agrivoltiac dual-use of land on the productivity of corn/soybean crops,
- develop agronomic models that will enable other farmers to evaluate the economic value of agrivoltaics on their land,
- collaborate with the local utility cooperative and evaluate business models that may involve utilities leasing dual-use land from farmers for agrivoltaic installations, enabling them to meet their renewable energy goals and providing a new income stream to farmers,

- contribute to the generation of solar energy jobs in rural farming communities, both for the installation and maintenance of solar installations, and
- provide solar technology trainees with exposure to the field of agrivoltaics through a collaboration with Renewable Energy Partners, a minority-owned solar developer and training provider (see Addendum).

The key technical risks/issues

Impact of Shading on Crop Yield: One of the main technical risks is that some of the arrays provide too much shading, such that crop yield would be depressed to unacceptable levels. This risk is a direct result of the current lack of knowledge that this project tries to remedy. If we determine larger amounts of shading to decrease crop yield, the team will make a decision as to whether to decommission and remove the arrays or modify them to lower shading levels. If even the smallest amount of shading here (7.5%) results in a disproportionate loss of crop income, which we feel is unlikely, all arrays may be removed by the end of the project.

Negative Impact from Farming Operations: While a strength of this project is that the concept is farmer-designed, there may still be unforeseen consequences of having the solar array in a regular production field. For instance, rocks may be kicked up by the farming equipment and damage the solar arrays; dust from farming operations may deposit on the solar panels and temporarily reduce PV production. If such problems are encountered, these observations in themselves will be valuable research results. We are confident that our team has the broad, inter-disciplinary expertise to address such problems as they arise.

The impact of EERE funding

Without EERE funding, the landowner plans to move ahead with the original plan to install a 40 kW array with 7.5% coverage. However, a research project that more broadly investigates the concept by using arrays with different amounts of shading and creates widely disseminated scientific data about crop yield and health, economic and environmental impact, integration with the local power distribution grid, as well as efforts to increase diversity, equity, and inclusion will only be possible with EERE funding.

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Addendum

Team members and expertise:

University of Minnesota Team:

Professor Uwe Kortshagen–Mechanical Engineering, University of Minnesota-Twin Cities (UMN-TC)–has worked on photovoltaic research for 15 years. He has directed research projects of over $45M, including several multi-investigator grants. He will direct the overall effort.

Eric Buchanan–UMN West Central Research and Outreach Center (WCROC), Morris, MN–is a renewable energy scientist. At WCROC, he has overseen the construction and instrumentation of three research solar arrays.

Professor Vivian Ferry–Chemical Engineering and Materials Science, UMN-TC–is an expert on modeling optical and thermal properties of photovoltaic devices.

Professor Gabriel Chan–Humphrey School of Public Affairs in Science, Technology, and Environmental Policy, UMN-TC. He is an expert in the economic impact of photovoltaics.

Professor Axel Garcia y Garcia–Agronomy and Plant Genetics, UMN-TC. His research focuses on improving Minnesota cropping systems, particularly corn-soybean, for productivity and profitability.

Beth Mercer-Taylor–Institute on the Environment, UMN-TC– is a sustainability education co-director. She will direct efforts on diversity, equity, and inclusion.

Renewable Energy Partners (REP) is a Black-owned and operated solar developer. REP also operates a training center that provides renewable energy job training to members of underserved communities. REP has experience with elevated solar structures, or solar canopies, in several different configurations, including two projects in active development this year. REP has also worked with major solar canopy system suppliers and has installed solar facilities in the service areas of Minnesota's electrical cooperatives. REP's services are performed by in-house personnel and strategic partnerships with electrical contractors, engineering firms, and other subcontractors as needed.

Agrivoltaic Farming Group (Olivia, MN):

Larry Rauenhorst–Farmer, Landowner–has a degree in Agricultural Engineering from the University of Minnesota. He has more than 37 years of experience farming commodity crops, including corn and soybean. The experimental work will be conducted on Mr. Rauenhorst's land, who will supervise the farming operations of this project.

Roland Rauenhorst–Farmer, Consultant, AS degree in Engineering from Willmar Community College; attended Mechanical Engineering program at North Dakota State University. Roland Rauenhorst has extensive experience as a farmer and as an engineer designing systems and components for numerous farming equipment companies.

John Baumgartner–Farmer, Consultant, B.S. Agronomy and Plant Genetics, University of Minnesota–is a former MN Assistant Commissioner of Agriculture and Midwest Area Director of the Agricultural Stabilization and Conservation Service, appointed by President George H. W. Bush. He founded several farming-related companies and is well connected with all farming stakeholder groups in the Midwest.

Parker Revier–Farmer, Consultant, B.A. Energy Technology, Creighton University 2017–is farming in Renville, Sibley, and Stevens County. He has experience in growing soybeans, corn, peas, and sweetcorn on rotation.

Prior Joint Work: As a whole, this team is a new collaboration. However, subsets of the team have a history of working together (Kortshagen, Ferry), (Mercer-Taylor, Chan, REP), (Olivia Team).

Access to Equipment: The University of Minnesota-Twin Cities is an R1 Research University. In FY2020, it ranked 13th among public universities in the US in terms of federal research funding, with total research expenditures of $1.04B. The research team will have ample access to equipment and facilities to conduct the proposed research.