Guidelines to Conduct Agrivoltaics Research in Wisconsin

Final Master’s Report

Submitted to the faculty
of the University of Wisconsin-Madison
in partial fulfillment of the requirements
of the degree of Masters of Science

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May 2024

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Acknowledgments

I would like to thank my advisor Dr. David Bart for the encouragement and guidance he has provided throughout my graduate studies. I am grateful for his support while I navigated my interests within the field of agroecology and while I found the project that excited me the most. I would like to thank Josh Arnold for working with me consistently throughout this project and Dr. Chris Kucharik for supporting my work as a part of my committee. I would like to thank Ian Aley for being an incredibly supportive supervisor, mentor, and friend, and for guiding me through balancing my responsibilities as a project assistant with the Office of Sustainability and as a graduate student.

I would like to thank my parents, Latha Karimpat Menon and Madhukumar Pooven Pillil, and my sister, Amrita Menon, for their unwavering support through all my academic and non-academic endeavors. Their constant support has been the backbone of all my successes so far.

I would like to thank my friends, both new and old, for encouraging me when things got uncertain or rough, and I would especially like to thank my partner, Shashank Shiva, for being the greatest pillar of support throughout my graduate school journey.

Finally, I would like to thank the University of Wisconsin-Madison and the Agroecology program for giving me the opportunity to pursue this degree. It has been an incredible learning experience both academically and professionally, and I am grateful for this chance to explore this new career path that I am joyous to be on.

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Introduction

Agrivoltaics is the practice of producing solar photovoltaic energy alongside agricultural practices on the same land. This approach presents a potential solution to address the challenge of limited land availability for renewable energy production as well as agriculture. In addition to yielding food and energy, agrivoltaic sites offer opportunities to enhance ecosystem services. Areas featuring native ecosystems within agrivoltaic setups can serve as natural buffers, mitigating water runoff, enhancing water quality, preventing soil erosion, and fostering pollinator habitats (Walston et al. 2022).

Nonetheless, numerous concerns exist regarding this practice, primarily stemming from the competition for sunlight between crops and solar panels, which may result in a trade-off between agricultural output and photovoltaic energy production. The solar panels used in agrivoltaic systems are typically taller than traditional ones to accommodate vegetation growth underneath, thereby increasing upfront costs for infrastructure and labor. Moreover, implementing efficient farming practices necessitates farming equipment and irrigation infrastructure, which can be both challenging and costly to integrate into a solar farm (Goldberg 2023).

Various studies have been conducted to address key concerns associated with agrivoltaics, such as the impact of solar panel shading on plant growth (Marrou et al. 2013) and the influence of vegetation on solar panel efficiency (Williams et al. 2023). However, much of this research has been conducted in European countries where agrivoltaics has been established for some time, or in Canada where solar energy production is well-developed.

Background

In 2019, the state of Wisconsin established a target to achieve 100% carbon-free electricity consumption by 2050, necessitating significant investment in renewable energy infrastructure, particularly solar farms. While imperative in combating climate change, these initiatives have faced considerable skepticism, notably from agricultural communities. Concerns revolve around the loss of farmland amidst population growth, safety issues associated with large solar farms near residential areas, and the alteration of rural and suburban aesthetics in Wisconsin (Kaeding 2022). Agrivoltaics emerges as a potential solution to mitigate the loss of agricultural land and preserve Wisconsin's visual appeal.

In the United States, agrivoltaic projects have been implemented in states like Colorado and Arizona, both states which have climates that are different from Wisconsin's. Consequently, there's a challenge in determining the suitability of agrivoltaic systems for Wisconsin's climate and cultural context. In early 2022, the University of Wisconsin-Madison’s Office of Sustainability collaborated with Alliant Energy - a public energy utility, and SunVest Solar to plan the establishment of a solar and agriculture research station within the University of Wisconsin-Madison’s Kegonsa Research facility to pioneer research efforts in agrivoltaics in Wisconsin.

UW-Madison Kegonsa Research Campus Solar

The Kegonsa Agrivoltaics Research station is a 15-acre solar farm in the Town of Dunn near Stoughton, Wisconsin and will produce approximately 2.25 MW of solar energy, enough to power about 450 Wisconsin homes. The solar arrays are set to be constructed early summer of 2024.

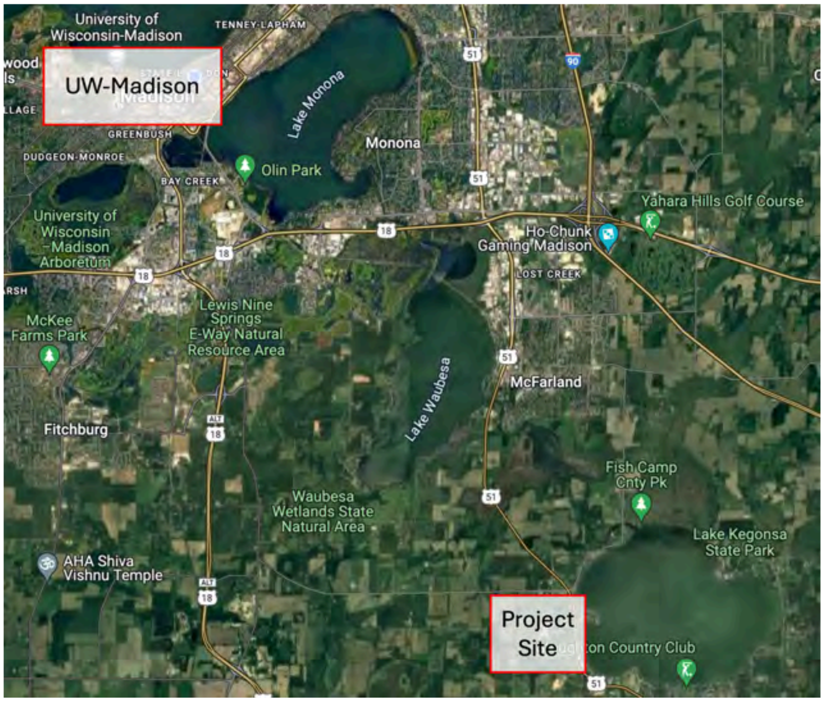


Figure 1. Project site location in relation to UW-Madison campus on Google Maps


Figure 2. Project Site on Google Maps

Design

The 15-acre site will house three different solar panel racking types; raised fixed-tilt solar panel racking, single-axis tracking panel racking, and the fixed-tilt solar panel racking systems. The entire site has been permitted for native pollinator planting and agricultural use.

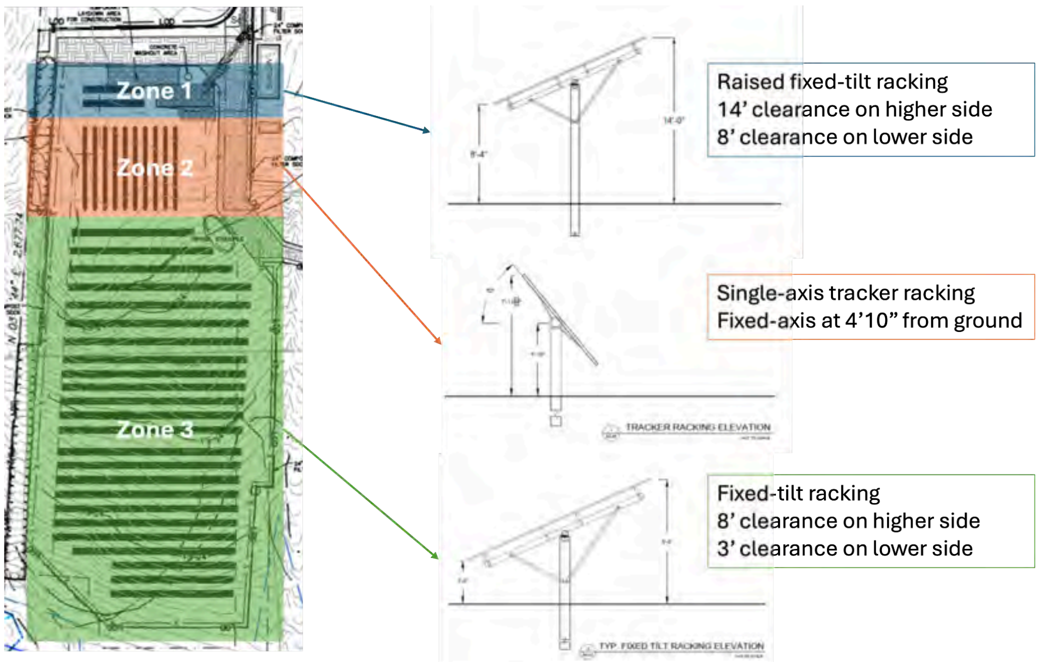


Figure 3. Racking zones within the agrivoltaics site

Purpose

Alliant Energy will oversee the construction, ownership, and maintenance of the facility. The renewable energy generated on-site will be integrated into Alliant Energy's distribution system. The UW-Madison Office of Sustainability will receive monthly lease payments, which are anticipated to be allocated towards sustainability initiatives. Faculty and students from the University of Wisconsin-Madison will utilize the facility for research and educational endeavors. One of the primary objectives of the site is to showcase the potential for successful implementation of agrivoltaic practices in Wisconsin.

Vegetation Management Plan

In October 2023, Alliant Energy shared the Vegetation Management Plan developed by Merjent, Inc., an environmental, restoration, and engineering firm. The plan details steps to prepare the site, develop, and install prescribed seed mixes. Other agrivoltaics sites in Wisconsin currently seed their land with native pollinator species and a similar strategy was prescribed for Kegonsa. The vegetation management plan currently only includes guidelines for native pollinator planting and maintenance and does not include methods to manage multiple agricultural research projects that are projected to take place on the site in the future.

Agroecology, Agrivoltaics, and Planetary Health

A fundamental aspect of agroecology involves safeguarding ecosystem services in agroecosystems, a departure from industrial farming approaches. The Kegonsa Agrivoltaics site offers a unique chance to harness an agroecosystem for energy generation while simultaneously fostering ecosystem services, facilitated by the presence of native pollinator species in close proximity to agricultural initiatives.

In the Spring of 2023, Victoria Salerno, a fellow graduate student, and I received the Planetary Health Research Award for our proposal to conduct pollinator monitoring on the site. Since planetary health is defined as the health of human civilization and the natural systems it depends on, this further helped focus the project efforts on protecting soil and water on the land, specifically during times when it is not in use. By focusing on soil, water, and pollinator protection, an agroecological perspective was incorporated into managing the site.

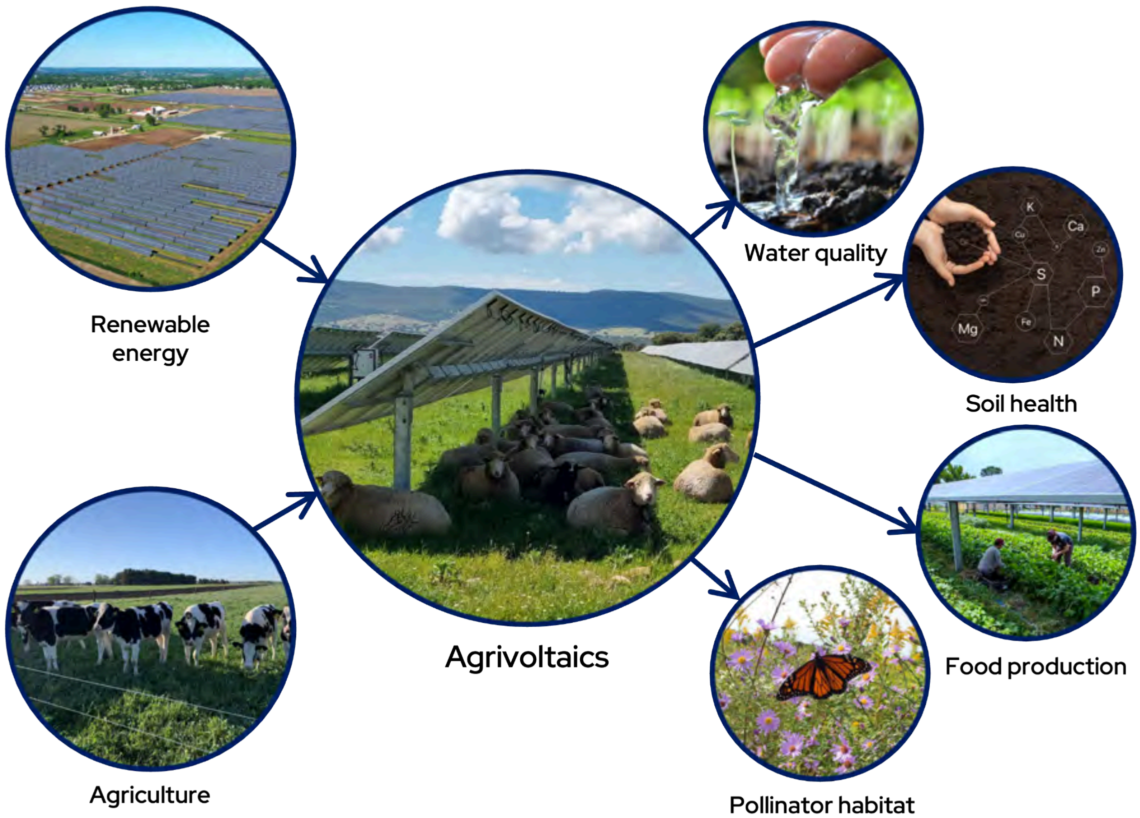


Figure 4. Schematic for Potential of Agrivoltaics

Project Overview

The Kegonsa Research station stands as Wisconsin's inaugural research facility solely devoted to agrivoltaics research. Presently, the vegetation management strategy focuses on introducing native pollinator species to the area. Given the station's objective to serve as a hub for agricultural exploration aimed at determining the feasibility of various agrivoltaics systems within Wisconsin's climate and culture, it is imperative to develop a comprehensive plan integrating research endeavors.

The goal of the project was to create guidelines to supplement the vegetation management plan that will serve to fulfill the goals of the Kegonsa agrivoltaics research station while taking steps to ensure the protection and monitoring of ecosystem services. After preliminary meetings and understanding the goals of the research site, I wanted to produce four documents that would be helpful for all the stakeholders to carry out research on the site. These are the deliverables of the project.

- Research Permit Guidelines
- Guidelines for Long-term Monitoring and Data Collection
- Transition Phase Methodology
- Future Crops for Planting

Methods

Meetings with Stakeholders

The Office of Sustainability organized periodic meetings with researchers and partnering energy utilities including Alliant Energy and Madison Gas and Electric to discuss the needs and goals of the site. Starting from October 2023, six meetings were held jointly among all groups involved and interested in the project. During the meetings, notes were taken on what goals were conflicting between groups, questions that participants had, and what elements were unclear to either party. There were several meetings to discuss the vegetation management plan, so this was a good time to note if there was any additional information that might be useful to provide to the participants to make research efforts a smoother process at the site.

Interviews with Researchers

After the initial meetings with stakeholders, research teams that either already had plans and funding to run projects on the site or were interested in doing so were interviewed. Although there were initial meetings with research groups where there was opportunity to have unstructured discussion, a semi-structured interview with prepared questions was planned for a final understanding of the research team's goals (see Appendix A). There was one final semi-structured interview conducted with each identified research team for a total of four interviews. These were conducted between December 2023 and March 2024.

The goal of the interviews was to understand the following aspects of the research projects:

- Purpose
- Timeline
- Description
- Required Equipment
- Perceived Challenges
- Desired Infrastructure
- Desired Support from the Office of Sustainability

To broaden the variety of research project teams interviewed, the selection was refined to include the following teams.

UW-Madison Extension Forage Crop Trials

Interviewees

Diane Mayerfeld - *Senior Outreach Specialist, UW-Madison Division of Extension*

Will Fulwider - *Regional Crops and Soils Educator, UW-Madison Division of Extension*

Native Pollinator Monitoring

Interviewees

Victoria Salerno - *Master's Student in Entomology and Agroecology*

James Crall - *Assistant Professor, Department of Entomology*

Soil Sensing and Monitoring at Kegonsa

Interviewee

Jingyi Huang - *Assistant Professor, Department of Soil Science*

Research Forward Agrivoltaics Project

Interviewee

Kyungdoe “Doe” Han - *Postdoctoral Research Associate, Department of Civil and Environmental Engineering*

Literature Review

Literature review was primarily focused on the three main topics to produce the final deliverables. The first phase was research on technical aspects of long-term monitoring including required instrumentation and systematic steps to carry out the process in an organized manner. The second phase was research on cost-effective and ecologically sound methods to protect land and water in periods of time when land is at rest. The third phase was research on crops for different purposes like food and medicine that had potential to grow in an agrivoltaics system considering limited availability of light and other resources like water availability. All literature review was conducted using academic search engines including Google Scholar and the UW-Madison library systems.

The Artificial Intelligence (AI) platform *scite.ai* was also utilized to identify academic sources. The advantage of using AI for literature review was the ability to combine studies to form connections between agriculture and solar energy production due to the limited resources currently available for agrivoltaics, specifically in the United States. References for all literature review is available in the references section of the report as well as for each individual document.

To help with research permit guidelines, existing agricultural research stations such as the Lakeshore Nature Preserve on UW-Madison campus and the Arlington research station's resources were consulted for inspiration.

Outcomes

Meetings with Stakeholders

The primary focus of the meetings with stakeholders was on the vegetation management plan provided by Alliant Energy and Merjent. The plan detailed steps for establishing native pollinator species, but questions arose regarding the integration of agricultural projects on the site. While the permit mentioned agricultural activities, the vegetation management plan did not address them, prompting the potential need to establish guidelines for transitioning between agricultural projects and for long-term monitoring of ecosystem services on the site. The first draft of the vegetation management plan included a few species in a section titled *"Crops for Future Planting"* . The purpose of this section seemed unclear and led to much discussion between the stakeholders and identified the need to provide a document that clearly outlined the purpose of this section and serve as a preliminary step to making decisions for future agrivoltaics projects. As a result, the potential crops for future planting document (Appendix F) was identified as a deliverable that could help supplement the vegetation management plan.

Interviews with Researchers

The interviews allowed for preliminary understanding of research efforts, timelines, needs, and suggestions for the site and the Office of Sustainability. From talking to the researchers, it was concluded that the average ideal timeline for all the projects spanned from 3-5 years, and some common concerns from the teams included equipment use, access to the site at odd times, and general communication requirements with the Office of Sustainability and Alliant Energy (see Appendix B for summaries of interviews with research teams). The information collected from researcher interviews further helped shape the guidelines for research permits (Appendix C), long-term monitoring plans (Appendix D), and transition phase methodology (Appendix E)

Final Deliverables

The outcomes from conversations with site stakeholders and literature review helped the development of the four final deliverables of the project: the Research Permit Guidelines (Appendix C), Long-term Monitoring Guidelines (Appendix D), Transition Phase Methodology (Appendix E), and Future Crops for Planting (Appendix F).

Limitations

A significant limitation was the construction delay of the research site, initially scheduled for Summer 2023 but postponed by a year. While this delay didn't directly impact this project, it did affect nearly all the research teams that were interviewed. However, it served as a valuable learning experience, as such delays are common in the field and teach us how to adapt over time.

Another limitation that affected multiple research groups was funding constraints. This made it challenging for teams to accurately plan the duration of their projects. Although our diverse research interests were positive, they also limited the level of detail incorporated into the guidelines. Nonetheless, as guidelines, their purpose is to provide a starting point for decision-making.

Additionally, time posed a limitation as the semester progressed, necessitating the use of earlier information for the vegetation management plan and research plans to meet deliverable deadlines. Consequently, the guidelines may not capture the most current information on these topics.

Next Steps

Once agrivoltaics research has been established on the site, it would be beneficial to create a website for the research station that could be the primary source of information about the site's activities. This website could be housed under the Office of Sustainability.

The Office of Sustainability should also highlight expectations of annual reports from researchers. The activity permit requires annual reporting to the Town of Dunn so having a consistent template would make it easier for the Office of Sustainability to compile all information from researchers to meet this requirement.

Outreach and educational events would be the next step to spread information about the project. Since the site is about a 20 minute drive from UW-Madison, the Office of Sustainability could potentially host a few events over the course of the academic year while offering transport to the site. Groups that might benefit from these events include university student groups, faculty members interested in research, Madison community members including children, and farmers in Dane County.

Conclusion

With the increasing need to move away from fossil fuel usage towards renewable energy production while also catering to the agricultural needs of a growing population, the establishment of agrivoltaics in Wisconsin is an exciting and promising endeavor. Agrivoltaics is an opportunity to redesign agricultural systems to one that can produce sustainable energy and food while ensuring that intentional care is given to the land to protect and replenish its ecosystem services so that it can naturally thrive for the years to follow.

In a transdisciplinary project like agrivoltaics, consistent and open communication between the many participants on the site is vital for its smooth operation. It presents an opportunity to cultivate a culture of interdisciplinary collaboration in academia where many times researchers tend to be isolated from other research happening on campus. Additionally, with this project, preliminary steps can be taken to incorporate land stewardship while pursuing agriculture and solar energy production.

Having been involved in this project from its inception, I am enthusiastic about the potential it holds for showcasing collaborative efforts in the realms of agriculture and renewable energy.

References

Goldberg, Zachary A. "Solar Energy Development on Farmland: Three Prevalent Perspectives of Conflict, Synergy and Compromise in the United States." *Energy Research & Social Science* 101 (July 2023): 103145. https://doi.org/10.1016/j.erss.2023.103145.

Marrou, H., L. Guilioni, L. Dufour, C. Dupraz, and J. Wery. "Microclimate under Agrivoltaic Systems: Is Crop Growth Rate Affected in the Partial Shade of Solar Panels?" *Agricultural and Forest Meteorology* 177 (August 2013): 117–32. https://doi.org/10.1016/j.agrformet.2013.04.012.

Walston, Leroy J., Tristan Barley, Indraneel Bhandari, Ben Campbell, James McCall, Heidi M. Hartmann, and Adam G. Dolezal. "Opportunities for Agrivoltaic Systems to Achieve Synergistic Food-Energy-Environmental Needs and Address Sustainability Goals." *Frontiers in Sustainable Food Systems* 6 (September 16, 2022): 932018. https://doi.org/10.3389/fsufs.2022.932018.

Williams, Henry J., Khaled Hashad, Haomiao Wang, and K. Max Zhang. "The Potential for Agrivoltaics to Enhance Solar Farm Cooling." *Applied Energy* 332 (February 2023): 120478. https://doi.org/10.1016/j.apenergy.2022.120478.

Kaeding, Danielle. "Residents share mixed feelings about state's largest proposed renewable energy plant in Dane County" *Wisconsin Public Radio* (January 2022): https://www.wpr.org/agriculture/residents-share-mixed-feelings-over-states-largest-proposed-renewable-energy-plant-dane-county

AghaKouchak, A., A. Farahmand, F. S. Melton, J. Teixeira, M. C. Anderson, B. D. Wardlow, and C. R. Hain. "Remote Sensing of Drought: Progress, Challenges and Opportunities." *Reviews of Geophysics* 53, no. 2 (June 2015): 452–80. https://doi.org/10.1002/2014RG000456.

B. Narasimhan, R. Srinivasan, J. G. Arnold, and M. Di Luzio. "ESTIMATION OF LONG-TERM SOIL MOISTURE USING A DISTRIBUTED PARAMETER HYDROLOGIC MODEL AND VERIFICATION USING REMOTELY SENSED DATA." *Transactions of the ASAE* 48, no. 3 (2005): 1101–13. https://doi.org/10.13031/2013.18520.

Cosh, Michael H., Tyson E. Ochsner, Lynn McKee, Jingnuo Dong, Jeffrey B. Basara, Steven R. Evett, Christine E. Hatch, et al. "The Soil Moisture Active Passive Marena, Oklahoma, In Situ Sensor Testbed (SMAP‐MOISST): Testbed Design and Evaluation of In Situ Sensors." *Vadose Zone Journal* 15, no. 4 (April 2016): 1–11. https://doi.org/10.2136/vzj2015.09.0122.

Franz, Trenton E., Ammar Wahbi, Mariette Vreugdenhil, Georg Weltin, Lee Heng, Markus Oismueller, Peter Strauss, Gerd Dercon, and Darin Desilets. "Using Cosmic-Ray Neutron Probes to Monitor Landscape Scale Soil Water Content in Mixed Land Use Agricultural Systems." *Applied and Environmental Soil Science* 2016 (2016): 1–11. https://doi.org/10.1155/2016/4323742.

R. Shamshiri, Redmond, Siva K. Balasundram, Abdullah Kaviani Rad, Muhammad Sultan, and Ibrahim A. Hameed. "An Overview of Soil Moisture and Salinity Sensors for

Digital Agriculture Applications.” In *Digital Agriculture, Methods and Applications*, edited by Redmond R. Shamshiri and Sanaz Shafian. IntechOpen, 2022. https://doi.org/10.5772/intechopen.103898.

Maddy, John K. “Crop Residue and Its Use to Control Soil and Water Loss” 76, no. 1 (1969).

Moonen, A.C., and P. Bàrberi. “An Ecological Approach to Study the Physical and Chemical Effects of Rye Cover Crop Residues on *Amaranthus Retroflexus* , *Echinochloa Crus*‐*galli* and Maize.” *Annals of Applied Biology* 148, no. 1 (February 2006): 73–89. https://doi.org/10.1111/j.1744-7348.2006.00038.x.

N. P. Woodruff, C. R. Fenster, W. W. Harris, and And Marvin Lundquist. “Stubble-Mulch Tillage and Planting in Crop Residue in the Great Plains.” *Transactions of the ASAE* 9, no. 6 (1966): 0849–53. https://doi.org/10.13031/2013.40115.

Prosdocimi, Massimo, Paolo Tarolli, and Artemi Cerdà. “Mulching Practices for Reducing Soil Water Erosion: A Review.” *Earth-Science Reviews* 161 (October 2016): 191–203. https://doi.org/10.1016/j.earscirev.2016.08.006.

Roder, Keoboulapha, Phengchanh, Prot, and Matias. “Effect of Residue Management and Fallow Length on Weeds and Rice Yield.” *Weed Research* 38, no. 3 (June 1998): 167–74. https://doi.org/10.1046/j.1365-3180.1998.00077.x.

Valbuena, Diego, Olaf Erenstein, Sabine Homann-Kee Tui, Tahirou Abdoulaye, Lieven Claessens, Alan J. Duncan, Bruno Gérard, et al. “Conservation Agriculture in Mixed Crop–Livestock Systems: Scoping Crop Residue Trade-Offs in Sub-Saharan Africa and South Asia.” *Field Crops Research* 132 (June 2012): 175–84. https://doi.org/10.1016/j.fcr.2012.02.022.

Djordjevic, Boban, Katarina Šavikin, Dejan Djurovic, Robert Veberic, Maja Mikulič Petkovšek, Gordana Zdunić, and Todor Vulic. “Biological and Nutritional Properties of Blackcurrant Berries (*Ribes Nigrum* L.) under Conditions of Shading Nets.” *Journal of the Science of Food and Agriculture* 95, no. 12 (September 2015): 2416–23. https://doi.org/10.1002/jsfa.6962.

Jamil, Uzair, Thomas Hickey, and Joshua M. Pearce. "Solar Energy Modelling and Proposed Crops for Different Types of Agrivoltaics Systems." Preprint. SSRN, 2023. https://doi.org/10.2139/ssrn.4579628.

Kjelgren, Roger, and Teresa Cerny-Koenig. "Evaluating a Line Source Irrigation System for Determining Water Requirements of Herbaceous Perennials." *Journal of Environmental Horticulture* 24, no. 4 (December 1, 2006): 225–29. https://doi.org/10.24266/0738-2898-24.4.225.

Marrou, H., L. Guilioni, L. Dufour, C. Dupraz, and J. Wery. "Microclimate under Agrivoltaic Systems: Is Crop Growth Rate Affected in the Partial Shade of Solar Panels?" *Agricultural and Forest Meteorology* 177 (August 2013): 117–32. https://doi.org/10.1016/j.agrformet.2013.04.012.

Nilson, Sarah E., Eric P. Burkhart, R. Teal Jordan, and Joshua D. Lambert. "Ramp (Allium Tricoccum Ait.) Weight Differs across the Harvest Season: Implications for Wild Plant Stewardship and Forest Farming." *Agroforestry Systems* 97, no. 1 (January 2023): 97–107. https://doi.org/10.1007/s10457-022-00790-3.

Tolekova, Shyryn, Turegeldy Sharmanov, Yury Sinyavskiy, Ramza Berzhanova, Ramazan Mammadov, Özge Kiliçarslan Aksoy, and Rusif YusiFli. "Antioxidant, Pharmacological, Medical Properties and Chemical Content of Rosa L. Extracts." *International Journal of Secondary Metabolite* 7, no. 3 (September 15, 2020): 200–212. https://doi.org/10.21448/ijsm.726140.

Wist, Tyler J., and Arthur R. Davis. "Floral Nectar Production and Nectary Anatomy and Ultrastructure of Echinacea Purpurea (Asteraceae)." *Annals of Botany* 97, no. 2 (February 1, 2006): 177–93. https://doi.org/10.1093/aob/mcj027.

Wolske, Eric T., Bruce E. Branham, and Kevin J. Wolz. "Growth and Productivity of 'Consort' Black Currant Grown under Varying Levels of Artificial Shade." *HortScience* 56, no. 1 (January 2021): 3–7. https://doi.org/10.21273/HORTSCI15115-20.

Appendices

Appendix A. Interview Questions

1. Please describe the purpose of your research.
2. What is the ideal timeline of your project? How long do you plan to run your trials?
3. Could you briefly describe each phase of your project? This would include the preparation, the life of your project, and the end.
4. What kind of equipment would you need for each phase?
5. What do you think are some of the challenges of carrying out this research on a solar farm?
6. What kind of infrastructure on the site would be helpful for the project?
7. What kind of pest control and weed control practices do you plan to implement as part of your project (if applicable)?
8. What do you think the end of your research project will look like? This is to help understand what transition steps would be suitable to move from one project to the next.
9. Are there any practices you suggest we could incorporate to prepare the land for the next research project which will most likely be an agricultural project?
10. Is there any potential at all to include animal grazing?
11. What kind of assistance would you appreciate from the Office of Sustainability while running the project?

Appendix B. Interview Summaries

- UW-Madison Extension Solar Grazing Research
- Soil Sensing and Monitoring at Kegonsa
- Research Forward Agrivoltaics Group
- Pollinator Monitoring at Kegonsa Agrivoltaics Site

UW-Madison Extension Solar Grazing Research

Interviewees: Diane Mayerfeld and Will Fulwider

Research Proposal

The UW-Madison Extension team would like to run trials to answer three research questions.

1. What forage mix will provide good forage quantity and quality under solar arrays for sheep?
2. How would shading from three different racking systems (fix-tilt at 2 spacings and single-axis tracker) affect forage production and quality compared to production under full sun?
3. Do solar panels provide a microclimate that affects winterkill of alfalfa compared to a control (no shading from panels)?

To answer these questions, the team would like to run trials using two forage mixes under all three panel configurations at Kegonsa, as well as an unshaded control in a randomized block set-up.

Timeline

Timeline is dependent on funding but they would like to run it for **at least** three years, the first year being the establishment year. With adequate funding, the ideal timeline would be five years.

Description

Preparation

Plots will be marked by spray painting the pylons as it would be an easier and more permanent solution compared to flags. Planting of seeds would be carried out using a small tractor or a walk-behind drill that would be borrowed from other UW ag research stations. Planting cover crops to reduce erosion prior to construction would be good and once construction is done, the trials would be planted. If pylons are not established during the time of seeding, the site map will be used to mark out the trial plots. In the case that construction is taking place during non-ideal planting conditions, a cover crop will be established and the rest of the planting will take place in the late summer or early fall, and would be left to overwinter.

First growing season

In order to simulate grazing, clippings of pastures will be taken, leaving 4-6 inches standing to allow for good regrowth. The samples will be assessed for biomass quantity and sent to a lab for quality analysis, including carbohydrate and protein content and digestibility. The plan is to simulate 4 grazing episodes every summer. This will continue throughout the project, for three summers. Species diversity would also be measured under different racking systems.

End of the project
In order to terminate the vegetation, the trials will either be mechanically terminated through tillage or chemically terminated using an herbicide and will be replaced with the native pollinator mix. If the project receives more funding, there is potential to continue the project with other forage mixes.

Control
The same procedure will be carried for trials outside of the array under full sun conditions.

Equipment Required
Drill or broadcaster for seeding. Since row width is a constraint, it would most likely be a walk-behind drill. A small tractor would also be helpful. A mower for mowing the trials to simulate grazing episodes. Quadrats and clippers to take biomass samples. A disc or rototiller may be used for mechanical termination of the trials, or they can be chemically terminated using a spraying backpack. A scale to weigh biomass.

Pest and weed control
Since the trials include mowing four times a year, chances of unwanted species showing up are low. In the chance there are species prevalent that either the research team or Alliant Energy does not want on the site, they will plan for mechanical or herbicide (spot treatments) removal.

Perceived Challenges
- Grazing would be challenging because sheep are not easily accessible in the nearby area and access for grazers to the field would be a constraint. Also, there are several other research projects taking place on site, and sheep might impact those projects. Hence the plan to simulate grazing.
- Keeping the vegetation low enough under the solar panels to make sure that there is enough airflow under the panels so as to not negatively affect solar panel efficiency. Thus it is important to find forage species that have good biomass production without excessive height growth.
- Finding ways to address the needs of both the Green Energy community and the Agriculture community since the definition of ‘agriculture’ is different for both communities.

Desired Support from the Office of Sustainability

- Facilitating two-way communication between the research team and Alliant Energy, including timing of activities, areas of concern, and site access.
- Potentially help with arranging some equipment (eg:- electric mowers)
- Communicating requirements for restroom facilities to research teams at all times.
- Outreach about what is learned

Soil Sensing and Monitoring at Kegonsa

Interviewee: Dr. Jingyi Huang

Purpose of Research

The research group studies two main topics:

- How to combine different tools and models to understand the movement of water, carbon, nutrients, and energy in the soil interface. Specifically how these change with climate change and management practices on the site.
- How can we use machine learning or AI-based approaches to analyze big data sets to understand how these management practices affect ecosystem services and how we can use these results to inform natural resource management.

For the agrivoltaics project in specific, they are interested in two main questions.

1. How do the management practices on the agrivoltaics site change the soil conditions, its properties, and fluxes in the soil?
2. How would it change feedback in the site - such as ecosystem fluxes, performance of the solar panels etc.?

Timeline

Timeline and project plans will largely depend on the funding available. Short - term projects can be completed in 1-3 years and long-term projects would take 5-10 years.

Description

The first step is for the team to collect information on all management practices taking place on the site including agricultural projects and solar panel installations. Once they have this information on hand, they will set up proximal and remote sensing tools to monitor soil conditions and answer the research questions posed in the proposal. The tasks will be manipulated according to other activities taking place on the site.

Equipment Required

The research team would require the implementation of proximal and remote sensing tools for soil monitoring. Sensors measure water content, salt content, and temperature of soil at different depths. They will also use satellite data to collect spatial information about the soil.

Perceived Challenges
Currently the greatest issue is funding required for the project. The team is trying to find funding sources at the moment.

Desired Information
The team would like to have the full record of the management history of the site and also information about the land prior to, during, and after construction of the solar arrays.

Desired Support from the Office of Sustainability
The team would appreciate facilitation of conversations with other research teams for collaboration on projects. They would also appreciate guidance on where to look for project funding, perhaps even directly from the Office of Sustainability. It would also be helpful if the Office of Sustainability can reach out to colleges to assist with looking for funding opportunities for all the researchers.

Research Forward Agrivoltaics Group

Interviewee: Dr. Doe Han

Purpose
The purpose of this research project is to study environmental changes caused by agrivoltaic practices. The team is looking at various factors including soil moisture, rainwater infiltration into the ground, and microclimate changes under the panels including wind tunnel effects. The group is also interested to experiment on and determine suitable crops for agrivoltaics sites.

Research efforts are being spearheaded by three principal investigators - Dr. Steve Loheide (Civil and Environmental Engineering), Dr. Ankur Desai (Department of Atmoshperic and Oceanic Sciences), and Dr. Christopher Kucharik (Department of Plant and Agroecosystem Sciences)

Timeline
It would take a minimum of one year to collect good baseline data since data is season dependent. The ideal timeline for the project would be 3 to 5 years, which is also dependent on funding available.

Description
The team would like to install instrumentation by the Fall of 2024 once construction has completed. After installation of instrumentation, data will be consistently collected and monitored for the duration of the project.
After the planned end of the project, if it is feasible, the sensors can be left on the site for an extended period of time and can help with long-term monitoring of the site. Long-term data can

be very beneficial and help with decision making for future projects or to advice policy and economic decisions.

Equipment Required

Soil moisture sensors, temperature sensors, and groundwater wells are to be set up on site. In order to do so they will require augers and well pipes. They will also use soil samplers to sample soil.

After installation of the well, they will need transducers. Wells are about 3 inches in diameter and about 3 m deep.

Weather stations will be installed to record wind direction and speed, irradiance, for eddy covariance studies, evapotranspiration measurement, air temperature, and air pressure.

Perceived Challenges

One of the main challenges is determining the amount of detail to go into with the project. The more detail desired, the more sensors will need to be deployed around the site. Another challenge is budgeting according to required resolution.

Desired Infrastructure

Since there is a lot of equipment and material to transport, it would be helpful to have something like a wheelbarrow to make those tasks more efficient.

Desired Assistance from the Office of Sustainability

The team would appreciate help with funding through the Sustainability Research Hub. It would also be helpful to share opportunities to acquire equipment or instrumentation. This could potentially be done by advertising the needs of the research team to other research labs on campus and could be facilitated by the Office of Sustainability.

The Office of Sustainability could potentially help set up a platform for confidential sharing of data among researchers. Since the results of the Research Forward team is dependent on groundcover and management practices on the agrivoltaics site, having access to that information would be very helpful.

Pollinator Monitoring at Kegonsa Agrivoltaics Site

Interviewees: Victoria Salerno (vasalerno@wisc.edu) and James Crall (james.crall@wisc.edu)

Purpose of Research

The purpose of this project is to set a baseline for pollinator presence, specifically bee presence prior to site construction, during construction, and after construction. Since there has been no pollinator monitoring on the site to date, the results of this project aim to fill that knowledge gap.

The team is interested to see what populations currently exist and how the changes in land use would affect the pollinator populations. Additionally, there is interest in identifying technology that can be used in a solar energy site to monitor pollinator species.

Timeline
Initial baseline data collection would take place over the first year but population scale studies would require the trials to run for multiple years. Victoria would like to have results when she wraps up her PhD program which would be in 3-4 years.

Description
Sampling would ideally start early spring around early April 2024. This would involve multiple methods like observational transect walks, net capture, or pan traps prior to construction, during construction, and after construction.
After baseline data collection, the plan is to create an automated bee hotel to be deployed at the site. New studies will be proposed from results of baseline data analysis.
Field season is usually early April through September. This is when most of the research activity will take place over the trial years.
The team would like to sample under the solar arrays as well as around the solar panel area.
The end goal would be to have some data on how agrivoltaics sites affect pollinator populations that can be used to inform decision making for future agrivoltaics projects.

Required Equipment
Currently no specific equipment is required for the project. If planning for planting specialty crops in the future, relevant planting equipment would be required. In the future electrical wiring and setup will be necessary for automated tracking and monitoring.

Perceived Challenges
Data collection during construction activity might be challenging but necessary to understand effects on pollinator populations.

Desired Infrastructure
Shared storage for all research projects on site would be beneficial. Electrical hook-ups and access.

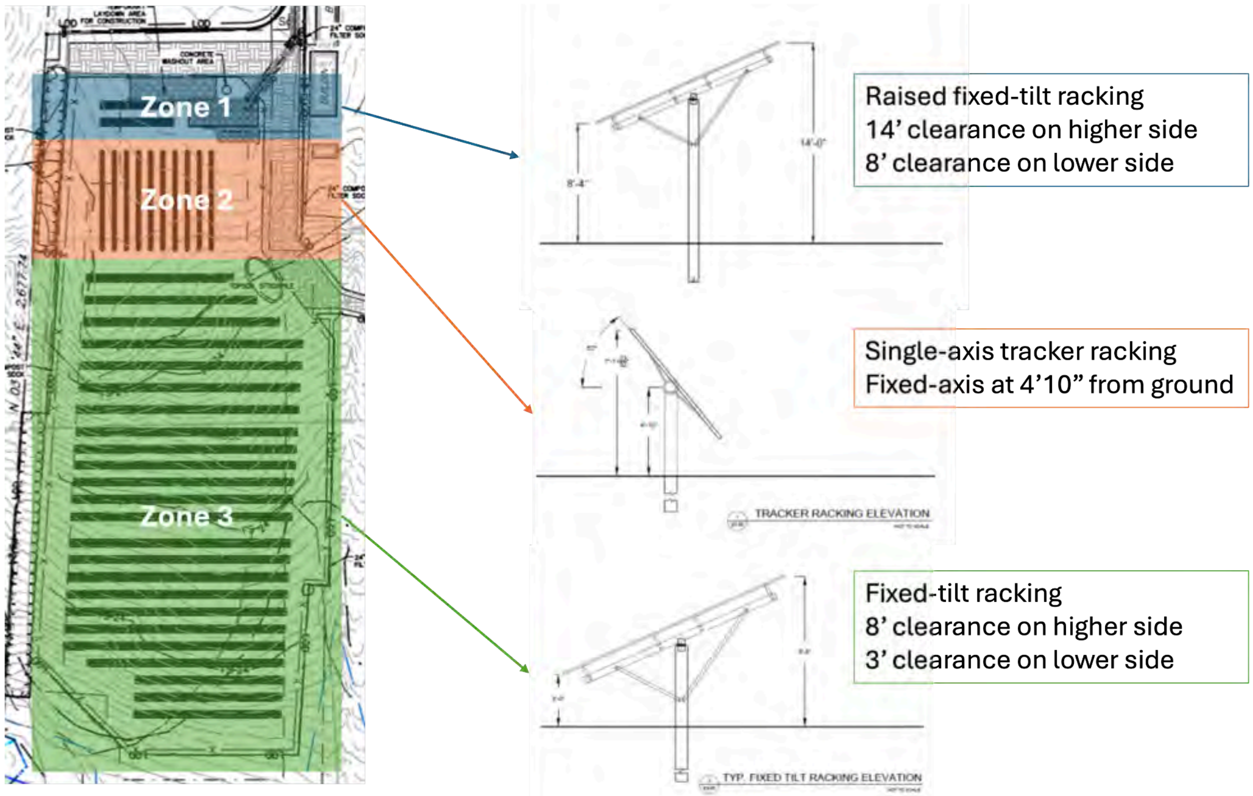
Desired Support from the Office of Sustainability

- Conveying timely updates on the timeline of construction or if there is availability of ethernet or wi-fi connection.
- Facilitating communication with researchers and Alliant Energy.

Appendix C. Kegonsa Research Permit Guidelines

If you are interested in conducting research at the Kegonsa agriculture and solar research station, please read the following information and fill out the required fields below.

Research Station Zones



Personal Details

*Fields marked *are mandatory*

1. Name (First and Last)*
2. Title
3. Institution/Department*
4. Phone*
5. Email*

Supervisor Information (if student)

Students please fill out this section

1. Advisor/Instructor Name (First and Last)
2. Advisor/Instructor Institution
3. Advisor/Instructor Phone
4. Advisor/Instructor Email

Research Details

1. Proposed start date
2. Proposed end date
3. Choose zone where you would like to carry out your research (refer to the beginning of the permit application for a visual representation of the zones including type of panel racking in each zone)
    - ☐ Zone 1
    - ☐ Zone 2
    - ☐ Zone 3
        - ☐ 40 feet pole to pole row spacing
        - ☐ 32 feet pole to pole row spacing
4. Please pick an activity type*
    - ☐ Undergraduate research
    - ☐ Graduate research
    - ☐ Teacher/Faculty research
    - ☐ Teaching
    - ☐ Other
5. Course number and title (if applicable)

6. Project title
7. Anticipated number of people involved*
8. Provide a brief description of the activity*
9. Choose the area(s) most relevant to your research activity*

   ☐ Pollinator habitat/conservation

   ☐ Native ecosystem restoration/research

   ☐ Forage crops

   ☐ Grazing

   ☐ Horticulture

   ☐ Solar energy efficiency

   ☐ Soil science

   ☐ Water resource management

   ☐ Other

   If other please describe:_______________________________________

10. Briefly describe the use of equipment (if any) for your project*
11. What measures will be taken to ensure safety regarding solar panel infrastructure?*
12. What measures will be taken to avoid any damage to solar panel infrastructure?*
13. Will you require entry to the site after regular working hours?*

    ☐ No

    ☐ Yes

    If yes, please explain:

14. Are you required to organize educational or outreach events as part of your research/project?*

☐ No

☐ Yes

If yes, please explain briefly:

15. Are you able to share data being collected for your project with other researchers?

☐ Yes

☐ No

If no, please explain (eg:- confidential data, embargoed data etc.)

16. Is there anything else you would like to convey that was not mentioned earlier in this application?

Permit Terms

By signing below, you agree to do the following if granted a research permit for this site.

- Provide an annual report or an end of project report if the project lasts less than one year.
- Participate in an annual meeting with other researchers to share updates.
- Adhere to safety protocols for conducting research on a solar energy site.
- Communicate with the Office of Sustainability in a timely manner in the event of any unforeseen circumstances.
- Communicate with the Office of Sustainability in case your project is dealing with sensitive data.
- Communicate with other researchers with active projects on the site in a timely manner if your activities may affect their work.
- Follow guidelines to prepare your research sites for the next project at the end of your project.
- Provide the necessary funds for conducting research activities on the premises.
- Share contact details with other researchers on site to collaborate on data collection and other overlapping activities unless otherwise communicated.
- Research activities will be run by solar utility engineers to assess safety concerns and are only allowed to proceed if deemed suitable for the site.

Signature: ________________________________

Date:

Appendix D. Guidelines for Long-Term Monitoring and Data Collection

Purpose

The Kegonsa Agrivoltaics site is a novel University of Wisconsin-Madison research site where agricultural research will take place on a 15 acre solar energy farm run by Alliant Energy. The goal is to collaborate with researchers from multiple disciplines to establish research projects on the site to have a holistic understanding of the effects of agrivoltaics practices on agricultural production, soil and water health, and solar panel efficiency among many other areas. One of the most important metrics to measure the effect of research projects on the site is to measure their effects on the site's ecosystem services, namely soil and water health. To accurately measure and evaluate effects of agrivoltaics practices on soil and water at the site, it is important to ensure the collection of accurate data for a long period of time, ideally throughout the lifespan of the research site.

This document aims to provide a guideline to the Office of Sustainability and Alliant Energy on how to ensure that long-term monitoring of the site is being conducted appropriately while also allowing for the possibility to conduct a variety of research projects on the site.

Limitations

This document will outline guidelines for choosing monitoring sites and maintaining communication between participants on the site. It will **not** provide guidelines on the specific instruments to use that would be ideal for this kind of research site. This is because the instrument type will be determined by the group implementing the project and the funding and resources available at the time. Literature sources regarding ideal instrument type will be provided in the references.

Data Requirements

For researchers who are interested in hydrology and soil data on the site, it is recommended to provide basic information including the following:

<u>Hydrology</u>

Depth to water table data - this data can be collected through daily readings either by installing a pressure transducer or by using a well tape.

<u>Soil</u>

Minimum required data for soil health would be organic matter content, available nitrogen, available phosphorus, available potassium, and bulk density. This data can be obtained by sending soil samples to the Wisconsin State Lab of Hygiene.

Methods

<u>Research Plot Assignments</u>

The default planting plan for the sites is to seed the entire site with native pollinator species. In this case, it would be informative if part of the site remains a prairie for the lifespan of the project. Research plots would have to be assigned eliminating these specific areas so as to have a control within the solar energy farm.

Figure 1. Zone 2 research and control plots with suggested plot dimensions

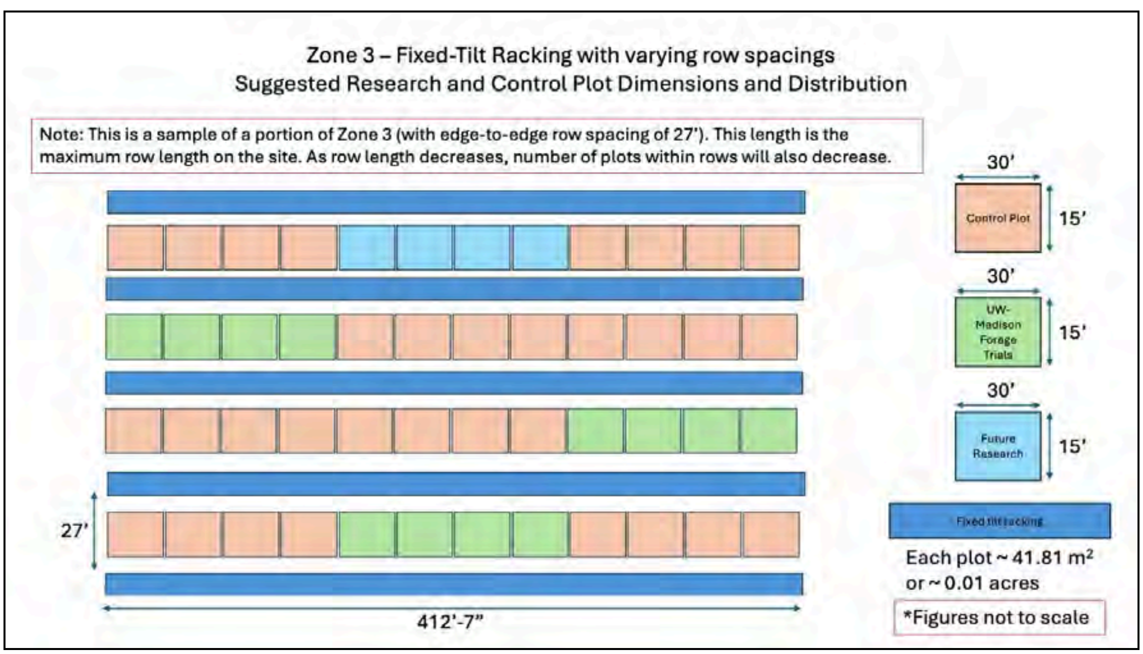


Figure 2. Zone 3 sample of research and control plots with suggested plot dimensions

Appropriate Site Selections

The Kegonsa Agrivoltaics site is on a south facing slope. It is surrounded by traditional agricultural fields on most sides but has a wetland area at the bottom of the site. These features would affect the soil and water profiles of the site at various points. To have an overall understanding of how the research projects are affecting soil and water quality, monitoring equipment must be placed while keeping the following factors in mind:

1. Panel configuration
2. Proximity to wetland area
3. Proximity to control prairie
4. Proximity to end of the row of panels

The instruments should be placed in as many locations as possible for the different permutations and combinations of the listed factors. For example, a sensor will be placed at the top of the site under the raised-tilted panels, and close to the center of a row with no native species. In the case that there is a limitation in funding or resources, the importance of each factor should be determined at the discretion of the team deploying the sensors.

Communication Protocol

A unique aspect of this research site is the presence of a variety of research projects that will be running for various amounts of time. It is therefore essential to establish a protocol that would ensure timely communication among research groups, the Office of Sustainability, and Alliant Energy in order to ensure accurate data collection and context for anyone who is analyzing long-term data since types of vegetation or different activities on the surface could potentially alter soil and water data.

Annual or Biannual Check-Ins

Planning for routine annual or biannual check-ins with research groups would be an effective way to ensure timely communication between Kegonsa participants. If meeting once a year, the period right before site preparation for the growing season would be appropriate, potentially in March. If meeting twice, the second meeting can take place at the end of the year right before or after the Fall semester ends.

Kegonsa Research Database

Establishing a shared research database for all the research activities being carried out in Kegonsa would ensure easy access to researchers during data analysis. For example, when collecting data from a research plot that has had multiple research projects over a short period of time, having detailed information about the activities would inform researchers while interpreting long and short-term soil and water data from that specific plot. This database should be managed either by someone from the Office of Sustainability or Alliant Energy, whichever is appropriate.

Format
Although having complete datasets accessible to all researchers would be ideal, this is impractical due to space constraints as well as for research integrity. All research teams will be requested to provide a brief summary of their project, a description of the type of data being collected, and contact details that will be made available for anyone who is interested in acquiring the data. Individuals can then approach the research team directly for more information or complete datasets if applicable.

Below is an example of what this information might look like for a soil monitoring project.

Name	John Doe
Contact Information	**Email:** jdoe@wisc.edu **Phone number:** (000)000-0000
Affiliation	UW-Madison Department of Soil Science
Project title	Changes in soil composition due to management practices.
Project start date	September 2023
Project status	Active
Description of Project	Our research question is to see how different management practices of lettuce production in agrivoltaics affects the composition of soil.
Type of data collected (include format if applicable)	Visual data (texture, color), Laboratory data (soil properties like alkalinity, organic matter composition through loss on ignition tests)
Additional Information	N/A

Location
A potential location for this database could be the Badgervoltaics SharePoint site. Badgervoltaics is a community of practice encompassing researchers, students, practitioners, and faculty members who are keen in joining the agrivoltaics discussion in Madison including the Kegonsa site. There is currently a Microsoft SharePoint platform for this community that is used to relay agrivoltaics information to the group.

Security and Sensitive Data
Most public platforms for groups have different accessibility levels for members. Members of the group should be given access after careful inspection of their role. Only those members who

are currently involved in a project or who are interested in setting up a project and have notified the Office of Sustainability will have access to information provided by other research teams.

In the case that data collected from a project trial is of sensitive nature, the research team should notify an Office of Sustainability member with explanation and evidence. Sensitive data will be distinguished into two categories - confidential data and embargoed data.

Confidential data is defined as data that is not intended for public dissemination. If research teams are collecting confidential data, they are not required to provide any information and may abide by their research protocol.

Embargoed data is defined as data that cannot be discussed at public meetings until they have been publicly released. If research teams are collecting embargoed data, they are required to report to the Office of Sustainability about expectations of when the embargo will be lifted and will subsequently be asked to provide information on data.

Summary

Agrivoltaics research is a new initiative in Wisconsin. With the increasing need to move towards renewable energy resources while also preserving agricultural land, it is imperative that we collect as much data as possible to help inform decisions for future agrivoltaic sites. Since keeping track of data on sites with multiple research types is a complex task, establishing protocols for siting and communication will help to ensure smooth collaborations. Ultimately, it is important to understand that no two agrivoltaics sites are the same and we have to plan for adaptive management to cater to the needs of the site and its goals.

References

AghaKouchak, A., A. Farahmand, F. S. Melton, J. Teixeira, M. C. Anderson, B. D. Wardlow, and C. R. Hain. “Remote Sensing of Drought: Progress, Challenges and Opportunities.” *Reviews of Geophysics* 53, no. 2 (June 2015): 452–80. https://doi.org/10.1002/2014RG000456.

B. Narasimhan, R. Srinivasan, J. G. Arnold, and M. Di Luzio. “ESTIMATION OF LONG-TERM SOIL MOISTURE USING A DISTRIBUTED PARAMETER HYDROLOGIC MODEL AND VERIFICATION USING REMOTELY SENSED DATA.” *Transactions of the ASAE* 48, no. 3 (2005): 1101–13. https://doi.org/10.13031/2013.18520.

Cosh, Michael H., Tyson E. Ochsner, Lynn McKee, Jingnuo Dong, Jeffrey B. Basara, Steven R. Evett, Christine E. Hatch, et al. "The Soil Moisture Active Passive Marena, Oklahoma, In Situ Sensor Testbed (SMAP‐MOISST): Testbed Design and Evaluation of In Situ Sensors." *Vadose Zone Journal* 15, no. 4 (April 2016): 1–11. https://doi.org/10.2136/vzj2015.09.0122.

Franz, Trenton E., Ammar Wahbi, Mariette Vreugdenhil, Georg Weltin, Lee Heng, Markus Oismueller, Peter Strauss, Gerd Dercon, and Darin Desilets. "Using Cosmic-Ray Neutron Probes to Monitor Landscape Scale Soil Water Content in Mixed Land Use Agricultural Systems." *Applied and Environmental Soil Science* 2016 (2016): 1–11. https://doi.org/10.1155/2016/4323742.

R. Shamshiri, Redmond, Siva K. Balasundram, Abdullah Kaviani Rad, Muhammad Sultan, and Ibrahim A. Hameed. "An Overview of Soil Moisture and Salinity Sensors for Digital Agriculture Applications." In *Digital Agriculture, Methods and Applications*, edited by Redmond R. Shamshiri and Sanaz Shafian. IntechOpen, 2022. https://doi.org/10.5772/intechopen.103898.

Appendix E. Transition Phase Methodology

Purpose

The Kegonsa Agrivoltaics site is a novel University of Wisconsin-Madison research site where agricultural research will take place on a 15-acre solar energy farm run by Alliant Energy. The goal is to collaborate with researchers from multiple disciplines to establish research projects on the site to have a holistic understanding of the effects of agrivoltaics practices on agricultural production, soil and water health, and solar panel efficiency among many other areas. The research station aims to house multiple agricultural research projects over the course of its lifetime. With many trials lasting from 3-5 years, there is potential for multiple projects to take place on the same plot within the lifetime of the agrivoltaics station.

This document outlines the methods to ensure smooth transitioning from one agricultural project to the next and is meant to help research teams set up or wrap up their trials while ensuring that all necessary actions are taken to protect the land from soil and water erosion while preserving other ecosystem services.

Communication

Whether setting up a new project or wrapping up a project, it is important to convey the project timeline to the team using the plot at the current time. The Office of Sustainability contact can help facilitate this conversation. This discussion should answer the following questions:

1. When is the current project set to wrap up?
2. When is the new project scheduled to start?
3. Who is responsible for executing the protocol for soil cover during the period when the plot is not being used?
4. What practices are going to be used to protect the soil?

Method

All the suggested soil protection methods aim to use practices that would be the most cost effective and that would cause the least disturbance to the soil. Determining the amount of time the land will be left to rest will determine the protocol that needs to be followed to ensure soil protection. General soil protection methods have been suggested based on time of rest between agricultural projects.

Mulching for less than 1 year

For a rest time of less than 1 year, the suggested method to protect the soil would be **mulching.** Mulching is the practice of laying material on the soil for many crop benefits including soil protection.

Crop residue mulching using field residue is the practice of mulching with the crop remains post harvest on a plot of land and is the suggested method for cost and time efficiency.

If the entire crop is being harvested leaving no residue behind, options for mulch include post-processing crop residues or purchased organic and biodegradable mulch.

General Mulching Steps:

- Retain the crop residue on the field from harvested crops or the crop residue from post-processing of crops to use as crop residue mulch.
- If purchasing mulch, aim to purchase dye-free, organic, and biodegradable mulch.
- Clear the field of any debris and make sure that large rocks and any mounds that might obstruct equipment are removed.
- Distribute the mulch evenly on the land using a rake.
- A mulch layer of 2-3 inches should be sufficient to control soil erosion. This should however be adjusted according to the slope and soil type.

Cover cropping for 1-2 years

For a rest time between 1-2 years, the suggested method is **cover cropping.** Cover cropping is the practice of planting temporary crops to protect soil and improve soil quality when the land would otherwise be fallow. Crop species chosen for cover cropping are dependent on when the crops are to be planted and how long they are to be grown before termination.

General Cover Cropping Steps:

- Choose the appropriate cover crops and determine the right time for planting.
- Sow cover crop seeds to recommended depth using a manual or machine-operated no-till seed drill.
- Monitor cover crop development and determine the right time to terminate the cover crops. In general, cover crops should be terminated past the flowering stage but before seeding and should be terminated 2-4 weeks before sowing of commodity crop seeds.
- Terminate cover crops using the desired method; either manually using a roller crimper or chemically using herbicide.

Depending on when the cover crops are to be planted, these are some suggestions for cover crops species and planting times:

Winter cover crops
Species: Winter Rye
Seeding time: Mid-Fall

Spring cover crops

Species: Oats, Spring Barley, Spring Triticale, Spring Wheat
Seeding time: Early April through mid-May (as soon as the ground thaws)

Summer cover crops
Species: Medium Red, Berseem, and Crimson Clovers
Seeding time: Mid-May through July (Early Summer)

Native pollinator species planting for more than 2 years

For a rest time that exceeds 2 years, or if there is no plan to conduct agricultural research on a plot, the suggested method is to seed with native pollinator prairie species. In this case, it would be best to use the native pollinator seed mix mentioned in the vegetation management plan for the site and follow the guidelines laid out in the document.

General steps for native pollinator species planting and maintenance

- Prepare the soil to ensure it is suitable for native pollinator species success, ensuring removal of agricultural and invasive weeds.
    - If avoiding the use of herbicides, remove or kill weeds using mechanical or manual equipment for tillage.
    - If the goal is to leave the soil undisturbed, the use of herbicides to kill unwanted weeds might be necessary.
- Plant appropriately stratified seeds to the required depth using a mechanical or manual seeder.
- Apply a layer of mulch on the seeds for protection, suppression of weeds, and for nutrition purposes.
- Monitor growth and development of pollinator species and assess for nutrition deficiencies, presence of pests and weeds, diseases, and water-stress.
    - Determine use of herbicides or manual removal in case of weeds.
    - Determine use of pesticides in case of pests.
    - Determine fertilizer use in case of nutrition deficiency.
    - Determine irrigation in case of water stress.
- In order to mimic disturbance regimes in nature, mow the pollinator species to suppress weeds and promote native pollinator growth as described in the vegetation management plan.

Conclusion

This document provides general guidelines depending primarily on the amount of rest time for land in between agricultural projects. These methods were chosen to prevent soil erosion but can be customized to provide other benefits including improving soil nutrition quality and increasing soil moisture retention. The best practice is to plan ahead of time and determine the method that would most likely lead to the success of the agricultural project.

References

Maddy, John K. “Crop Residue and Its Use to Control Soil and Water Loss” 76, no. 1 (1969).

Moonen, A.C., and P. Bàrberi. “An Ecological Approach to Study the Physical and Chemical Effects of Rye Cover Crop Residues on *Amaranthus Retroflexus* , *Echinochloa Crus‐galli* and Maize.” *Annals of Applied Biology* 148, no. 1 (February 2006): 73–89. https://doi.org/10.1111/j.1744-7348.2006.00038.x.

N. P. Woodruff, C. R. Fenster, W. W. Harris, and And Marvin Lundquist. “Stubble-Mulch Tillage and Planting in Crop Residue in the Great Plains.” *Transactions of the ASAE* 9, no. 6 (1966): 0849–53. https://doi.org/10.13031/2013.40115.

Prosdocimi, Massimo, Paolo Tarolli, and Artemi Cerdà. “Mulching Practices for Reducing Soil Water Erosion: A Review.” *Earth-Science Reviews* 161 (October 2016): 191–203. https://doi.org/10.1016/j.earscirev.2016.08.006.

Roder, Keoboulapha, Phengchanh, Prot, and Matias. “Effect of Residue Management and Fallow Length on Weeds and Rice Yield.” *Weed Research* 38, no. 3 (June 1998): 167–74. https://doi.org/10.1046/j.1365-3180.1998.00077.x.

Valbuena, Diego, Olaf Erenstein, Sabine Homann-Kee Tui, Tahirou Abdoulaye, Lieven Claessens, Alan J. Duncan, Bruno Gérard, et al. “Conservation Agriculture in Mixed Crop–Livestock Systems: Scoping Crop Residue Trade-Offs in Sub-Saharan Africa and South Asia.” *Field Crops Research* 132 (June 2012): 175–84. https://doi.org/10.1016/j.fcr.2012.02.022.

Appendix F. Potential Crops for Future Planting in Southern Wisconsin Agrivoltaics

As we explore vegetation suitable for cultivation in agrivoltaic sites in Wisconsin, it is imperative to prioritize consumable crops that hold cultural and economic significance within the agricultural community of Wisconsin.

With limited prior exploration in the domain, it proves challenging to anticipate the most suitable crops for implementation on an agrivoltaic site. Utilizing modeling studies aids in simulating various factors such as solar irradiation availability, allowing for comparison with the solar irradiance requirements of crops to determine their suitability for agrivoltaic sites in Southern Wisconsin. Referencing trials conducted in other regions can be valuable, although it is important to acknowledge the variations in climate, soil conditions, and water availability across different locations. These factors can significantly influence crop suitability and productivity in agrivoltaic systems. Exploring emerging crops and their resilience, particularly in shaded conditions, can further aid in identifying suitable crops for agrivoltaic sites.

Horticultural Crops

In a modeling study conducted by Jamil et al. 2023, an investigation into solar irradiance within agrivoltaic sites was undertaken, focusing on vertical solar module arrays positioned at distances of 5 m, 15 m, and 45 m. These configurations were simulated across three locations in Canada: London, Calgary, and Winnipeg. The climate in Wisconsin, specifically southern Wisconsin is similar to that in London, Ontario, and many crops species that were identified for agrivoltaics in Ontario are also popular in Wisconsin agriculture and deemed suitable for agrivoltaics in Wisconsin. The following crops were determined to be tolerant to partial-shade, do not grow very tall, and already have established markets in Wisconsin and thus are potentially suitable for agrivoltaic sites in Southern Wisconsin.

 Lettuce	 Beets	 Collards

 Peas	 Kale	 Bok Choy
 Arugula	 Fava Beans	 Celery

Emerging Crops

Emerging crops are those that are gaining importance or popularity in agricultural practices due to various factors such as resilience to environmental conditions, nutritional value, market demand, or suitability for specific cropping systems. Among the array of emerging crops deemed suitable for Wisconsin agriculture, certain berry varieties have been recognized for their shade tolerance, cold-hardiness, and low maintenance requirements, rendering them potentially suitable for Wisconsin agrivoltaic setups. These crops offer significant market value owing to their nutritional content, characterized by high levels of antioxidants and essential vitamins. Furthermore, there exists potential for marketing these berries as fresh produce or processing them into jams, jellies, and other preserves.

 Blackcurrant	 Honeyberry

Wisconsin Native Species

Agrivoltaic sites have the potential to facilitate the cultivation of native Wisconsin plant species, which can serve both consumption and medicinal purposes. Additionally, these sites can enhance pollinator plant diversity and offer essential food and habitats for pollinator insects. Species like the Pale Purple Coneflower *(Echinacea pallida)* and Pasture Rose *(Rosa carolina)* boast vibrant flowers that attract pollinators while also contributing to pollinator habitats. Furthermore, they possess medicinal properties or edible parts such as leaves and shoots. Another native species, the Wild Ramp *(Allium tricoccum)*, not only has medicinal value but is also utilized in traditional cuisine due to its garlic-like flavor. These species naturally thrive in environments with varying light availability, such as forest ecosystems or the edges of forests and prairies, making them well-suited for shade tolerance. Although there does not seem to be a significant market for them at the moment, these might be potential species to integrate with more commercial crops to improve species diversity which might lead to improvement of soil and water health.

A popular native species that is known to be shade tolerant is American ginseng *(Panax quinquefolius)* and one that many people are curious about. However, there is evidence that ginseng can contribute to reduced microbial activity, nutrition depletion, and the development of soil-borne diseases. It is also a labor intensive and expensive process to grow ginseng and it can only be grown once in a specific area. For these reasons, ginseng is not recommended for planting in the early stages of agrivoltaics in Wisconsin, unless these issues are taken into consideration and ample area is provided specifically for ginseng cultivation.

		
Pale Purple Coneflower *(Echinacea pallida)*	Ramps *(Allium tricoccum)*	Pasture Rose *(Rosa carolina)*

References

Jamil, Uzair, Thomas Hickey, and Joshua M. Pearce. 2023. "Solar Energy Modelling and Proposed Crops for Different Types of Agrivoltaics Systems." Preprint. SSRN. https://doi.org/10.2139/ssrn.4579628.

Kjelgren, Roger, and Teresa Cerny-Koenig. 2006. "Evaluating a Line Source Irrigation System for Determining Water Requirements of Herbaceous Perennials." *Journal of Environmental Horticulture* 24 (4): 225–29. https://doi.org/10.24266/0738-2898-24.4.225.

Marrou, H., L. Guilioni, L. Dufour, C. Dupraz, and J. Wery. 2013. "Microclimate under Agrivoltaic Systems: Is Crop Growth Rate Affected in the Partial Shade of Solar Panels?" *Agricultural and Forest Meteorology* 177 (August): 117–32. https://doi.org/10.1016/j.agrformet.2013.04.012.

Nilson, Sarah E., Eric P. Burkhart, R. Teal Jordan, and Joshua D. Lambert. 2023. "Ramp (Allium Tricoccum Ait.) Weight Differs across the Harvest Season: Implications for Wild Plant Stewardship and Forest Farming." *Agroforestry Systems* 97 (1): 97–107. https://doi.org/10.1007/s10457-022-00790-3.

Tolekova, Shyryn, Turegeldy Sharmanov, Yury Sinyavskiy, Ramza Berzhanova, Ramazan Mammadov, Özge Kiliçarslan Aksoy, and Rusif YusiFli. 2020. "Antioxidant, Pharmacological, Medical Properties and Chemical Content of Rosa L. Extracts." *International Journal of Secondary Metabolite* 7 (3): 200–212. https://doi.org/10.21448/ijsm.726140.

Wist, Tyler J., and Arthur R. Davis. 2006. "Floral Nectar Production and Nectary Anatomy and Ultrastructure of Echinacea Purpurea (Asteraceae)." *Annals of Botany* 97 (2): 177–93. https://doi.org/10.1093/aob/mcj027.

Wolske, Eric T., Bruce E. Branham, and Kevin J. Wolz. 2021. "Growth and Productivity of 'Consort' Black Currant Grown under Varying Levels of Artificial Shade." *HortScience* 56 (1): 3–7. https://doi.org/10.21273/HORTSCI15115-20.

Li, Shaoyong, Haiwei Wei, Daqian Qi, Wenwen Li, Yan Dong, Fu-Ang Duan, and Shou-Qing Ni. "Planting American Ginseng (Panax Quinquefolius L.) Caused Soil Acidification and Bacterial and Fungal Communities Changes," March 2, 2023. https://doi.org/10.21203/rs.3.rs-2580466/v1.

Kasper, Madeline. "Ginseng: The Official Herb of Wisconsin," n.d.