AgriVoltaics World Conference 2024
Best Practices
https://doi.org/10.52825/agripv.v3i.1357

Published: 12 May 2025

Lessons Learned from Three Agrivoltaic Installations in New Jersey

A.J. Both, Bill Bamka, Thierry Besançon, Dunbar P. Birnie, III, Clint Burgher, Daniel Giménez, Serpil Guran, Michael Kornitas, Pete Nitzsche, David Robinson, W. Ross Rucker, Ethan Schoolman, David Specca, Kevin P. Sullivan, Daniel L. Ward, Mike Westendorf, and Christian A. Wyenandt

Rutgers University, New Brunswick, NJ 08901, USA

Correspondence: A.J. Both, both@sebs.rutgers.edu

Abstract. Agrivoltaics is a new technology that has the potential to positively impact commercial farming by combining agricultural practices with the generation of solar energy. While some yield reduction is to be expected, resulting from less sunlight reaching the plant canopy and ground occupied by support structures, the generated electricity provides a low-risk supplemental income to farmers. In order to combine farming with electricity generation, agrivoltaic systems use a lower ground coverage ratio compared to normal solar farms and the PV panels are often mounted higher above the ground in order to facilitate the movement of agricultural equipment and to reduce the contrast between shaded and non-shaded areas.

With funding provided from the state of New Jersey and the New Jersey Agricultural Experiment Station (NJAES), we designed and installed three unique agrivoltaic research systems at Rutgers/NJAES farms. These projects were recently completed and are generating electricity that is exported to the grid. This paper discusses the lessons we have learned along the way, including all the steps necessary to see an agrivoltaic project through to completion.

Keywords: Agriculture, Construction, Photovoltaics, Renewable Energy

1. Introduction

1.1 Rutgers Agrivoltaics Program

Agrivoltaics is new to New Jersey and may play a key role in the state's future energy production and farm viability. The state of New Jersey is committed to maintaining its storied agricultural industry, has challenging land use issues since it is the most densely populated state in the nation, and is actively planning to substantially increase electricity generation from renewable energy sources (solar and wind). Both farmers and solar developers have expressed an interest in using agrivoltaics as an effective way to address these challenges. However, neither the state government nor any of New Jersey's institutions of higher education had experience with agrivoltaics. Leadership at the New Jersey Agricultural Experiment Station provided seed funding to form a team of faculty and staff interested in conducting research and outreach on this topic. As a result, the Rutgers Agrivoltaics Program (RAP) was formed in 2021 and tasked with investigating the suitability of agrivoltaics for New Jersey farms [1]. All team members of RAP are co-authors on this paper.

1.2 Dual-Use Solar Energy Pilot Program

At the same time RAP was formed, the New Jersey state legislature authorized the Dual-Use Solar Energy Pilot Program and tasked the New Jersey Board of Public Utilities (BPU) to administer it, in coordination with the New Jersey Department of Agriculture, the State Agricultural Development Committee, and the New Jersey Department of Environmental Protection [2]. The BPU also administers the New Jersey Clean Energy Program [3]. The BPU reached out to RAP for Pilot Program support based on the team's experience designing and constructing agrivoltaic research and demonstration systems and on the team's Extension outreach expertise that is part of Rutgers University's Land-Grant mission. The confluence of activities, mandates, funding, and urgency have created a unique environment for New Jersey to play a key role in the exploration of agrivoltaics as a means to address several varied challenges facing agriculture, population growth, climate change, and the resulting need for a rapid and sustainable expansion of renewable energy sources.

1.3 Research and Demonstration Installations at Rutgers University

The New Jersey state legislature provided funding to install research and demonstration agrivoltaic systems at three farms operated by Rutgers University, namely the Clifford E. and Melda C. Snyder Research and Extension Farm in Pittstown, NJ, the Cook College Animal Farm in New Brunswick, NJ, and the Rutgers Agricultural Research and Extension Center (RAREC) in Upper Deerfield, NJ. After a bidding procedure, RAP selected Advanced Solar Products (Flemington, NJ) as the design-build developer. Construction of the three sites was completed during the spring of 2024 and consisted of three unique installations using bifacial panels mounted either in a fixed vertical orientation, or on single-axis trackers. Pictures of these installations are shown in Figures 1-3. The figure captions provide additional detail. During the design and construction process, we encountered a variety of challenges that are described in this paper in the hope that they can be useful for the design and construction of future agrivoltaic installations.

All three research and demonstration systems were installed using remote net-metering arrangements with the local electric utility companies (Jersey Central Power and Light in Pittstown, Public Service Electric and Gas in New Brunswick, and Atlantic City Electric in Upper Deerfield). The bifacial photovoltaic panels used at all three sites were manufactured by ZNShine (monocrystalline passivated emitter and rear contact ZXM6-NHLDD144 Series, rated at 450 W_{DC} and with a bifaciality of 70±5%, Changzhou, China). Panel dimensions were 1.04 by 2.09 m with a thickness (including the aluminum frame) of 3 cm. The vertical racking system was supplied by SunStall (Sunzaun system, Novato, CA), and the single-axis tracking systems were supplied by ArcTech (Kunshan, China). Inverters were supplied by SolarEdge (Herzliya, Israel).

Figure 1. *Cook College Animal Farm, New Brunswick, NJ (170 kW$_{DC}$): Planned for grazing large animals and hay production. Three randomized blocks, each with a control area, three rows with 61 cm (2 feet) clearance height, and three rows with 1.22 m (4 feet) clearance height. Row spacing: 6.10 or 12.19 m (20 or 40 feet). Each North-South-oriented row has 21 vertical bifacial panels.The rows with darker colored panels are installed with the front side facing West and the rows with the lighter appearance are panels installed with the front side facing East. Drone image taken looking toward the North-East (image courtesy of Advanced Solar Products).*

Figure 2. *Rutgers Agricultural Research and Extension Center, Upper Deerfield, NJ (255 kW$_{DC}$ installed, 48.6 kW$_{DC}$ grid-connected, single-axis trackers with a pivot point 2.44 m (8 feet) above ground level): Staple and specialty crop production. Three randomized blocks, each with a control area, three rows with single rows of panels, and three rows with double rows of panels. Row spacing: 10.36 m (34 feet). Each North-South-oriented row has either 21 or 42 bifacial panels. Drone image taken looking toward the East (image courtesy of Advanced Solar Products).*

Figure 3. *Clifford E. and Melda C. Snyder Research and Extension Farm, Pittstown, NJ (95 kW_{DC} installed, 82.4 kW_{DC} grid-connected, single-axis trackers with a pivot point 2.44 m (8 feet) above ground level): hay production. Two treatment blocks, each with a control area and five rows with single rows of panels. Row spacing: 9.75 m (32 feet). Each North-South-oriented row has 21 bifacial panels. Drone image taken looking toward the South-East (image courtesy of Advanced Solar Products).*

2. Design and Construction Challenges

Regulatory and political challenges

- The relatively long queue for larger projects requiring interconnection approval from the regional transmission organization (PJM).
  - While none of the RAP projects were large enough to encounter this challenge, future commercial projects may very well require interconnection approval and will then have to deal with long wait times (in some cases up to two years) before their application is reviewed.
- The time it takes the BPU to implement the Dual-Use Solar Energy Pilot Program and the potential permanent program as its successor.
  - Developing a regulatory program that outlines program rules and aims to learn from approved pilot projects takes time, especially considering the variety of stakeholders and allowing for adequate time to provide input.
- The availability of an incentive program that helps offset the added costs and reduction in electricity generation when comparing an agrivoltaic system with a traditional solar farm.
  - Compared to a solar farm, an agrivoltaic system produces less electricity per unit of land and is more expensive to build per unit of system capacity. As a result, and especially during the early stages of state-wide program development, agrivoltaic systems will only be financially attractive when additional incentives are provided to the farmer or developer.
- The municipal permitting process can take longer than expected, even when ordinances are in place that permit the installation of agrivoltaic systems.
  - Most municipal officials in New Jersey are unfamiliar with the nuances of agrivoltaics, resulting in additional time needed for the permitting process.

- Not everyone will be enamored by the idea of converting agricultural fields into agrivoltaic systems. Designers and solar developers need to be proactive with stakeholders in order to address resistance or concerns.
  - Constructing solar energy systems on farms will change the aestheticis of farmland. This is a concern for some, especially in a state such as New Jersey that has a very active farmland preservation program. Educating concerned stakeholders and citizens about the benefits of agrivoltaics can help alleviate these concerns.
- Having political support for agrivoltaics is key for developing a regulatory framework that benefits all stakeholders, including the public at large, through the expanded generation of renewable energy.
  - The support of politicians for agrivoltaics can be very helpful in shaping the public debate about renewable energy solutions, while at the same time maintaining a strong and viable agricultural industry.
  - The RAP team prioritized outreach to agricultural organizations and state agencies in New Jersey as it sought funding to build its own agrivoltaic systems. This outreach helped establish political and funding support.

Grid and utility challenges

- Each local utility company will have specific interconnection rules, charges, procedures, and timelines. It may also take many months for utility companies to review, provide feedback, and ultimately approve applications to export power. These factors are not always easy to discover upfront.
  - Our projects encountered substantial differences in how each electric utility company accommodated the installations of our projects. Our assessment is that these differences were due to company culture as well as the availability of interconnection capacity on the electric grids they manage.
- Most rural electric grids will not have the capacity to receive electricity generated from agrivoltaic systems. This is especially true when the projected output of a proposed agrivoltaic system exceeds the output of a typical residential solar installation.
  - After review by the electric utility, the local grid capacity for one of our projects was deemed insufficient to interconnect our entire agrivoltaics installation. Full interconnection was only acceptable to the utility company if expensive upgrades to the substation were paid for upfront. Our project budget did not allow for these upgrades. As a result, only approximately one-fifth of the installed capacity was grid-connected for that one project.
- Once approved, a project could experience substantial interconnection costs due to substation capacity enhancement costs and direct transfer trip modernization costs.
  - In our case, the added cost for full interconnection for one of our projects would have added almost \$3 per installed W_{DC} of system capacity.

Financial challenges

- Due to the relatively high upfront costs (in some cases exceeding \$4/W_{DC}), financing agrivoltaic projects can be challenging.
  - With the exception of self-financed projects, arranging for financing can be challenging due to the relatively small margins in agriculture and the currently high interest rates. On the other hand, adding an agrivoltaic system to a farm reduces risks by providing a more reliable source of supplemental income.
- Financial incentives are needed to make agrivoltaics more attractive to farmers and solar developers. How such incentives are structured is very important.
  - Incentives can be structured in differents ways, for example as tax credits and accelerated deductions, loans, grants, renewable energy credits, mark-ups to the price of electricity generated (so-called adders). The way such incentive programs are administered will have an impact on the beneficiaries and therefore on the attractiveness of on-farm agrivolatics.

  - The federal Inflation Reduction Act of 2022 enabled non-profit entities and universities to reduce the cost of installing renewable energy infrastructure including agrivoltaic systems by receiving a direct payment as high as 30% of total infrastructure costs.

Information challenges

- Research results from agrivoltaic studies conducted in a specific geographical area are not necessarily useful when considering projects in a different geographical area.
  - Agrivoltaics is new to New Jersey. As a result, we studied the literature to learn about applications in other parts of the country and across the world. However, we quickly discovered that due to differences in geographical and meteorological conditions, a limited number of published research resulted in outcomes that can be applied to installations designed for New Jersey.
- While agrivoltaics research is a relatively 'hot' area of academic pursuit, the number of published results is still very limited.
  - Agrivoltaics is also relatively new to the U.S. and few studies have been published that report results based on adequate statistical rigor. As a result, this novel approach that combines agriculture with renewable energy production is still very much in its infancy. This creates opportunities for research, but makes the design of commercial systems more challenging.
- Knowledge about agriculture: Solar developers have limited understanding of agriculture and will need to be informed about specific agricultural needs in order for an agrivoltaics project to be successful.
  - In order to make better predictions for the amount of electricity that can be generated with a specific agrivoltaic system, design and simulation tools are needed. While efforts are under way to develop these tools (for example [4]), it may take some time before they can be tested and validated.

Design challenges

- Knowledge about agriculture: Solar developers have limited understanding of agriculture and will need to be informed about specific agricultural needs in order for an agrivoltaics project to be successful.
  - Examples include the size and operation of (large) farming equipment, the need to minimize soil compaction during contruction, crop rotations, the possible need for crop irrigation, applications of crop chemicals, and the tendency of certain animals to interact with system features in the field.
- Project focus: Farmers interested in agrivoltaics want to maintain the highest possible agricultural production, while solar developers are focused on maximizing electricity generation. These aims are not necessarily well aligned.
  - Farmers use their land to produce crops and graze animals. Their practices are specific and necessary in order to guarantee maximum profits. Solar developers are focused on installing systems that produce as much electricity as possible for the lowest price. Aligning these different focus areas is key to implementing a successful agrivoltaics project.
- Farm fields are sometimes less than ideal for maximum solar energy production.
  - Not every farm field is rectangular, oriented North-South, or unobstructed by nearby buildings or treelines. As a result, it may not always be possible to orient an agrivoltaic system for maximum electricity generation (for example with North-South rows). A compromise may be needed to accommodate the agricultural use of the field.
- For the land to easily convert back to agriculture at the end of the useful life of an agrivoltaic system, the use of concrete as anchors for support posts should be discouraged.
  - Concrete anchors would be more difficult to remove and may create additional disturbance to the top soil when they have to be removed.
- For vertical bifacial systems, the bifaciality factor requires careful consideration of the (front and back) orientation of the panels.

  - For the North-South rows of vertical bifacial installations, the front side of the panels can be installed either facing East or West. Factors such as nearby obstructions (e.g., treelines) and average sky conditions during the morning and afternoon (e.g., on average the sky is hazier during the afternoon) can be used to determine the optimal panel orientation.
- Elevating solar panels above ground level in order to facilitate easier movement of agricultural equipment and reduce the impact of shadow patterns is a useful strategy, but will also necessitate the use of stronger support posts that may have to be installed deeper into the ground.
  - Stronger and taller support posts are more expensive to purchase and install. On the other hand, elevated panels create fewer obstructions for farming equipment and can improve visibility across the field.
- Design-build projects require sustained input from the ultimate system owner/user in order for the projects to be successful (i.e., making sure all system components are installed with future agricultural use in mind).
  - The ultimate end-user of a field with an agrivoltaic system should be involved in the design and construction of any system. An agrivoltaic system designed without the input and approval from the owner/user is less likely to be successful.
- Lightning strikes and hail damage are real risks, and are difficult to predict.
  - The occasional malfunction of a small number of panels is something that can be remedied relatively easily. However, substantial damage due to a lightning strike or hail is much more challenging to address due to the high replacement cost involved.
- Research results from agrivoltaic studies conducted in a specific geographical area are not necessarily useful when considering projects in a different geographical area.
  - The main reasons for this challenge are local differences in weather, soil, pest and disease pressures, and local agricultural practices.

Equipment procurement challenges

- Unexpected supply chain issues can delay the completion of agrivoltaic projects for many months.
  - Our projects experienced longer-than-expected shipping delays for some of the racking and electrical components. Such delays can have a major impact on the expected completion date and therefore the start of electricity generation as well as when the land can return to productive agricultural operations.
- In the U.S., certain agrivoltaic design options are more challenging to source than in other countries (e.g., single-axis tracking systems that can rotate ±90 degrees from horizontal, and vertical bifacial systems).
  - In order to minimize the impact of tracking panels on agricultural operations (primarily equipment movement), we wanted to use trackers that could rotate ±90 degrees from their horizontal position. However, such trackers were not available for projects at our size scale at the time we were designing our systems. Instead, we settled on systems that can rotate ±60 degrees from horizontal. However, we still think that tilting the panels all the way to vertical is of interest for future systems.
- It is recommended to keep several panels in reserve to replace damaged panels at any time during the life of the installation. The particular panel make and model used during construction may no longer be available at some point in the future.
  - While this is an issue for all systems designed to operate for a couple of decades or longer, agrivoltaic systems require maintenance and repairs and it is a good practice to have a certain number of spare parts available at all times (e.g., 2-5% of the panels installed).

Construction challenges

- Rocky fields make driving support posts challenging, and can drive up installation costs when refusals have to be remediated. Using stronger and fewer posts could help to overcome this issue.
  - Figure 4 shows an example of the damage caused to a post after it hit an underground rock during installation. One of our projects experienced a post refusal rate of almost 8%. The remediation consisted of augering a new hole, filling and compacting the hole with aggregate, and reinstalling a new post. The total cost for the remediation of all refusals was approximately $100,000.
- Agrivoltaic system installation requires post placement and trenching that could result in soil compaction due to heavy equipment movement. This can especially be a challenge when soil moisture levels are high during construction (e.g., as a result of frequent or heavy precipitation).
  - Figure 5 shows an example of the impact of equipment movement during the installation of an agrivoltaics project. Where possible, tracked vehicles should be used in order to minimize soil compaction.
- When trenching is required for the underground placement of electrical conduit, care should be taken to keep the excavated topsoil separate from the subsoil so it can be can be placed back at the top of the backfilled trench.
  - While this practice may be obvious to farmers, a solar contractor may not appreciate its importance. Good communication during the construction process can prevent this challenge from becoming an issue.
- Underground trenching for the installation of electrical conduit requires the installation of surface-accessible connector/combiner boxes. The placement of these boxes should be decided after considering their potential impact on agricultural activities (i.e., they should be in line with the posts and not interfere with the movement and use of farm equipment).
  - Figure 6 shows an example of an in-ground electrical combiner box that was placed in a less than ideal location. Every time farm equipment is used, the operator has to make sure the equipment does not hit the combiner box. It would have been better to install the combiner box in line with the posts that support the racking system.
- When electrical conduit needs to be run from a series of solar panels into an underground trench, it should be protected from possible damage by burying it at a depth below the operating depth of deep tillage equipment and from operating farm equipment in close proximity or inadvertently making contact with the conduit.
  - Figure 7 shows an example of minimally-protected electrical conduit installed in a location that makes it prone to an inadvertent collision by farm equipment. A stronger post should have been installed to protect the conduit, or the conduit should have been routed to the nearby support post that holds up the racking system. The latter approach was not used in this case so as not to weaken the uplift resistance of the post.

Figure 4. *A damaged post (C-channel) as a result of hitting an underground rock during installation. A new post was installed after an 18-inch hole was augered into the ground and filled with compacted aggregate. Photograph by A.J. Both.*

Figure 5. *Example of the impact of equipment movement on the soil surface after a heavy rain event. Photograph by A.J. Both.*

Figure 6. *In-ground conduit connecter box that was installed in an inconvenient location with respect to farming operations. Photograph by A.J. Both.*

Figure 7. *Conduit riser that was installed some distance away from a support post because the manufacturer claimed that underground conduits installed along the post would adversely impact the post's wind uplift strength. Photograph by A.J. Both.*

Operational challenges

- In order to assess the impact of an agrivoltaic system on crop yield or animal production, a properly-sized control area without panels is needed to ensure this impact can be assessed correctly. In addition, it may take as many as three production seasons to properly account for weather-induced variability of agricultural production.
    - Without an adequately sized control area, it will be difficult if not impossible to assess the impact of an agrivoltaic system on agricultural yield. The control area should be large enough so as to make its yield representative and to minimize the impact of soil variability.
- A farmer should consider growing a cover crop on a new agrivoltaics field for the first planting in order to help identify areas of soil compaction, uneven crop growth, and to visually assess the impact of the solar panels on a crop. This could mean losing one season of crop production but it will improve the soil quality and help with planning future crops.
    - We grew cover crops prior, during, and in some cases after installation for all three of our agrivoltaic systems and found that practice to be useful. In one instance, the cover crop helped reduce the impact of heavy equipment movement during system installation.
- Residual construction effects on agricultural land could include soil compaction in construction equipment parking areas and drive lanes, soil disturbance (e.g., putting subsoil on top of topsoil), and soil contamination by accidental or careless draining of chemicals.
    - Farmers are well-aware of these issues and the impact they can have on successive crops. However, contractors may follow typical construction practices that are usually less concerned with soil issues important for farming. These issues should be discussed prior to any work being done in the field.
- Single-axis tracking systems require more attention and maintenance than fixed tilt and vertical bifacial systems for the movement of the panels to work as intended.
    - While our tracking systems are new, it is already apparent that they need more attention and maintenance compared to our vertical bifacial system. We hope to report more on this in the future as we gain more experience.

- Parking single-axis tracking systems horizontally during periods with high wind speeds can reduce the chance of system damage. This feature should be automated.
  - For our tracking systems, this feature is indeed automated so that it can be enacted whenever high wind conditions are present.
- Driving large agricultural equipment close to agrivoltaic systems requires extra attention and time in order to avoid unintended collisions that can cause substantial damage.
  - Figure 8 shows a tractor equipped with a precision guidance system driving near one of our single axis tracking systems. Despite the use of a guidance system, the tractor operator needs to develop confidence and may initially drive slower to avoid a collision.

Figure 8. *A tractor equipped with a precision guidance system is driving near one of our single-axis tracking systems that has a maximum tilt angle of ±60 degrees from horizontal. Photograph by P. Nitzsche.*

3. Future activities

The RAP team secured funding from the U.S. Department of Energy (through the Foundational Agrivoltaics Research for Megawatt Scale, or FARMS program) that will, in part, be used to conduct crop and animal trials at our three research and demonstration sites. The crop trials include experiments with hay, staple crops such as corn and soybean, and vegetable crops such as eggplant, lettuce, pepper, spinach, and tomato. At the end of each regular growing season, cover crops (e.g., cereal rye) will be planted to maintain soil health and reduce erosion. The animal trials will include grazing of beef cattle. Results of these experiments will be published and shared widely with the agrivoltaics community and its various stakeholders. Additional research is planned for a comprehensive evaluation of the impact of agrivioltaic systems on soil health, and for a life cycle assessment that compares the environmental impact of agrivoltaic systems versus common agricultural practices. Outcomes of our research activities are intended to result in establishing best practices that can help inform New Jersey land owners, farmers, and developers, as well as the state regulatory agencies tasked with implementing the Dual-Use Solar Energy Pilot Program. Additionally, we hope that our efforts will contribute to national and international research and demonstration projects on agrivoltaics.

Data availability and underlying & related material

Individuals interested in learning more about the activities of the members of the Rutgers Agrivoltaics Program are encouraged to contact David Specca, RAP team lead, at specca@njaes.rutgers.edu.

Author contributions

Conceptualization: All co-authors; Funding acquisition: All co-authors; Project administration: DS, DW; Visualization: AJB, PN, Advanced Solar Products; Writing – original draft: AJB; Writing – review and editing: All co-authors.

Competing interests

The authors declare that they have no competing interests.

Funding

Funding for the activities of the Rutgers Agrivoltaics Program has been provided by the New Jersey State legislature, the New Jersey Board of Public Utilities, The U.S. Department of Energy, and the New Jersey Agricultural Experiment Station.

Acknowledgement

We gratefully acknowledge the institutional support we received that allowed us to investigate, design, and construct the three agrivoltaic systems that were built at Rutgers University farms.

References

[1] Rutgers Agrivoltaics Program. Available at: https://agrivoltaics.rutgers.edu/
[2] New Jersey Legislature. 2021. Dual-Use Solar Energy Pilot Program. Bill S3484. Available at: https://www.njleg.state.nj.us/bill-search/2020/S3484/bill-text?f=S3500&n=3484_S1
[3] New Jersey Clean Energy Program. Available at: https://njcleanenergy.com/
[4] Rucker, W.R. 2024. Understanding and improving tandem solar cells and developing agrivoltaics for the Garden State. Ph.D. Dissertation. Rutgers University Libraries. 178 pp. Available at: https://rucore.libraries.rutgers.edu/rutgers-lib/71894/