Agrivoltaics with Row Crops as a Pathway to Solar Farming on Cropland

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Abstract

Expansion of utility scale solar farming on cropland in the Midwestern United States is leading to community opposition to what is perceived as a significant diversion of land from the production of food/feed (row) crops. To address this conflict, there is growing interest in agrivoltaics that co-locates solar energy generation and row crop production on the same land. Row crop agrivoltaics is yet to occur at scale. We discuss the potential drivers, economic incentives and barriers for scaling row crop agrivoltaics and its implications for conserving land and for the costs of food and energy production. We conclude with a discussion of the institutional and market changes needed for row crop agrivoltaics to transition from concept to solution by increasing the social acceptability of producing solar energy on cropland.

Introduction

Solar energy production has seen rapid growth in the US in recent years due to declining cost and favorable policies and has accounted for the largest share of all new electricity-generating capacity additions since 2019 (EIA, 2026, SEIA, 2023). Utility-scale photovoltaic solar systems are the dominant form of solar development in the US, accounting for 63% of cumulative solar capacity in 2022 (Bolinger et al., 2023). Utility scale solar energy is land-intensive and cropland is well-suited for it because it provides large, continuous tracts of relatively low cost, flat, well-drained land, with unobstructed solar radiation, in the proximity of grid infrastructure (Adeh et al., 2019). This lowers the capital costs of site preparation and enables economies of scale by combining multiple, nearby parcels into larger projects. In 2020, over 93% of utility-scale solar capacity was in rural areas with 66% of solar farms in the Midwest installed on land that was previously cropland (Maguire et al., 2024).

The aggregate amount of US cropland currently being used for solar energy is relatively small, about 0.5% of farmland acres in 2020 (Maguire et al., 2024). Studies estimate that the upper bound on the area requirements of forecasted solar will range from 1.1% to 2.4 % of the area of croplands in 2050, even if we assume all new solar power capacity is installed on cropland (Diffendorfer et al., 2024). Although the aggregate amount of land under solar farming is expected to remain small (DOE, 2021; Sorensen, 2022), the share of cropland converted to solar farming can be large in some counties with farmland located close to the transmission grid and a small amount of land remaining in agriculture. As a result, there is growing opposition at a local and national level to conversion of cropland to utility scale solar energy generation resulting in bans on solar energy development in many counties in the US; as of 2022 there were 839 local zoning restrictions related to solar development in the US (Susskind et al., 2022). At least 22 counties in nine states have set limits on the number of agricultural acres that can be used for solar power, to impede its buildout (Lopez et al.,2023). This opposition is leading to delays and cancellations of solar projects and challenges for solar developers to access the lowest cost land for energy development.

Land lease rates offered by solar energy developers are often several-fold higher and more certain than the returns from crop production. This has led many landowners to benefit from leasing their land for solar development (Moore et al., 2021). A large share of these landowners in the Midwest do not operate their land or live in rural communities; thus, solar farming displaces tenants and transfers the income from the land from rural to urban areas with no benefits to the local community in which it is occurring. This can lead to uneven distribution of benefits and burdens within and across different population groups in rural and urban areas; concentrating benefits among distant landowners and solar energy developers located in urban areas while local communities face reduced access to land and higher land prices. Moreover, the loss of cropland to solar farming in small rural communities can make existing agribusinesses and supply chains unviable and create stranded infrastructure (Ross, 2024). Stakeholder interviews also indicate opposition to solar farming because it poses a threat to aesthetics, identity, heritage, and place-based attachment for the community associated with farming (Swanson et al., 2025; Goldberg, 2023; Sorensen et al., 2022; Moore et al., 2022). Conversion of agricultural lands to solar energy generation also raises concerns about how to best maintain other ecosystem services such as soil health and fertility (Sturchio and Knaap, 2023).

Agrivoltaics is an emerging solution that enables agricultural operations interspersed with panels or underneath raised panels on the same land. Agrivoltaics has the potential to provide numerous benefits, including reducing soil moisture loss and the need for irrigation in arid and semi-arid conditions, protection for crops from extreme temperatures and precipitation and higher yields of shade-tolerant crops, compared to growing these crops in full sun (Barron-Gafford et al., 2019; Knapp and Sturchio 2024; Dinesh and Pearce, 2016; Laub et al., 2022; Schweiger and Pataczek, 2023). Agrivoltaics has also been found to increase solar panel yield due to cooling by the vegetation surrounding it by some studies (Barron-Gafford et al., 2019; Khanna et al., forthcoming). A recent analysis shows the benefits of co-locating solar panels with perennial vegetation on corn acres in the Midwest for reducing nutrient run-off and providing local wildlife habitat (Sturchio et al. 2025).

Agrivoltaic sites emerging in the Midwest have largely integrated pollinator-friendly habitat or sheep grazing with solar panels; these are feasible without making modifications to a conventional solar farm. Experience with growing row crops interspersed with solar panels is limited to experimental sites (Kim et al., 2025) and yet to occur on large scale commercial operations (Dohlman et al., 2024). For agrivoltaics to be adopted at scale and address the perceived conflict between food/feed and energy production on cropland in the US Midwest, it will need to integrate row crop production with solar panels. A salient issue then is whether row crop agrivoltaics will appeal to solar developers, farmers and local communities and enable the spread of solar farming on cropland. We provide a perspective on this with a focus on the Midwestern US, with millions of acres of land in industrial scale corn, soybean and wheat production for livestock feed surrounded by well-developed infrastructure and supply chains to store, process and deliver it. We rely on emerging scientific evidence, including from a multi-institutional, interdisciplinary research project funded by the USDA investigating sustainable co-location of agriculture and photovoltaic electricity systems (SCAPES).

Agrivoltaics with Row Crops in the US Midwest

Growing row crops in between or underneath solar panels at current scales of production in the US Midwest will require modifications to the height of the panels and the spacing between panels, to decrease the likelihood of crops shading panels and reducing energy production and to allow agricultural operations with conventional farm equipment. Row crops range in height from 1 meter (soybeans and wheat) to about 3 meters (conventional corn) (Berti et al., 2021); thus, growing even relatively shorter crops can require raising solar panel height above the typical height (approximately 0.5m at the lowest edge) of panels in a conventional fixed-tilt solar farm. Agrivoltaic solutions involve making choices about the configurations of solar panels and crops, design and density of panels, type of panels used and height and spacing between panels. Panels can be either vertical, fixed tilt or track the sun with single, double or triple axis and be monofacial or bifacial; these choices will affect how solar irradiance is shared between panels and crops and the size of the equipment that can be operated between panels (Sarr et al., 2023). Additionally, row crop agrivoltaics require increasing the spacing between rows of panels to accommodate large scale agricultural equipment and allow for light to reach crops. In a typical single-axis tracking solar farm in the Midwest the distance between panels is 5.5 meters; this is too narrow to operate conventional farm equipment needed for tilling, planting, and harvesting row crops. The operation of this equipment will require wider spacing between panel rows which is two to three times larger than that in a conventional solar farm. Additionally, production of crops next to panels also requires leaving some land unused as buffer areas around and under panels and at the ends of rows to enable farm equipment to turn and operate between panel rows (Khanna et al., forthcoming).

Effect of Agrivoltaics on Row Crop Yields and Energy Generation

Evidence of the implications of growing shade intolerant row crops, such as corn and soybeans, in the Midwest next to or underneath solar panels is limited to a few experimental sites (Kim et al., 2025; Turnley et al. 2024) and to simulation models that extrapolate findings to a regional scale (Jia et al. 2026a, 2026b). This research shows that the impact on crop yields varies across crops, climatic conditions and configuration of the agrivoltaic infrastructure. Kim et al. (2025) found that while the impact of agrivoltaic farming on sorghum yield was statistically insignificant, soybean yield declined by 75% relative to conventional full sun farming conditions. Similarly, the yield of corn grown underneath tall solar panels was found to decline substantially, with the negative impact increasing as the density of panels increased (Turnley et al. 2024). Extrapolating these impacts of Agrivoltaics to agricultural lands that are primarily rainfed (not irrigated) using the Community Land Model version 5 (CLM5), Jia et al. (2026a,b) show that agrivoltaics generate strongly divergent yield responses along east–west climate gradients. In the more humid eastern Midwest, panel shading reduces photosynthetically active radiation, causing substantial yield losses for maize (20–25%) and soybean (10–16%), whereas in more arid western regions, shading alleviates heat and water stress, leading to moderate maize losses (10–12%) but soybean yield gains (5–7%), under a scenario with solar panel ground coverage ratio of 33%. These process-based simulations further indicate that agrivoltaics enhance soil moisture and carbon assimilation in water-limited environments but reduce productivity in wetter regions due to light limitation.

The height, density, and configuration of the solar panel array in an Agrivoltaic setting have implications for the choice of crops that can be grown and crop rotations. Shorter panels will limit the ability to practice continuous corn or corn-soybean rotations that are typical in the Midwest (USDA, 2024). Farmers in this region would be restricted to rotations compatible with agrivoltaics (such as continuous soybean or soybean-wheat) which have been disfavored because they are relatively less profitable.

While agrivoltaics may reduce crop yields per unit land it does enable energy generation on the share of land with solar panels. Under some conditions energy output per panel may increase due to vegetation-induced cooling (Sarr et al., 2023). Evidence of the vegetation-induced solar panel cooling effect is mixed with some studies finding an increase in solar energy yield per panel under dryland conditions (Barron Gafford et al., 2019) and others finding no effect in humid temperate conditions (Choi et al., 2024).

The concept of land equivalent ratio (LER) is an ecology metric that has been utilized to examine the efficiency of agrivoltaics compared to crops alone or solar energy alone. The LER is defined as the sum of the ratio of solar energy yield with agrivoltaics to solar alone and the ratio of crop yield with agrivoltaics to crops alone. It is a dimensionless metric that can be greater, equal to, or less than one. Agrivoltaic systems with specialty or forage crops in arid or semi-arid environments have often demonstrated LER values well above 1, sometimes exceeding 1.5 (Barron-Gafford et al., 2019; Dinesh & Pearce, 2016). Even in the case of row crops, Kim et al. (2025) and Jia et al. (2026b) find that integrating crops with solar electricity generation achieves an LER above 1, despite shade-induced crop yield reductions, indicating that the combined productivity of land is higher with the co-location of solar energy generation and crop production relative to a monofunctional use of that land.

Effectiveness of Agrivoltaics in Conserving Land

Despite the potential for an LER greater than 1 with row-crop agrivoltaics, large scale conversion of land from conventional farming to agrivoltaics can lead to displacement of some crops that are not suitable for agrivoltaic settings and lower absolute quantities of production of row crops planted, due to shading induced reduction in yield and loss of land to buffer areas and solar panels. This will imply the need for bringing more land into crop production elsewhere, at the extensive margin, to meet the same levels of aggregate production of those crops. Similarly, solar energy generation per unit land may decline due to lower density of panels in an agrivoltaic setting compared to a conventional solar farm, despite a potential increase in energy generation per panel. This will reduce total solar electricity generation or require more land for the same level of electricity production, which could exacerbate the land use conflicts in communities.

As compared to monofunctional uses of land for food and energy production which concentrate intensive row crop production in the most productive land areas and place solar energy installations in the lowest energy production cost areas, agrivoltaics could lead to the need for more land area to meet the same aggregate amount of solar energy and crop production. Khanna et al. (forthcoming) find that agrivoltaic deployment with soybean production could require approximately 20% more land to achieve the same soybean output as a conventional crop-only field in the U.S. Midwest. An agrivoltaics system would lead to less-intensive crop and less-intensive solar energy production and spread it out over a larger land area and thereby increase the extensive margin of crop and solar energy production. This can raise concerns about converting non-cropland to crop and energy production and be counter-productive to conservation goals.

Economic Incentives for Row Crop Agrivoltaics for Farmers and Solar Developers

The preference of solar developers and farmers for solar alone or crops alone, respectively, compared to agrivoltaics will depend not only on effects of productivity but also on profits for the solar developer and the farmer. A higher LER does not indicate higher profitability, and therefore, does not ensure that solar developers and farmers would have economic incentives to choose agrivoltaics instead of solar farming or crop farming alone, respectively. The key economic drivers of the choice to adopt agrivoltaic solutions for a solar developer include the effect on the upfront capital costs and the operating and maintenance costs which include managing vegetation on the solar farm. Raising the height of panels and burying the electricity cables underground to enable crop production significantly raises the initial installation costs of panels (30-40%) due to the need for taller steel posts, deeper foundations, more reinforced supports and greater labor time (Horowitz, 2020). These costs could potentially be offset in part by lower vegetation management costs and lower land lease costs.

Khanna et al. (forthcoming) show that agrivoltaic configurations are currently economically uncompetitive relative to conventional solar farming systems. Taller panels can potentially more than double total system costs and may raise the cost of solar electricity to be more than twice that from conventional solar energy generation alone, despite modest gains in energy output and savings in land or vegetation management (McCall et al., 2023). Agrivoltaics could also reduce economies of scale that are achieved by concentrating solar energy generation in its most suitable locations and raise electricity generating costs by increasing the distance from the transmission grid. Moreover, agrivoltaic installations that span county lines and that require coordination of crop choices and management across multiple farm owners will raise the transaction costs for solar energy development. Solar developers are, therefore, not likely to find it profitable to make any alterations to the height and spacing of panels. Regulatory incentives for agrivoltaics, such as tax credits and favorable zoning laws, as well as market conditions that allow solar energy developers to charge a higher price of electricity from downstream customers for electricity generated from agrivoltaic installations. Survey respondents in Germany reported a willingness to pay a higher price for electricity from agrivoltaics compared to solar farming alone because they perceived less negative impacts of agrivoltaics on landscape attractiveness as compared to solar panels alone (Zeddies et al., 2025).

The economic incentives for farmers to adopt agrivoltaics instead of solar farming or crop farming will depend on the relative returns to land from these alternative uses and the modifications to agricultural operations required. For non-operating landowners seeking to earn the highest return on land, solar farming offers rental rates that are several-fold higher and more certain than the agricultural land rental price; thus, leasing land to solar generation alone is likely to be the preferred choice. For owner-operators, agrivoltaics offers a mechanism to maintain access to farming and diversify income sources from the same land and co-mingle panels with green spaces. With sufficiently high lease rates and returns for vegetation management, the overall returns to cropland for an owner-operator can be higher and less risky than from using it for crop production alone despite lower crop yields on the farmed portion of the land. Tenant farmers may also prefer operating in an agrivoltaic site instead of losing all access to land if it is converted to a conventional solar generation site. However, the need to switch cropping systems or change crop rotations and acquire new farming equipment can raise the cost of crop production.

Agrivoltaics as an Enabler for Solar Farming on Cropland

Looking beyond solar developers and farmers, a key question is whether row crop agrivoltaics can reduce community opposition to solar farming on cropland. By enabling agricultural production and preventing large tracts of land under solar farming only, Agrivoltaics allows for preservation of the social fabric and place-based attachment for a community that is threatened by solar farming. By permitting tenants to continue farming, agrivoltaics can reduce the adverse impacts of solar energy production on agricultural employment. With low density solar energy generation, Agrivoltaics can spread out the economic benefits of solar farming over a larger land area and may be perceived as being more equitable than solar farming alone where benefits may be concentrated among a few landowners. Surveys in the US indicate that over 80% of respondents would be more likely to support solar development in their community if it is integrated with agricultural production (Pascaris et al. 2022) and that the potential to reduce community opposition and obtain a social license to operator was a key motivator for solar developers to develop agrivoltaic installations (Mishra et al. 2026).

However, there is currently no standardized definition of agrivoltaics, in terms of solar panel configuration, panel density, panel height and ground coverage ratio. Utility scale solar developers have limited incentives for modifying spacing or height of panels and may view agrivoltaics as a nominal technology-fix to address land use conflicts and gain acceptance by the agricultural community rather than as an approach that addresses their underlying concerns with solar farming on cropland. However, farming between short panels and narrow rows may only appeal to some small and beginning farmers or tenant farmers, that may otherwise not have access to agricultural land, willing to modify crops planted and equipment used. Moore et al. (2021) note that commercial farmers identifying themselves as corn and soybean farmers do not view producing other crops for forage or other specialty markets as farming and are skeptical about the feasibility of agrivoltaics.

Additionally, under the existing approach to solar farming, energy generation and crop production are two different businesses with solar developers lacking familiarity with crop farming and farmers unfamiliar with the solar industry. Developers finance the project and provide landowners with a fixed lease rate for the lifetime of the project. The returns to the land from solar energy generation may create some solar-related jobs locally but most fiscal resources leave the community. This would not fundamentally change even with agrivoltaics if landowners are simply leasing land to the developer and have limited opportunities for co-optimizing food and energy production on the same land. Moreover, the need for large scale investment and financing to establish a solar farm will require alternative models for corporatization of an agrivoltaic installation by a community of farmers. In the absence of that, current concerns with solar farming being imposed on farmers (rather than co-developed) and leading to a transfer of wealth from the land and the local community to urban areas will remain with agrivoltaics as well. New agrivoltaic business models that promote smaller-scale, farmer- or community-centric installations in which the farmer owns or co-owns solar energy development to generate solar energy for on-farm use and to supply the excess to the grid may provide more socially acceptable opportunities for co-producing row crops and solar energy.

Agrivoltaics is an emerging industry that is currently being offered as an opportunistic solution to appease opposition from the agricultural community by fitting in agriculture with minimal modifications to solar energy generation. It's important to note that agrivoltaic approaches can be as diverse as agriculture itself, solar infrastructure integrated with specialty crops, pollinator plants, pastures and rangelands and even orchards and vineyards (Macknick et al., 2022). Here we focus on row crop agriculture and it is clear that Agrivoltaics with row crops is currently suboptimal from agronomic, economic, and electricity-generation perspectives and thus challenging to scale up. For row-crop agrivoltaics to enable a more comprehensive solution to the conflicting demands on land, significant changes in technology, institutions, and markets will be needed; these could include a shift from utility-centric models of solar energy generation and agrivoltaics ownership to farmer owned and operating systems with more distributed models of energy production. The choice between monofunctional land use vs agrivoltaics hinges on the specific local context, shaped not only by economic factors but also by social, cultural, and community-driven influences. Transitioning land for solar energy development necessitates collaboration with the agricultural community to establish mutually acceptable land-use practices that address social equity concerns and the potential disruption to established ways of life rather than relying solely on transactional arrangements.

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