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Cover Page Footnote

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Tools of the Trade

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Agrivoltaic Decision Tools for Perennial and Field Crop Farmers

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Abstract. This article describes a series of spreadsheet-based tools to help farmers estimate costs, revenues, and yields from agricultural production under different configurations of agrivoltaic installations for field and perennial crops. Crop-specific log books allow farmers to project changes in activity-level costs from the field due to agrivoltaic installations. The whole-farm tool helps farmers aggregate activity-level net returns up to the farm level to calculate projections of trade-offs between crop production with or without agrivoltaic installations. We present tools for lettuce and cranberries, but the tools are comprehensive and inclusive and so can be modified for other perennial and field crops.

INTRODUCTION

Renewable energy production goals in the United States include significant increases in ground-mounted solar installations that are targeted to cover up to 10.3 million acres of land by 2050 (U.S. Department of Energy [DOE] & the National Renewable Energy Laboratory [NREL], 2021). In establishing this goal, the U.S. DOE proposes that some portion of coverage could be attained by increasing agrivoltaic installations, in which solar energy production is colocated on productive agricultural land. Ideally, agrivoltaics present an opportunity to meet renewable energy goals while supporting food and fiber production, farm profitability, and rural communities (DOE & NREL, 2021). Figure 1 shows an example of agrivoltaic lettuce production.

Figure 1. Lettuce production under agrivoltaic installation. Photo credit: Sam Glaze-Corcoran

Robust and research-based impacts of agrivoltaics on agricultural production and operation profitability, however, are not yet available to farmers, as the agrivoltaic concept is new. There are no published research results or decision tools that farmers can use to make informed decisions regarding whether or in what configuration agrivoltaics might be a good fit for their operation. Several research projects are underway to understand how best to support the expansion of solar power in agriculture and build a foundational knowledge base that can inform farmers' and policymakers' choices when pursuing goals including sustainable energy production, farm economic viability, and farmland protection (Breger et al., 2020; Dupraz et al., 2011; Guerin, 2019). At the same time, solar developers, state governments, and other stakeholders actively advocate for farmers to adopt agrivoltaics.

To provide farmers and Extension providers with tools to help farmers make informed decisions, as well as to support future research to understand trade-offs between agricultural and energy production from agrivoltaics, we developed agrivoltaic decision tools for farm-level agricultural production decisions. Decision tools aid farm decision-making—for example, whether to build commercial kitchens (Bowser & Holcomb, 2018) or optimize bale-wrapping (Pruitt & Lacy, 2014). This study provides two tools that allow farmers to compare agricultural production on land under agrivoltaics to land without agrivoltaics as a starting point for further financial assessment. As developed, the tools are designed for lettuce and cranberries and rely on generalized assumptions for agricultural yield trade-offs that reflect impacts of arrays on agricultural production costs and revenues. The tools are designed to be modified to reflect different crops and farm-specific contexts. The tools can be used to develop inputs for the Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) 1.0 Agrivoltaic Financial Calculator, a module in NREL's System Advisor Model, a free techno-economic software model that facilitates decision-making for people in the renewable-energy industry (Macknick et al., 2022).

FEATURES

The two spreadsheet-based tools can be used together or separately to help farmers determine whether or how to best incorporate agrivoltaics into their operation. User guidance is embedded in each Excel Workbook. Users provide information in aqua or light gray cells. Salmon-colored cells pull data from other worksheets.

The crop-specific log book identifies farm-level activities, while the whole-farm tool helps farmers aggregate activities-level net changes up to the farm level to calculate projections of trade-offs between crop production with or without agrivoltaic installations. Data entered into the log book are subsequently imported into the whole-farm tool. The whole-farm tool has several additional data-entry worksheets to identify costs and revenues as they relate to the entire farm operation to calculate net revenues per acre. An overview of the relationships between different worksheets within each tool and between the two tools is shown in Figure 2.

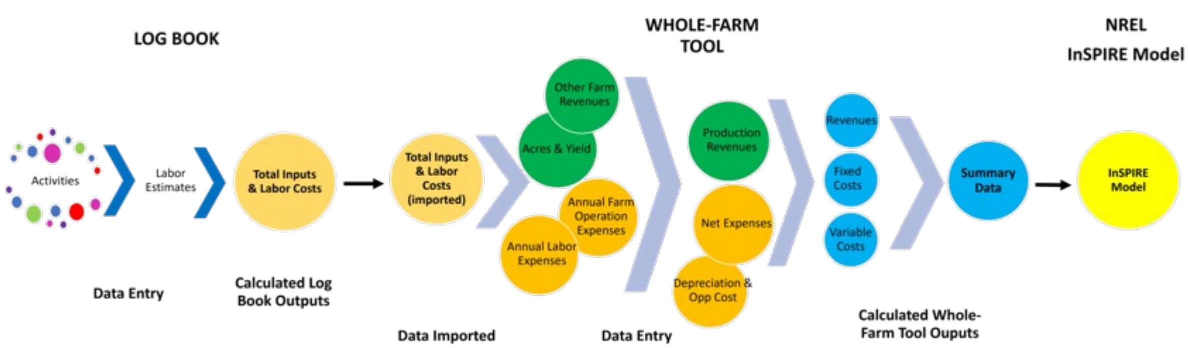

Figure 2. Decision tool schema.

CROP-SPECIFIC LOG BOOK

The first worksheet identifies crop-specific activities, first without agrivoltaic installations and then with installations of different configurations (e.g., spacing, height, different technologies). The second worksheet draws entries from activities entered in the first worksheet. Using a slider, the user estimates relative labor costs of performing the activity under different configurations.

For example, tillage without agrivoltaics may take a few hours of a farm manager's time, using a tractor and fuel. The farmer enters the activity, labor time, and input costs into the activities worksheet. Under an agrivoltaic configuration, a farmer may feel more cautious, taking more time and using more fuel. Or, they may choose to use a less efficient but also less risky piece of equipment to avoid mistakenly affecting a solar panel.

The activity, labor time, and input costs that the user enters into the worksheets are compiled across activities and automatically calculated in two separate worksheets—"Inputs and Supplies" and "Labor Hours and Costs"—where they can be compared. These two worksheets are imported into the whole-farm tool. Figure 3 shows the "Inputs and Supplies" sheet.

Inputs and Supplies (Non-Labor)

Average Fuel Costs

Gasoline/ Gallon	$ 4.00
Propane/ Gallon	$ 3.00
Diesel/ Gallon	$ 5.00
Electricity/KwH	$ 0.26

No Agrivoltaics

Input / Supply	Input Type/ Unit	Units Used in Activity	Cost per Unit Type	Total Cost Per Category	Total Input/ Supply Costs
Fuel	Gasoline/ Gallon	7	$ 28.00		
	Propane/ Gallon	0	$ -		
	Diesel/ Gallon	18	$ 90.00		
	Electricity/KwH	20	$ 5.20		
				$ 123.20	
Equipment Hire Costs			$ 213.00		
				$ 213.00	
Other Input Supplies/ Costs			$ 3,000.00		
				$ 3,000.00	
Chemicals Costs					
				0	
Total Inputs and Supplies (Non-Labor)					***$ 3,336.20***

Figure 3. Log book "Inputs and Supplies" sheet.

WHOLE-FARM TOOL

The first step is for the user to import the "Inputs and Supplies" worksheet from the log book into the "Inputs(Imported)" whole-farm tool, and the "Labor Hours and Costs" worksheet from the log book into the "Labor Hours Cost(Imported)" in the whole-farm book. This process can be as simple as copying/pasting the salmon-colored cells.

The user can enter line-item annual revenues (Green Tabs) and expenses (Orange Tabs) into the relevant worksheets to obtain calculated totals, or they can enter estimated totals directly into the summary (Blue Tabs) worksheets, depending on their interest in understanding detailed impacts of fixed versus variable costs in estimating trade-offs. If entering line items, the next step is to enter a previous year's harvest into "Acres and Yield" to provide a baseline and then estimate changes in yields per acre under different configurations. Solar configuration options are available in the InSPIRE Agrivoltaics Financial Calculator. Finally, the user enters the revenues per pound into the green "Production Revenues" tab along with any market-specific factors and "Other Farm-Related Revenues." Then, they enter data into "Annual Farm Operation Expenses," "Annual Labor Expenses," and "Depreciation & Opportunity Cost." "Net Expenses" calculates previously entered data.

The "Summary Data" worksheet pulls calculated data from all revenues and expenses worksheets to provide a comparison of net revenues from the baseline year, with no agrivoltaics, and projected configurations over 3 years. It provides calculations of net revenues per unit, revenues per acre, and proportions of fixed, variable non-

These Values are can be used in the NREL InSPIRE DUAL USE FINANCIAL MODEL

NET REVENUES from Configurations

Calendar Year 2022 (Base Year)

	Revenues from Configuration	Net Revenues Variable Costs Assigned to	Fixed Costs Assigned to Configuration	Net Revenue from Configuration
No Agrivoltaics Acres	$ -	$ -	$ -	0
Acres with Configuration A				
Agrivoltaic Installations	$ -	$ -	$ -	0
Acres with Configuration B				
Agrivoltaic Installations	$ -	$ -	$ -	0
Acres with Configuration C				
Agrivoltaic Installations	$ -	$ -	$ -	0

Calendar Year 2023 (Year 1)

	Revenues from Configuration	Net Revenues Variable Costs Assigned to Configuration	Fixed Costs Assigned to Configuration
No Agrivoltaics Acres	$ 269,325.00	$ 5,434.20	$ 13,701.17
Acres with Configuration A			
Agrivoltaic Installations	$ 538,650.00	$ 5,372.00	$ 35,231.59
Acres with Configuration B			
Agrivoltaic Installations	$ 299,250.00	$ 5,422.70	$ 19,573.11
Acres with Configuration C			
Agrivoltaic Installations	$ 578,550.00	$ 5,333.70	$ 37,841.34

Calendar Year 2024 (Year 2)

	Revenues from Configuration	Net Revenues Variable Costs Assigned to Configuration	Fixed Costs Assigned to Configuration
No Agrivoltaics Acres	$ 628,425.00	$ 6,250.00	#REF!
Acres with Configuration A			
Agrivoltaic Installations	$ 658,350.00	$ 3,263.06	$ 44,369.55
Acres with Configuration B			
Agrivoltaic Installations	$ 219,450.00	$ 7,220.80	$ 14,789.85
Acres with Configuration C			
Agrivoltaic Installations	$ 239,400.00	$ 7,310.32	$ 16,134.38

Net Revenues (Calendar Year 2022)

	Net Revenue per Acre	Net Revenue per Barrel
No Agrivoltaics Acres		
Acres with Configuration A		
Agrivoltaic Installations		
Acres with Configuration B		
Agrivoltaic Installations		

Net Revenues (Calendar Year 2023)

	Net Revenue from Configurations	Net Revenue per Acre	Net Revenue per Barrel
No Agrivoltaics Acres	**$ 250,189.63**	$ 3,069.81	$ 2.65
Acres with Configuration A			
Agrivoltaic Installations	**$ 498,046.41**	$ 18,446.16	$ 2.64
Acres with Configuration B			
Agrivoltaic Installations	[illegible]	[illegible]	[illegible]

Net Revenues (Calendar Year 2024)

	Net Revenue from Configurations	Net Revenue per Acre	Net Revenue per Barrel
No Agrivoltaics Acres	**#REF!**	#REF!	#REF!
Acres with Configuration A			
Agrivoltaic Installations	**$ 610,717.39**	$ 18,506.59	$ 2.64
Acres with Configuration B			
Agrivoltaic Installations	[illegible]	[illegible]	[illegible]

Figure 4. Whole-farm summary sheet.

agrivoltaic, and variable agrivoltaic costs harvested under different configurations. The whole-farm tool is designed to generate outputs that can be easily entered into the InSPIRE model discussed above. These calculated values are provided in the "Summary Data" worksheet, highlighted in yellow. Figure 4 shows the "Whole-Farm Summary Sheet." The InSPIRE model allows farmers to use on-farm revenues and costs under different assumptions regarding purchasing, leasing, using subsidies, contractual payments, and other capital costs and revenues associated with the actual solar-array installations and energy production and sales.

SUMMARY

By using decision tools, farmers and Extension providers can estimate trade-offs associated with agrivoltaic installations to make informed decisions about whether or in what configuration agrivoltaics make sense for an operation. Potential trade-offs identified by the tools in this article may include changes in agricultural production under solar panels, changes in costs of production, changes in on-farm practices, and so forth. Extension providers could use the Agrivoltaic Decision Tools to help farm operators assess the trade-offs between lettuce and cranberry production that would occur with and without agrivoltaics. Extension providers could easily modify the tool parameters to reflect different field and perennial crops. To understand how these trade-offs relate to potential benefits from agrivoltaics, farmers and Extension providers could take outputs from these tools and use them in the InSPIRE Agrivoltaic Financial Calculator developed by NREL. The workbooks could serve as a basis for smartphone or tablet applications or could be used alongside existing cost- and activity-tracking apps.

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