Improving Productivity of Cropland through Agrivoltaics

Alexander Nassar[1], Ivan Perez-Wurfl[1], Carolin Roemer[1], Ziv Hameiri[1]

[1]*University of New South Wales, Kensington, NSW 2052, Australia*

Introduction

The concept of combining photovoltaics (PV) with agriculture (agrivoltaics or APV) is being explored across the globe and has established field trials in countries including, but not limited to, Germany, Vietnam, Italy, France, Japan and Chile [1]. An agrivoltaic system involves positioning solar panels directly above or near active agricultural land to provide some form of shading to the crops and to generate electricity from the solar array [2]. The usefulness of this concept is seen when considering the abundance of land that becomes available to the PV market if that land can be shared with the agricultural sector. For instance, consider that in 2016 Australia used 372 million hectares of land for agriculture, of which 8.3% was designated cropland [2]. Therefore, even if some proportion of this cropland (say an 8th) are retrofitted with overhanging PV systems, Australia's effective solar generation area would increase by roughly four million hectares. This would greatly enhance the renewable energy sectors ability to satisfy baseload energy requirements of the national grid.

At first glance the concept of shading plants seems counterintuitive to the perception that cropland should be without obstructions. However, agrivoltaics recognises that crops do not require every hour of sunlight to photosynthesise. Consequently, the solar energy resource can effectively be shared with photovoltaic technology to increase the productivity of the land without greatly decreasing the yield of the crop, and in some cases, increasing crop yield [3]. This is achieved by spacing the rows of solar panels in such a way that the shadows caused by the panels still permit crops to photosynthesise sufficiently in addition to reducing heat related stress caused by the environment. As such, this study aims to review existing literature about agrivoltaics and use experimentation to explore if the advantages they provide are great enough to justify their introduction into Australian agriculture. A key parameter for this study is land productivity that is measured using "land equivalent ratio" (LER) which is a combination of crop yield (measured in kilograms) and energy production (measured in watt-hours). Equation 1 demonstrates how this is calculated:

$$LER = \left(I_E \left(\frac{Energy_{APV}}{Energy_{SF}} \right) + I_Y \left(\frac{Yield_{APV}}{Yield_{farm}} \right) \right) \quad (1)$$

The interest in energy (I_E) and the interest in yield (I_Y) are values between 0 and 1 that represent how the owner of the system prioritises energy output and crop yield. These coefficients are used to present different points of view that a landowner can use to interpret the results of an agrivoltaic trial. Additionally, $Energy_{APV}$ is the energy generated by the PV array for a stilt mounted agrivoltaics system, $Energy_{SF}$ is the energy generated from an equivalent ground mounted solar farm, $Yield_{APV}$ is the crop yield of the agrivoltaic system and $Yield_{farm}$ is the crop yield of a traditional farm (without overhead solar panels) [4].

Method

In this study, a small-scale agrivoltaic system is investigated in the western suburbs of NSW, Australia. The photovoltaic output of the simulated array is modelled using the program System Advisory Model [5]. The crop yield is calculated by growing crops under nearly identical conditions using two plots of soil (each plot is 13.4 meters by 1.15 meters). One plot serves as the traditional farm setting (no shading), while the second plot functions as an agrivoltaic-like setting (partial shade). In this plot the solar panel shadows are created using black tarps that are suspended one meter above the crops with 1.3 meters between each tarp. Based on measurements, we estimate 50% shading; meaning half of the plants are shaded at any given day time between 9am and 4pm. The selected crops for the first season are lettuce (Green Mignonette) and silverbeet (Fordhook Giant).

The used harvesting method for both plants involved using a pitchfork to loosen the soil beneath the plant and then remove the plant from the ground with everything intact. The main body of roots is cut from the plant and only the remaining, marketable part of the crop, is weighed on electronic scales. This is repeated for every plant in both plots. During harvesting, random plants are selected to undergo drying for three hours by being placed into dehydrators. After the drying process, the plants are weighed again. A Chlorophyll meter (CHL PLUS from atLEAF) is used to measure the relative chlorophyll content of the plant leaves. This is measured to provide an indication of plant growth if all the crops are killed before they can be harvested, due to extreme weather, pests or disease. Moreover, a soil lab test was conducted on both plots to ensure it was able to grow crops, as well as to ensure near identical conditions for both plots.

Results and Discussion

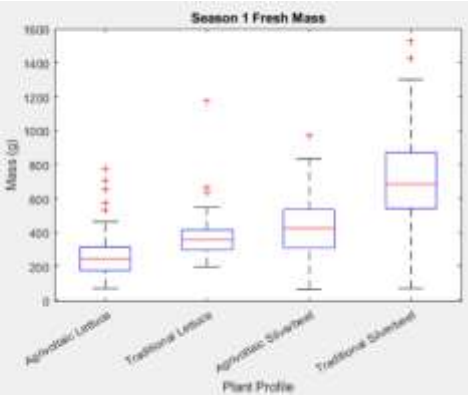

Figure 1: Fresh mass per lettuce and silverbeet plant.

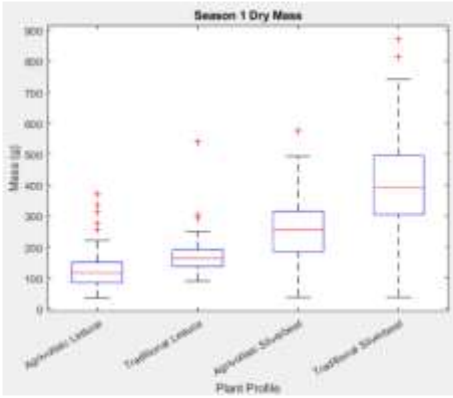

Figure 2: Dry mass per lettuce and silverbeet plant.

Figure 1 presents the fresh mass of the crops, while Figure 2 shows the dry mass of representative crops from each group. The latter is a better indicator of the plant mass, since water in the leaves can impact the fresh mass measurement. We assumed that the agrivoltaic plot could produce at least 90% of the yield of a traditional plot. However, in terms of fresh mass, the agrivoltaics plot only grew 72% of the lettuce that the traditional plot grew. Additionally, the agrivoltaics plot grew 60% of the silverbeet that the traditional plot grew. The most likely reason for the lower agrivoltaic output is the amount of shading being too high for that growing period (end of March to the end of May). Even though the first season contradicts our initial assumption, it is too early to conclude how the agrivoltaic system will perform in subsequent seasons (winter and spring). Note that no significant difference can be observed in the chlorophyll measurements (see Figure 3), indicating that the main difference is the crop mass.

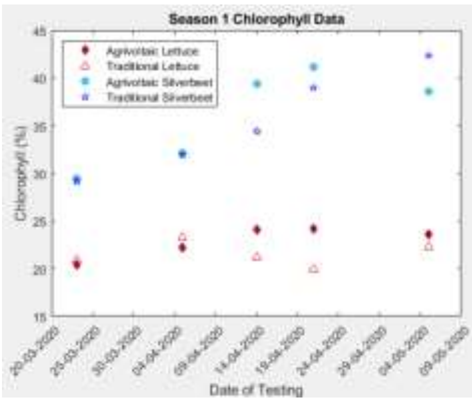

Figure 3: Chlorophyll data for lettuce and silverbeet.

For the agrivoltaic approach to provide benefit to the landowner, the LER of Equation 1 needs to be larger than (I_E + I_Y). Table 1 presents the required $\frac{Energy_{APV}}{Energy_{SF}}$ to fulfill this condition for the case of silverbeet ($\frac{Yield_{APV}}{Yield_{farm}}$ = 0.6) as a function of I_E and I_Y. As can be seen, the required ratio has strong dependence on the landowner's point of view. If the landowner highly values crop yield (higher I_Y values), the ratio $\frac{Energy_{APV}}{Energy_{SF}}$ should be very high, limiting the application of agrivoltaics for these cases. However, if the user highly values the generated electricity (or values the electricity and the crops the same), a relatively low value of $\frac{Energy_{APV}}{Energy_{SF}}$ (<1.4) already provides a benefit. Note that in its simple form, the LER approach ignores other important factors, such as initial investment, maintenance cost, soil condition and many more. The limitations of the LER approach and possible improvements for it will be discussed in the conference.

Table 1 : The required $\frac{Energy_{APV}}{Energy_{SF}}$ as a function of I_E and I_Y to provide benefit for the agrivoltaic approach (assuming the silverbeet case).

I_E \ I_Y	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
0.05	1.40	2.20	3.00	3.80	4.60	5.40	6.20	7.00	7.80	8.60
0.15	1.13	1.40	1.67	1.93	2.20	2.47	2.73	3.00	3.27	3.53
0.25	1.08	1.24	1.40	1.56	1.72	1.88	2.04	2.20	2.36	2.52
0.35	1.06	1.17	1.29	1.40	1.51	1.63	1.74	1.86	1.97	2.09
0.45	1.04	1.13	1.22	1.31	1.40	1.49	1.58	1.67	1.76	1.84
0.55	1.04	1.11	1.18	1.25	1.33	1.40	1.47	1.55	1.62	1.69
0.65	1.03	1.09	1.15	1.22	1.28	1.34	1.40	1.46	1.52	1.58
0.75	1.03	1.08	1.13	1.19	1.24	1.29	1.35	1.40	1.45	1.51
0.85	1.02	1.07	1.12	1.16	1.21	1.26	1.31	1.35	1.40	1.45
0.95	1.02	1.06	1.11	1.15	1.19	1.23	1.27	1.32	1.36	1.40

Conclusion

Since the experiment has been only one-third completed, it is difficult to determine if all the plants will respond the same way to the shade. Despite this, if wisdom is to be gained from other studies then it can be estimated that growing Season 2 (June to September) will experience a similar difference in crop yield between the agrivoltaic and traditional plots due to winter having less available solar energy. On the contrary, growing Season 3 (September to November) should present a decreased difference in crop yield and possibly even higher yield for the agrivoltaics system due to the increase in solar energy. The results will be discussed in full when the experiment has concluded in November of this year (2020).

References:

[1] Fraunhofer ISE, "Agrophotovoltaics: resource efficient land-use," 23 November 2017. [Online]. Available: https://www.smart-agropv.com/static/Datos_ficagropvr15/reportes/3_Presentation_APV_Chile_Schindele_Bopp_22.Nov.2017_final_public.pdf. [Accessed 19 February 2020].

[2] Australian Bureau of Statistics, "Land management and farming in Australia, 2016-17," 26 June 2018. [Online]. Available: https://www.abs.gov.au/ausstats/abs@.nsf/mf/4627.0. [Accessed 5 April 2020].

[3] T. Sekiyama and . A. Nagashima, "Solar sharing for both food and clean energy production: performance of agrivoltaic systems for corn, a typical shade-intolerant crop," *Environments,* vol. 65, no. 6, pp. 1-12, 2019.

[4] C. Dupraz, H. Marrou, G. Talbot and L. Dufour, "Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes," *Renewable Energy,* vol. 36, no. 10, pp. 2725-2732, 2011.

[5] National Renewable Energy Laboratory, *System Advisory Model,* United States: National Renewable Energy Laboratory, 2020.