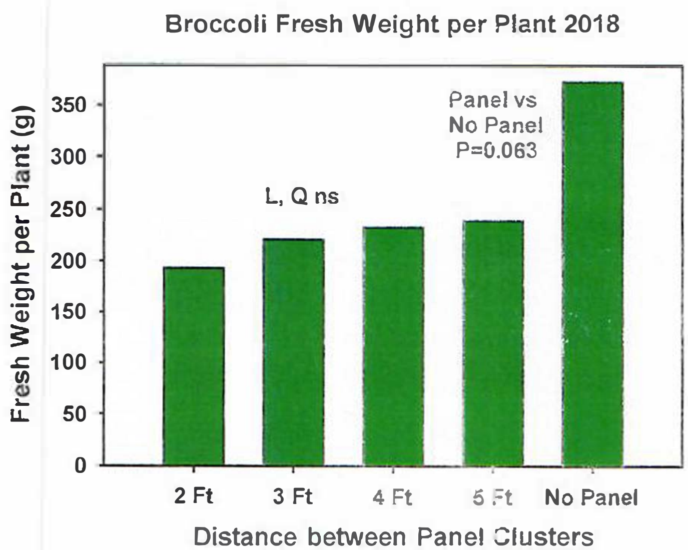
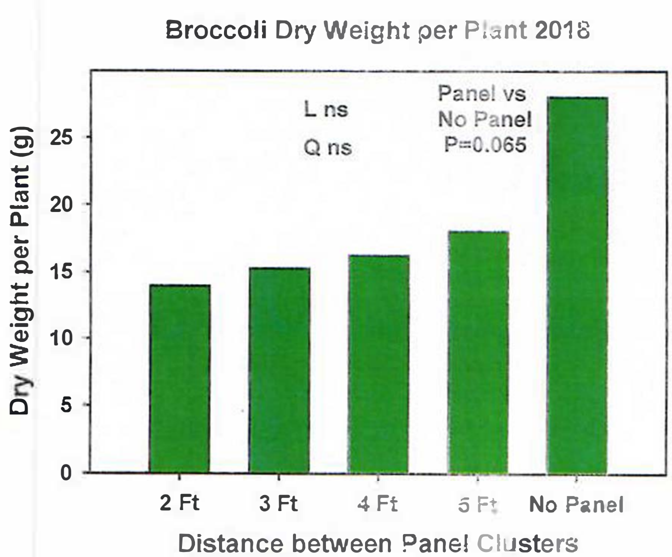
2018 UMass Dual-Use Solar Agricultural Report and Final Report Summary

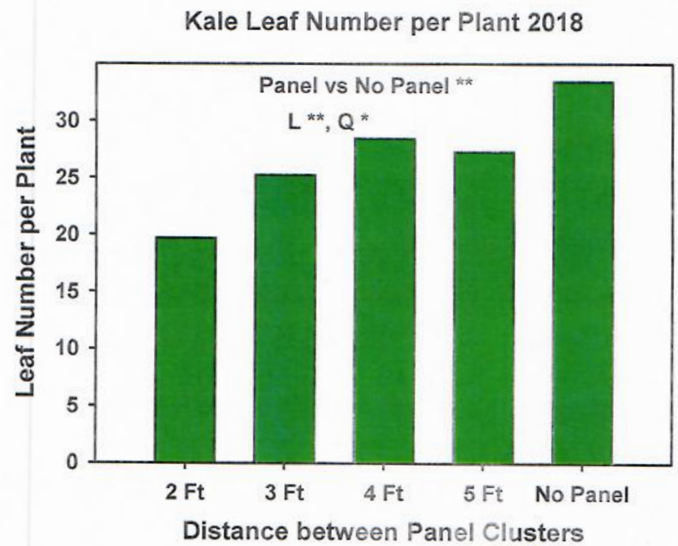
In 2018 the growing season was similar to 2017 although the Fall had more rain. Temperatures were moderate unlike 2016. This did not affect the growth of the early planted crops in 2018 but did along with rabbit predation influence second crops which were to variable to harvest.

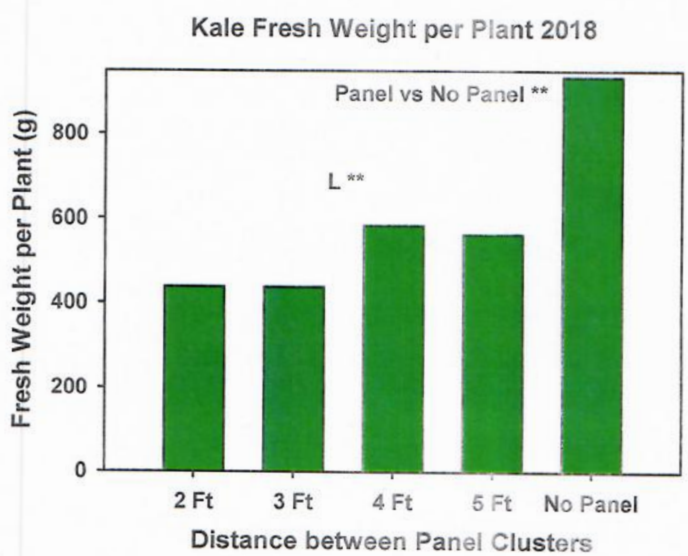
Yield of crops under shade from panel clusters were less than the yields from the control no panel crops. This confirms that shade from panels reduces yields except in a hot dry year (2016) and a farmer would need to evaluate if such a yield reduction was reason enough to avoid the Dual Use approach. An economic analysis might show that the lower yield was acceptable when revenue was being generated from sale of the electrical power.

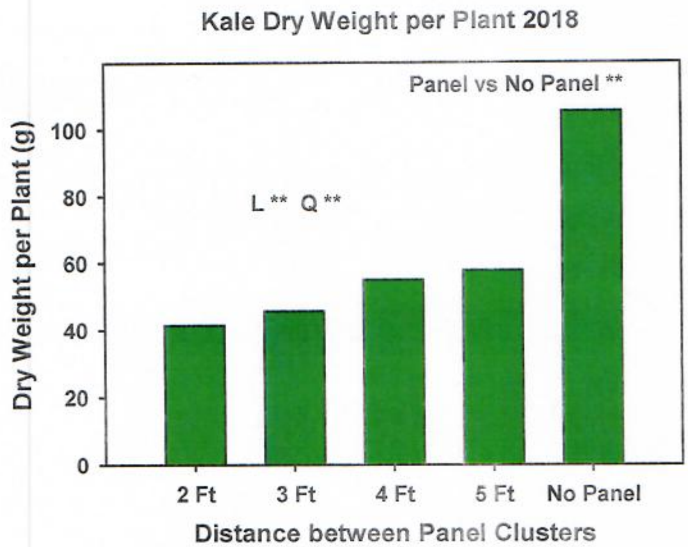


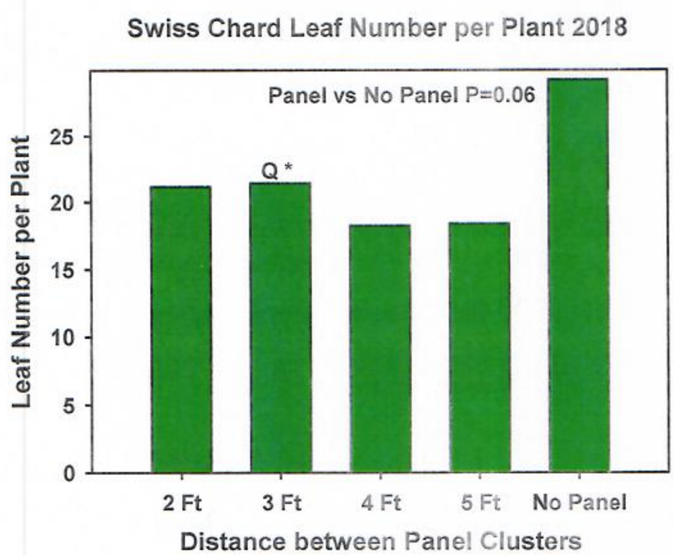


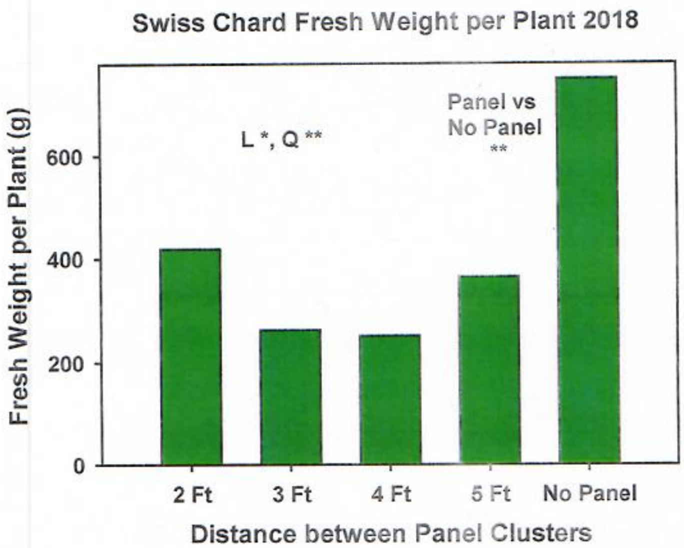
Yields of crops with shade from panels although less than the control, were similar to the yields in 2016 when the heat reduced or limited the yield of crops in the unshaded controls. For Broccoli and Kale in 2018 there wa a linear trends meaning the wider the gap from 2ft to 5ft the crop yields were increased. For Swiss Chard and Pepper the yields were more variable across the spacing gaps.

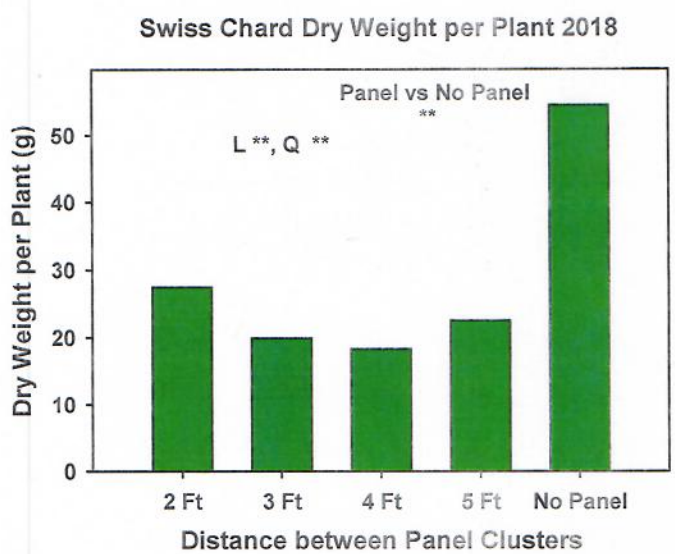


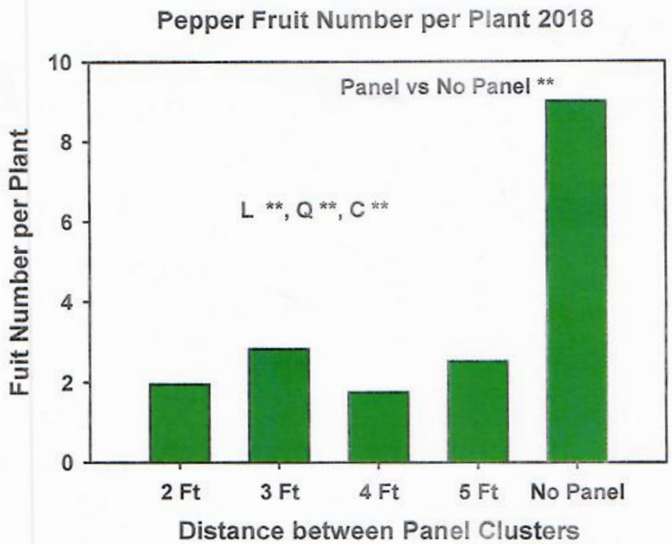


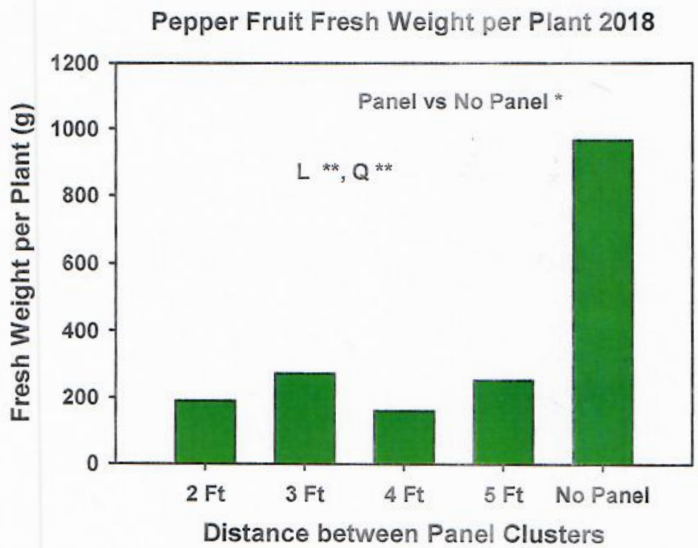

Kale Dry Weight per Plant 2018
Panel vs No Panel **
L ** Q **
Dry Weight per Plant (g)
0
20
40
60
80
100
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

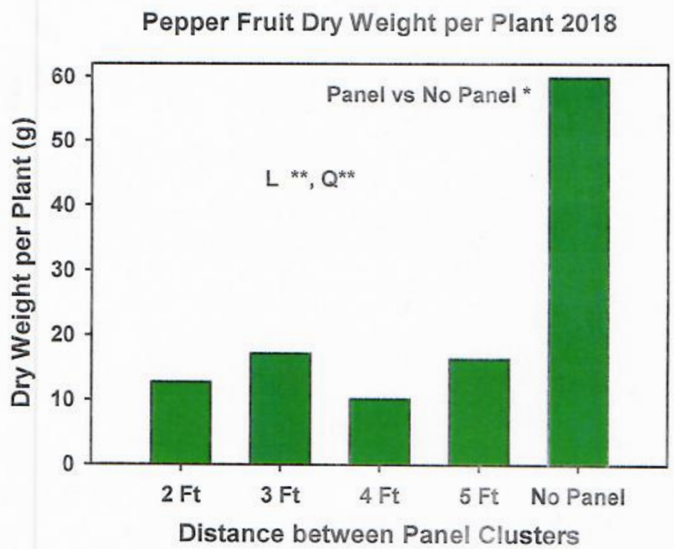

Swiss Chard Leaf Number per Plant 2018
Panel vs No Panel P=0.06
Q *
Leaf Number per Plant
0
5
10
15
20
25
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Swiss Chard Fresh Weight per Plant 2018
Fresh Weight per Plant (g)
0
200
400
600
L *, Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Swiss Chard Dry Weight per Plant 2018
Dry Weight per Plant (g)
0
10
20
30
40
50
L **, Q **
Panel vs No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Pepper Fruit Number per Plant 2018
Panel vs No Panel **
L **, Q **, C **
Fuit Number per Plant
0
2
4
6
8
10
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Pepper Fruit Fresh Weight per Plant 2018
Panel vs No Panel *
L **, Q **
Fresh Weight per Plant (g)
0
200
400
600
800
1000
1200
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters



In 2018 a graduate student (Kristen Oleskewicz) assisted in management of the crops and she has almost completed her MS Degree. She analyzed the crops for contents of major nutrients (NPK) which are shown below. In all crops except Swiss Chard there was no differences among shading treatments or between shading treatments and the no panel control. For Swiss Chard the narrow gap (2ft) had the highest concentrations of N and P and for P the average value for gap treatments was different from the No Panel control but this was not significant for N.

Nutrient Analysis for Broccoli - 2018

Panel Spacing	Nitrogen	Phosphorus	Potassium
2 ft	4.93	0.72	1.43
3 ft	4.00	0.68	1.51
4 ft	4.81	0.66	1.34
5 ft	4.51	0.51	1.31
No Panel	4.87	0.64	1.29
Sign. Panel vs. No Panel	ns	ns	ns
Sign. Gap Trend	ns	ns	ns

Nutrient Analysis for Kale - 2018

Panel Spacing	Nitrogen	Phosphorus	Potassium
2 ft	2.77	0.48	2.35
3 ft	2.85	0.50	3.22
4 ft	2.61	0.49	2.11
5 ft	2.76	0.51	2.92
No Panel	2.69	0.47	2.32
Sign. Panel vs. No Panel	ns	ns	ns
Sign. Gap Trend	ns	ns	ns

Nutrient Analysis for Swiss Chard - 2018

Panel Spacing	Nitrogen	Phosphorus	Potassium
2 ft	3.05	0.30	4.87
3 ft	2.65	0.26	5.38
4 ft	2.67	0.39	3.80
5 ft	2.73	0.26	5.04
No Panel	2.74	0.22	5.18
Sign. Panel vs. No Panel	ns	*	ns
Sign. Gap Trend	Q	L	ns

Nutrient Analysis for Pepper Fruit - 2018

Panel Spacing	Nitrogen	Phosphorus	Potassium
2 ft	2.02	0.42	2.94
3 ft	1.99	0.44	2.85
4 ft	1.95	0.41	2.80
5 ft	1.97	0.42	2.82
No Panel	2.01	0.42	2.67
Sign. Panel vs. No Panel	ns	ns	ns
Sign. Gap Trend	ns	ns	ns

Light readings were taken with multiple readings behind the panels near noon for all spacing gaps. These were calculated as a percentage of the no shade control. All readings were similar and 67-69 % of the non-shaded, no panel light reading. This indicates much light scattering from gap to the shaded area. More light comes into the growing plants with the wider gap but this did not seem to effect the sçattering of light in the shaded area from the panels. This lower level of light from shaded areas may have been below the compensation point for some crops especially on overcast or cloudy days.

Maintenance of crop growth with gaps between clusters of solar panels occurs in large part because of the shifting shade and sun patterns throughout the day. In the morning the sun shines from the east casting the shadow from the panel clusters to the west. The opposite occurs in the afternoon, and at solar noon the shade is directly behind the panel cluster.

Light Readings (Percentage of No Panel Control) - 2018

Panel Spacing	Percent*
2 ft	27.2
3 ft	40.4
4 ft	51.7
5 ft	62.2
Sign. Gap Trend	L

* Multiple readings taken near solar noon midway behind the panel cluster. This indicates considerable light scattering from the non-shaded gap.

Crops in all shaded and non-shaded areas had trickle irrigation weekly as needed. Soil moisture readings were taken to check availability of soil water in the upper soil profile (0-8"). The average of all samples showed no differences among gaps or with the no panel control. However, soil samples taken directly behind the panels in shaded areas showed that the no panel control had higher soil moisture compared to samples collected from behind panels. This indicates panels shielded the growth area from some rain that the no panel area received.

Soil Moisture Determinations % (Av. of 3 dates) - 2018

Panel Spacing	Overall Values	Behind Panels
2 ft	28.5	28.6
3 ft	27.2	26.3
4 ft	27.3	28.0
5 ft	27.8	25.5
No Panel	28.9	32.1
Sign. Panel vs. No Panel	ns	**
Sign. Gap Trend	ns	ns

Summary of All Years

The climatic conditions in 2016 were hot and dry and although all crops were irrigated the yields of shades plots were similar or better than the yields in the no panel control. Leaf temperature readings, in partial shade this year, were 15°F lower than leaf temperatures in full sun. This afforded the shaded plots an advantage reducing negative losses from the daily shifting shade pattern. In 2017 and 2018 the temperatures were more moderate, with more rain throughout the growing season, resulting in much higher yields from the no panel control while shaded areas had yields similar or slightly lower than the yields in 2016.

This indicates there is a crop yield cost to shade from solar panels. Reduced yields in shaded plots may be acceptable given the revenues coming from electricity generated by solar panels positioned above growing crops. The more light that passes through the gaps between panel clusters (wider spacing) the higher the yields were but not in all cases. Other unknown factors in the crop-soil-aerial environment added to variability seen among yields, where 2ft and 3ft gaps sometimes had yields higher than the 4ft or 5ft gaps.

Overall, erecting solar panels over farm fields can and should be done in a way to ensure the farmland can continue to produce agricultural products rather than placing solar panels at or near ground level taking the field out of agricultural production for many years if not all time.

Further studies should be conducted to further validate these results. Of note is the Massachusetts SMART program providing incentives to solar installers to keep 50% of the land unshaded by solar panels. This program has in part been based on the results from the solar array at the University of Massachusetts farm in South Deerfield. Many groups have toured the Deerfield solar installation with positive feedback on the research being conducted. Yesterday, April 25, 2019, the innovation in agriculture shown in the Deerfield studies was presented to about 12 groups of college and high school students and faculty/staff, and was well received at the Sustainathon, which was held at the Springfield Technical Community College.

This report is developed by Stephen Herbert with assistance from Kristen Oleskewicz, and with funding from NREL.

April 25, 2019