Dual-use of Farmland & Renewable Energy

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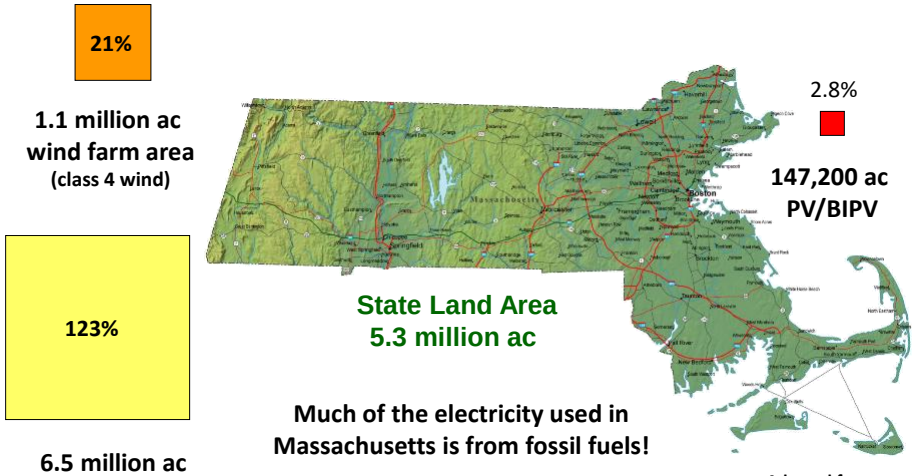
PV – Photovoltaic Solar Farms

Rationale

- There is a need for sustainable renewable energy sources.
- We suggests solar power as an area of greatest promise for Massachusetts .
- However, traditional ground mounted solar installations on farmland remove arable land from potential agricultural use.

LAND AREA REQUIREMENTS for
Electricity Consumption in MA = 53 million MWh
Total US Consumption = 3,150 million MWh



Agricultural Test Site

UMass Farm South Deerfield

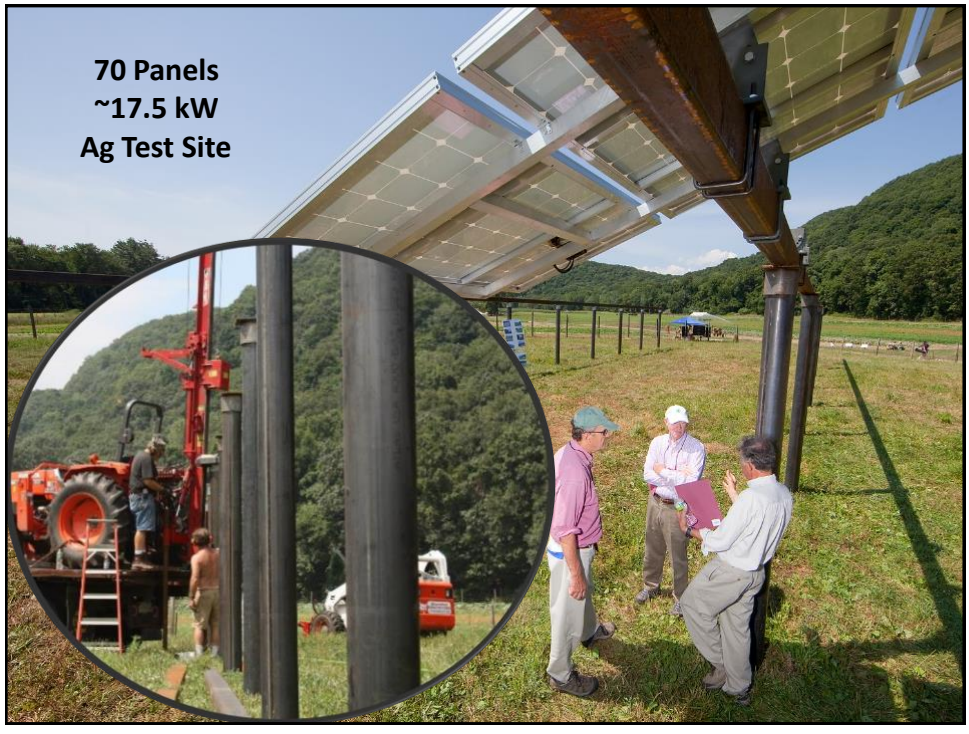
70 + 36 = 106 Panels ~26 kW

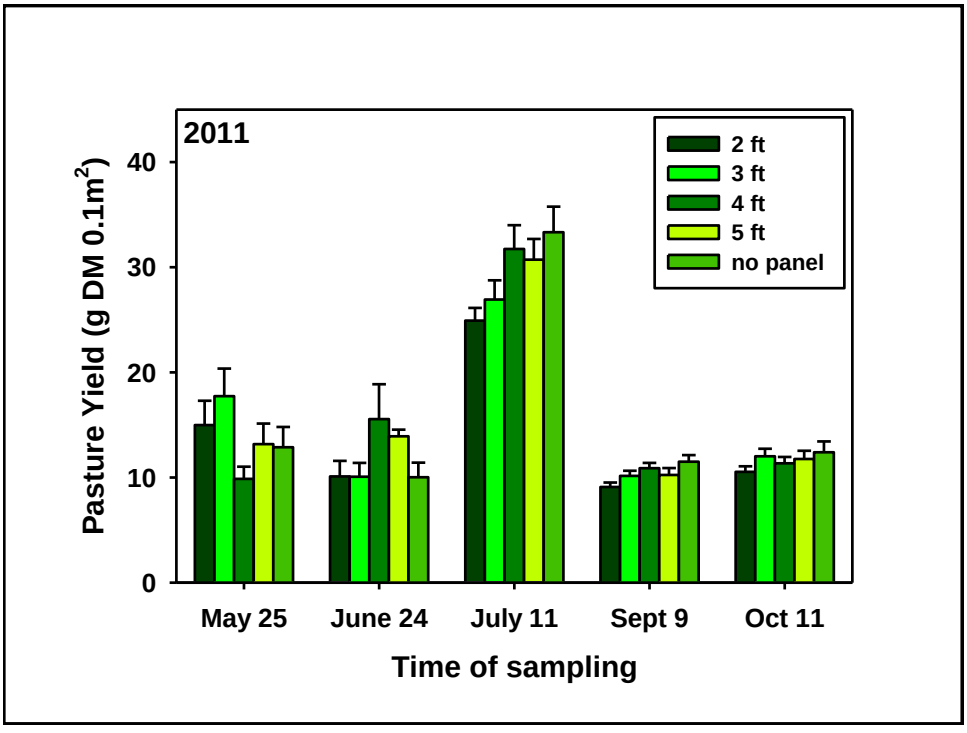
Solar Array Layout

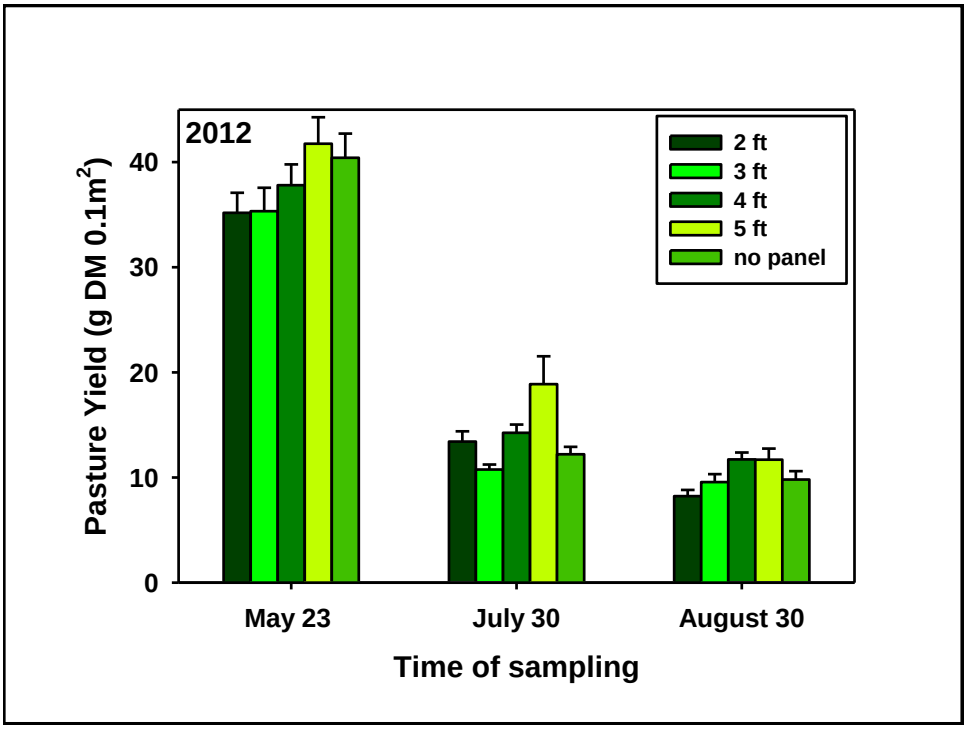
- Panels were installed (2010) about 7.5ft (2.3m) off the ground.
- There were spaces between panel clusters varying from 2 to 5ft.
- Non-invasive design was used.
- Initial crop evaluation was with pasture and grazing with cattle (2011-2014).

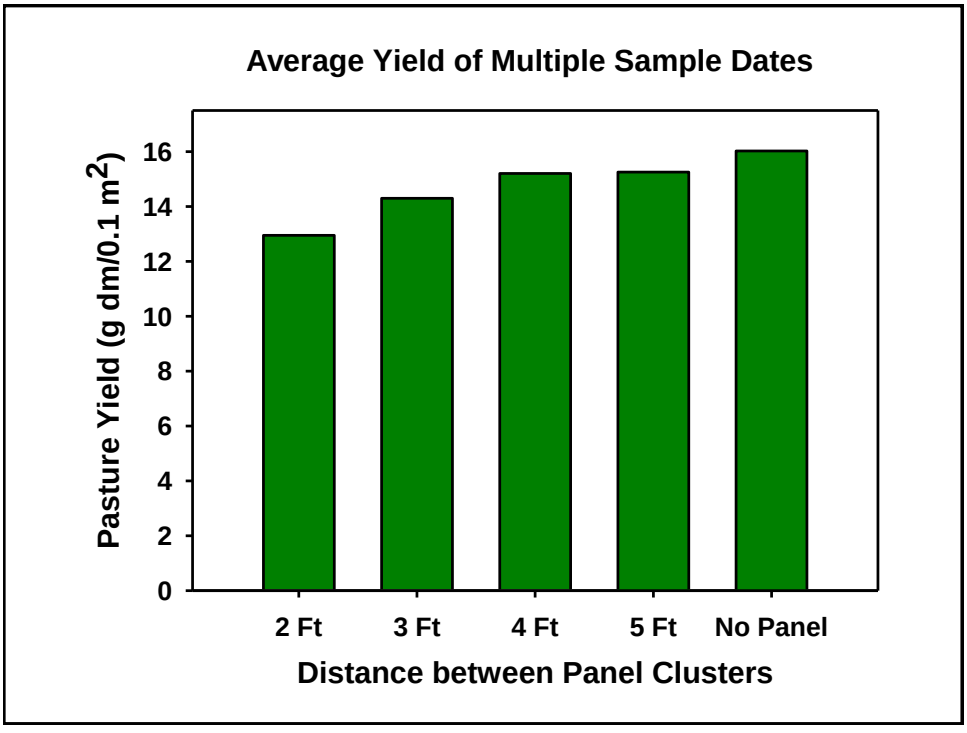
Standard Pole Mounted Installation

Not used in UMass Study




2011
2 ft
3 ft
4 ft
5 ft
no panel
Pasture Yield (g DM 0.1m^2)
0
10
20
30
40
May 25
June 24
July 11
Sept 9
Oct 11
Time of sampling


2012
2 ft
3 ft
4 ft
5 ft
no panel
Pasture Yield (g DM 0.1m2)
0
10
20
30
40
May 23
July 30
August 30
Time of sampling


Average Yield of Multiple Sample Dates
Pasture Yield (g dm/0.1 m2)
0
2
4
6
8
10
12
14
16
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

Pasture Yield Summary

- The previous slide indicates on average yields were increased with more space between panels.
- With 3.5 to 4 feet between panel clusters a yield of 90% to 95% of the control without shade from solar panels.
- This seems an acceptable yield given the benefit from electrical power generated by the solar panels.

Broccoli, Swiss Chard, Kale, Pepper under shade and unshaded plots transplanted June 7, 2016.

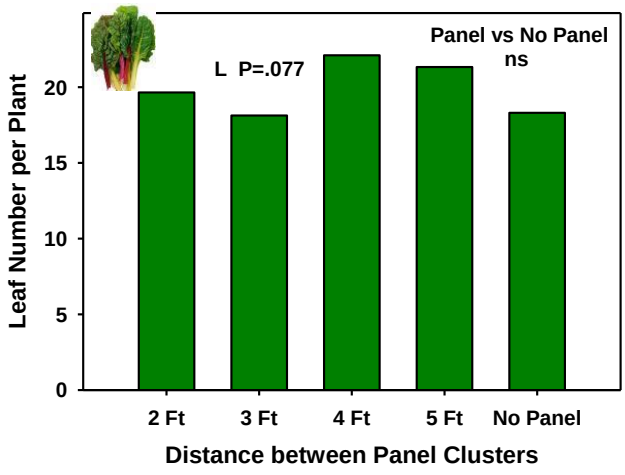
Future crops: Common Bean and Cabbage were planted as second summer crops. Cabbage failed because of the heat and drought in 2016.

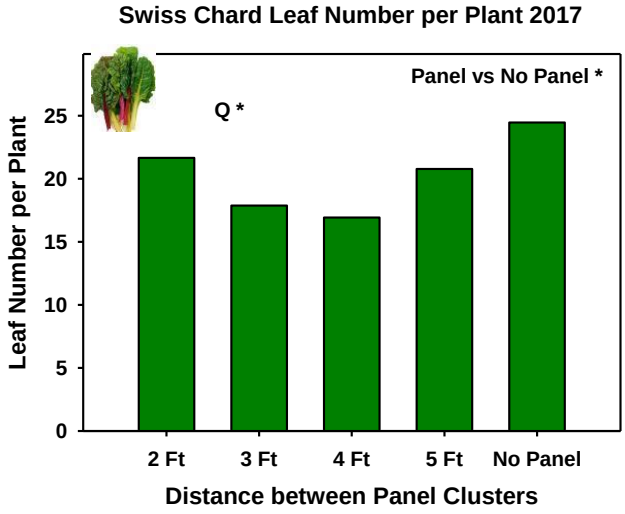

Morning Shade Pattern on
Test Area prior to Planting

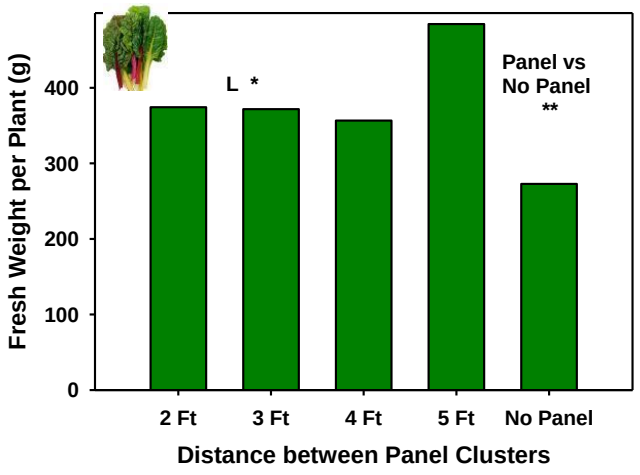

Transplanting Broccoli, Swiss
Chard, Kale and Pepper

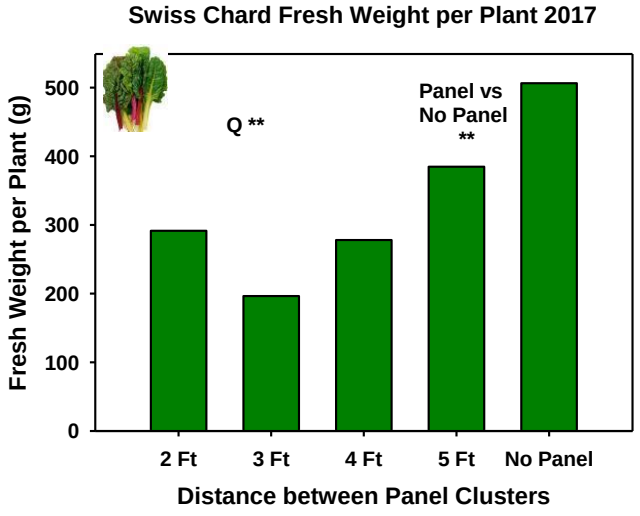
Transplanting Broccoli, Swiss Chard, Kale and Pepper in No Panel Control Plots

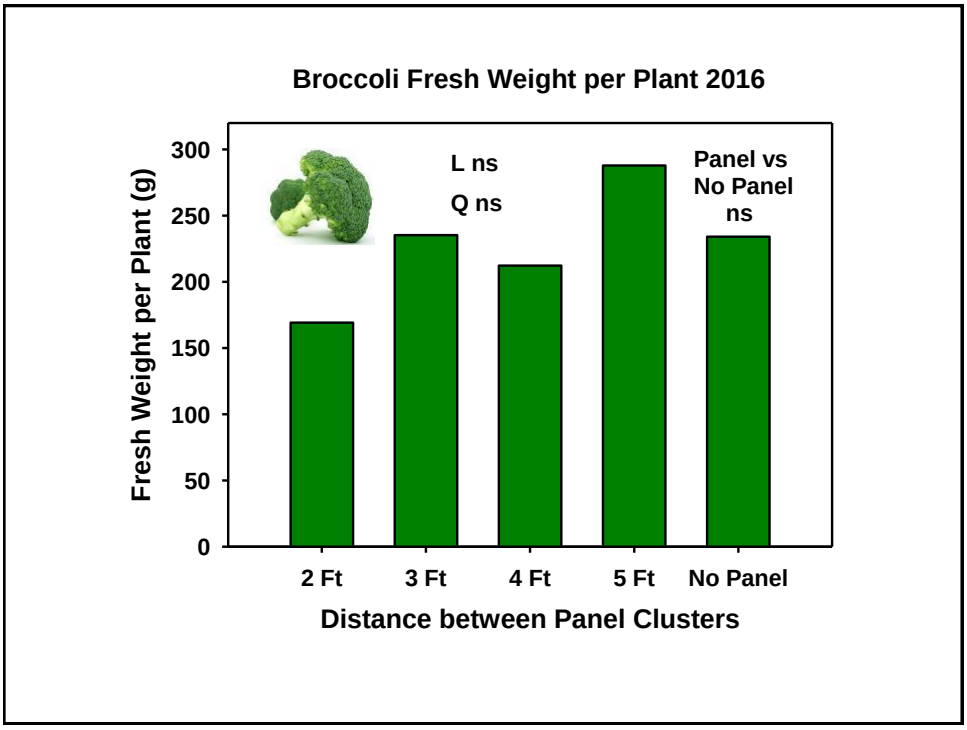
Broccoli, Swiss Chard, Kale and Pepper growth July 11, 2016

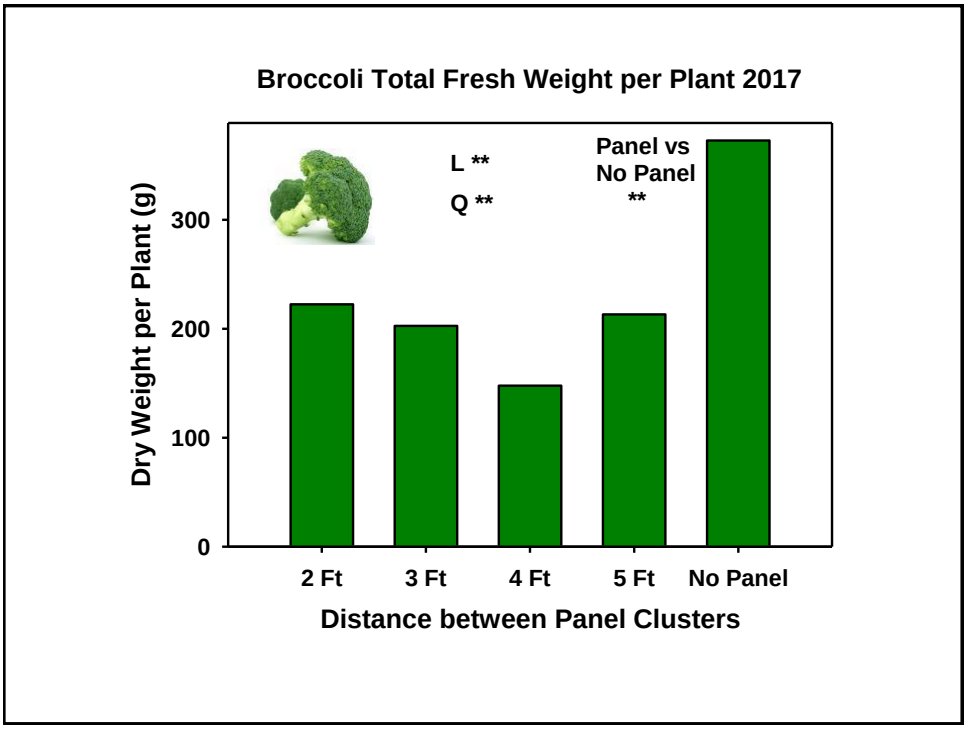

Swiss Chard Leaf Number per Plant 2016
Panel vs No Panel
ns
L P=.077
Leaf Number per Plant
0
5
10
15
20
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

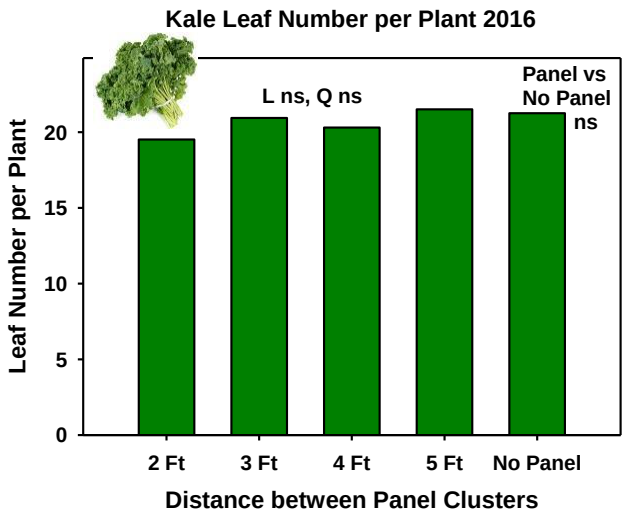

Swiss Chard Leaf Number per Plant 2017
Panel vs No Panel *
Q *
Leaf Number per Plant
0
5
10
15
20
25
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

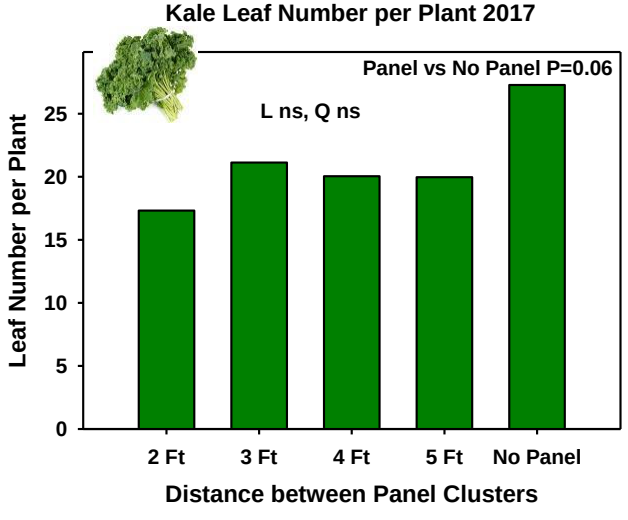

Swiss Chard Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
0
100
200
300
400
L *
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

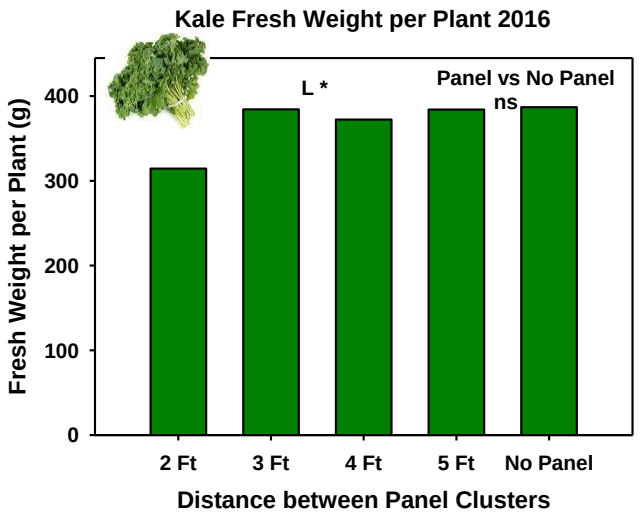

Swiss Chard Fresh Weight per Plant 2017
Fresh Weight per Plant (g)
0
100
200
300
400
500
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

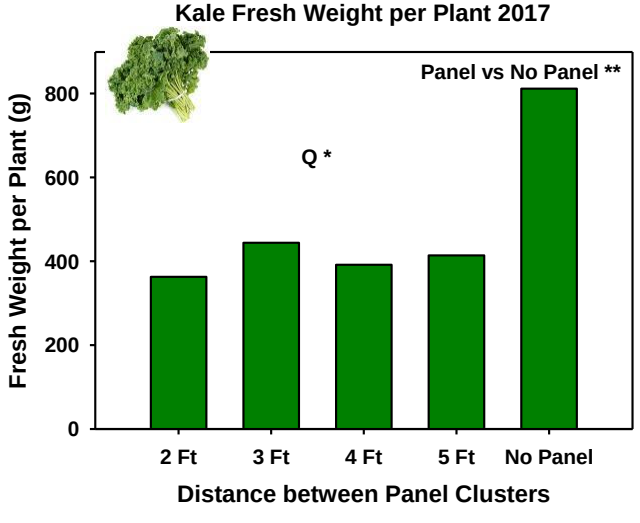

Broccoli Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
300
250
200
150
100
50
0
L ns
Q ns
Panel vs
No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

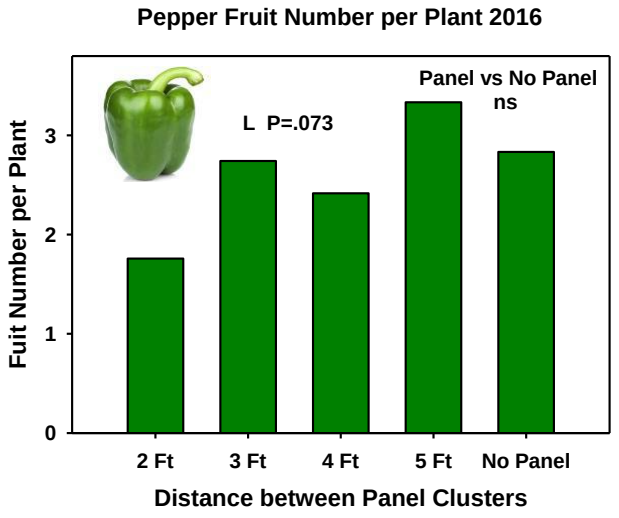

Broccoli Total Fresh Weight per Plant 2017
Dry Weight per Plant (g)
300
200
100
0
L **
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

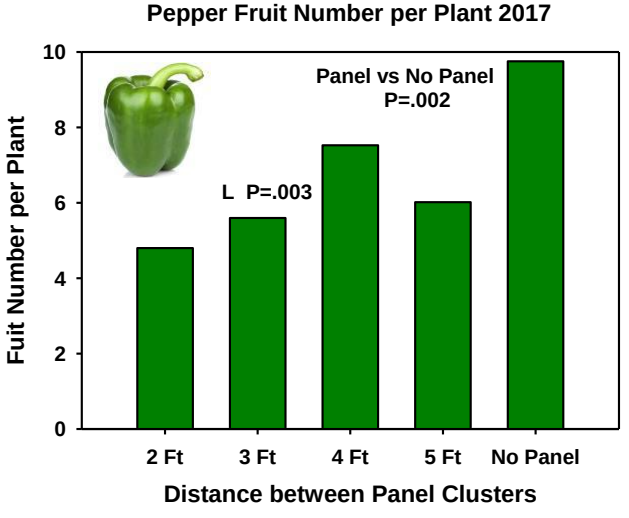

Kale Leaf Number per Plant 2016
L ns, Q ns
Panel vs
No Panel
ns
Leaf Number per Plant
0
5
10
15
20
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

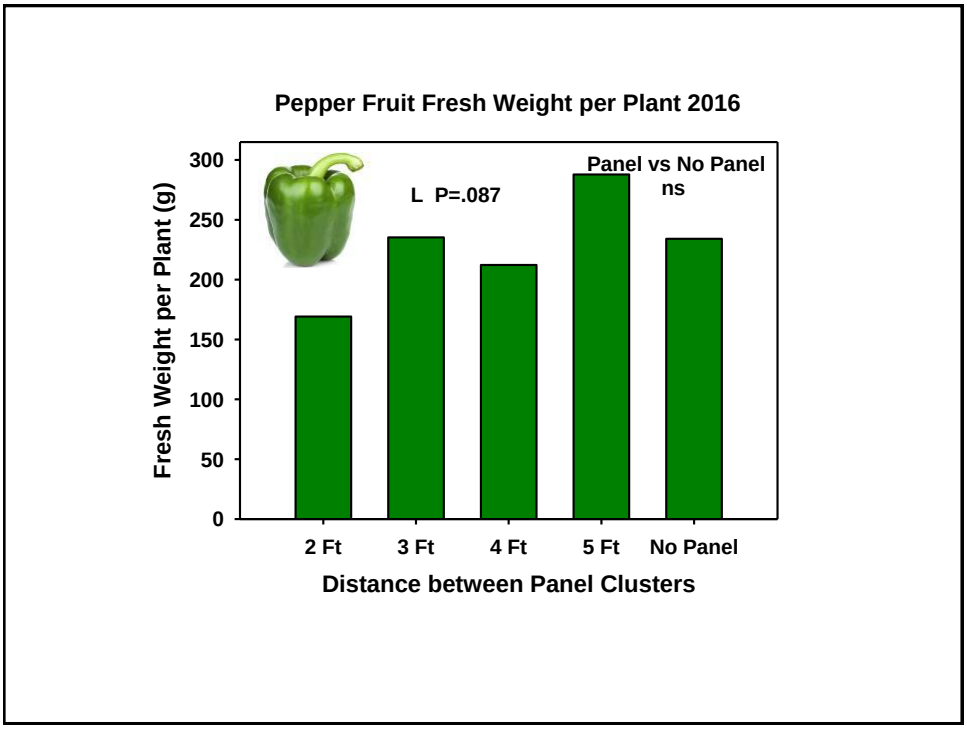

Kale Leaf Number per Plant 2017
Panel vs No Panel P=0.06
L ns, Q ns
Leaf Number per Plant
0
5
10
15
20
25
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

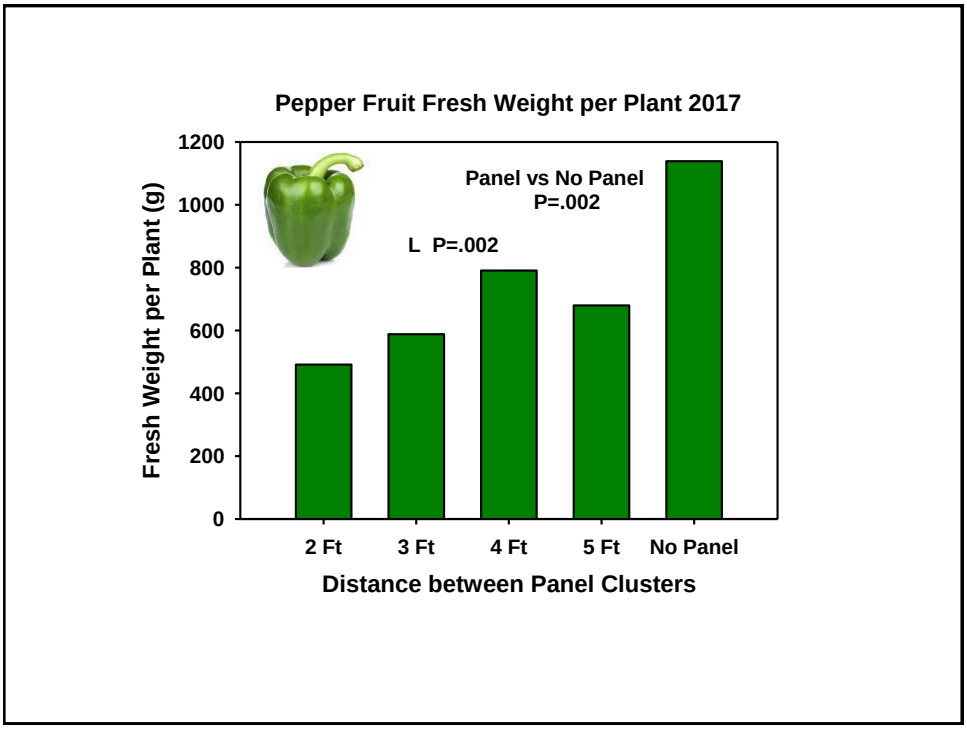

Kale Fresh Weight per Plant 2016
L *
Panel vs No Panel
ns
Fresh Weight per Plant (g)
0
100
200
300
400
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

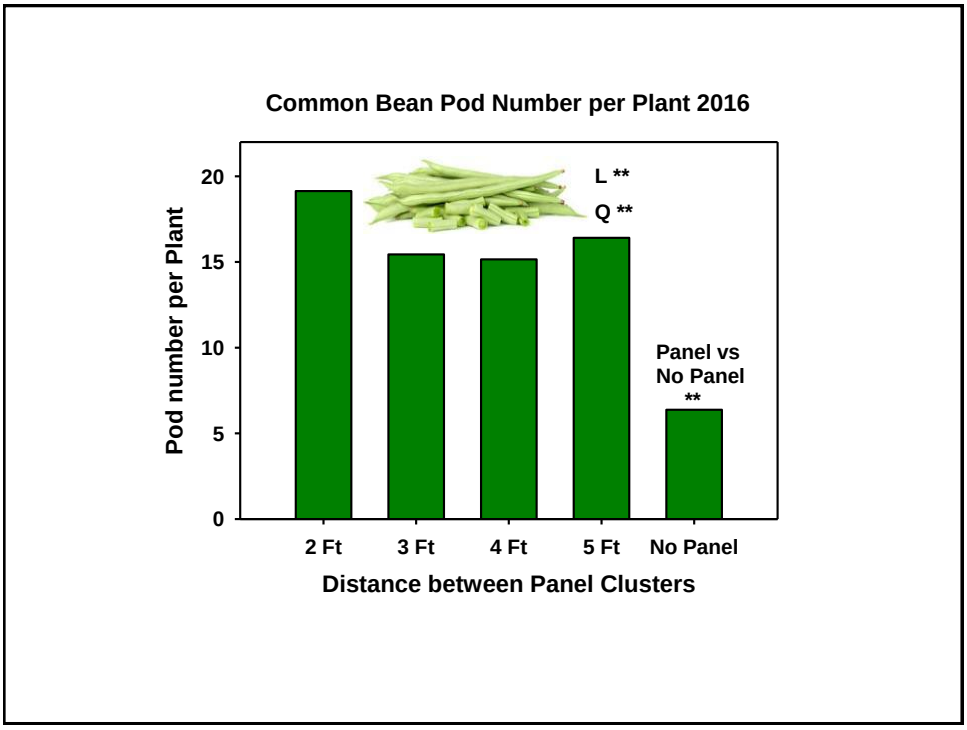

Kale Fresh Weight per Plant 2017
Panel vs No Panel **
Q *
Fresh Weight per Plant (g)
0
200
400
600
800
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

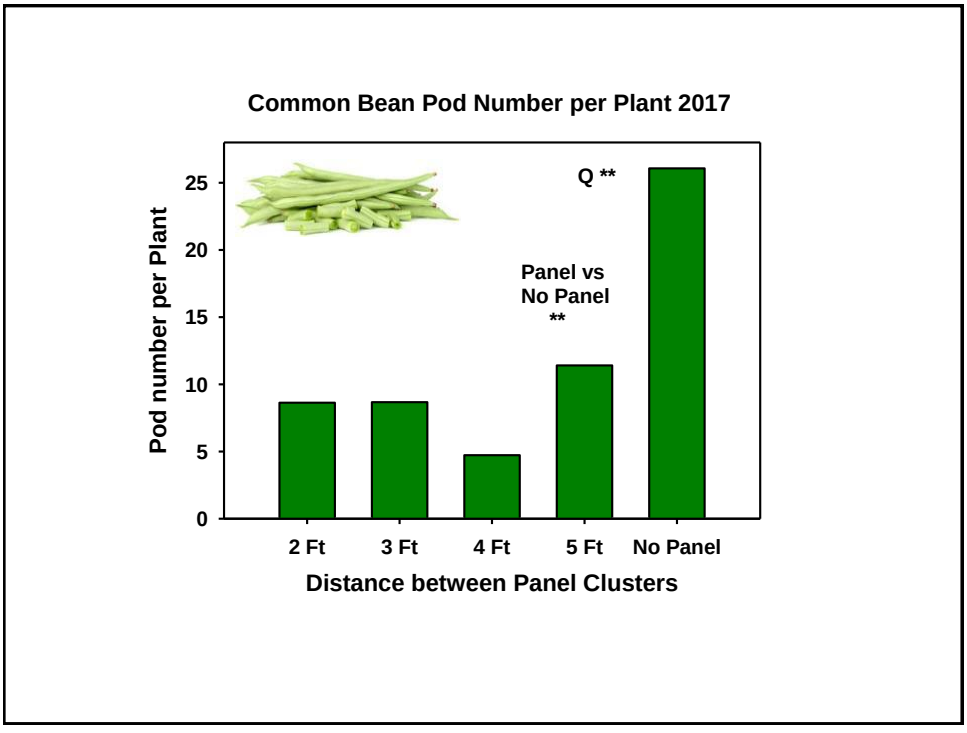

Pepper Fruit Number per Plant 2016
Panel vs No Panel
ns
L P=.073
Fuit Number per Plant
0
1
2
3
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

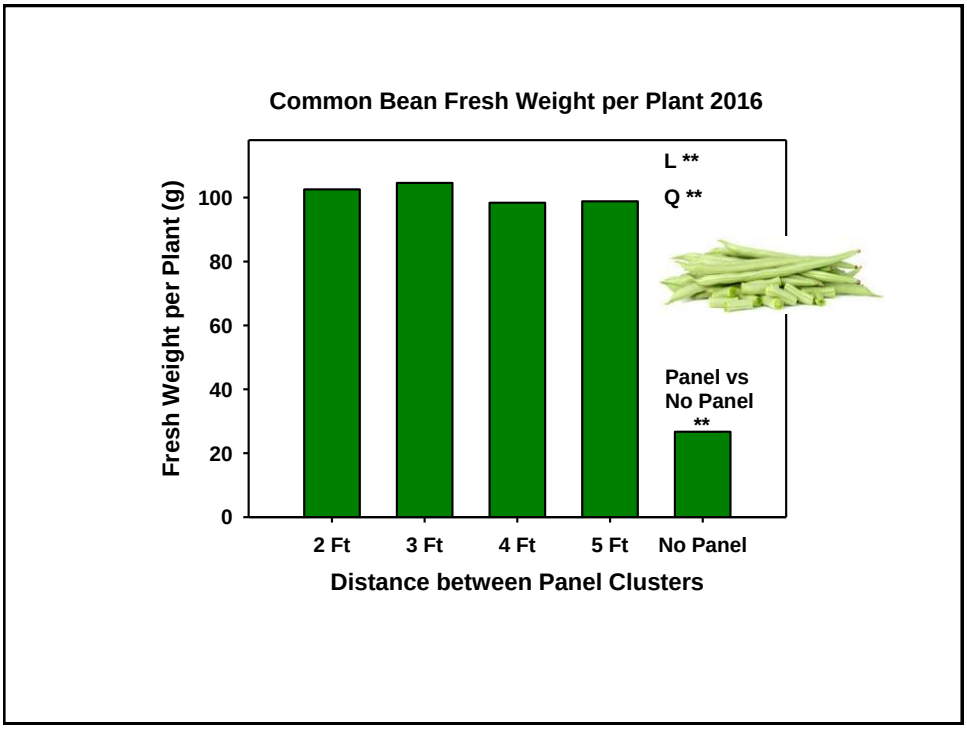

Pepper Fruit Number per Plant 2017
Panel vs No Panel
P=.002
L P=.003
Fuit Number per Plant
0
2
4
6
8
10
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

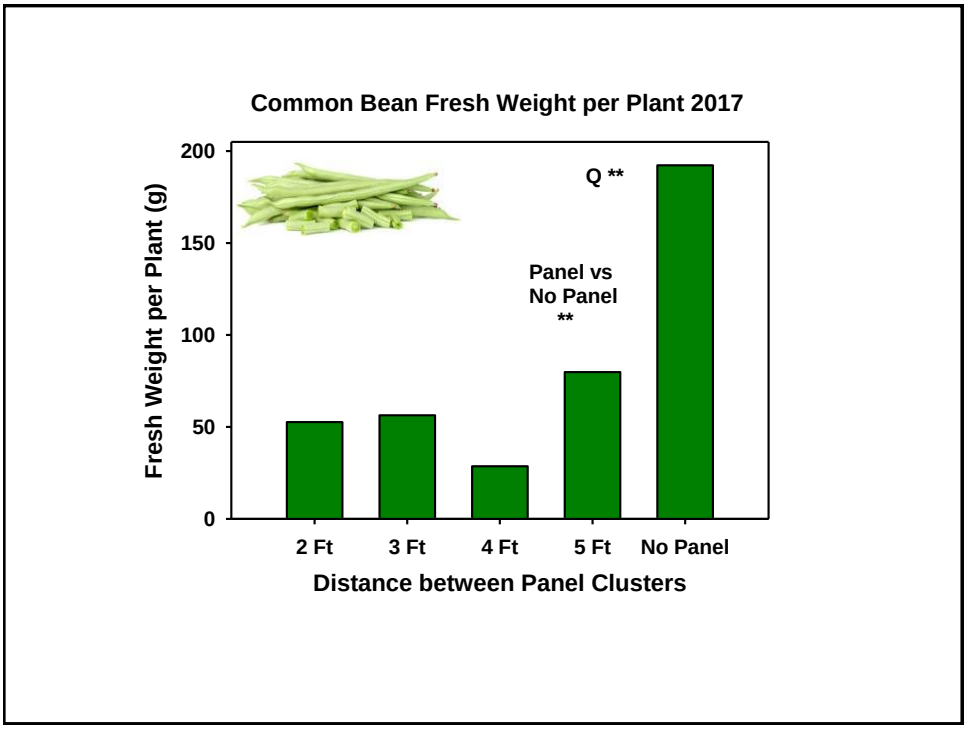

Pepper Fruit Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
300
250
200
150
100
50
0
L P=.087
Panel vs No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

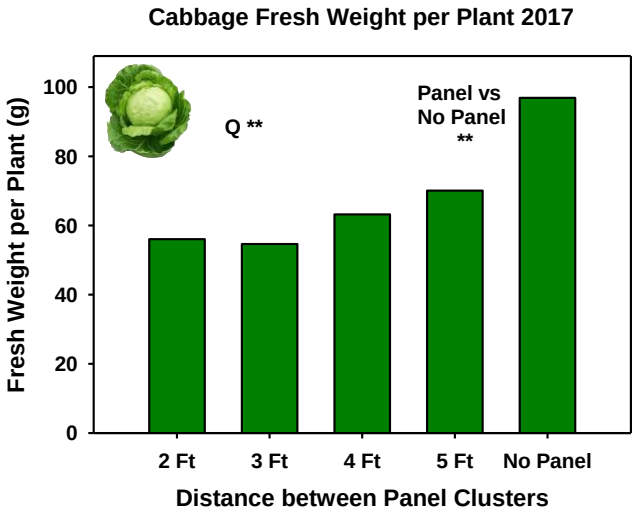

Pepper Fruit Fresh Weight per Plant 2017
Fresh Weight per Plant (g)
1200
1000
800
600
400
200
0
Panel vs No Panel
P=.002
L P=.002
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Common Bean Pod Number per Plant 2016
Pod number per Plant
20
15
10
5
0
L **
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Common Bean Pod Number per Plant 2017
Pod number per Plant
25
20
15
10
5
0
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Common Bean Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
0
20
40
60
80
100
L **
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Common Bean Fresh Weight per Plant 2017
Fresh Weight per Plant (g)
0
50
100
150
200
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters



Initial Conclusions -2016

- All crops, Broccoli, Swiss Chard, Kale, Pepper and Common Bean grew successfully during the drought and heat of the 2016 summer in Massachusetts, however, cabbage failed due to heat stress.
- Leaf temperature was 15^{o}F cooler under the shade of PV panels on clear days contributing to higher yields of shade plots vs. unshaded.
- More shade decrease yield in some crops but not all, and bean had higher yield with more shade possibly related to lower heat stress in mid to late summer.
- Crops were watered daily due to the lack of summer rainfall so moisture availability was not an issue.

Initial Conclusions -2017

- All crops, Broccoli, Swiss Chard, Kale, Pepper (first crops), and Common Bean and Cabbage (second crops) grew successfully during the cooler summer in 2017 in Massachusetts.
- The lack of heat stress on most days in 2017 resulted in higher yields of unshaded plots vs. shaded plots.
- More shade decrease yield in some crops but not all, and the higher yield bean with shade was reversed for unshaded related to lower heat stress in 2017.
- Crops were watered as needed in 2017 which had good summer rainfall.

2019 to 2021 Design