Vegetables under Solar PV 2016-17

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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.

Agricultural Test Site

UMass Farm South Deerfield
106 Panels ~25 kW

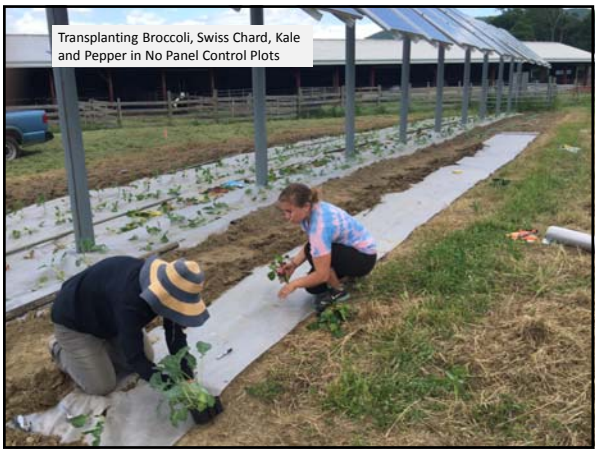
Solar Array Layout

- 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).

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

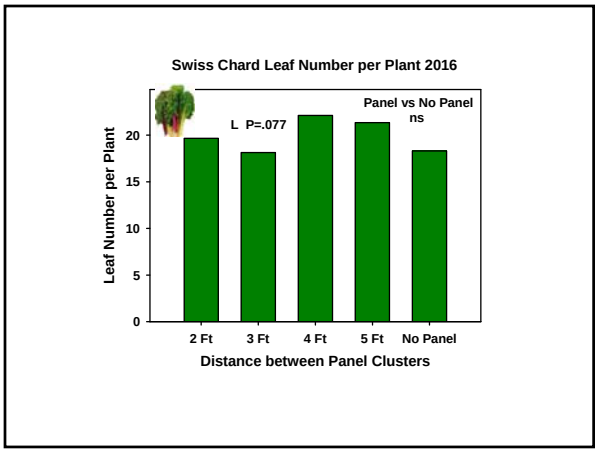
Future crops: Common Bean and Cabbage were planted as second summer crops. Cabbage failed because of the heat and drought in 2016.

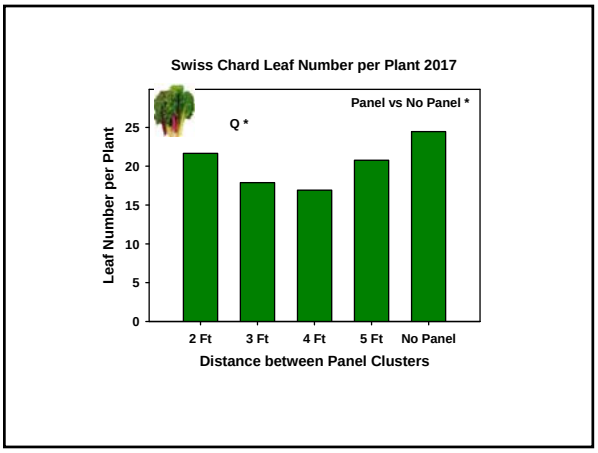

Transplanting Broccoli, Swiss Chard, Kale and Pepper

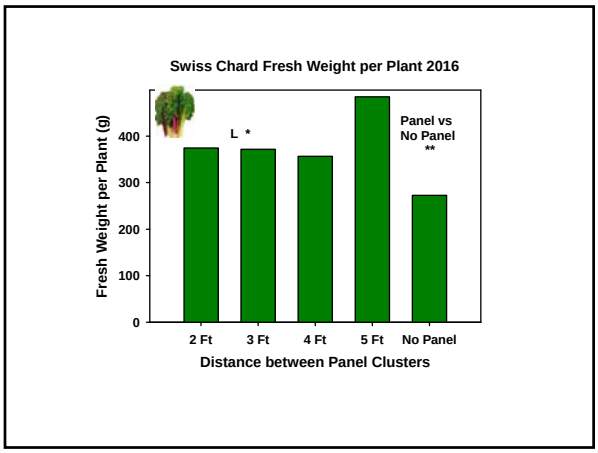

Transplanting Broccoli, Swiss Chard, Kale and Pepper in No Panel Control Plots

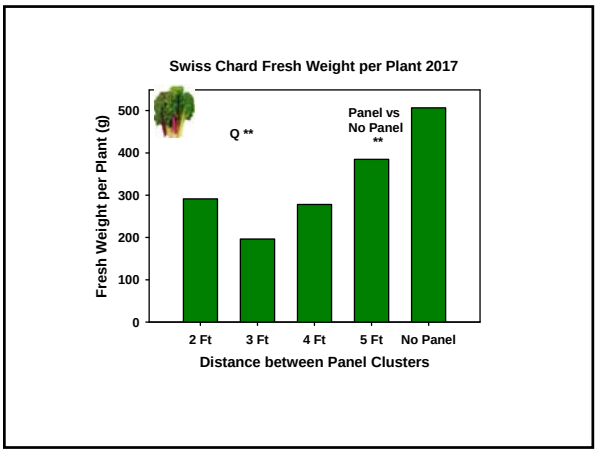

Broccoli, Swiss Chard, Kale and Pepper growth July 11, 2016

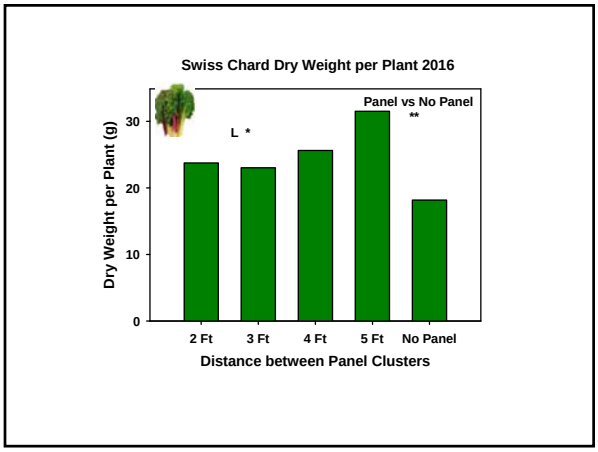

First harvest of Swiss Chard, July 11, 2016

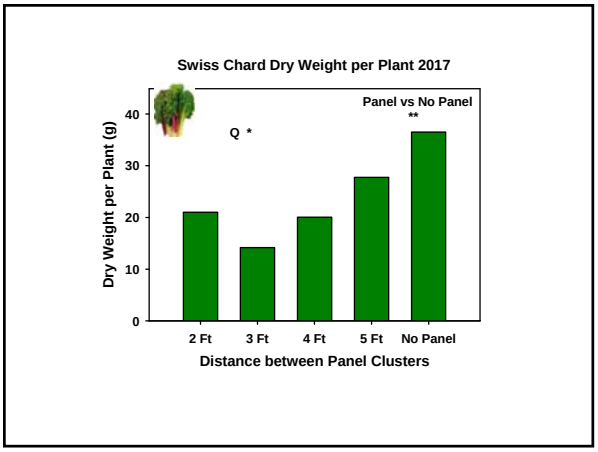

Swiss Chard Leaf Number per Plant 2016
Panel vs No Panel
ns
L P=.077
Leaf Number per Plant
0
5
10
15
20
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

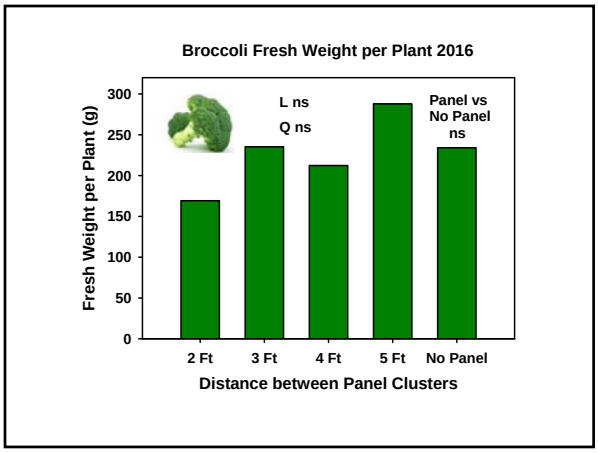

Swiss Chard Leaf Number per Plant 2017
Panel vs No Panel *
Q *
Leaf Number per Plant
0
5
10
15
20
25
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

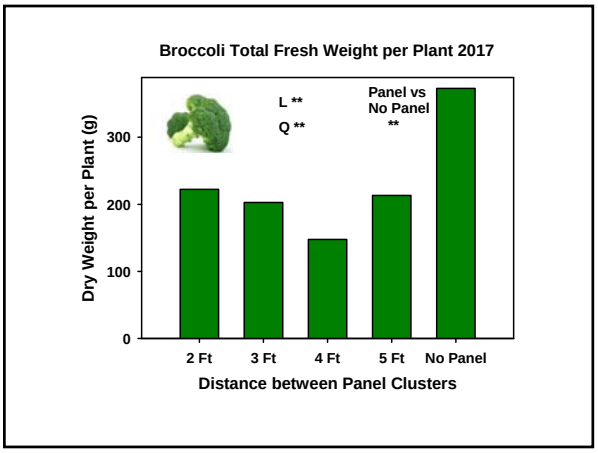

Swiss Chard Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
0
100
200
300
400
L *
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

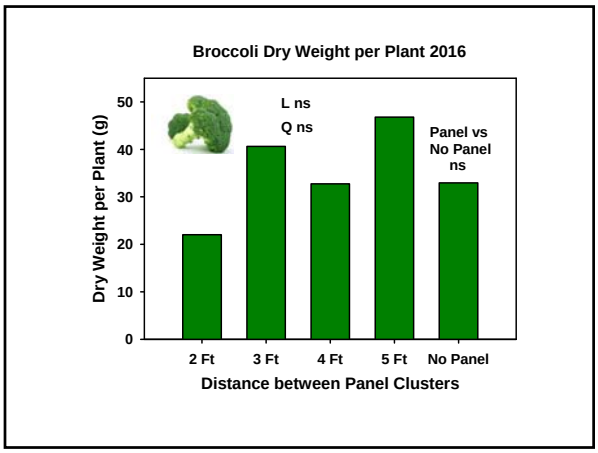

Swiss Chard Fresh Weight per Plant 2017
Fresh Weight per Plant (g)
0
100
200
300
400
500
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

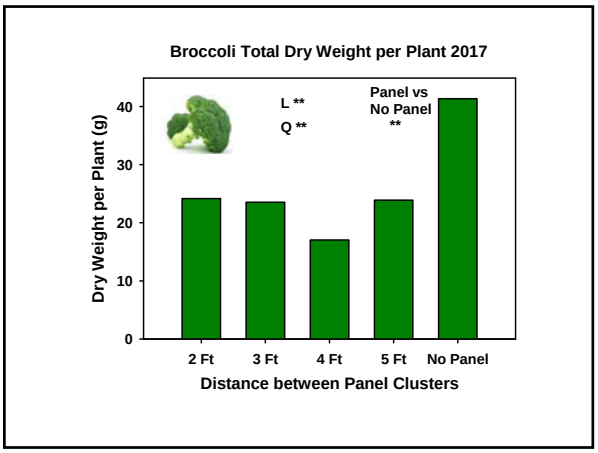

Swiss Chard Dry Weight per Plant 2016
Dry Weight per Plant (g)
0
10
20
30
L *
Panel vs No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

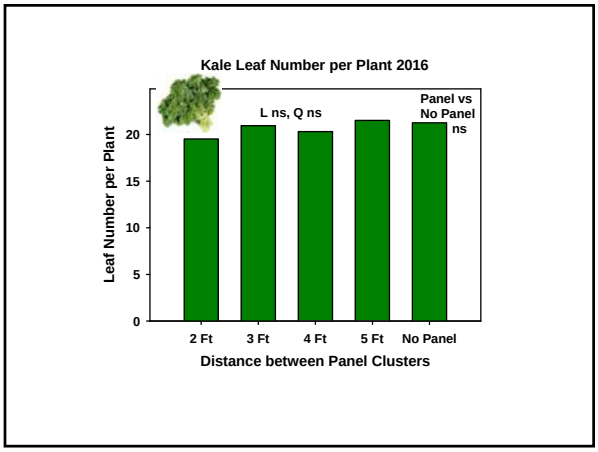

Swiss Chard Dry Weight per Plant 2017
Dry Weight per Plant (g)
0
10
20
30
40
Q *
Panel vs No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

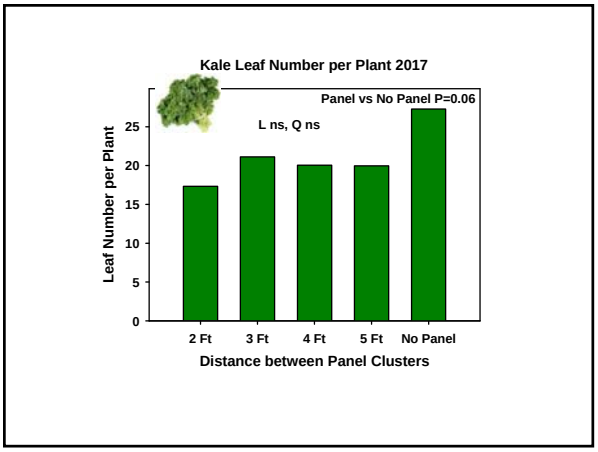

Broccoli Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
0
50
100
150
200
250
300
L ns
Q ns
Panel vs
No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

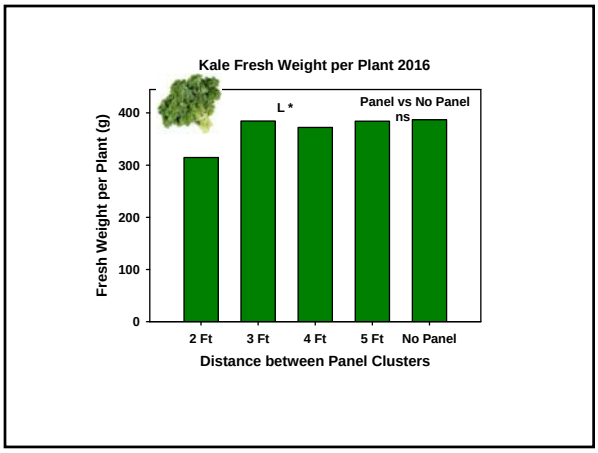

Broccoli Total Fresh Weight per Plant 2017
Dry Weight per Plant (g)
0
100
200
300
L **
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

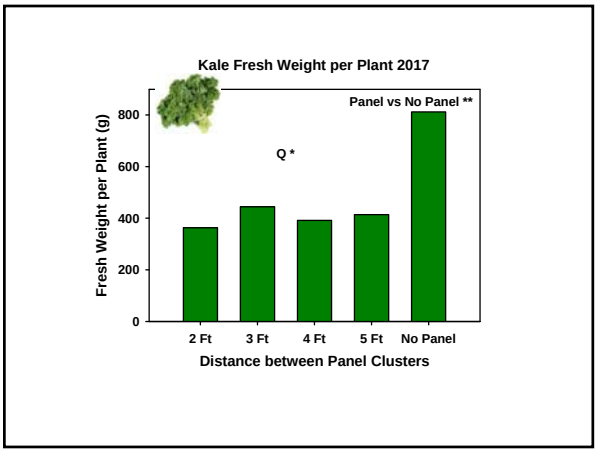

Broccoli Dry Weight per Plant 2016
Dry Weight per Plant (g)
0
10
20
30
40
50
L ns
Q ns
Panel vs
No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

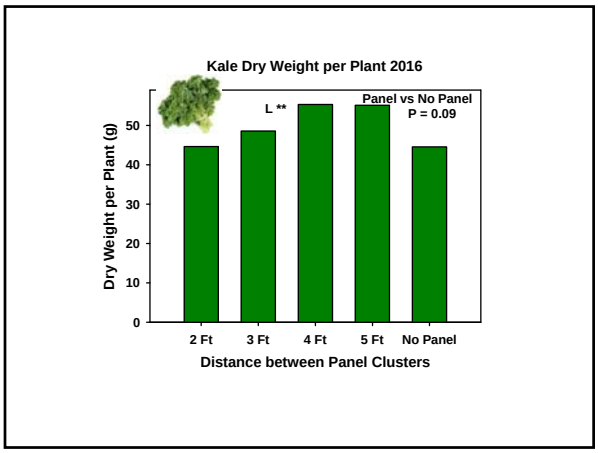

Broccoli Total Dry Weight per Plant 2017
Dry Weight per Plant (g)
0
10
20
30
40
L **
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

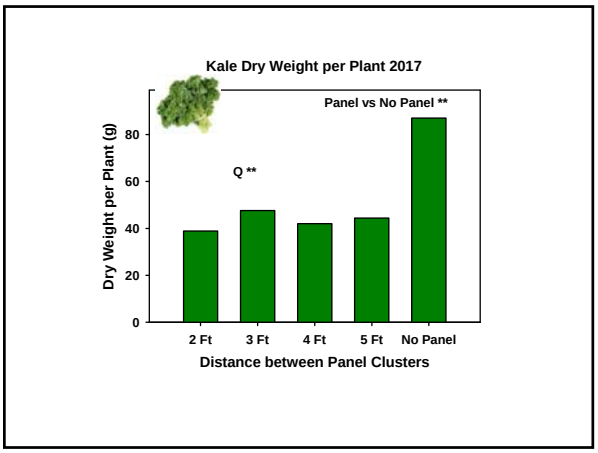

Kale Leaf Number per Plant 2016
Leaf Number per Plant
0
5
10
15
20
L ns, Q ns
Panel vs
No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

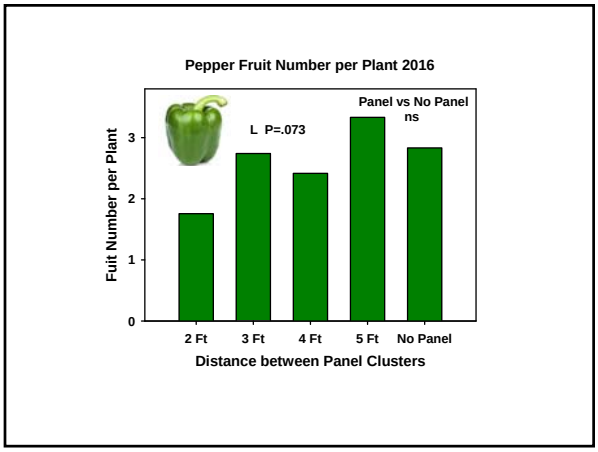

Kale Leaf Number per Plant 2017
Leaf Number per Plant
0
5
10
15
20
25
Panel vs No Panel P=0.06
L ns, Q ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

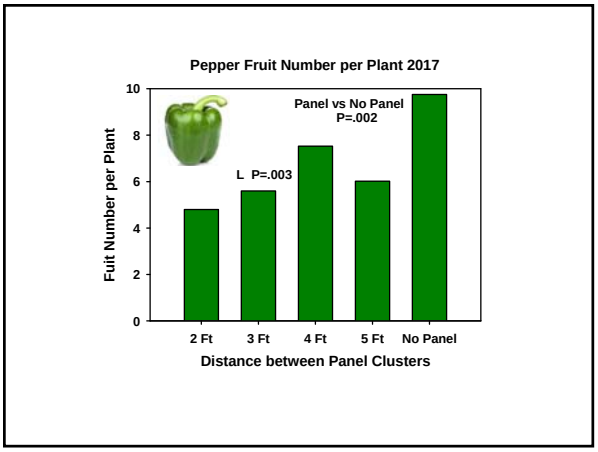

Kale Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
0
100
200
300
400
L *
Panel vs No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

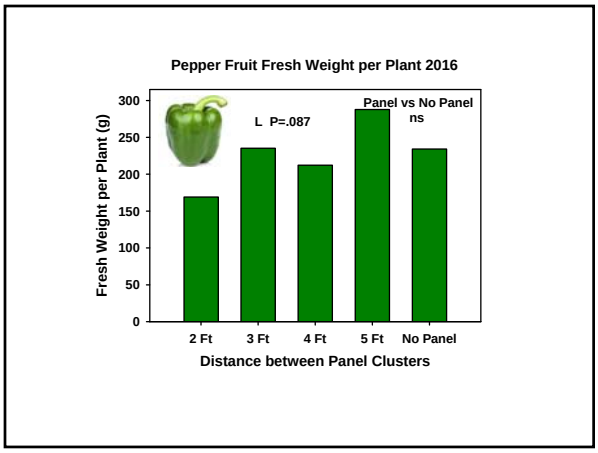

Kale Fresh Weight per Plant 2017
Fresh Weight per Plant (g)
0
200
400
600
800
Panel vs No Panel **
Q *
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

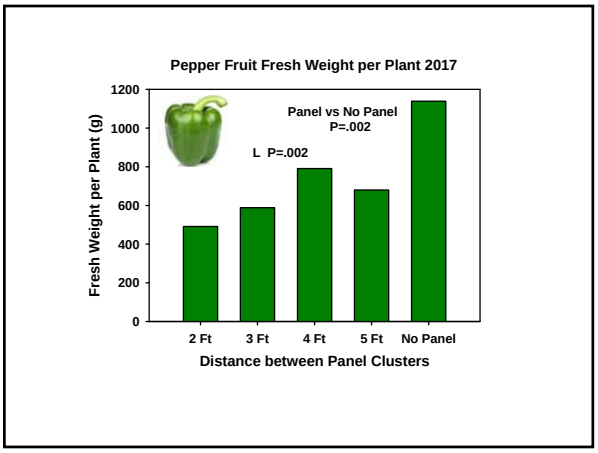

Kale Dry Weight per Plant 2016
L **
Panel vs No Panel
P = 0.09
Dry Weight per Plant (g)
0
10
20
30
40
50
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

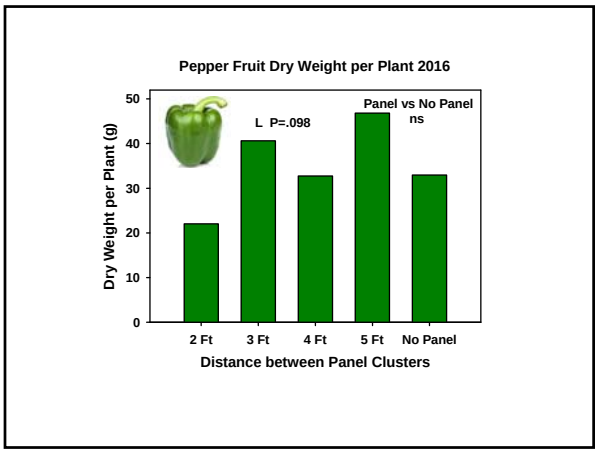

Kale Dry Weight per Plant 2017
Panel vs No Panel **
Q **
Dry Weight per Plant (g)
0
20
40
60
80
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

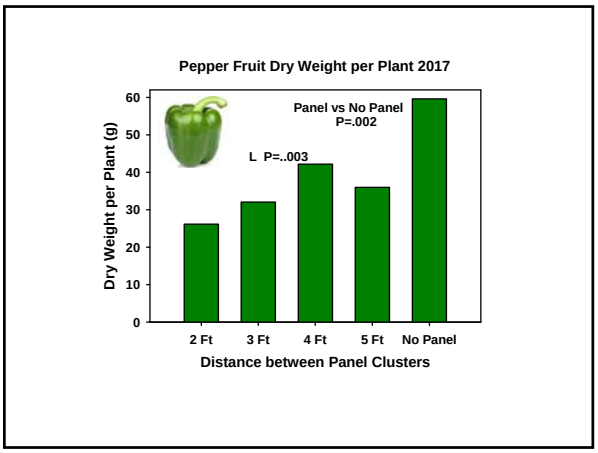

Pepper Fruit Number per Plant 2016
L P=.073
Panel vs No Panel
ns
Fuit Number per Plant
0
1
2
3
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

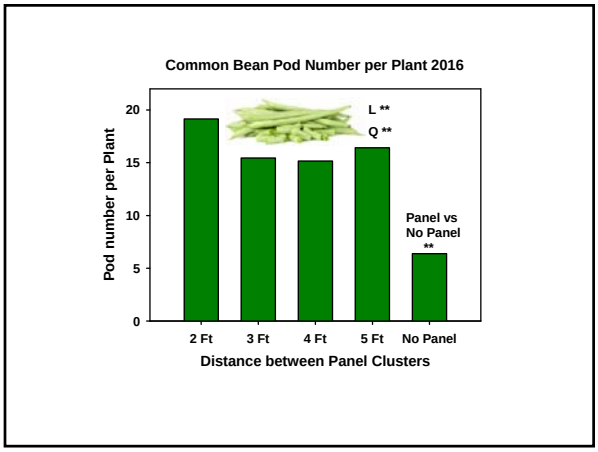

Pepper Fruit Number per Plant 2017
Panel vs No Panel
P=.002
L P=.003
Fuit Number per Plant
0
2
4
6
8
10
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

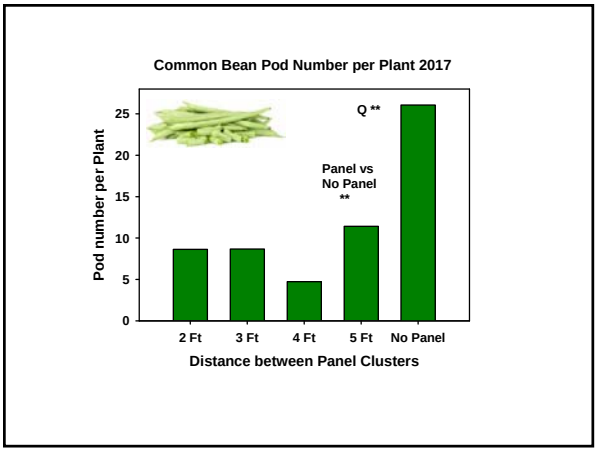

Pepper Fruit Fresh Weight per Plant 2016
L P=.087
Panel vs No Panel
ns
Fresh Weight per Plant (g)
0
50
100
150
200
250
300
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

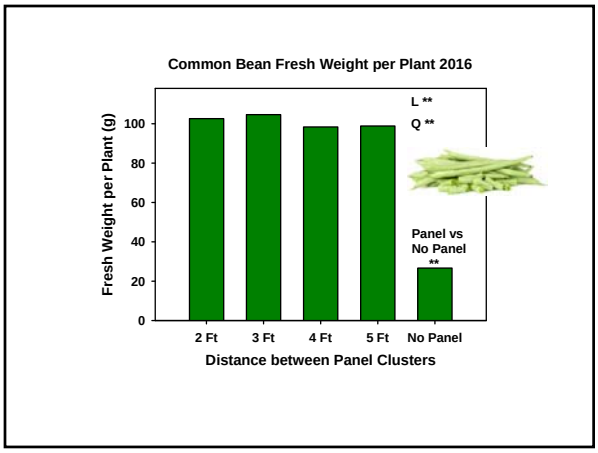

Pepper Fruit Fresh Weight per Plant 2017
Panel vs No Panel
P=.002
L P=.002
Fresh Weight per Plant (g)
0
200
400
600
800
1000
1200
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

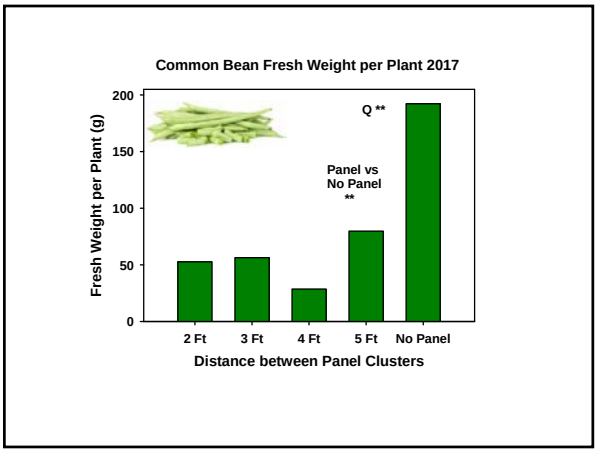

Pepper Fruit Dry Weight per Plant 2016
Dry Weight per Plant (g)
L P=.098
Panel vs No Panel
ns
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

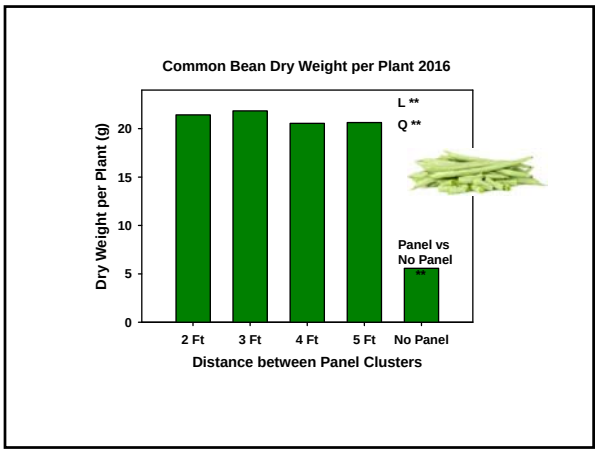

Pepper Fruit Dry Weight per Plant 2017
Dry Weight per Plant (g)
Panel vs No Panel
P=.002
L P=..003
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

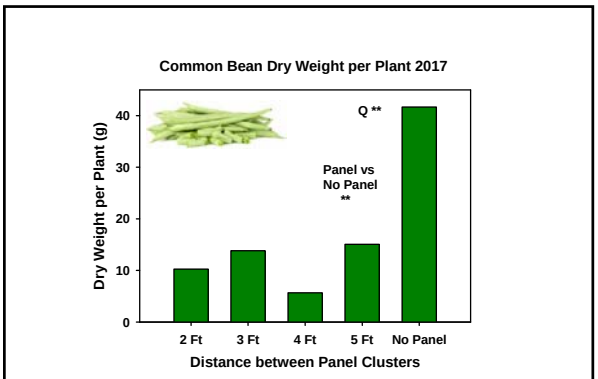

Common Bean Pod Number per Plant 2016
Pod number per Plant
L **
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters

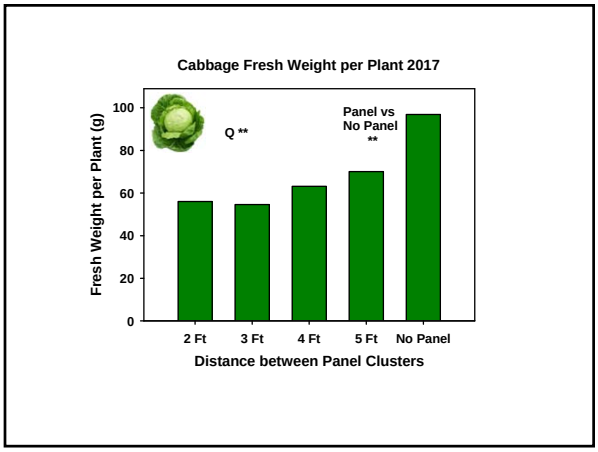

Common Bean Pod Number per Plant 2017
Pod number per Plant
Q **
Panel vs
No Panel
**
2 Ft
3 Ft
4 Ft
5 Ft
No Panel
Distance between Panel Clusters


Common Bean Fresh Weight per Plant 2016
Fresh Weight per Plant (g)
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)
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 15ºF 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.