Report on Data from Time to grow crops in 2011, rev2

This report documents the results of SARE project FNE11-718, Planning tool for succession planting of crops, particularly lettuce, broccoli, and corn. 2011 Growing season.

Summary

Diversified farms grow many crops. Grocery store, farm stand, and restaurant customers want a steady supply of "every" crop. Scheduling plantings for constant supply of crops through the year is a major planning question for growers. Planning a constant supply of many crops is a challenge because time to maturity varies throughout the season, and there are no planning tools to help growers predict time to harvest. This project measured the time to harvest for many plantings of 2 varieties of lettuce, one variety of broccoli and one variety of corn, and provides a planning tool for scheduling succession planting of crops. The main variables are seen to be temperature above the plants "base growing temperature", and the amount of light as the calendar year progresses. The temperature is the largest variable, year to year.[1]

As more growers practice winter growing, these issues will become even more pronounced. Winter growing was not be addressed by this project, but the results should be useful. For instance, knowing the effects of time and temperature numerically will allow growers to make more educated (calculated) investments in supplemental heating and lighting or crops in the fall, winter and spring.

Results from 2011 season and data show that the time temperature and light requirements are:

Broccoli, 34,000 GDDf*HD (40 F base), from Seeding.

Corn, 27,000 GDDf*HD (50Fbase)

Greenstar Lettuce, 25,000 to 30,000 GDDf*HD (40 F base), from Seeding.

Vulcan Lettuce, about 28,000 GDDf*HD (40 F base), from Seeding.

So, this data suggests that if one had a greenhouse with lighting and heat so that Light and Temperature were controlled, And if the Light was on 16 hours per day, and the temperature was a constant 75F, that Vulcan Lettuce should grow from seed to a full head in 50 days (assuming a 40 F base). Similarly, if to save fuel, the greenhouse was at 65F, the same lettuce should take 70 days to grow to full size.

Of course, conditions in the field are much more variable.

[1] The amount of light varies through the season but is repeatable year to year.

Contents

Remaining Questions

At the time of writing this report, several detailed questions remain. However, most of these are beyond the scope of the proposed project.

- What to do with the soil temperature data? We have the data and have looked at some in terms of the GDD with 50 F base. What matters?
- How does soil temperature track air temperature?
- How the three sets of two air temperature probes track each other?

- Is the GDD*HD significant for 'warm season' crops? They will be killed by a frost in the spring or the fall, unless grown in a greenhouse. So the GDD * HD method for corn, tomatoes, etc may be overly complex. But for Brassicas and other cool / cold season crops the approach is valid.
- How wide is the GDD*HD harvest window? Is this a constant?
- How does this approach extend into winter growing in heated or unheated structures?
- How is base temperature determined?
- How does this help with understanding the effects of climate change?
- Why do we get temperature variations within the day, is this due to poor sun shielding? Conduction up the thermal cable? thermal heating of the data logger?, or other?
- For winter growing, how important is the angle of incidence of the light? We will likely need a light meter for winter growing.

Farm Profile

Blue Ox Farm is a certified Organic Vegetable Farm in Enfield NH with about 10 acres tilled in 2011. We grow for the local Coop, local Restaurants, Farmers Market, and CSA. We grow about 1 to 1.25 acre each of Lettuce and Broccoli, and about ½ acre of corn. The remaining is a wide variety of crops. Most of the soils are on the wet side, new fields are less wet.

Participants

Becky Sideman was the technical advisor on the project. Cynthia Walthour did the seeding, most of the tracking of the plants through the seeding and transplanting, and much of the data collection during harvest (particularly Lettuce), with Dave Winters also helping with the lettuce harvest. The corn and Broccoli were harvested by Dave Winters, Jake Torrey, Dave Gagne, and Steve Fulton through the season (the same people also did the data recording on the cards). Steve Fulton did some of the tracking and most of the analysis of the data, Steve was also responsible for setting up and placing the thermal probes.

Economics

These results will have an effect on the economics of the farm, when they are implemented.

Method for forecasting when a crop will be ready to harvest

Planning a years production of crops that are planted in succession requires experience, plus a bit of guessing what the weather might be during the season. This report presents a methodology to eliminate some of the guessing that is based on historical weather information from a growers area.

Plants need time, light, and heat to grow. Growing Degree Days (GDDf) are a relatively well known method to understand biological processes such as when an insect pest will appear, or when a crop will be mature. Data for crop maturity shows that the GDD for a crop to mature is not constant, but varies through the season. Some, or maybe all, of the variation is due to day length variation.

A proposed means to combine the effects of time, light, and heat are the Growing Degree Day * Hours Daylight (GDDf*HD)[2].

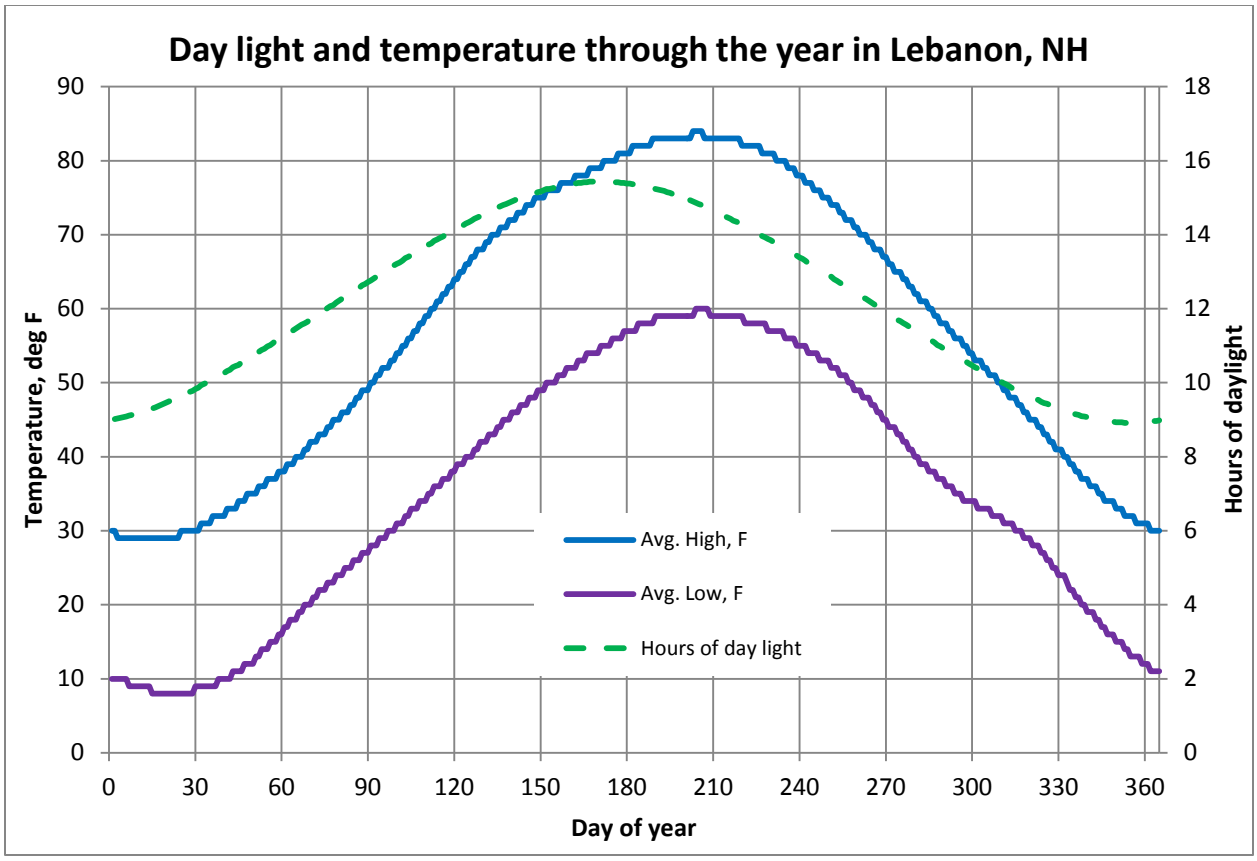
The data suggests that the GDD*HD (Growing Degree Days * Day Light Hours) is as follows

- Everest Broccoli, 34,000 GDDf*HD (40 F base), from Seeding.
- Mystique Corn, 27,000 GDDf*HD (50F base), from Seeding
- Greenstar Lettuce, 25,000 to 30,000 GDDf*HD (40 F base), from Seeding.
- Vulcan Lettuce, about 28,000 GDDf*HD (40 F base), from Seeding.

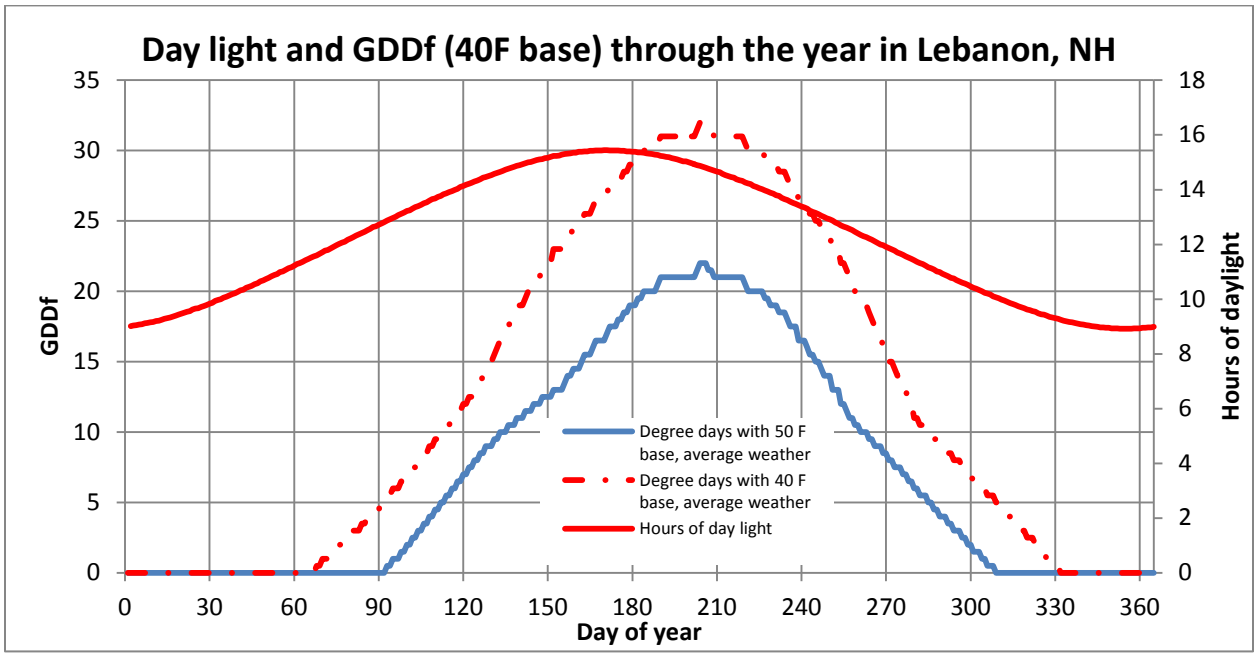
So, this data suggests that if one had a greenhouse with lighting and heat so that Light and Temperature were controlled, And if the Light was on 16 hours per day, and the temperature was a constant 75F, that Vulcan Lettuce should grow from seed to a full head in 50 days (assuming a 40 F base). Similarly, if to save fuel, the greenhouse was at 65F, the same lettuce should take 70 days to grow to full size.

Of course, conditions in the field are much more variable. The Figure below shows the average daily temperatures (high and low) for Lebanon NH. It also shows the number of daylight hours in Lebanon NH (http://www.weather.com/outlook/travel/businesstraveler/wxclimatology/daily/USNH0123 reference).

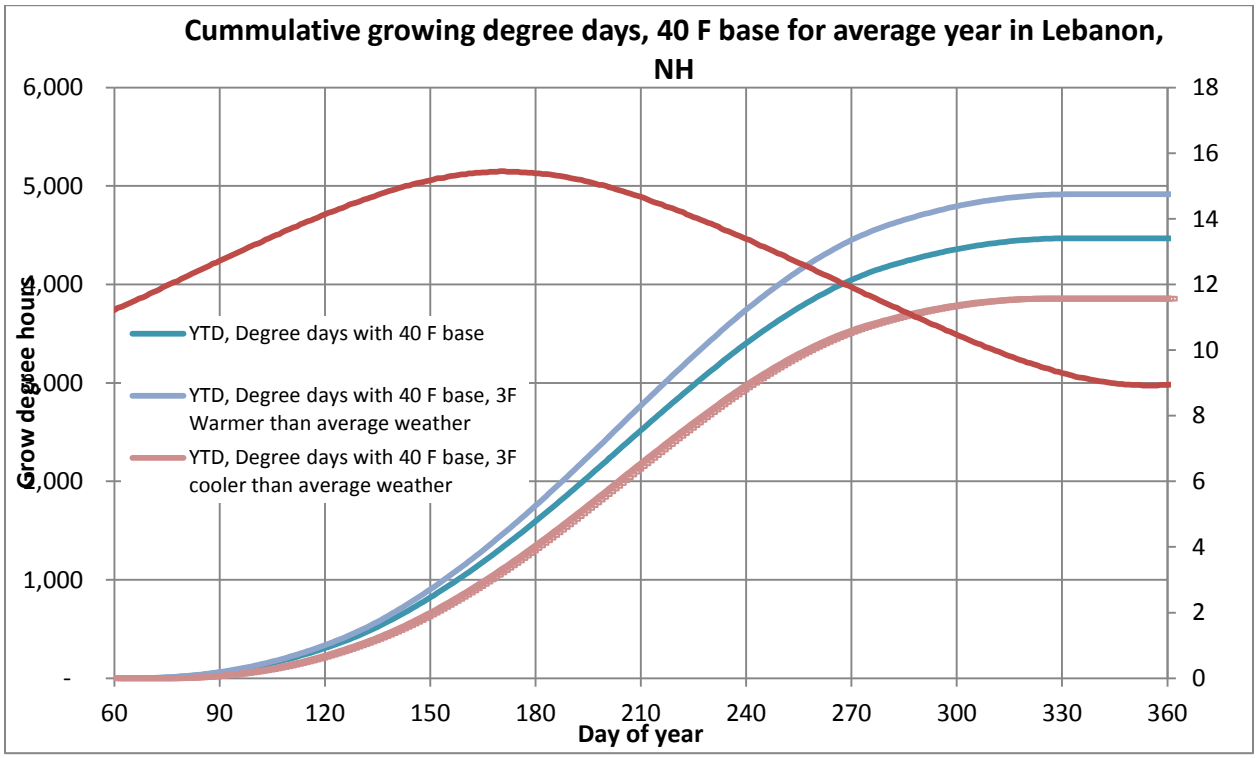
[2] The “f” means that the temperatures are in degrees Fahrenheit vs Celcius



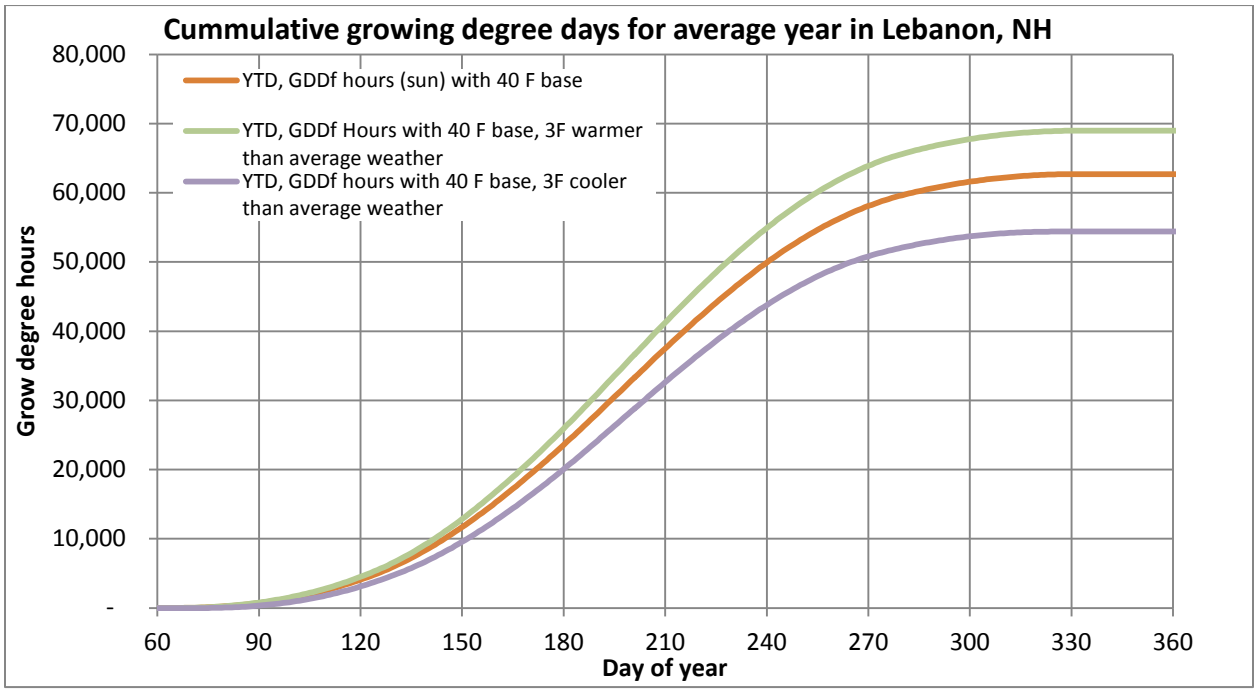
Following is a figure showing the GDDf (Growing Degree Days in Fahrenheit days) through the year, also with a 40 F base temperature. This was developed using the Average Annual temperature from a weather station near the farm that reports summary temperatures to the Internet, not Data taken at Blue Ox Farm.



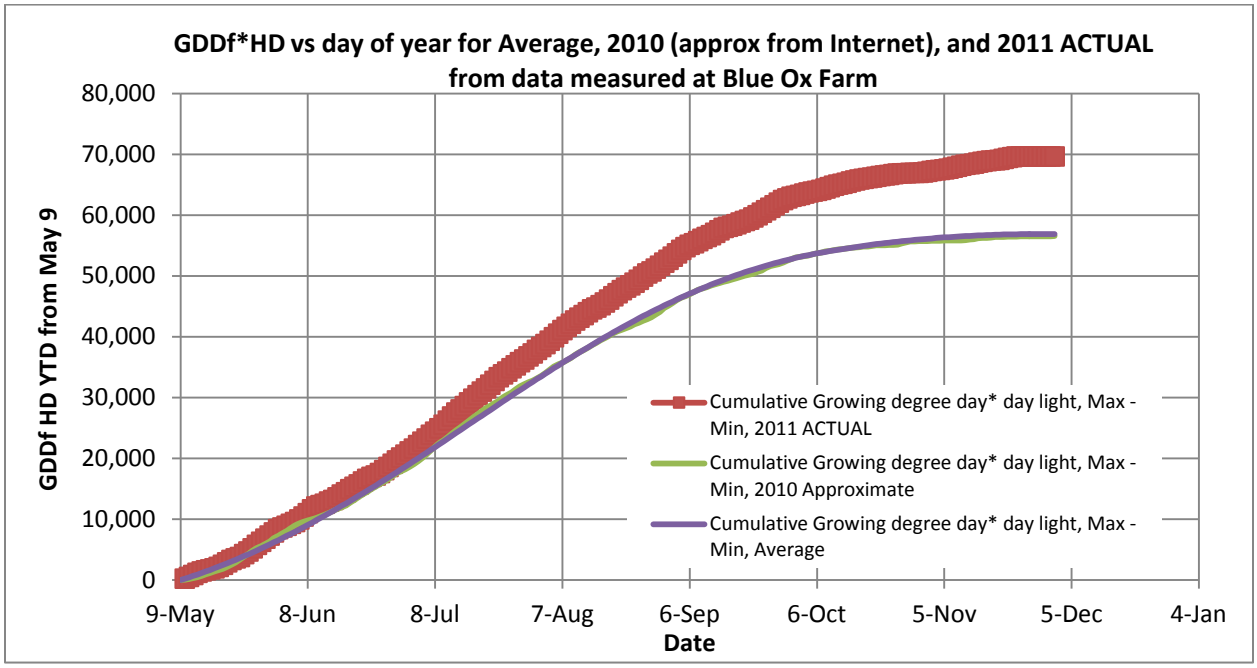
The figure below looks at the same information, only on a cumulative basis, also for a 40F base. Note that I have added arbitrary 3F warmer, and 3F cooler lines in the plot to start to think about how temperature variations in the real world should effect the growing of plants (relative to a schedule).

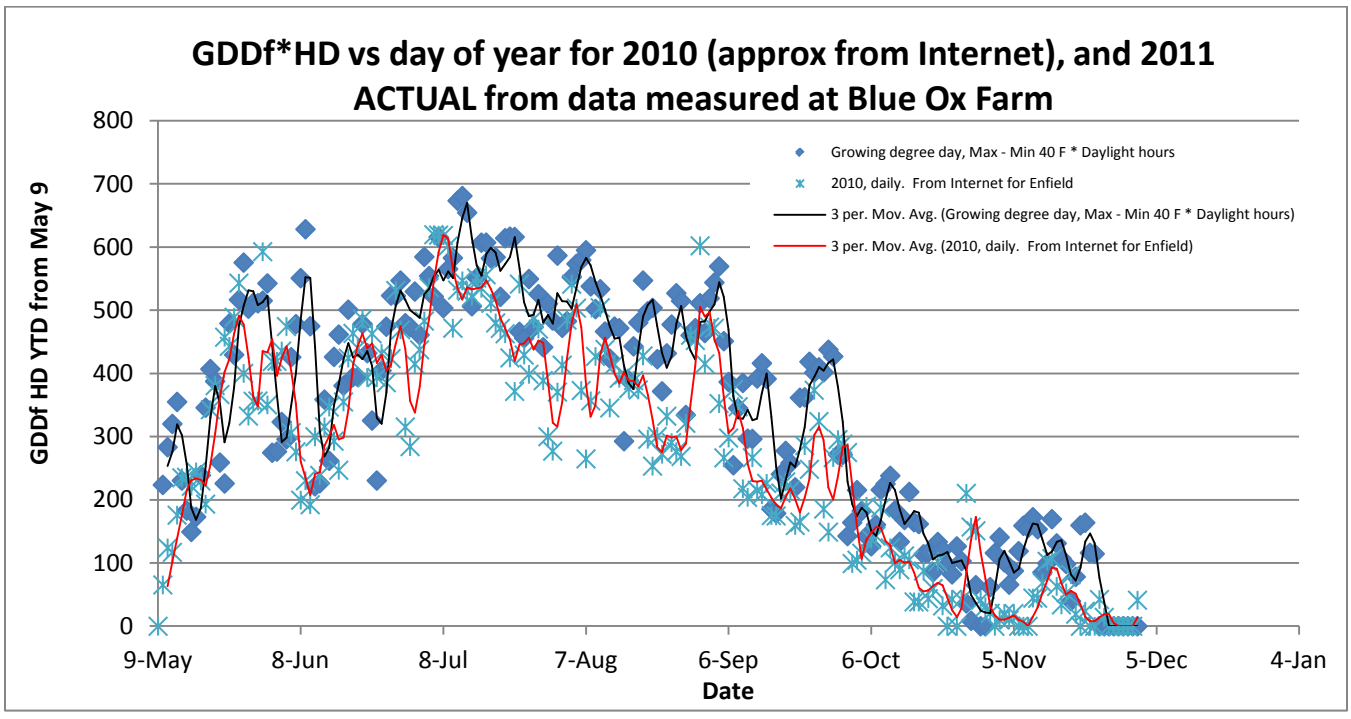


Similarly we can look at the Cumulative GDDf*HD through the year.



So if a Lettuce seed is planted on May 27 (day 147), it should be harvestable 28,000 GDDf from that date, or July 31 in an average year, July 26 in a 3F warmer year, and August 8 in a 3F cooler year (all in Enfield). Vulcan seed planted in 2011 on May 27 was harvested July 23rd! Greenstar was July 24. 2011 was warm. (or the Blue Ox fields are warmer than the not-fully-specified sites in Lebanon or Enfield from the Internet from which the 2010 and the average historical temperature Information was taken).



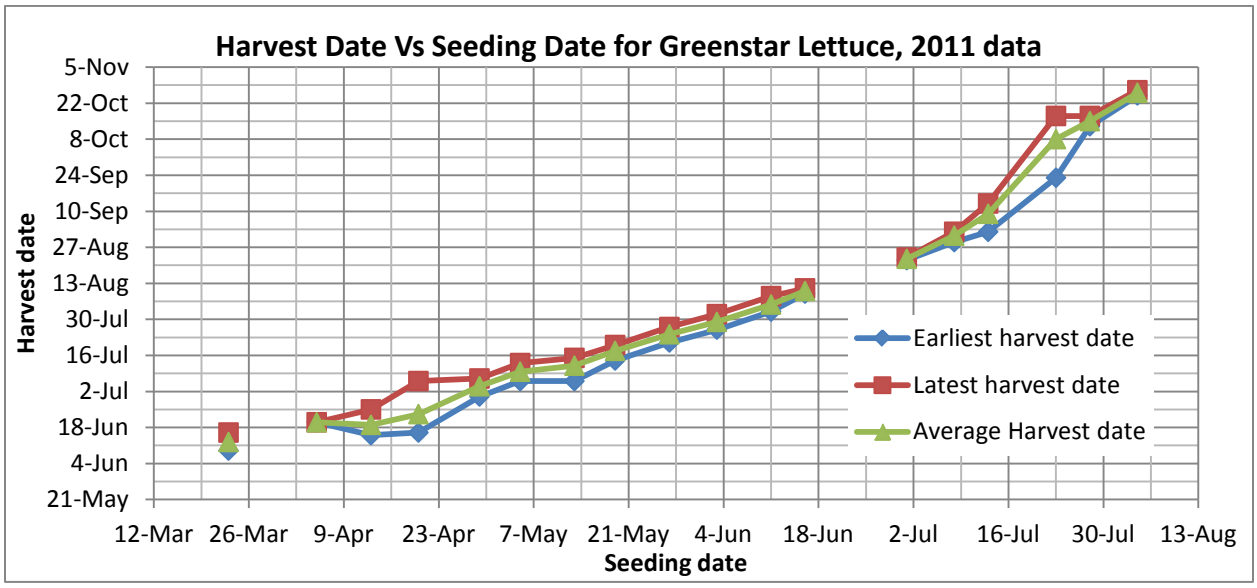


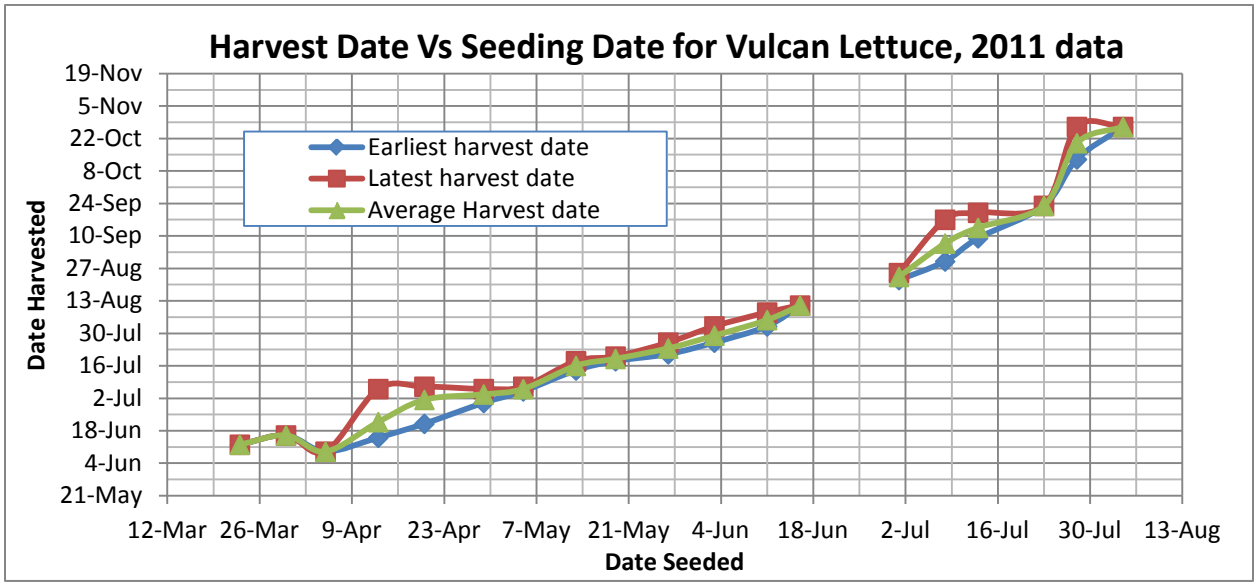
Above data showing that 2011 was generally warmer than 2010 most all summer and fall.

Planning tools for growing

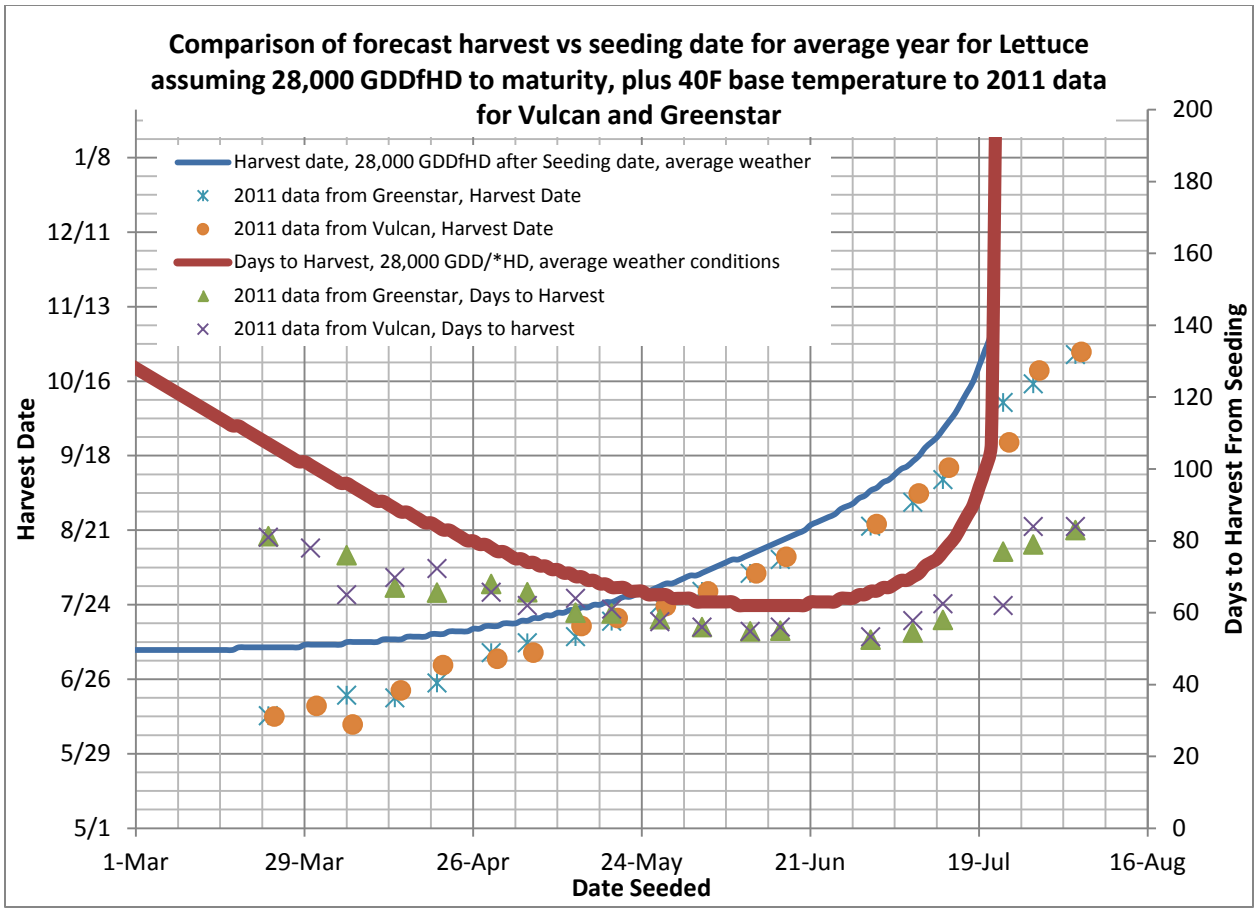
The main output from this project was to be a planning tool, or tools, that could be used. This section is that tool. These plots are valid for Enfield NH. Farms at the same latitude will have the same day length, temperatures vary as well. These plots are made in Excel and require the day length, and the high and low temperatures for a location to make the predictions.

Graphically we can show when we seeded the plantings, and when we harvested to see what happened in 2011. See the following plots for lettuce. These give a guide for when the crop is harvestable vs the date seeded.

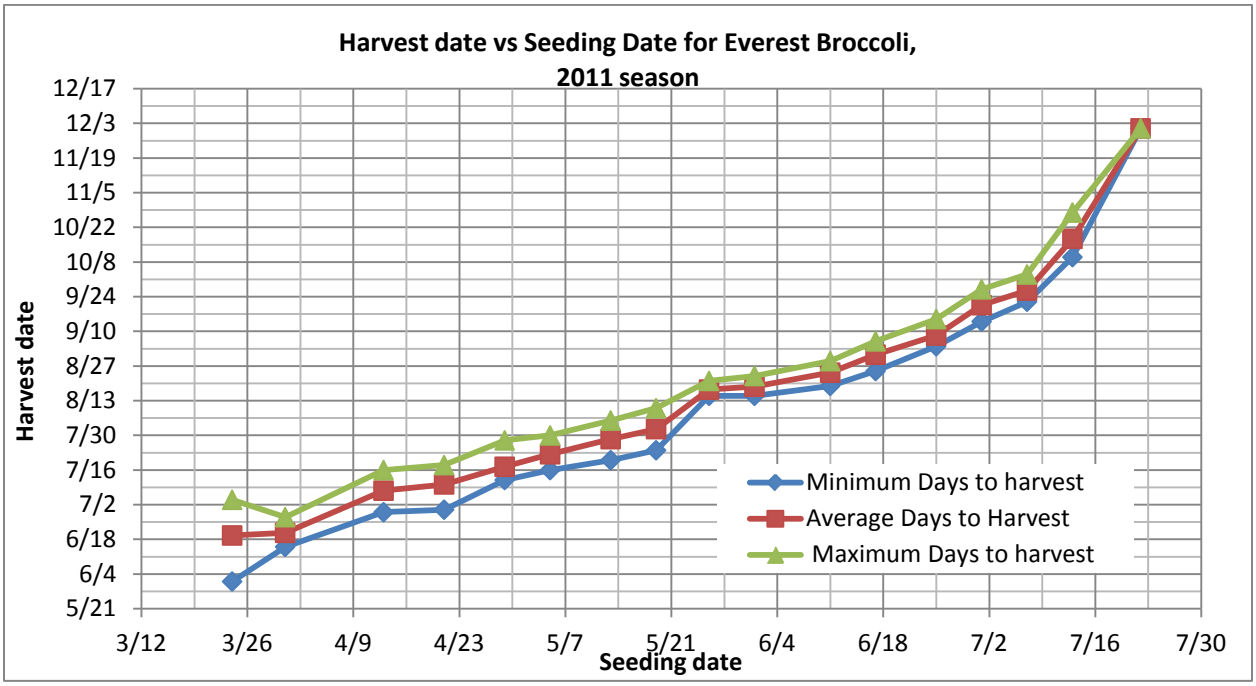


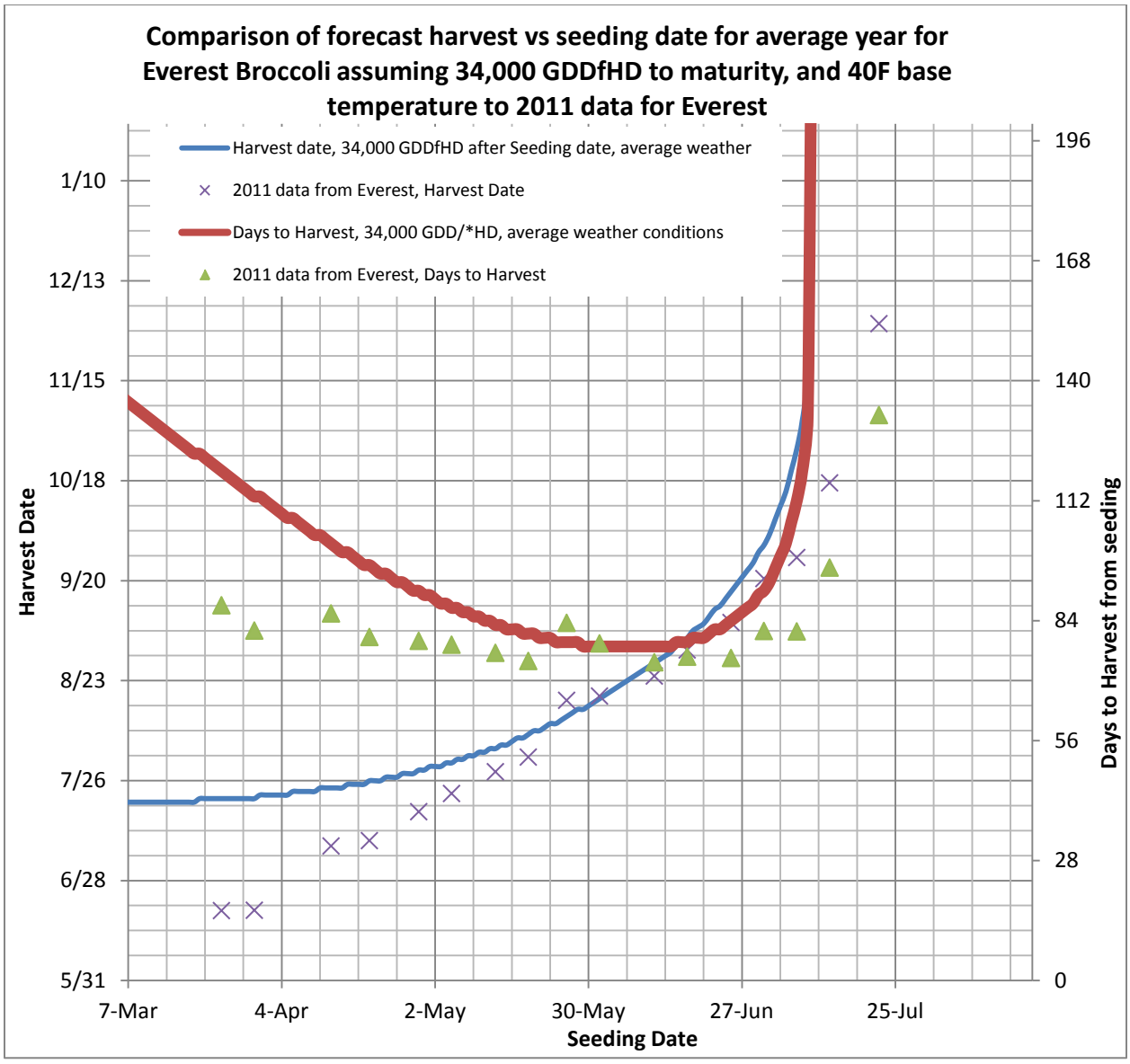


We then calculate when the lettuce would be ready during a year with average temperatures. This is seen in the next plot, as well as with the 2011 data.



Similarly for Broccoli,

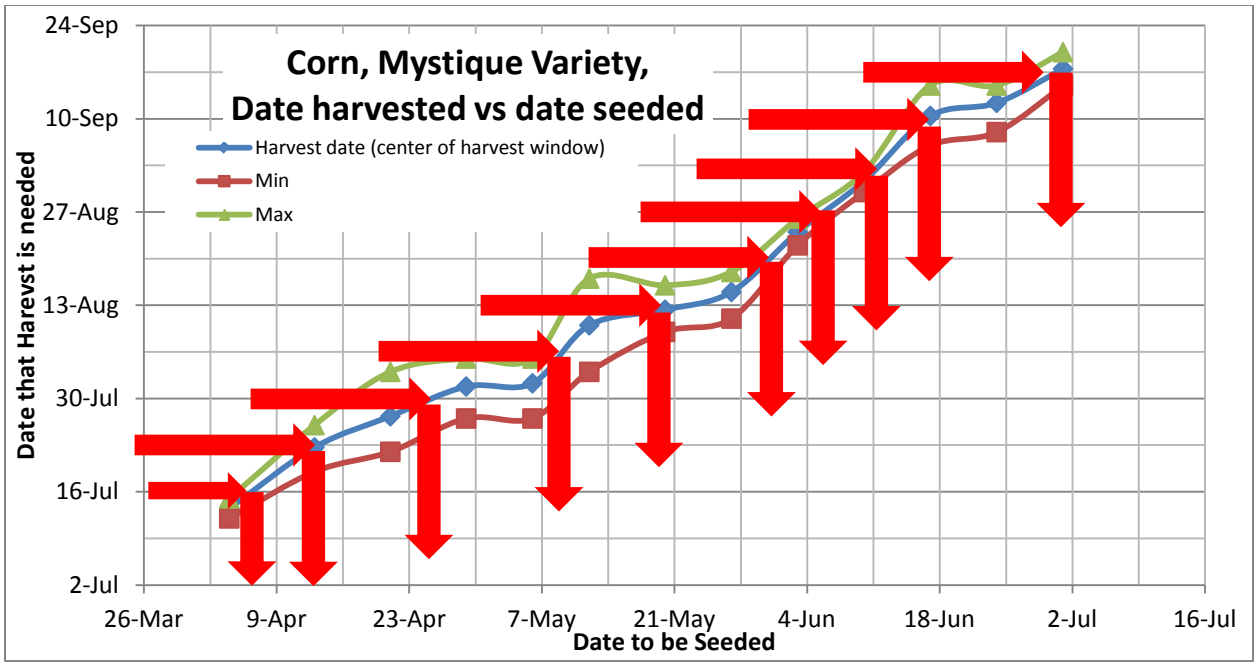


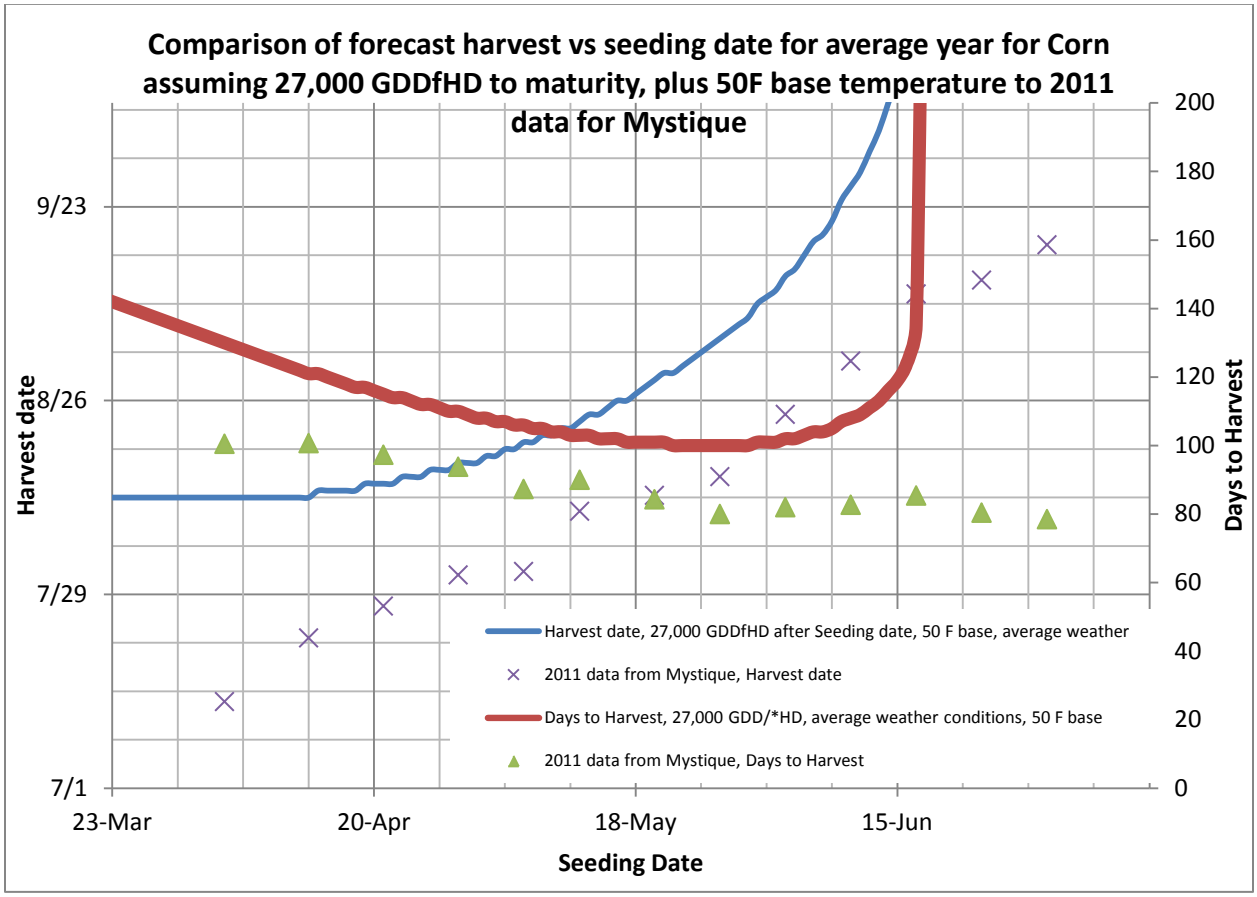


Note that the data from 2011 shows that Everest Broccoli came in earlier than forecast. Of course there is season to season variation, but also, all crops were started in a heated greenhouse, this was all plantings prior to June 1. Further, the first two plantings of broccoli were planted in different soil, and covered by row cover for about 2 weeks, a further boost to growth.

What is happening in the fall is not as clear. In large part this is due to 2011 fall being warm, but also, the historical data cuts out the peak temperatures, which may be significant in marginal growing conditions.

Lettuce shows the same effects.

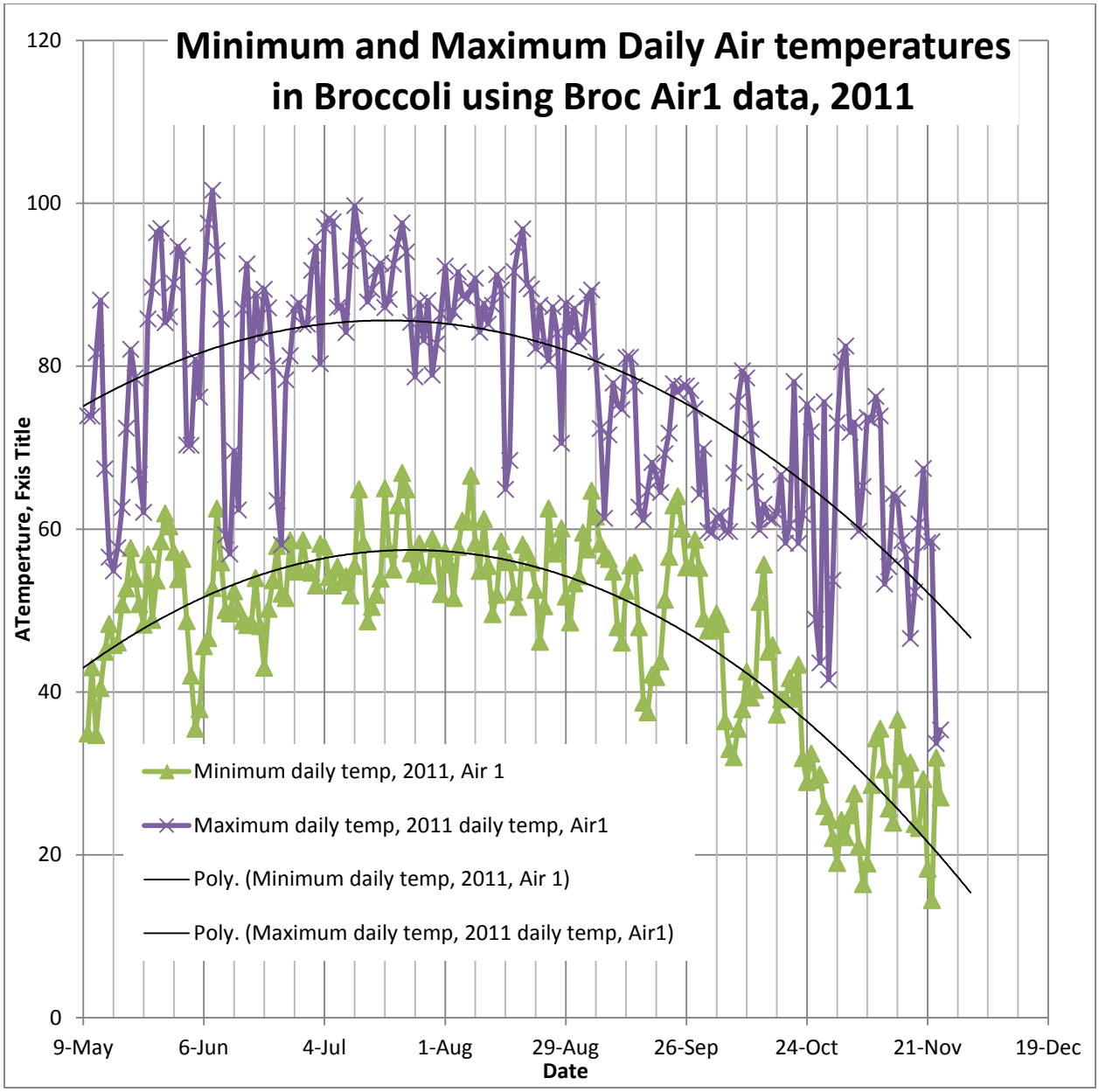

Corn, Mystique Variety,
Date harvested vs date seeded
Harvest date (center of harvest window)
Min
Max
Date that Harevst is needed
24-Sep
10-Sep
27-Aug
13-Aug
30-Jul
16-Jul
2-Jul
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
Date to be Seeded


Comparison of forecast harvest vs seeding date for average year for Corn assuming 27,000 GDDfHD to maturity, plus 50F base temperature to 2011 data for Mystique
Harvest date
9/23
8/26
7/29
7/1
Days to Harvest
200
180
160
140
120
100
80
60
40
20
0
23-Mar
20-Apr
18-May
15-Jun
Seeding Date
Harvest date, 27,000 GDDfHD after Seeding date, 50 F base, average weather
2011 data from Mystique, Harvest date
Days to Harvest, 27,000 GDD/*HD, average weather conditions, 50 F base
2011 data from Mystique, Days to Harvest

Temperature data from 2011, graphical summary

All temperature probes seem to be working correctly, and agree reasonably well with each other when at the same conditions.

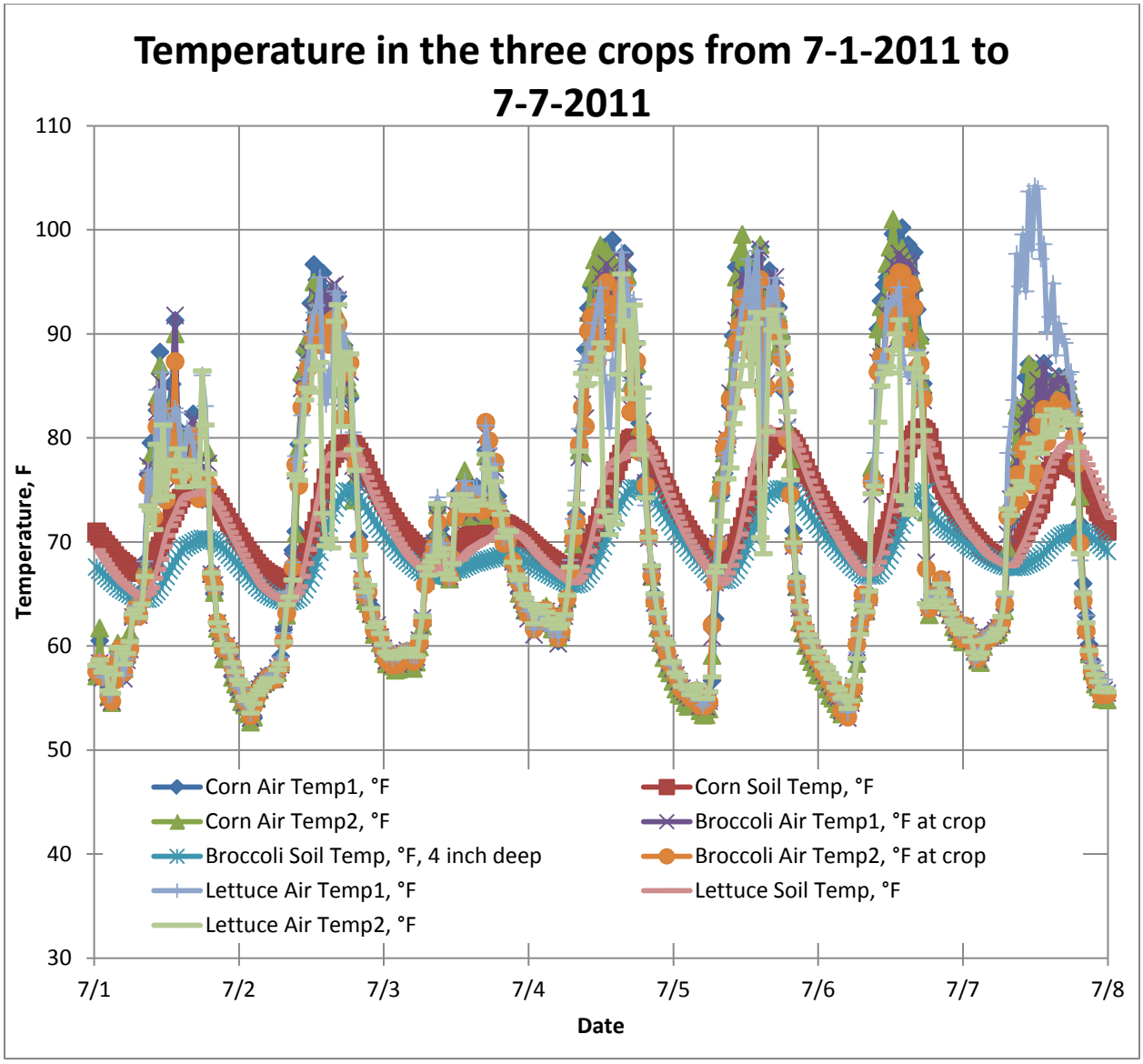
Air temperatures over crops



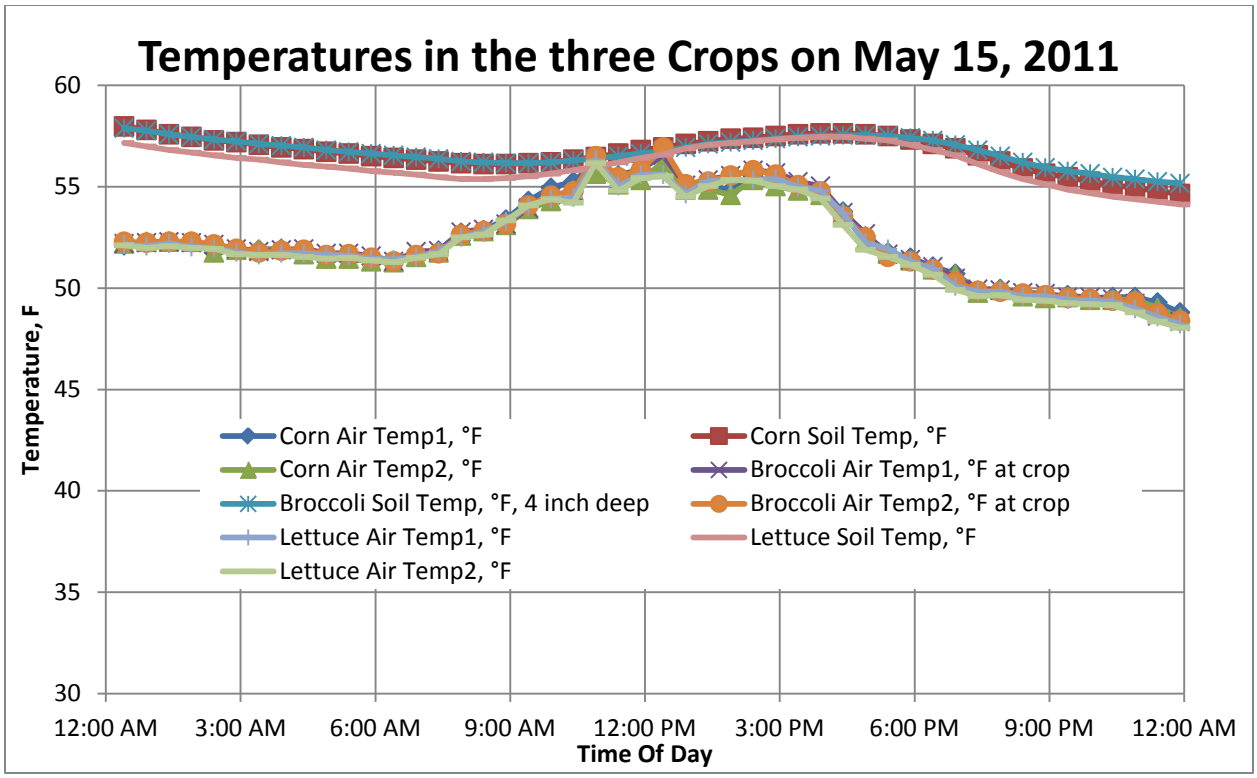
Air temperatures over the crops are more easily understood (to date) by looking at data over a period of a few days, rather than the season.

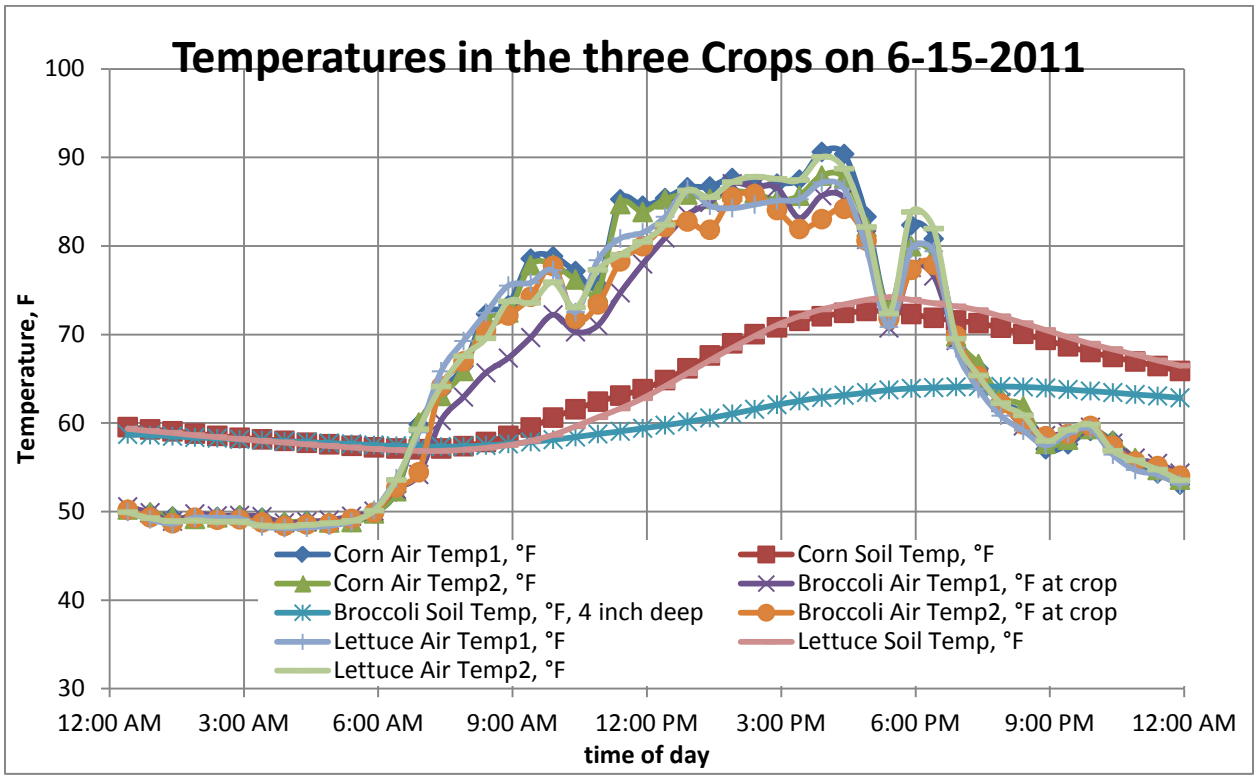
Soil temperatures (at 4 inch depth) vary much more than I expected during the day. The broccoli soil temperature is consistently lower temperature than the corn soil temp and the Lettuce soil temp.

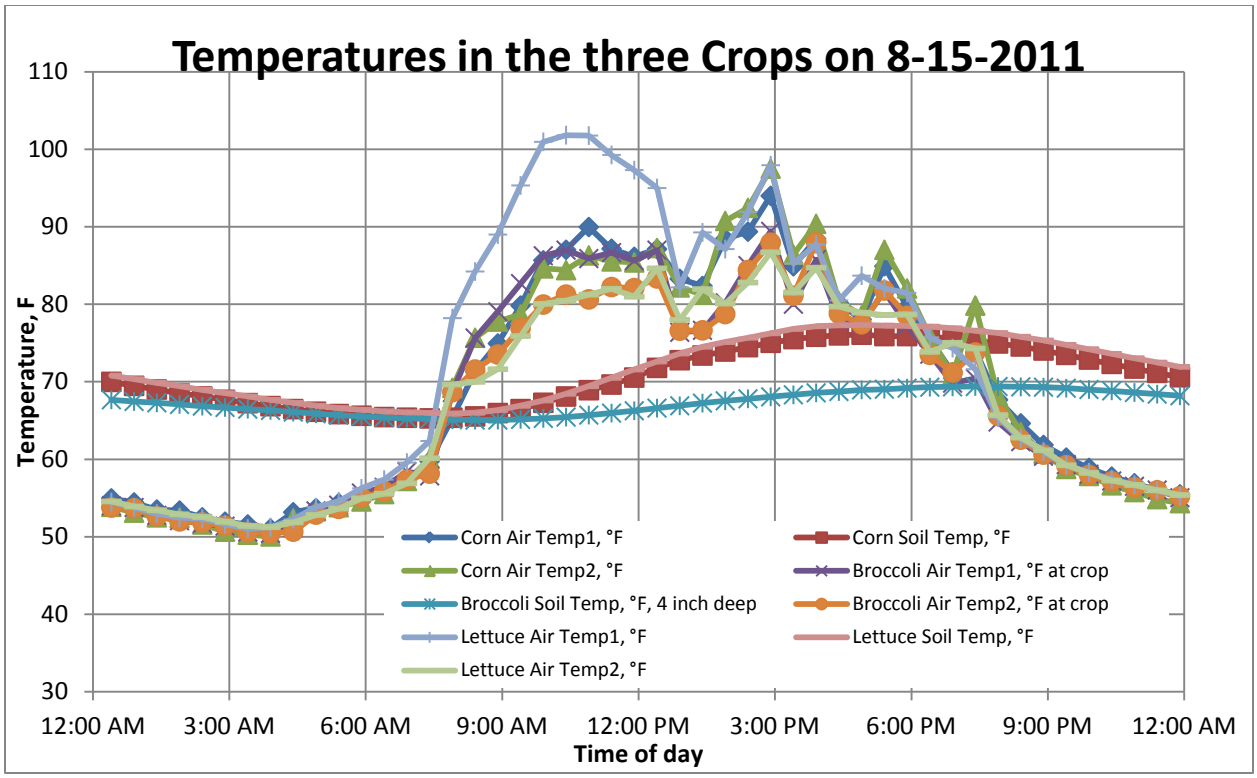
It is not understood what happened to Lettuce air temp #1 on 7-7. Likely there is a shielding from the sun issue.

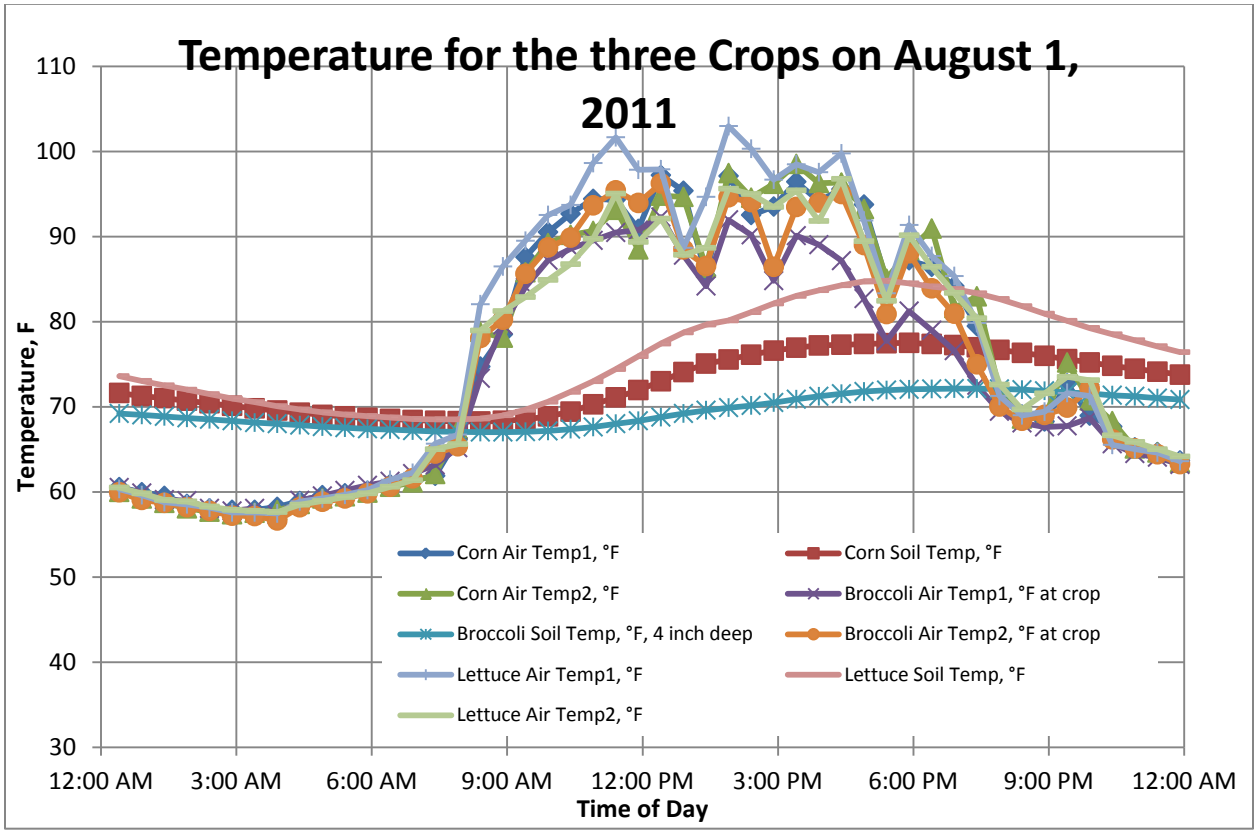


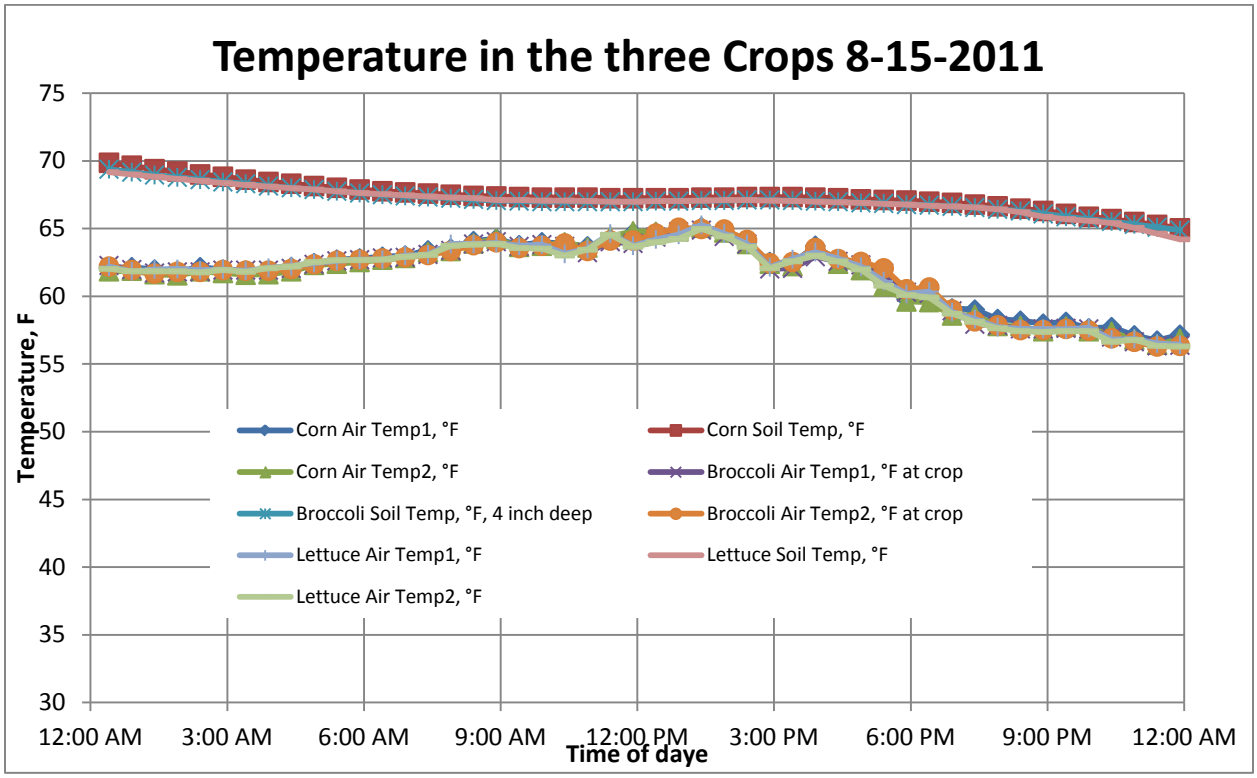
The following plots show individual days through the growing season, roughly every 30 days. The broccoli soil temperature is consistently lower temperature than the corn soil temp and the Lettuce soil temp. Note that the agreement between all thermal probes is generally pretty good.

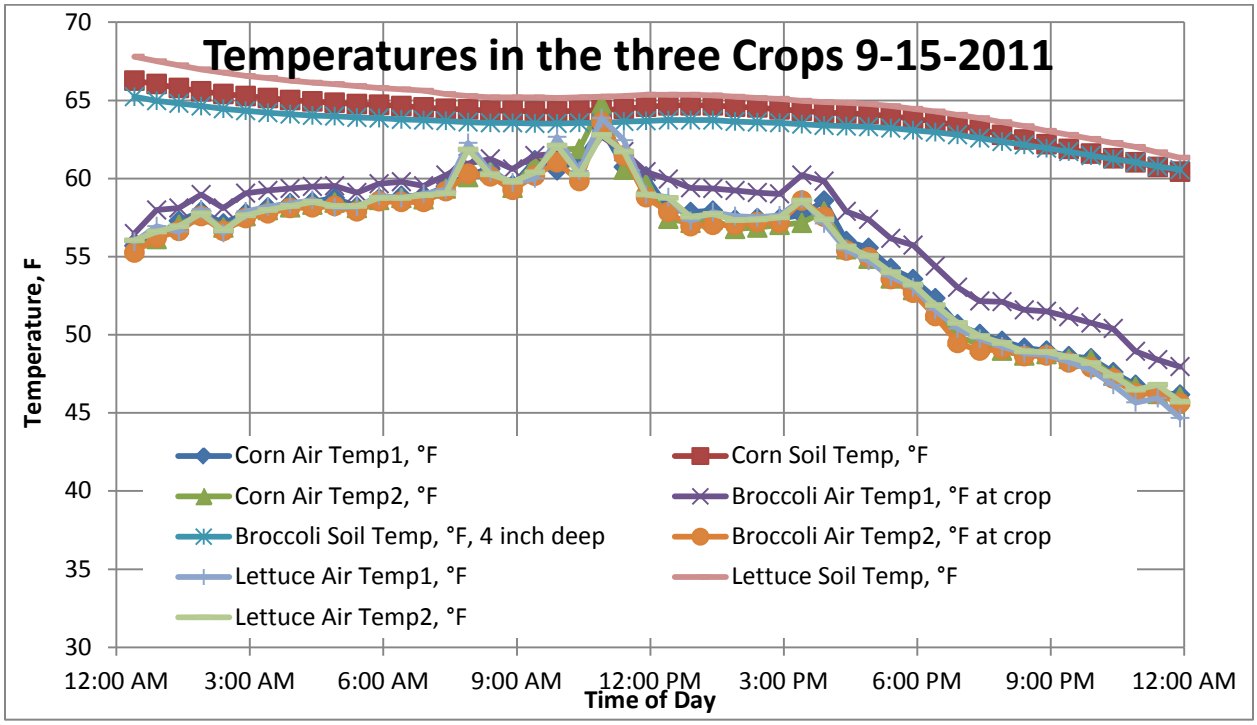

Temperatures in the three Crops on May 15, 2011
Temperature, F
60
55
50
45
40
35
30
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
Time Of Day
Corn Air Temp1, °F
Corn Soil Temp, °F
Corn Air Temp2, °F
Broccoli Air Temp1, °F at crop
Broccoli Soil Temp, °F, 4 inch deep
Broccoli Air Temp2, °F at crop
Lettuce Air Temp1, °F
Lettuce Soil Temp, °F
Lettuce Air Temp2, °F

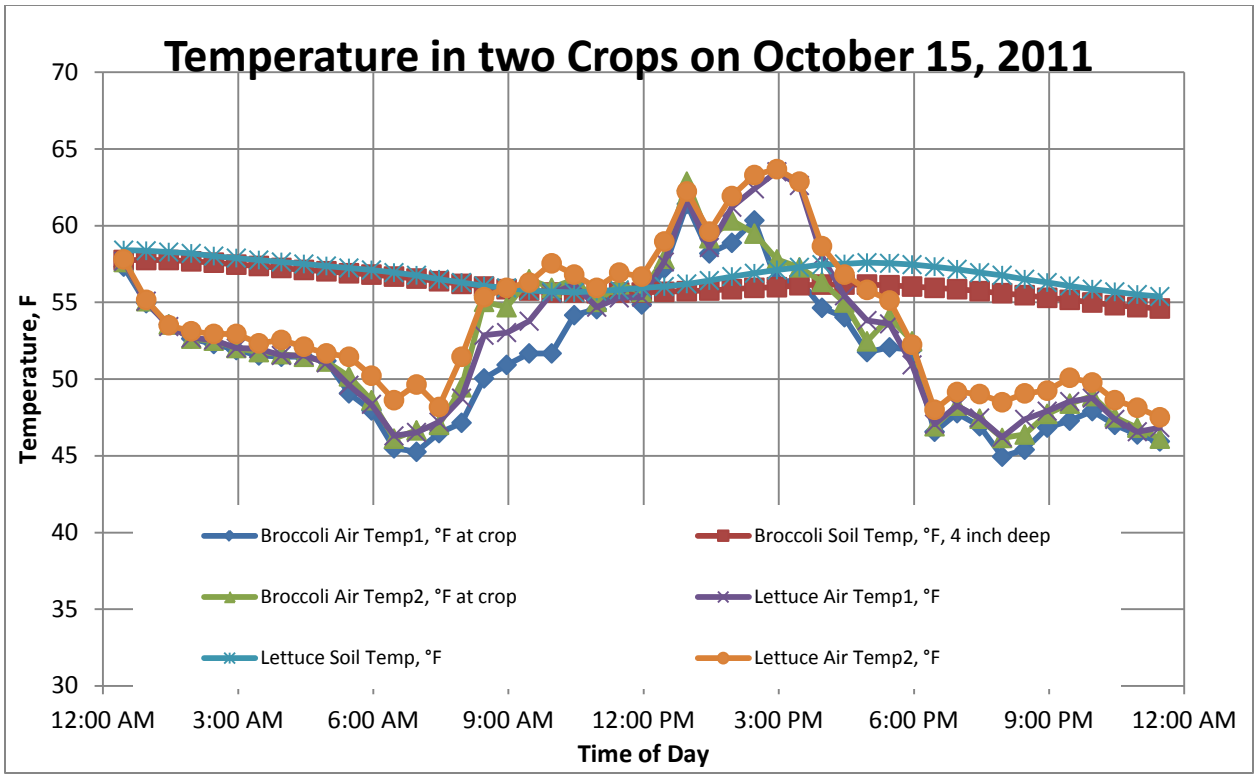

Temperatures in the three Crops on 6-15-2011
Temperature, F
100
90
80
70
60
50
40
30
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
time of day
Corn Air Temp1, °F
Corn Soil Temp, °F
Corn Air Temp2, °F
Broccoli Air Temp1, °F at crop
Broccoli Soil Temp, °F, 4 inch deep
Broccoli Air Temp2, °F at crop
Lettuce Air Temp1, °F
Lettuce Soil Temp, °F
Lettuce Air Temp2, °F


Temperatures in the three Crops on 8-15-2011
Temperature, F
110
100
90
80
70
60
50
40
30
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
Time of day
Corn Air Temp1, °F
Corn Soil Temp, °F
Corn Air Temp2, °F
Broccoli Air Temp1, °F at crop
Broccoli Soil Temp, °F, 4 inch deep
Broccoli Air Temp2, °F at crop
Lettuce Air Temp1, °F
Lettuce Soil Temp, °F
Lettuce Air Temp2, °F

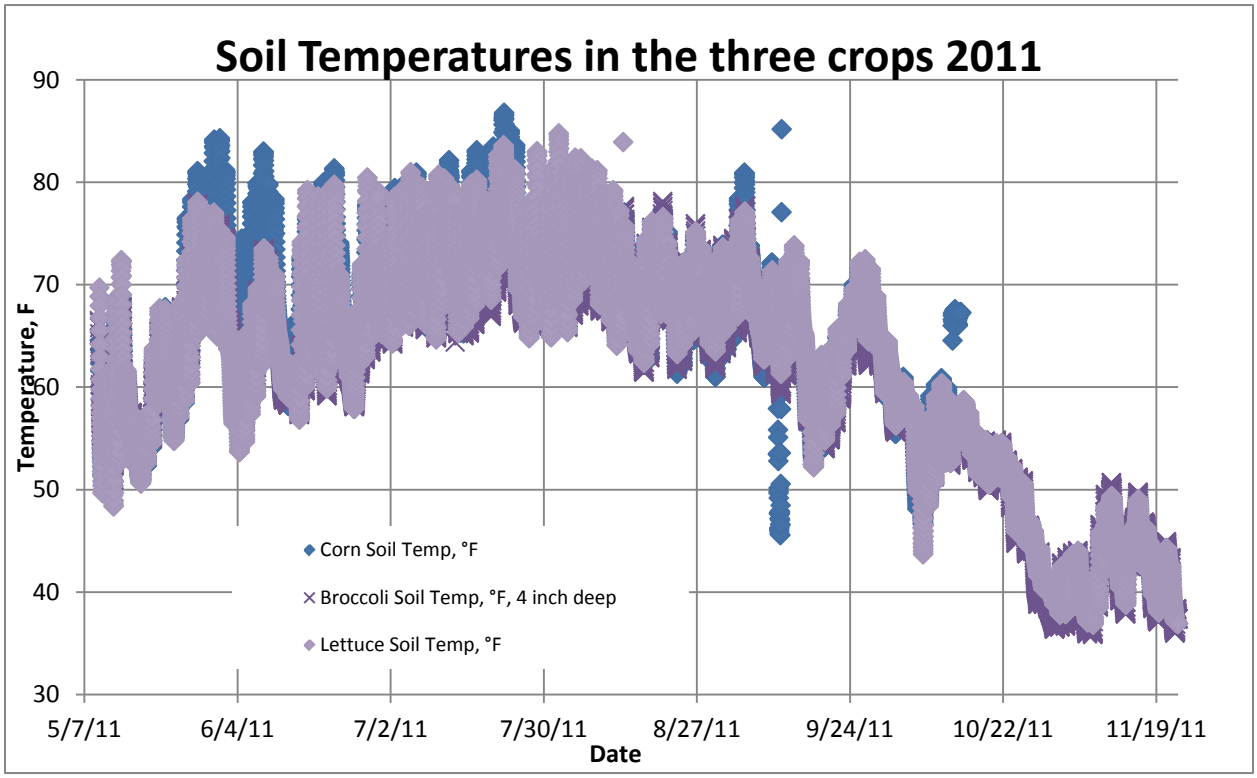

Temperature for the three Crops on August 1, 2011
Temperature, F
110
100
90
80
70
60
50
40
30
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
Time of Day
Corn Air Temp1, °F
Corn Soil Temp, °F
Corn Air Temp2, °F
Broccoli Air Temp1, °F at crop
Broccoli Soil Temp, °F, 4 inch deep
Broccoli Air Temp2, °F at crop
Lettuce Air Temp1, °F
Lettuce Soil Temp, °F
Lettuce Air Temp2, °F


Temperature in the three Crops 8-15-2011
Temperature, F
75
70
65
60
55
50
45
40
35
30
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
Time of daye
Corn Air Temp1, °F
Corn Soil Temp, °F
Corn Air Temp2, °F
Broccoli Air Temp1, °F at crop
Broccoli Soil Temp, °F, 4 inch deep
Broccoli Air Temp2, °F at crop
Lettuce Air Temp1, °F
Lettuce Soil Temp, °F
Lettuce Air Temp2, °F

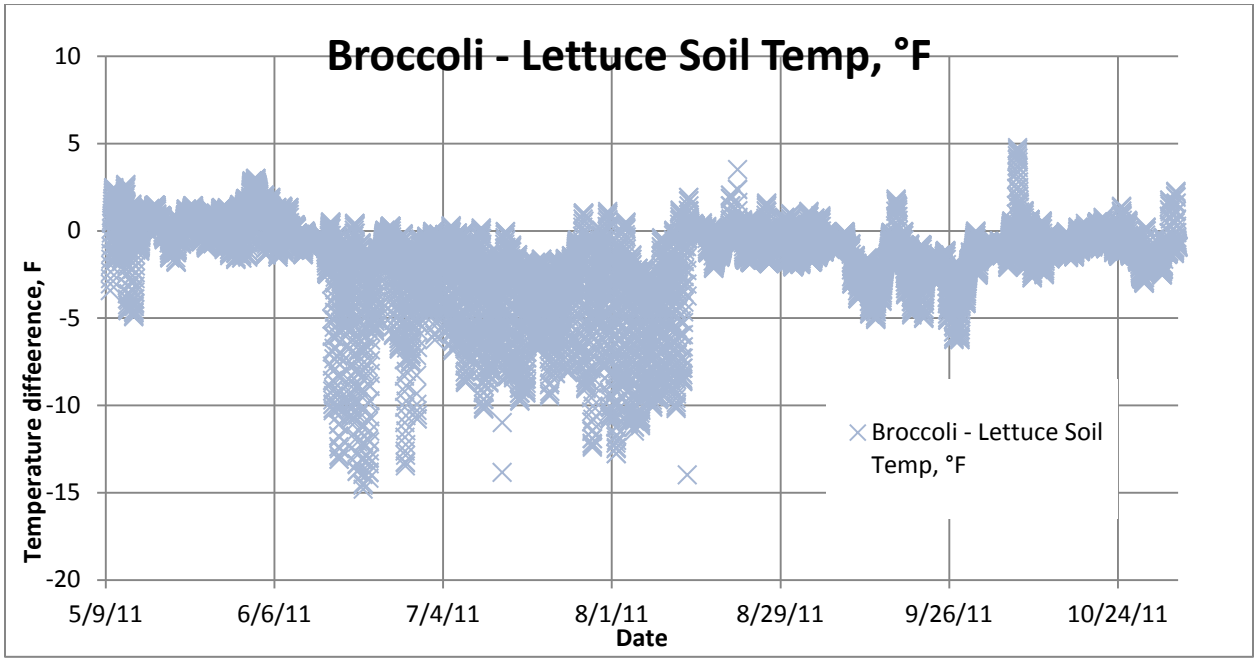

Temperatures in the three Crops 9-15-2011
Temperature, F
70
65
60
55
50
45
40
35
30
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
Time of Day
Corn Air Temp1, °F
Corn Soil Temp, °F
Corn Air Temp2, °F
Broccoli Air Temp1, °F at crop
Broccoli Soil Temp, °F, 4 inch deep
Broccoli Air Temp2, °F at crop
Lettuce Air Temp1, °F
Lettuce Soil Temp, °F
Lettuce Air Temp2, °F



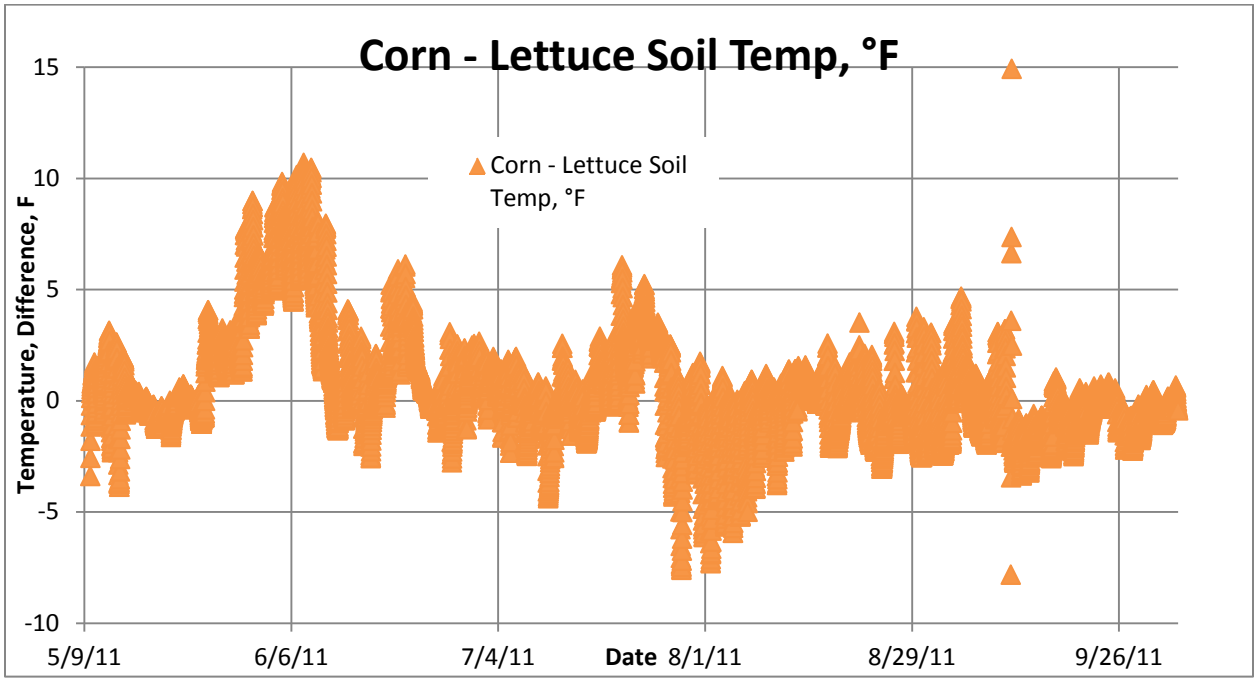
The following figure shows the soil temperatures for the season. Hard to tell what is happening here as there is so much information.



Broccoli soil temperature Averages 1.6F below Lettuce soil temp. Both are on white plastic, so presumably the Broccoli plants shade the plastic more than the lettuce.



Corn Averages 0.5 F above Lettuce soil temp, Presumably this is the difference between the bare soil (corn) and white plastic. However, I had expected a much bigger difference due to the white plastic. The difference in early June is much larger, this is when the corn is small and does not shade the bare soil, when the corn has grown taller, the difference is not as large as the soil on the corn is shaded, and the lettuce is still largely in the sun but on white plastic.



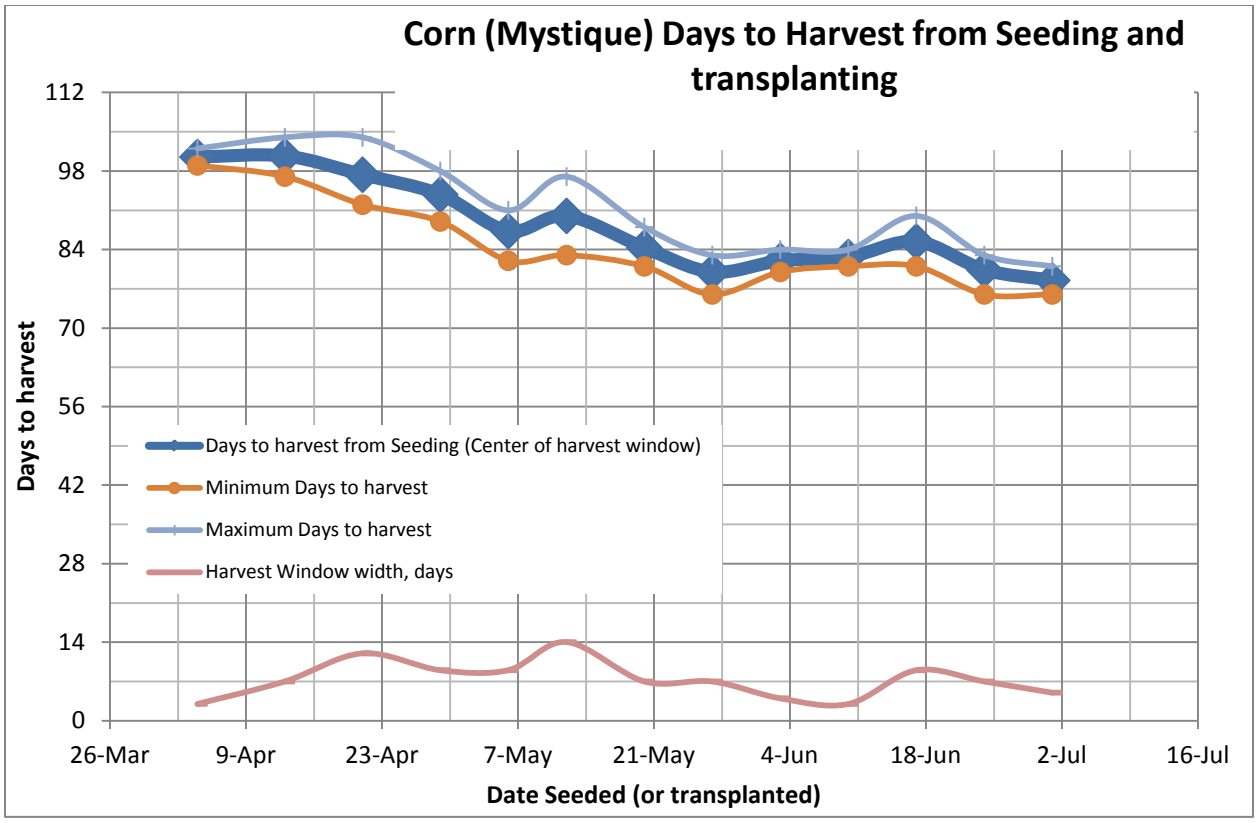
Following is the data by crop

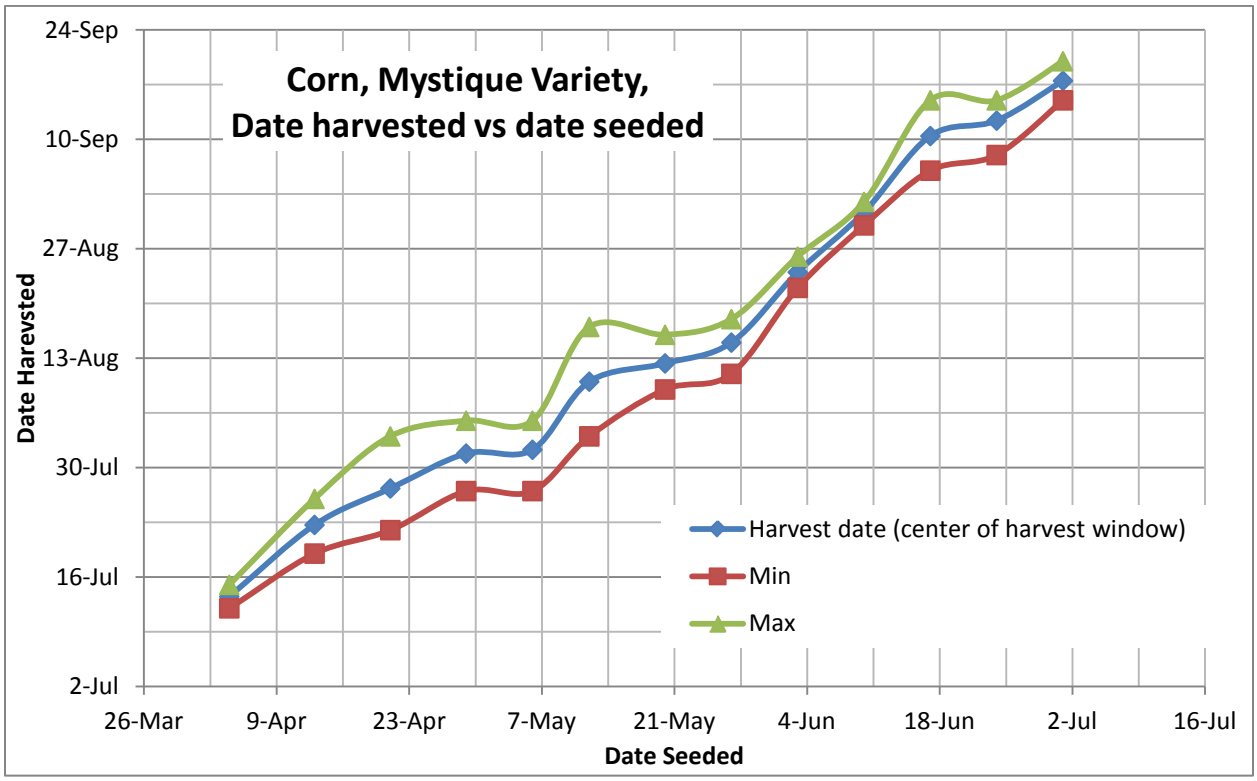
Corn, Mystique (variety from Johnny's Selected Seeds, listed by JSS as a 74 day maturity)

Total Planned	9,500
Total Seeded	11,165
Total transplanted	5,080 (?)
Total Harvested	4,628 (?)
Total sold	7,031 (?)

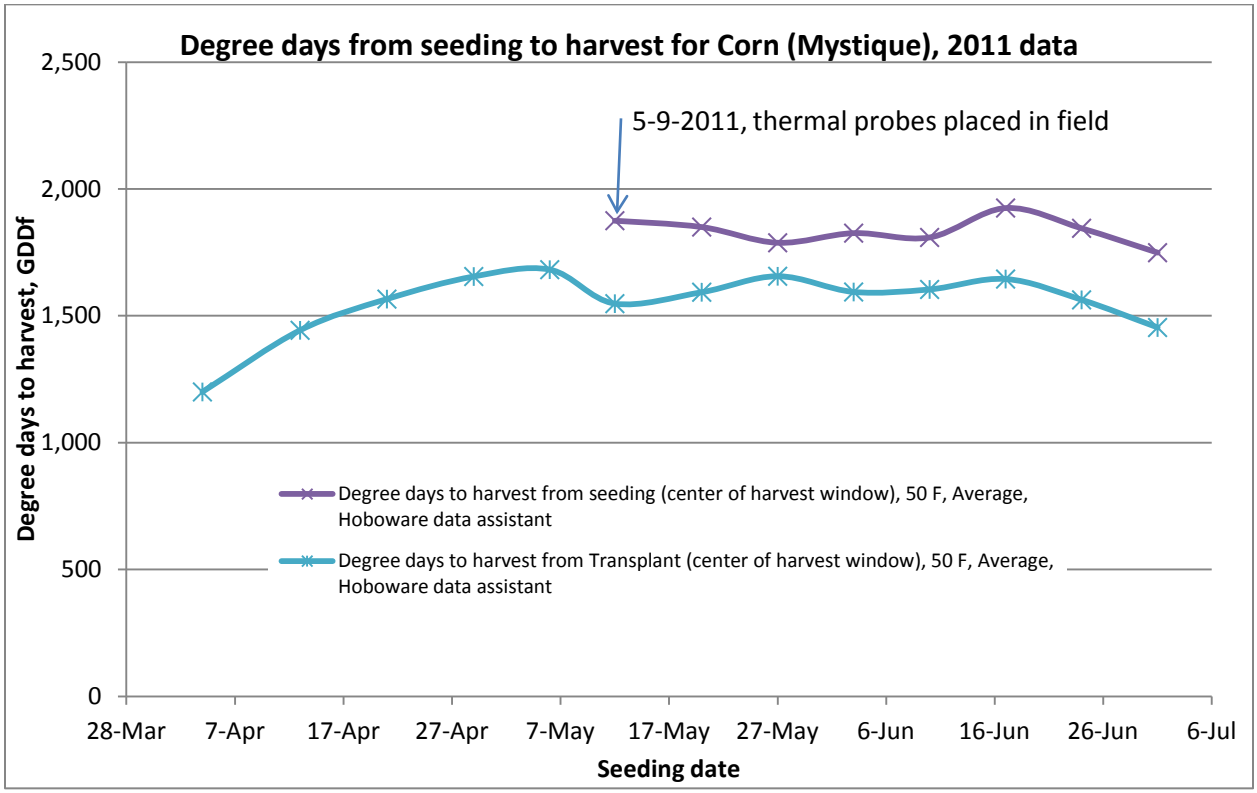
Assume Base temperature = 50F

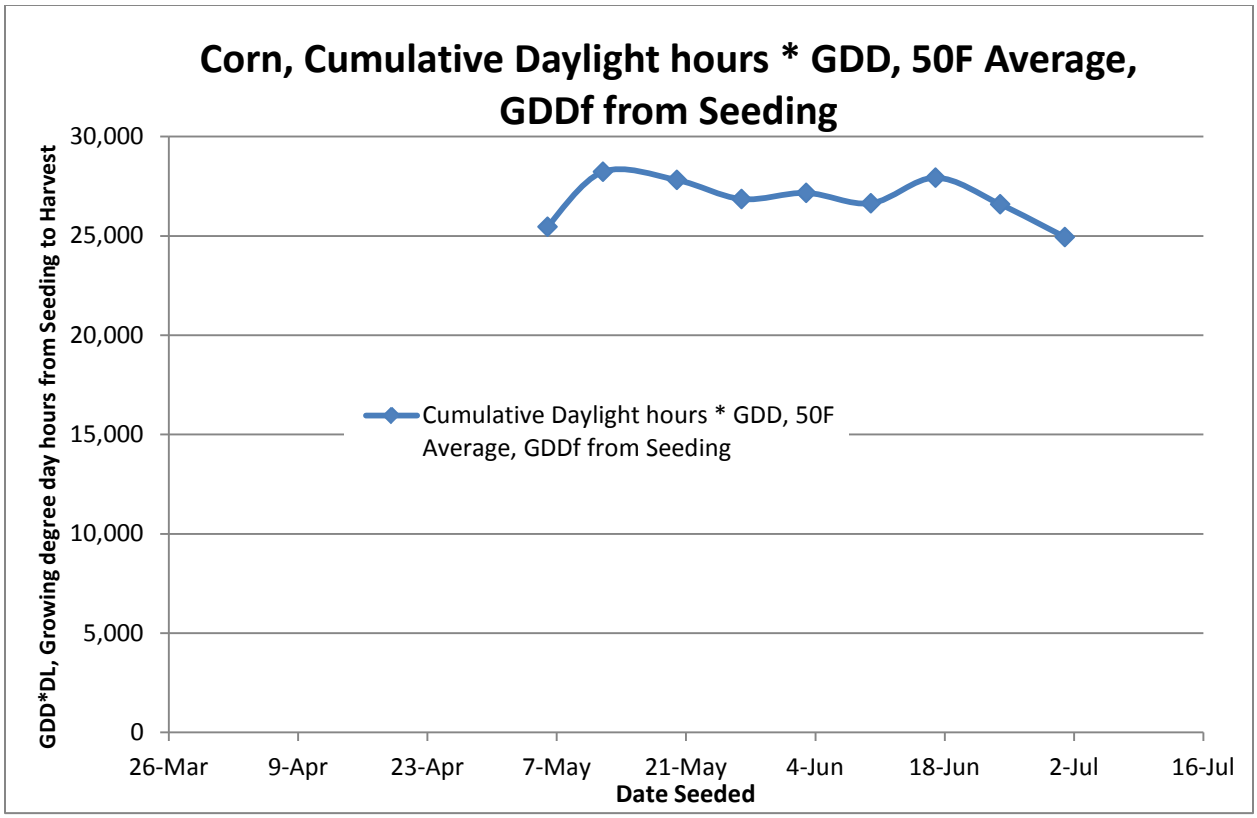
Planting#	Date Seeded	Date Transplanted	Days to harvest from Seeding (Center of harvest window)	Harvest date (center of harvest window)	Minimum Days to harvest	Maximum Days to harvest	Harvest Window width, days
M1	4-Apr	9-May	100.5	7/13	99	102	3
M2	13-Apr	9-May	100.7	7/22	97	104	7
M3	21-Apr	9-May	97.3	7/27	92	104	12
M4	29-Apr	19-May	93.8	7/31	89	98	9
M5	6-May	24-May	87.3	8/1	82	91	9
M6	12-May	2-Jun	90.0	8/10	83	97	14
M7	20-May	2-Jun	84.3	8/12	81	88	7
M8	27-May	10-Jun	80.0	8/15	76	83	7
M9	3-Jun	16-Jun	82.0	8/24	80	84	4
M10	10-Jun	23-Jun	82.7	8/31	81	84	3
M11	17-Jun	1-Jul	85.4	9/10	81	90	9
M12	24-Jun	6-Jul	80.4	9/12	76	83	7
M13	1-Jul	13-Jul	78.5	9/17	76	81	5
M14	7-Jul	21-Jul					

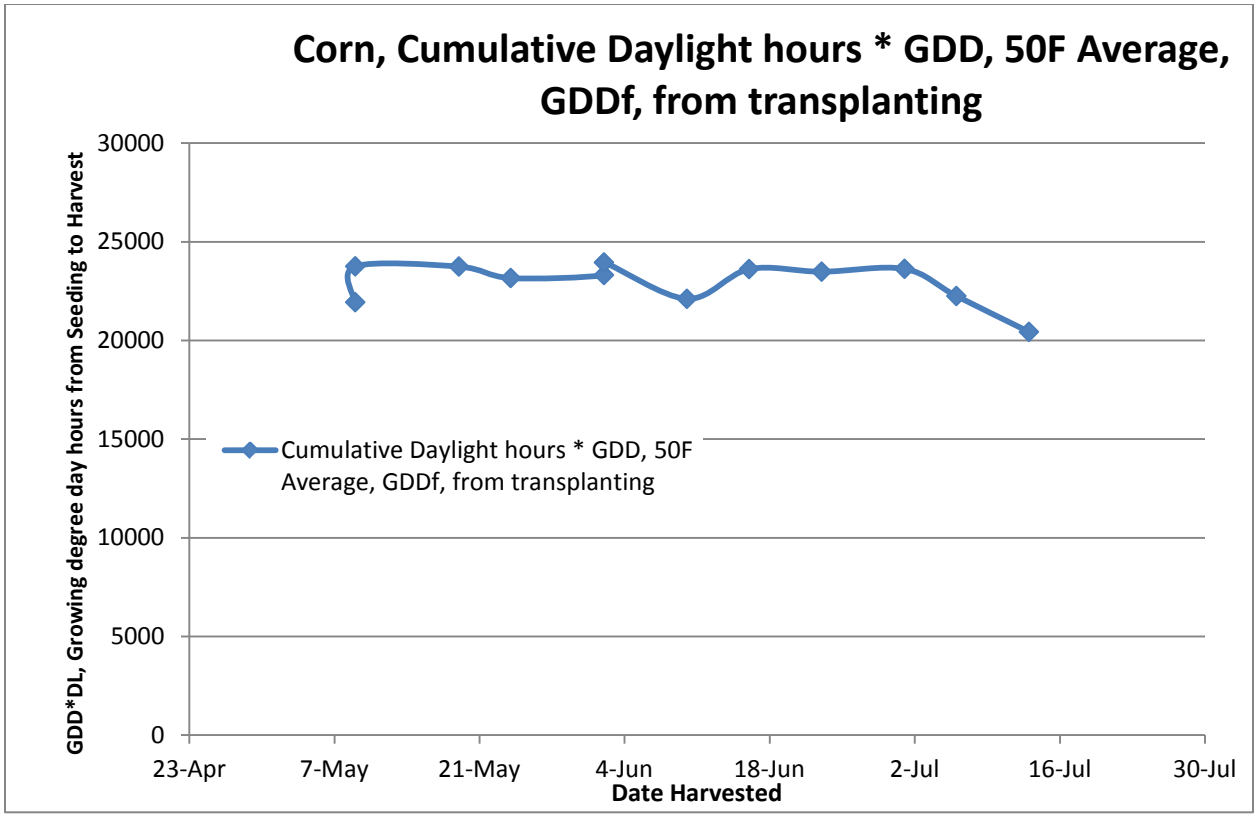

Corn (Mystique) Days to Harvest from Seeding and transplanting
112
98
84
70
56
42
28
14
0
Days to harvest
Days to harvest from Seeding (Center of harvest window)
Minimum Days to harvest
Maximum Days to harvest
Harvest Window width, days
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
Date Seeded (or transplanted)


Corn, Mystique Variety,
Date harvested vs date seeded
24-Sep
10-Sep
27-Aug
13-Aug
30-Jul
16-Jul
2-Jul
Date Harevsted
Harvest date (center of harvest window)
Min
Max
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
Date Seeded

Planting #	Degree days to harvest from seeding (center of harvest window), 50 F, Average, Hoboware data assistant	Degree days to harvest from Transplant (center of harvest window), 50 F, Average, Hoboware data assistant	Comments
M1	No data, started in Greenhouse	1,200	Mostly eaten by raccoons
M2	No data, started in Greenhouse	1,443	Moderate damage by Raccoons
M3	No data, started in Greenhouse	1,566	
M4	No data, started in Greenhouse	1,655	
M5	No data, started in Greenhouse	1,682	
M6	1,875	1,548	
M7	1,850	1,593	
M8	1,788	1,656	
M9	1,826	1,594	
M10	1,809	1,604	
M11	1,925	1,645	
M12	1,845	1,563	
M13	1,749	1,454	
M14			More Raccoons




Corn, Cumulative Daylight hours * GDD, 50F Average, GDDf from Seeding
GDD*DL, Growing degree day hours from Seeding to Harvest
30,000
25,000
20,000
15,000
10,000
5,000
0
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
Date Seeded
Cumulative Daylight hours * GDD, 50F Average, GDDf from Seeding

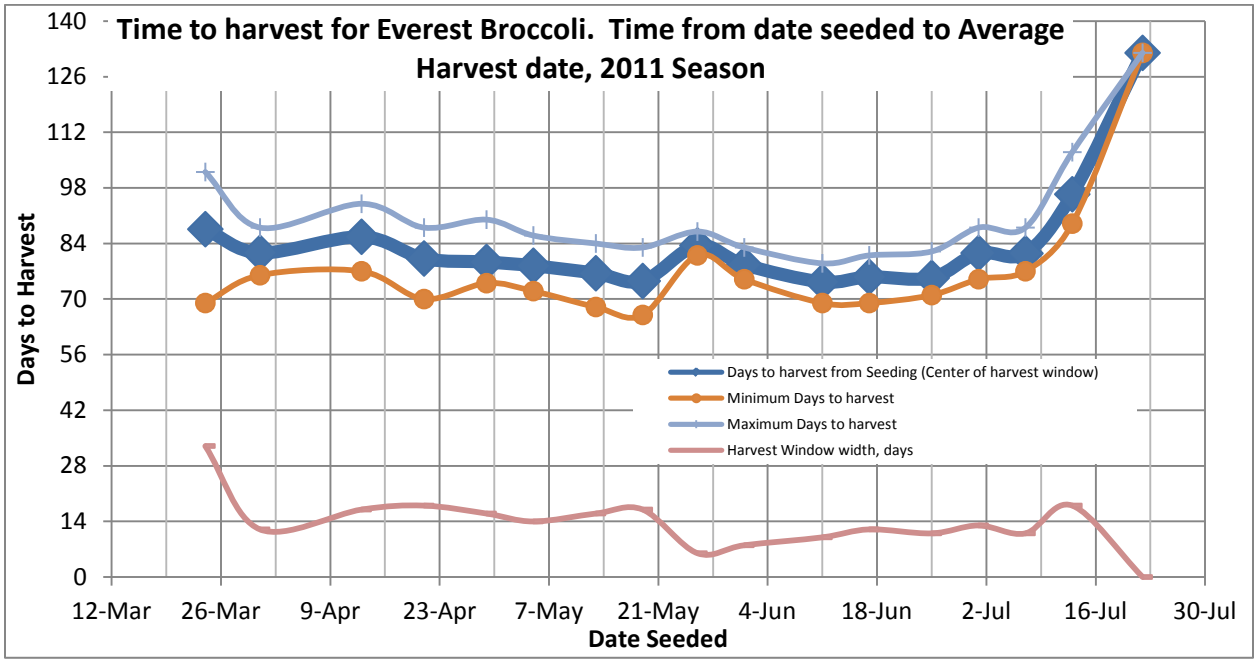

Corn, Cumulative Daylight hours * GDD, 50F Average, GDDf, from transplanting
GDD*DL, Growing degree day hours from Seeding to Harvest
30000
25000
20000
15000
10000
5000
0
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
30-Jul
Date Harvested
Cumulative Daylight hours * GDD, 50F Average, GDDf, from transplanting

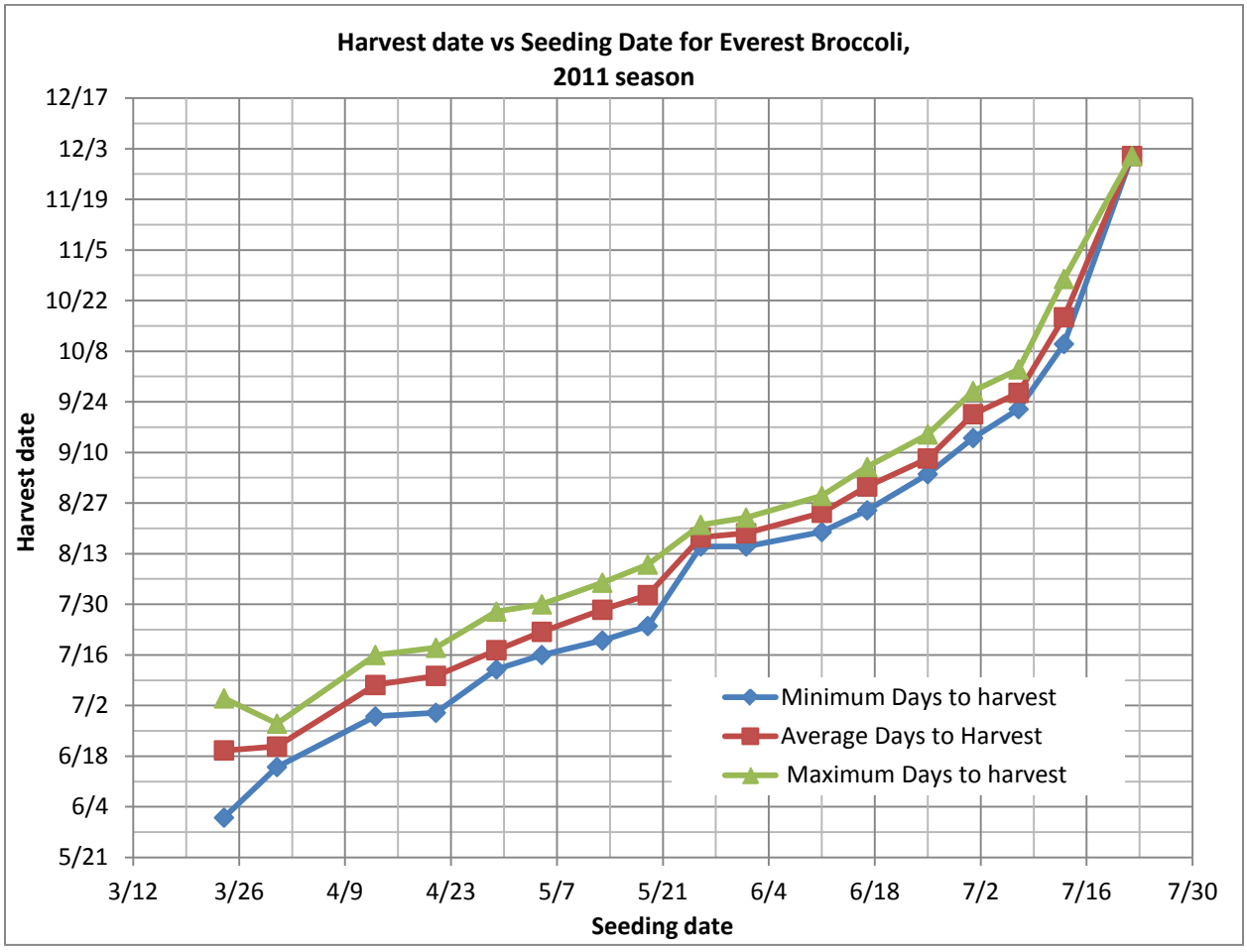
Broccoli (Everest from Seedway) 40F Base Growing Temperature

Total Planned 11,280
Total Seeded 11,385
Total transplanted 8,900 (on record)
Total Harvested and sold as Crowns 2,060# (on record)
Total sold as crowns 2,256# (includes 2nd variety not in study)

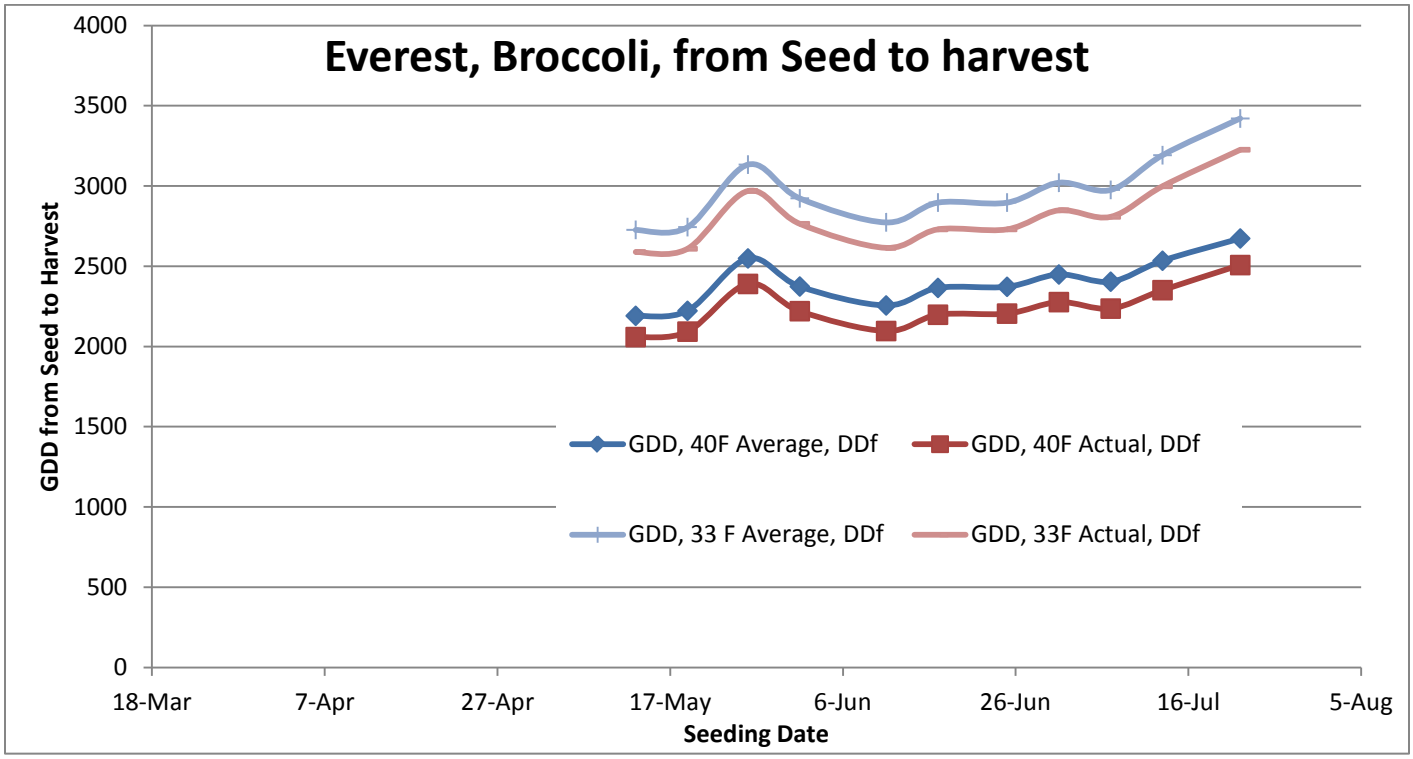
	Date Seeded	Date Transplanted	Average Days to harvest from Seeding	Minimum Days to harvest	Maximum Days to harvest	Harvest Window width, days	Comments
E1	24-Mar	9-May	87.6	69	102	33	Deer damage, Bursey Field, no plastic
E2	31-Mar	9-May	81.7	76	88	12	Wood Chuck Damage, Deer damage, smaller heads. Bursey Field, no plastic
E3	13-Apr	13-May	85.7	77	94	17	109 lost to root maggot
E4	21-Apr	17-May	80.2	70	88	18	58 lost due to root maggot
E5	29-Apr	23-May	79.3	74	90	16	136 lost to root maggot
E6	5-May	1-Jun	78.4	72	86	14	25 to root maggot(?)
E7	13-May	10-Jun	76.5	68	84	16	NO losses to root maggot
E8	19-May	17-Jun	74.6	66	83	17	more harvest dates, can't read
E9	26-May	1-Jul	83.5	81	87	6	Lots of black specs on Broc
E10	1-Jun	1-Jul	78.7	75	83	8	Diseased, reduced yield
E11	11-Jun	7-Jul	74.3	69	79	10	
E12	17-Jun	14-Jul	75.6	69	81	12	
E13	25-Jun	21-Jul	75.3	71	82	11	
E14	1-Jul	27-Jul	81.6	75	88	13	
E15	7-Jul	27-Jul	81.5	77	88	11	
E16	13-Jul	14-Aug	96.4	89	107	18	
E17	22-Jul	17-Aug	132.0	132			Likely would be larger harvest window but frozen out

Data for Broccoli

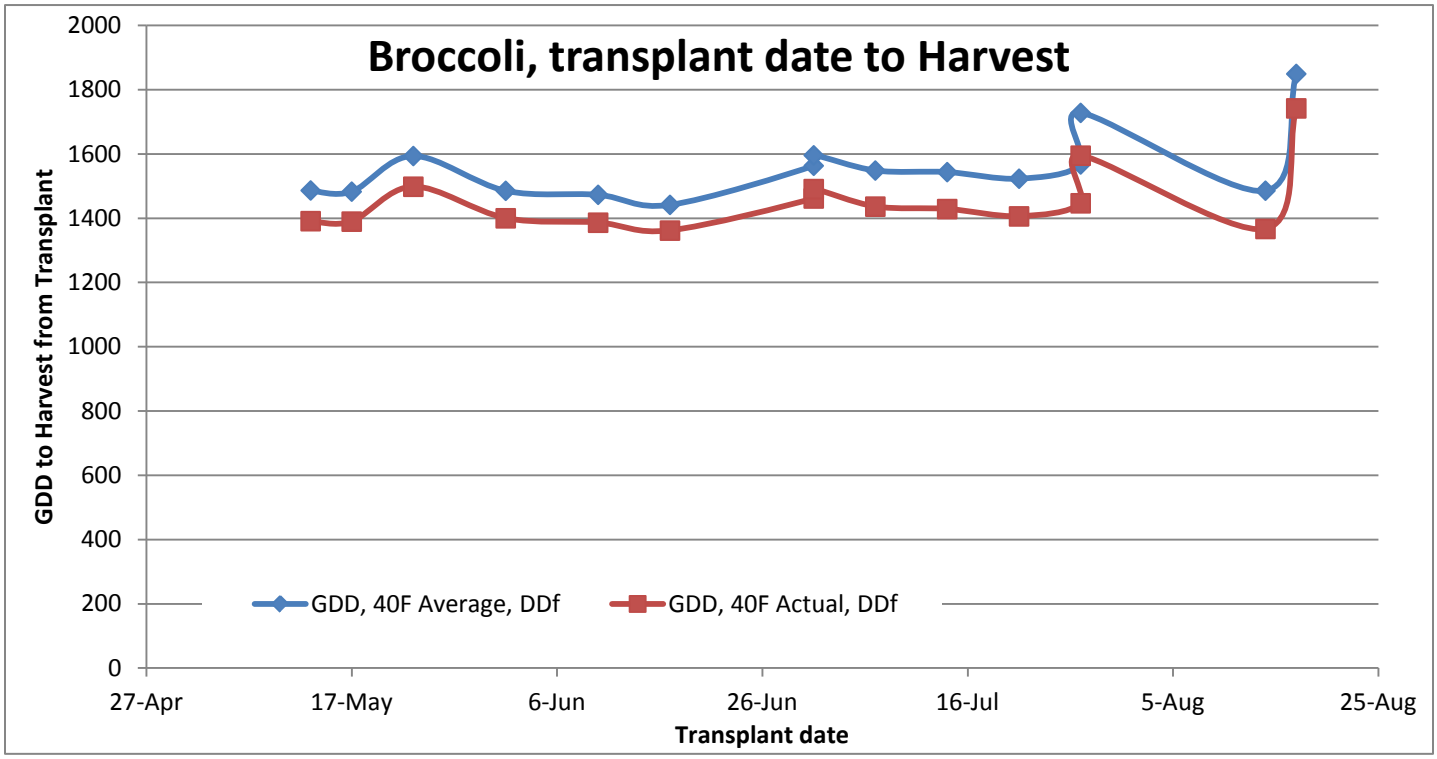




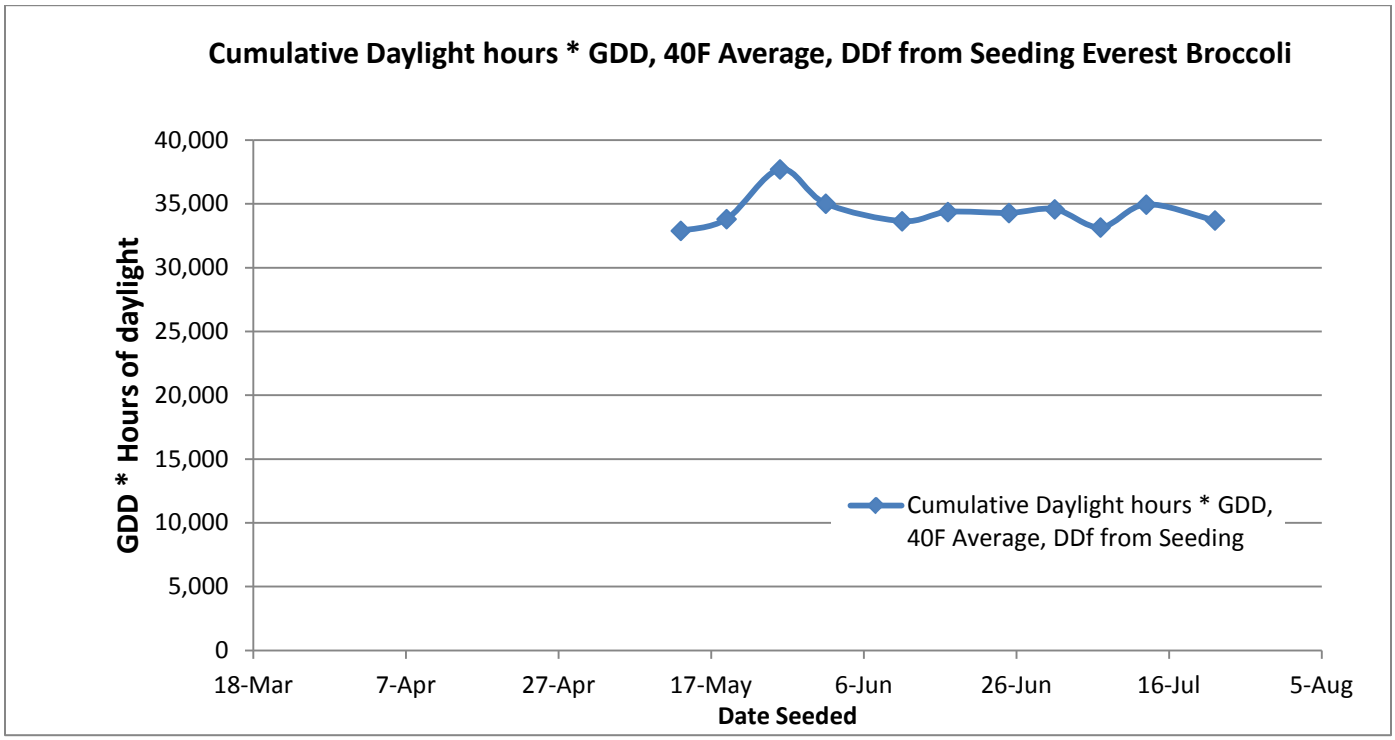
Growing degree days to harvest for Broccoli, 2011 season. Note DDf is Degree Day Fahrenheit

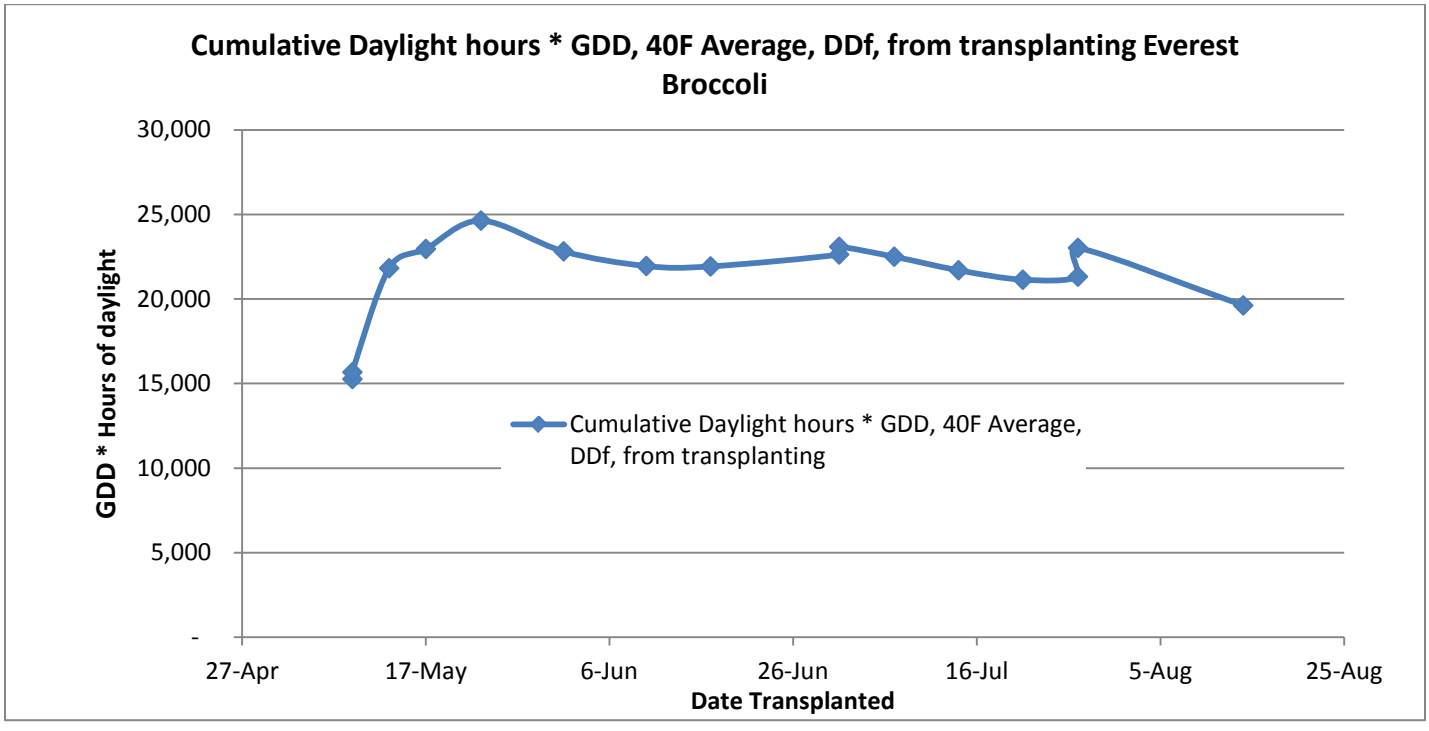


Note that the first 6 plantings were started in the greenhouse and in the greenhouse until transplant. So, will have a different # GDD than outside, and thermal probes started May 9, 2011. The first 6 plantings are not shown in the "from seed to harvest" plot above.



GDD*DH. Note that this is almost constant. Something that would be expected if we were accounting for everything of importance. A positive sign that this is an accurate representation. Note that the first 6 plantings did not have full set of temperature data from seeding and are not plotted for that reason.



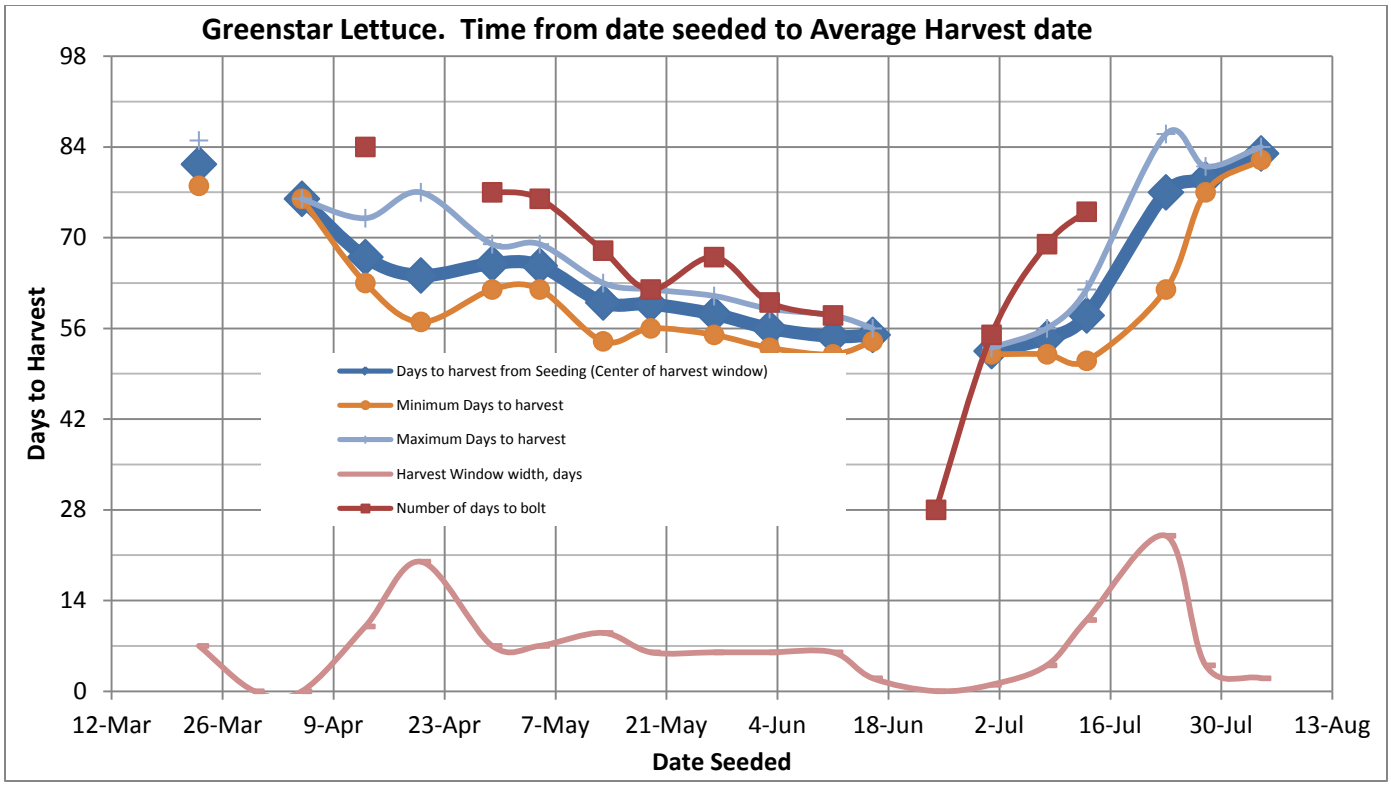


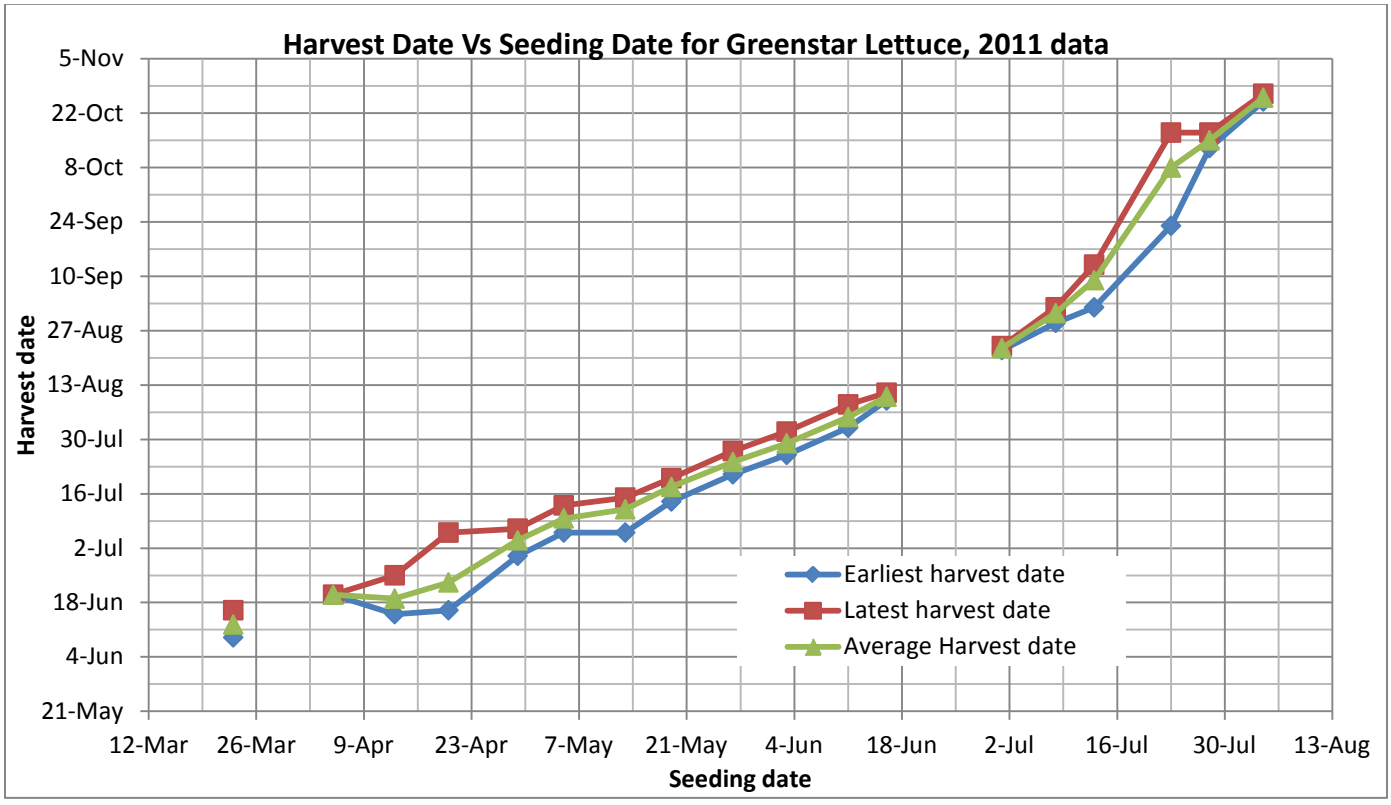
Lettuce, Greenstar

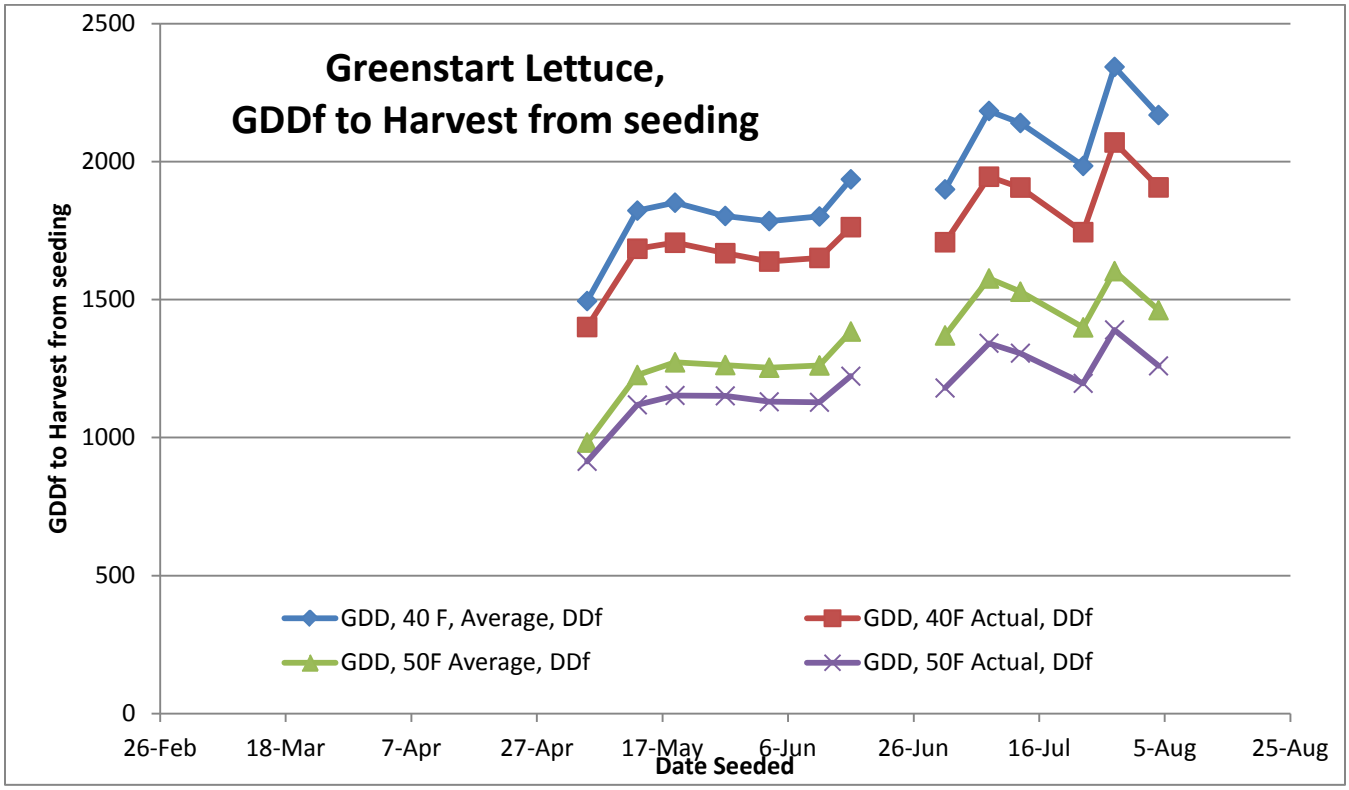
Total Planned	6,270
Total Seeded	6,380
Total transplanted	4,410
Total Harvested	1,993
Total sold as Greenleaf	3,894
Total sold as Lettuce	2,718
Total sold as Lettuce, leaf	148

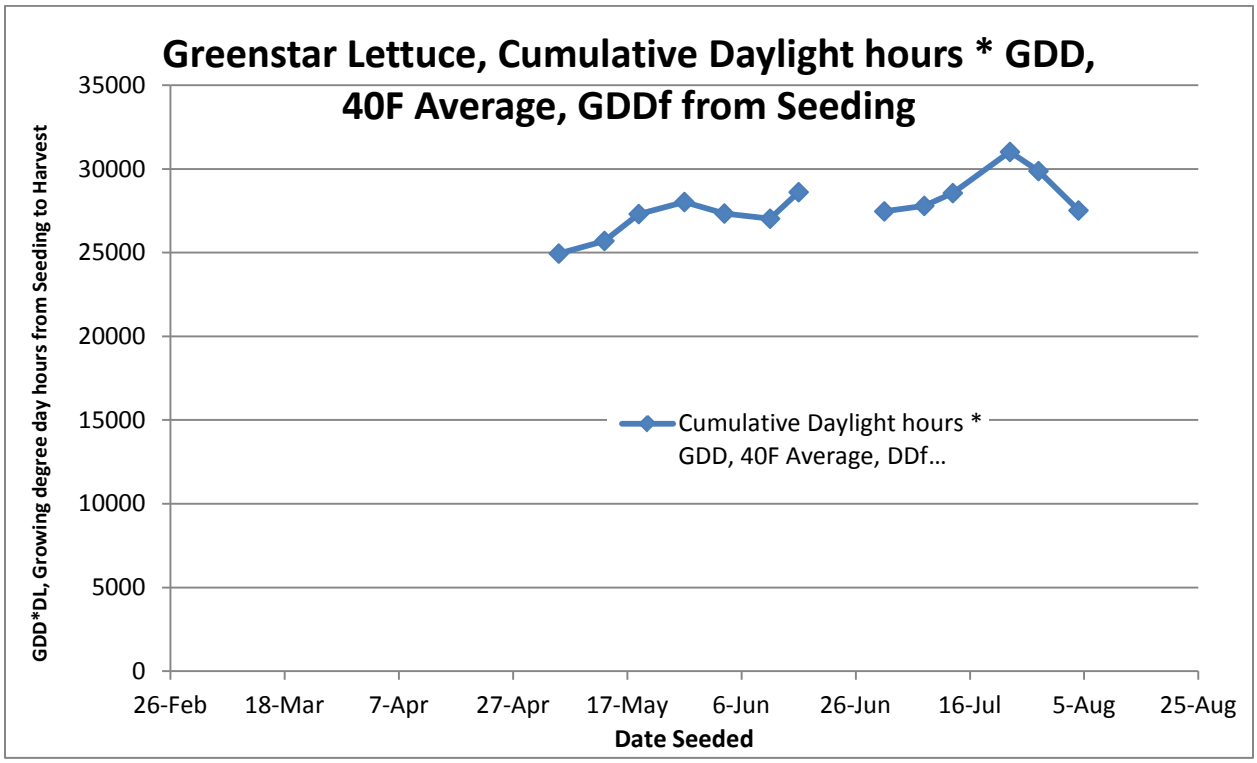
Totals include Tropicana in Greenleaf,
Totals include Tropicana and red leaf for leaf lettuce, plus romaine as Lettuce

	Date Seeded	Date Transplanted	Days to harvest from Seeding (Center of harvest window)	Minimum Days to harvest	Maximum Days to harvest	Harvest Window width, days	Add loss info ???	Comments
GS1	23-Mar	27-Apr	81.3	78	85	7		Deer damage, Bursey field, no plastic, no raised bed
GS2	30-Mar	27-Apr				0		No Harvest Data, , Bursey field, no plastic, no raised bed
GS3	5-Apr	27-Apr	76.0	76	76	0		Bursey field, no plastic, no raised bed
GS4	13-Apr	13-May	67.0	63	73	10		First in Big Field
GS5	20-Apr	17-May	65.6	61	77	16		0
GS6	29-Apr	23-May	68.0	67	69	2		0
GS7	5-May	1-Jun	65.7	62	69	7		0
GS8	13-May	10-Jun	60.0	54	63	9		0
GS9	19-May	10-Jun	59.8	56	62	6		0
GS10	27-May	23-Jun	58.2	55	61	6		0
GS11	3-Jun	30-Jun	56.0	53	59	6		0
GS12	11-Jun	6-Jul	54.8	52	58	6		0
GS13	16-Jun	13-Jul	55.0	54	56	2		0
GS14	24-Jun	22-Jul				0		Bolted in trays, never transplanted
GS15	1-Jul	22-Jul	52.5	52	53	1		0
GS16	8-Jul	27-Jul	54.5	52	56	4		0
GS17	13-Jul	2-Aug	58.0	51	62	11		85% Harvest
GS18	23-Jul	17-Aug	77.0	62	86	24		Deer Damage, Not sizing, Bottom rot, Harvest some small and bag
GS19	28-Jul	22-Aug	79.0	77	81	4		Deer Damage, Not sizing, Bottom rot, Harvest some small and bag
GS20	4-Aug	31-Aug	83.0	82	84	2		Deer Damage, Not sizing, Bottom rot, Harvest some small and bag

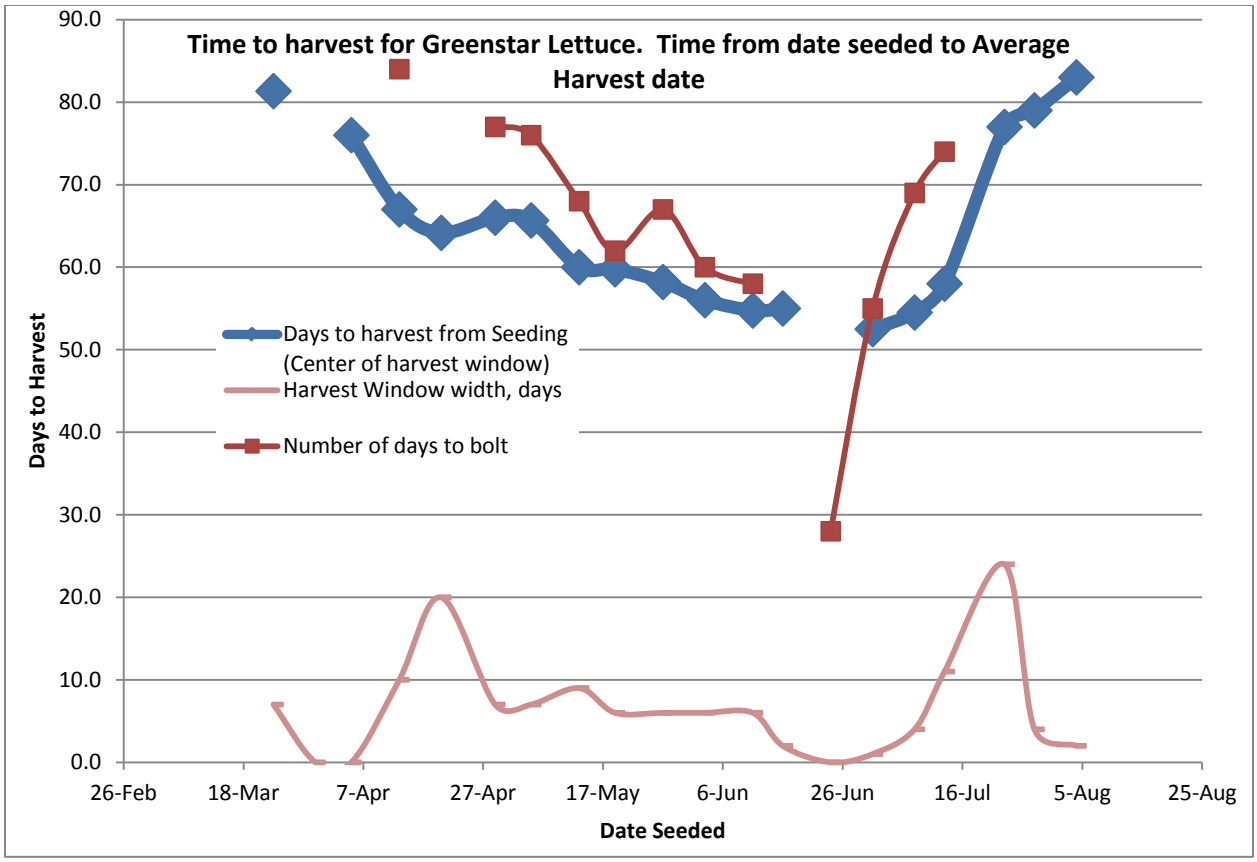

Greenstar Lettuce. Time from date seeded to Average Harvest date
Days to Harvest
98
84
70
56
42
28
14
0
12-Mar
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
30-Jul
13-Aug
Date Seeded
Days to harvest from Seeding (Center of harvest window)
Minimum Days to harvest
Maximum Days to harvest
Harvest Window width, days
Number of days to bolt


Harvest Date Vs Seeding Date for Greenstar Lettuce, 2011 data
Harvest date
5-Nov
22-Oct
8-Oct
24-Sep
10-Sep
27-Aug
13-Aug
30-Jul
16-Jul
2-Jul
18-Jun
4-Jun
21-May
12-Mar
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
30-Jul
13-Aug
Seeding date
Earliest harvest date
Latest harvest date
Average Harvest date





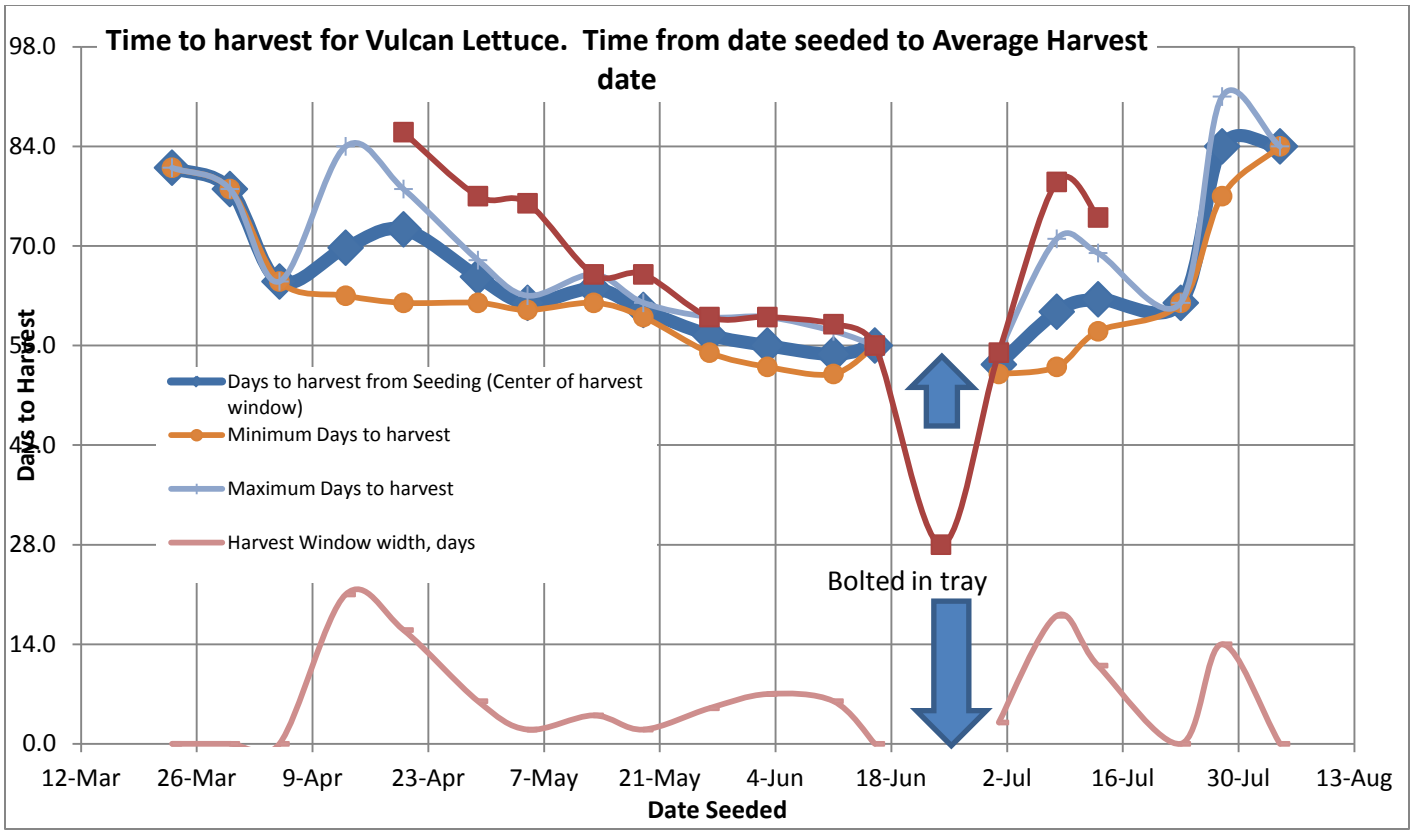
Another Physiological limit is bolting. This sets the longest that the lettuce can be in the field.

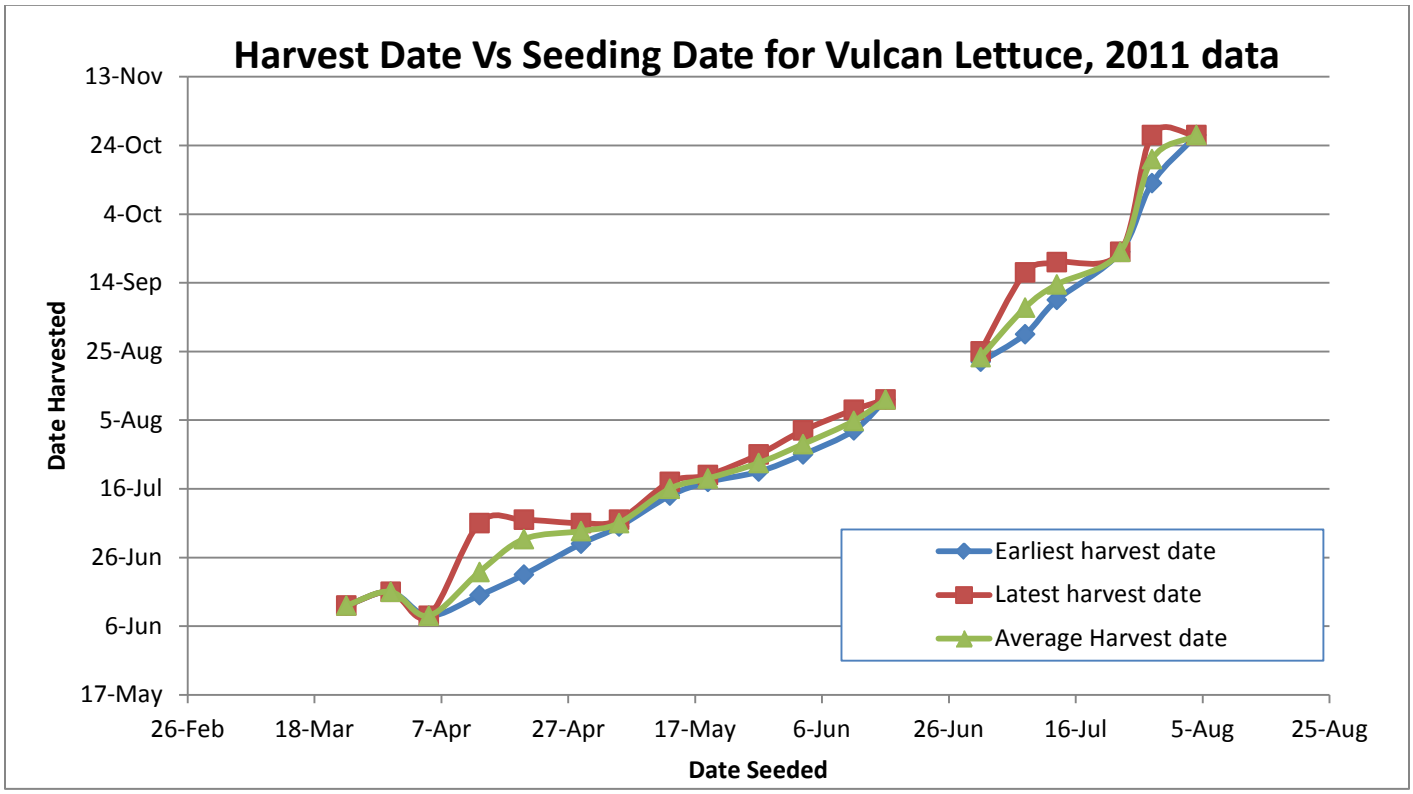

Time to harvest for Greenstar Lettuce. Time from date seeded to Average Harvest date
Days to Harvest
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Days to harvest from Seeding (Center of harvest window)
Harvest Window width, days
Number of days to bolt
26-Feb
18-Mar
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug
Date Seeded

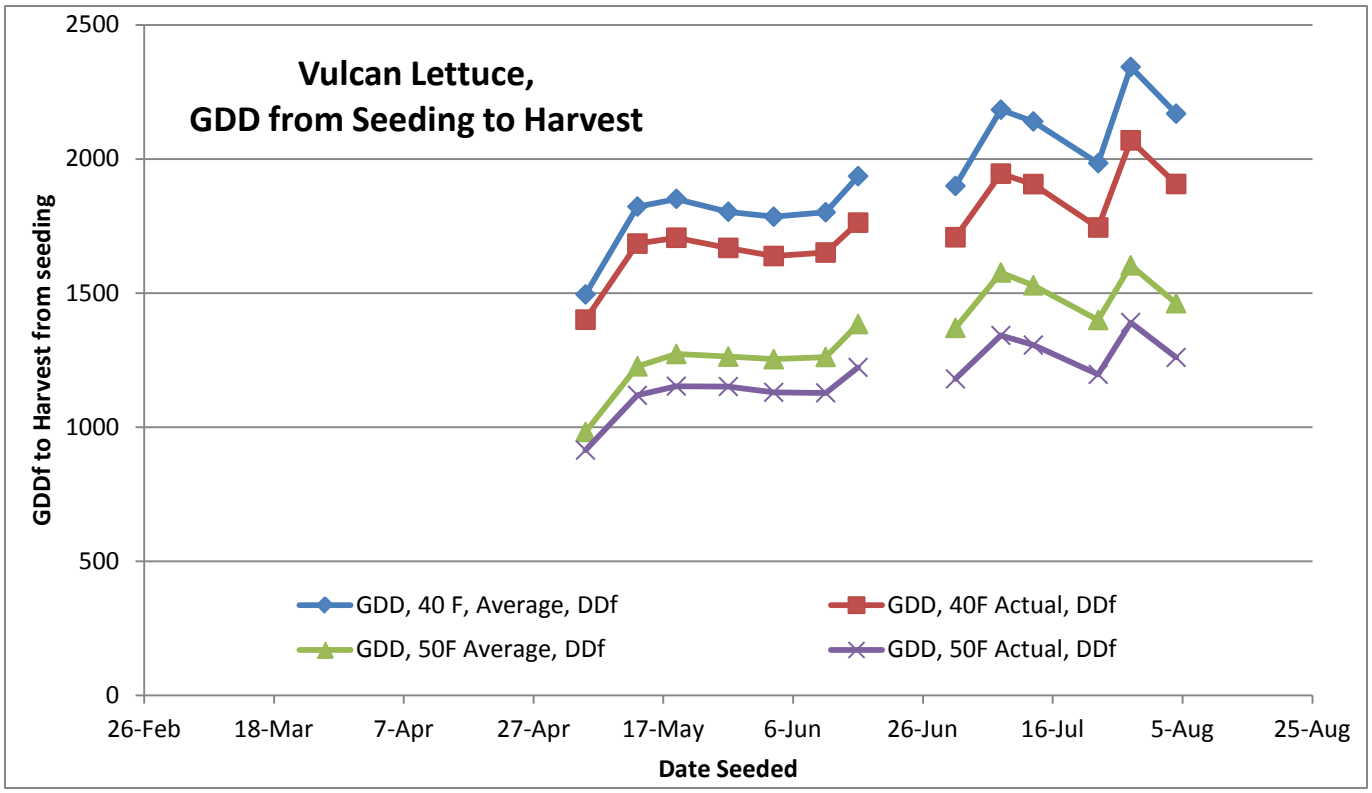
Vulcan Lettuce

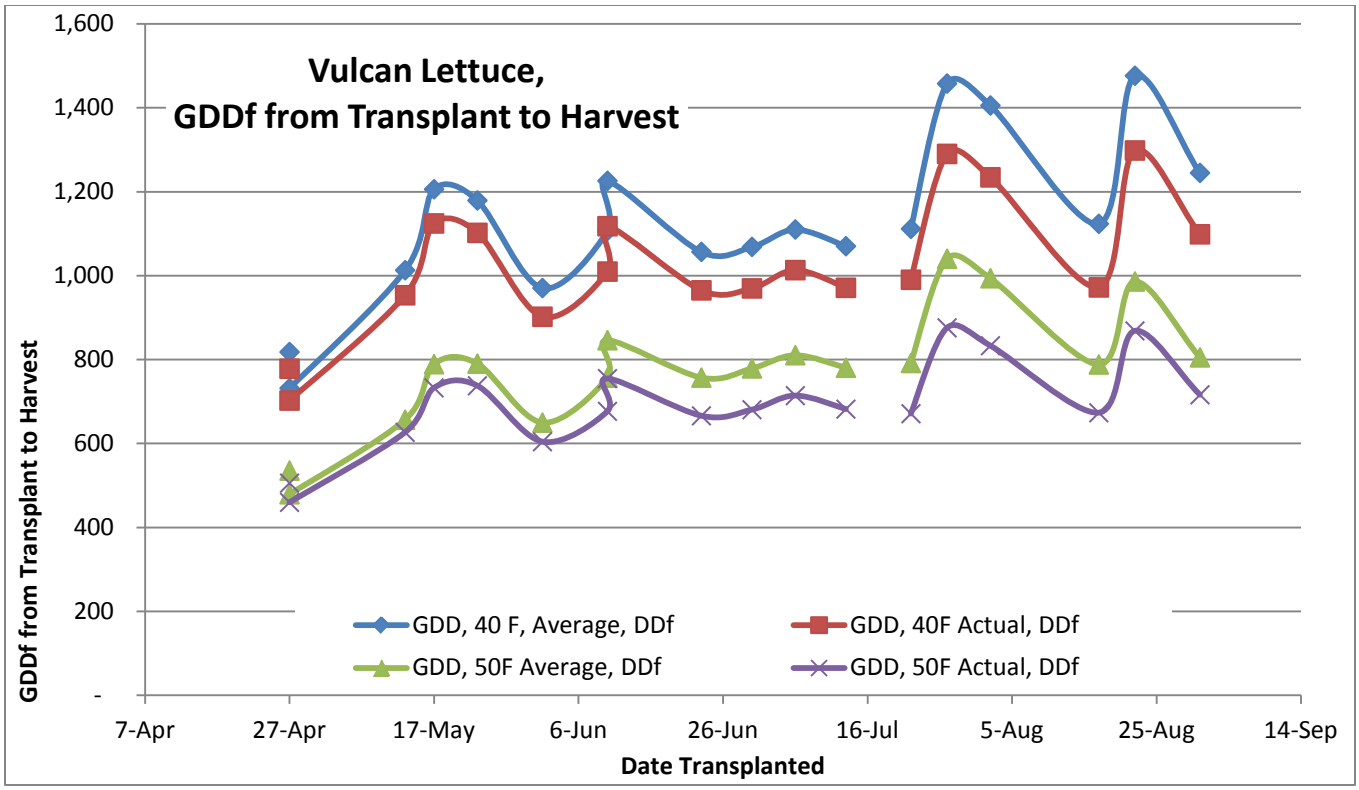
Total Planned	4,510
Total Seeded	4,510
Total transplanted	3,045
Total Harvested	1,428
Total sold as Redleaf	2,772
Total sold as Lettuce	2,718

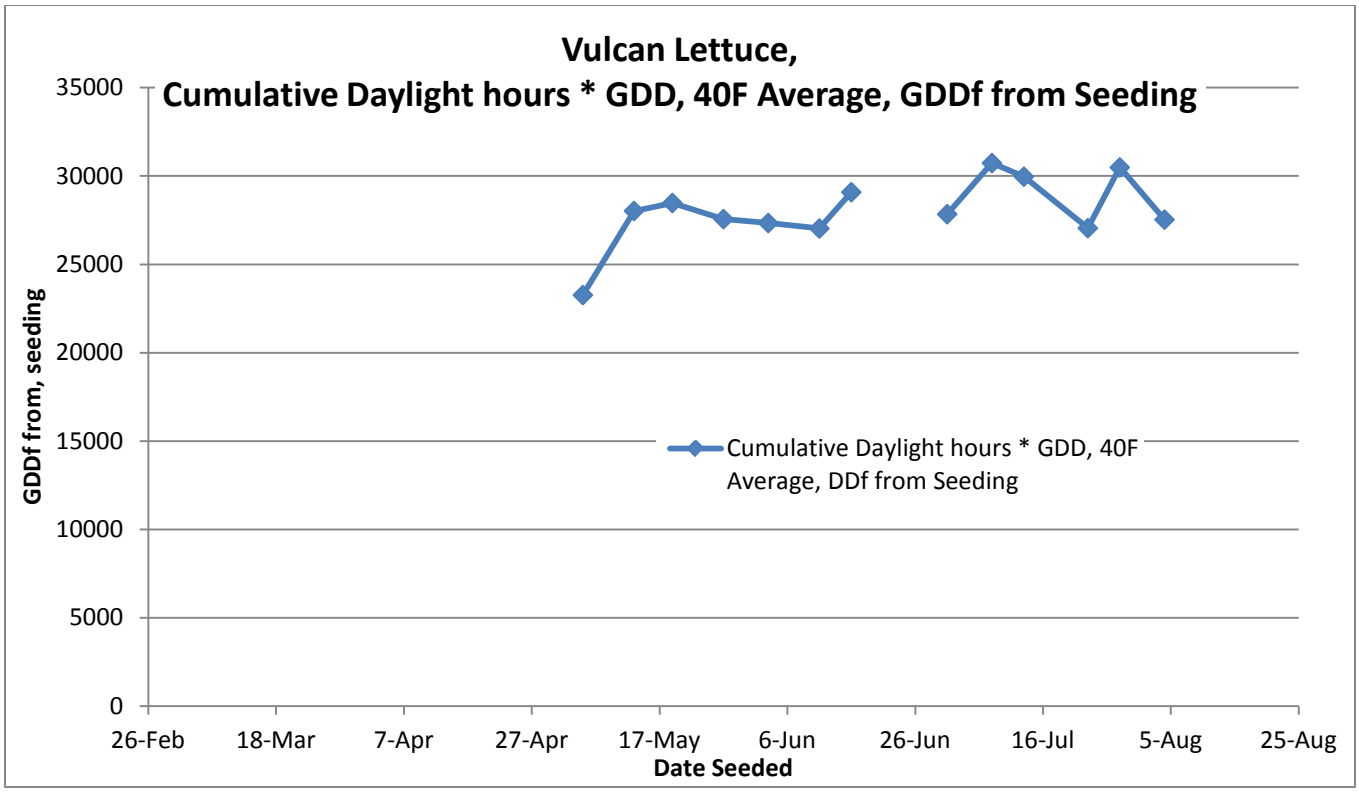
	Date Seeded	Date Transplanted	Days to harvest from Seeding (Center of harvest window)	Minimum Days to harvest	Maximum Days to harvest	Harvest Window width, days	Add loss info???	Comments
V1	23-Mar	27-Apr	81.0	81	81	0		Bursey field, no plastic, no raised bed
V2	30-Mar	27-Apr	78.0	78	78	0		Bursey field, no plastic, no raised bed
V3	5-Apr	27-Apr	65.0	65	65	0		Bursey field, no plastic, no raised bed
V4	13-Apr	13-May	69.8	63	84	21		First in Big Field
V5	20-Apr	17-May	72.3	62	78	16		Lots of bottom Rot
V6	29-Apr	23-May	65.7	62	68	6		0
V7	5-May	1-Jun	62.0	61	63	2		0
V8	13-May	10-Jun	64.0	62	66	4		0
V9	19-May	10-Jun	61.0	60	62	2		0
V10	27-May	23-Jun	57.5	55	60	5		0
V11	3-Jun	30-Jun	56.0	53	60	7		0
V12	11-Jun	6-Jul	54.8	52	58	6		0
V13	16-Jun	13-Jul	56.0	56	56	0		All bolted in field, none harvested
V14	24-Jun	22-Jul						Bolted in trays, never transplanted
V15	1-Jul	22-Jul	53.3	52	55	3		0
V16	8-Jul	27-Jul	57.3	53	63	10		99% harvest
V17	13-Jul	2-Aug	62.5	58	69	11		100% Harvest
V18	23-Jul	17-Aug	62.0	62	62	0		Generally not sizing up
V19	28-Jul	22-Aug	84.0	77	91	14		Generally not sizing up
V20	4-Aug	31-Aug	84.0	84	84	0		Generally not sizing up

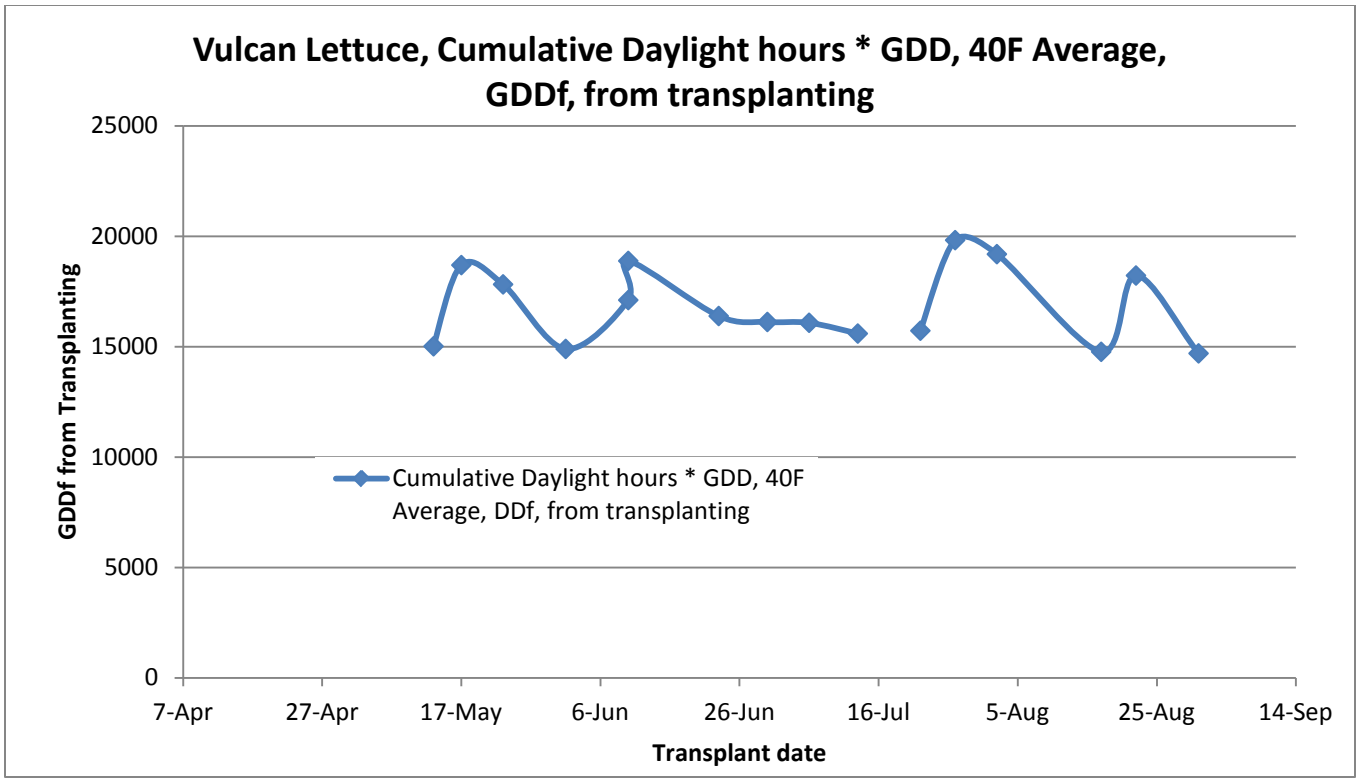

Time to harvest for Vulcan Lettuce. Time from date seeded to Average Harvest date
Days to Harvest
98.0
84.0
70.0
56.0
42.0
28.0
14.0
0.0
Days to harvest from Seeding (Center of harvest window)
Minimum Days to harvest
Maximum Days to harvest
Harvest Window width, days
Bolted in tray
12-Mar
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
30-Jul
13-Aug
Date Seeded


Harvest Date Vs Seeding Date for Vulcan Lettuce, 2011 data
Date Harvested
13-Nov
24-Oct
4-Oct
14-Sep
25-Aug
5-Aug
16-Jul
26-Jun
6-Jun
17-May
Earliest harvest date
Latest harvest date
Average Harvest date
26-Feb
18-Mar
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug
Date Seeded


Vulcan Lettuce,
GDD from Seeding to Harvest
GDDf to Harvest from seeding
2500
2000
1500
1000
500
0
26-Feb
18-Mar
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug
Date Seeded
GDD, 40 F, Average, DDf
GDD, 40F Actual, DDf
GDD, 50F Average, DDf
GDD, 50F Actual, DDf


Vulcan Lettuce,
GDDf from Transplant to Harvest
GDDf from Transplant to Harvest
1,600
1,400
1,200
1,000
800
600
400
200
-
GDD, 40 F, Average, DDf
GDD, 40F Actual, DDf
GDD, 50F Average, DDf
GDD, 50F Actual, DDf
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug
14-Sep
Date Transplanted


Vulcan Lettuce,
Cumulative Daylight hours * GDD, 40F Average, GDDf from Seeding
GDDf from, seeding
35000
30000
25000
20000
15000
10000
5000
0
Cumulative Daylight hours * GDD, 40F Average, DDf from Seeding
26-Feb
18-Mar
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug
Date Seeded


Vulcan Lettuce, Cumulative Daylight hours * GDD, 40F Average, GDDf, from transplanting
GDDf from Transplanting
25000
20000
15000
10000
5000
0
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug
14-Sep
Transplant date
Cumulative Daylight hours * GDD, 40F Average, DDf, from transplanting

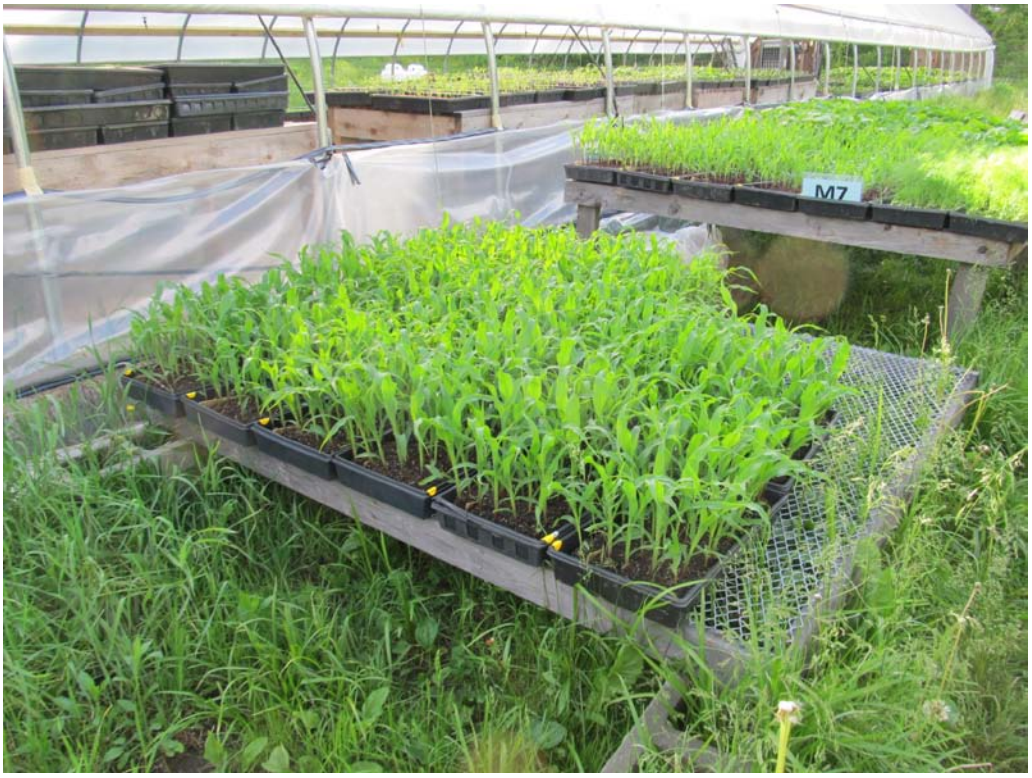
Photos

Below. A planting of Broccoli in seeding area. Note tag.

Thermal probes in Broccoli

Thermal probes in Broccoli on plastic

Corn just before transplanting, in seeding are. Note tags.



First planting of Corn

Soil temperature probe in Corn soon after transplant and initial setup.

Air temperature 1 (lower) probe in Corn soon after transplant and initial setup. Note Datalogger as well.

Corn, 1st three plantings and probes just after setup

Sensors in first 3 plantings of lettuce and 2 plantings of broccoli (no plastic)


Date Seeded
Date Transplanted
Date(s) Harvested
V2


E1
E2

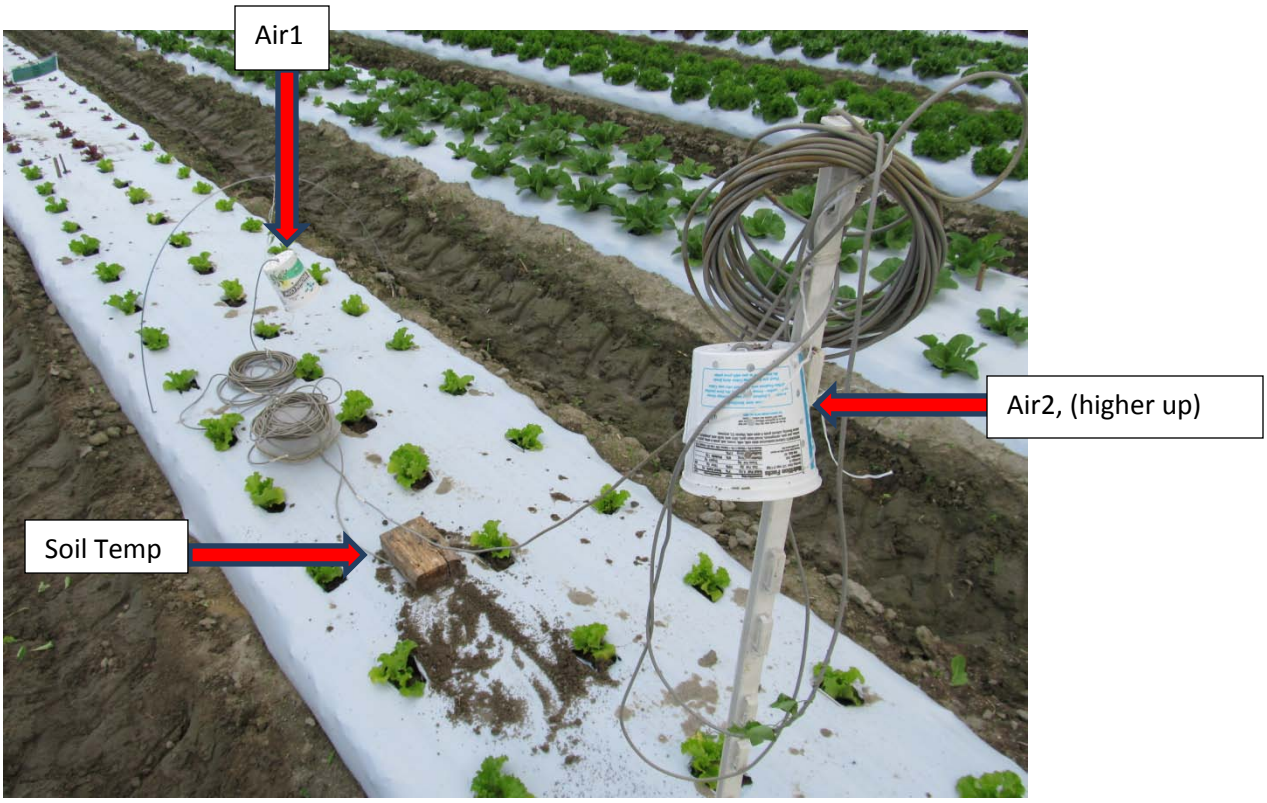

E3
E2

Note tags in the field for different plantings. Also Lettuce thermal probes.

Lettuce during harvest, note a few heads left to see when they bolt.


Date Seeded 5-19-11
Date Transplanted 6·10·11
Date(s) Harvested


GS9
V9



Three sensors in lettuce

Methods

All crops in this study were started as transplants in 2 inch soil blocks, grown to a transplantable size, and transplanted using a waterwheel. A set of waterproofed card stock tags (5.5 x 8.5) was used to track each planting, see photos.

At seeding the seeding date was recorded on the tags with a permanent marker and they were placed in the transplant trays. Each tray in the planting was also marked with a wooden marker that had the crop name and seeding date.

At Transplant the transplant date was recorded on the tags and the tags were placed on wire hoops, one at each end of the planting. The wooden tags were (generally) also placed in the row in case the plastic coated tags blew before the wire hoops were set.

During harvest the tags were used to record the dates harvested, and as much as possible, the amount harvested.

- Broccoli. We recorded the date harvested, and the approximate weight of crowns harvested. (we harvest in 5 gallon buckets, one 5 gallon bucket being about 10 pounds. For fractions of a bucket we estimated the weight based on the volume).
- Corn. We recorded the date and the number of top ears harvested
- Lettuce. We recorded the date and the number of heads of lettuce harvested. We also tried to record heads that were harvestable (we have a ¾ pound minimum head size). We also tried to leave at least one head per planting and see when that head bolted to establish a maximum harvest window.

Practical issues with methods

We had no issues with the seeding. We did not seed on the exact dates on the seeding schedule all the time, but we use the actual date seeded, not the planned dates for data analysis.

Transplanting was done when the plants were 'ready' to transplant, and when the tractor was available with a crew. This was a once or twice a week occurrence. The first three plantings of corn were transplanted on the same day as the field was not ready, and the ground was cool, so the first planting of corn was pretty large (about 1 foot tall), generally we transplanted corn at 4-6 inch. Similarly, the first 3 plantings of lettuce, and 2 plantings of broccoli were planted on bare ground, without raised beds or plastic due to practical issues. One planting of lettuce (of each type mid season) bolted in the trays as the plants were too small one week, and bolted by the next.

Harvest. We had some problems with the permanent markers writing on the plastic tags when the tags were wet with rain, or morning dew. So the yield data was not as comprehensive as we wanted (but yield was not a primary focus of this study).

Fields and soils

Fields used are flat and open with full sun. Soils are primarily Silt loams with Moderate drainage, Pootatuck, with some Rippowam (poor drainage). The first three Lettuce, and 2 broccoli were on

Instrumentation used.

Temperature was measured using ONSET TMC50-HD thermal probes, and recorded on ONSET HOBO model U12-008 data loggers. The thermal probes with the U12 data logger are listed as being accurate to ±0.45F (for 0 to 50C range), the U12 Data loggers record the data to 0.05 F resolution. The data-loggers were programed to take thermal measurements every 30 minutes (48 per day). Thermal probe response time is listed as 2 minutes in air.

Daylight hours was taken from the ____ Website for standard day length in Lebanon, NH. This was not measured.

Data analysis was done with HOBOWARE version 3.1.2 and Microsoft EXCEL.

Sensor placement

Soil temperature probes were all placed 4 inches below the soil surface, with at least 12 inches of cable buried as well. A 4 inch deep trench was dug, and the thermal probe pushed into the side wall of the trench so that it would be under un-disturbed soil. The trench was then filled. There were two air temperature probes for each crop.

Crop	Lower Air Probe height	Upper Air Probe Height
Broccolli	~6 to 12 inch above ground level	~1.5 ft above ground level
Corn	1.5 ft above ground level	4 to 5 ft above ground level
Lettuce	~6 to 12 inch above ground level	~1.5 ft above ground level

Calculation of Growing Degree Day (GDD).

There are many definitions of Growing Degree Day (GDD). The general concept is that biological activity (growth for plants) is related to the amount of Time at or above a temperature.

Growing degree day for a single day is:

$$\frac{\qquad\qquad\qquad\qquad}{}$$

(this is the average temperature for the day, less the base temperature. It is never negative.)

Min temp = minimum air temperature that day

Max temp = Maximum air temperature that day

Base Temp = base temperature, below which no plant growth is presumed to occur.

I used Hoboware version 3.1.2 to calculate all GDD presented herein. The two methods used were the Average data method, this is based on the minimum and Maximum temperatures for the day, as well as the base temperature (this only requires the daily HIGH and LOW to calculate). I also used the "Actual" data method which is a more continuous integration of the data. Air Temp#1 was used for analysis. If not specifically identified, the data presented is done with the average method so that it is applicable to those without data collection systems, but with a means to record and track the daily high and low temperatures. Limited comparison of the two methods shows that they are similar. For instance, based on the Lettuce data set, there were 5,136 GDDf*HD (average)in 2011 based on 40F base temperature and using the AVERAGE method, using the same data and the ACTUAL method for GDD, we had 4,591 GDDf*HD (actual) in 2011. The Broccoli temperature data set shows 4,808 (ave) vs 4,535 (Actual). I suspect that the difference between Lettuce and Broccoli probes are that the Lettuce probes was in full sun, the Broccoli probes was shaded by the plant when the plant grew up.

Base temperatures were determined from references.

Broccoli, 40 F

Corn, 50 F (proposal says 60F, further research says 50F is the best estimate in the literature)

Lettuce, 40 F (Wikipedia says 42F (5.5 C), I use 40F in calculation)

Calculation of Growing Degree day * Daylight Hours (GDDDH?)

This is defined (by me) as GDD for a day, times the day length (in hours). Day length is defined by the length of time between actual dawn, to actual twilight. (NOT civil time, which is 1 hr longer per day).

Weather summary

I calculate (using Excel and average annual temperatures) that the Enfield Lebanon area will have 4,468 GDDf with a 40 F base. Data set for 2011 says that 2011 season had 4808 GDDf (40 deg base) from May 10 to 12-1-2011 (using the Average method, which is based on the min and max temp in a day, not an integration). So, 2011 was warmer than average. This was my guess without looking at the data.

	Average temperature	2011
40 F base, average method	4,468 GDDf	4,808 GDDf
50 F base, average method	2,603 GDDf	3,114 GDDf
60 F base, average method	1,309 GDDf	1,810 GDDf

Average weather data from _____ source at airport.

References