SWROC High Tunnels:

Extending the Season for Organic Vegetable Production

Final Report to The Ceres Trust

Paulo Pagliari, Soil Scientist

Lee Klossner, Research Fellow

Pauline Nickel, Head

University of Minnesota, Southwest Research and Outreach Center

March 2014

INTRODUCTION

High tunnels are plastic covered, low-energy use structures capable of extending the growing season earlier in the spring and later in the fall, increasing the availability and amount of locally grown food. 2012 was the last year for the research being conducted with funds from The Ceres Trust in the high tunnels at the University of Minnesota's Southwest Research and Outreach Center (SWROC) near Lamberton. The research conducted in the SWROC tunnels have resulted in a wealth of research-based information to local organic high tunnel growers. The research was highlighted at the annual Extending the Season Field Day's in 2011 and 2012, and the 2011 and 2012 Organic Field Days organized by the SWROC. Results from the trial were presented as a poster presentation at the 2013 Midwest Organic and Sustainable Education Service (MOSES) conference, and as an oral presentation at the Third Crop Producers meeting in March of 2013 at Fairmont, MN. Recently results were presented in a poster presentation at the ASA-CSA-SSSA international annual meeting held in November 2013 at Tampa, FL. The organic high tunnel project provided an excellent way to reach out to organic producers with new, research-based information about organic production methods and get their inputs on what problems they are faced with and how we can help. The SWROC has also formed an organic committee composed of organic producers and faculty from the SWROC. This committee has met several times over the past two years (2011 and 2012) and they have expressed the need for research-based information on soil fertility and nutrient management on organic cropping systems. Therefore, presenting the organic growers with scientific data on how to improve soil health should be a priority for SWROC and many others organic researchers.

The objective of the high tunnel program at the SWROC is an experimental-based research and outreach program focusing on extending the growing season for organic vegetable production. This research that is ending was centered on soil and plant fertility and variety trials for Southwestern Minnesota. Results of this research provide information for organic growers, and will be submitted for publication in peer reviewed journals. In addition, we work to collaborate with University of Minnesota high tunnel research in other parts of the state, and with University of Minnesota Extension Educators, as interest in organic and local food continues to expand.

HIGH TUNNEL CONSTRUCTION AND MAINTENANCE

Originally the plan was to build two new high tunnels at the SWROC, and use a prior existing tunnel as the third tunnel for replicated experiments. Eventually a decision was made to build three new tunnels instead of two, so all three tunnels would begin production at the same time. This turned out to be a good decision because a severe storm on June 26, 2010 destroyed the prior existing high tunnel.

After researching options, three FieldPro gothic-style 30' x 48' high tunnels were purchased from Poly-Tex (Castle Rock, MN). These were constructed at the SWROC on certified (Midwest Organic Services Association – MOSA) organic land in early August 2010. Due to our windy prairie location, the tunnels were built in close proximity to wind breaks and all the ground posts were cemented in. For optimal capture of solar radiation in spring and fall, the tunnels were orientated east-west, as is recommended for our latitude.

After construction, the bed areas in the tunnels were prepared with a one-time application of 28 lbs per square foot of sand to create better vegetable growing conditions. High tunnel beds measure 40' x 2', or 80 sq ft., with five beds in each tunnel, giving us space for tours and for small trials along the edges. By the end of the 2010 growing season, electrical and water lines were put in, and thermostatic-controlled side roll-ups were installed and calibrated. Two 1" flatube tapes, spaced 11" provide water to each bed, black plastic mulch is used for moisture retention and weed control.

Data collection equipment (air and soil) was ordered for use to begin in early spring 2011. Soil moisture is monitored with tensiometers and electronic sensors. Plot layout, experimental design, and data collection plans were also made this year.

The high tunnels survived the winter of 2010/2011 well and the plastic on all three tunnels supported a heavy snow-load. Minor repairs were needed in the spring, including patching some tears in the lower plastic, and fixing two of the six automatic side roll-up mechanisms. The plastic cover on one of the tunnels required replacement, after a wind storm on September 29, 2011 ripped the plastic from the support structures, but caused no additional damage. We believe the high tunnel would have been completely destroyed, if the ground posts had not been cemented in. The winter of 2011/2012 was mild with little snow fall and moderate temperatures, there was only minor maintenance issues with the high tunnel structures.

EXPERIMENTAL PLAN

One of our first research objectives was to test what, if any, fertility benefits exist to planting a leguminous (hairy vetch) fall green manure in high tunnel beds. Due to the potential of high levels of production, fertility can be a concern in high tunnels. This can be especially true in organic high tunnels where synthetic fertilizers are prohibited.

An important change was made in the winter of 2010/2011 to our experimental plan. We decided to expand the trials to include three, instead of two, soil fertility treatments. We had previously planned two treatments: planting, or not, an overwintering cover crop. The new plan includes three treatments: a) an overwintering cover crop, b) a spring compost application, and c) an overwintering cover crop with spring compost application. We felt these treatments would give us better data on whether using a cover crop in organic high tunnels has a beneficial effect on soil and plant fertility.

Because of this change, 2011 did not include a cover crop treatment. In fall 2010, hairy vetch had already been planted into the previously planned plots. To rectify this, in February 2011, the above-ground vetch was removed prior to soil preparation. As well, we took soil samples and tested for differences where the cover crop had been planted, and none were found. Thus, treatments for the 2011 season were: a) a spring compost application (100 lb N acre^{-1}), and b) a no compost treatment. 2012 was the first production year to include the three soil fertility treatments: a) an overwintering cover crop, b) a spring compost application, and c) an overwintering cover crop with spring compost application.

For the 2012 production season hairy vetch was planted (35 lb acre^{-1}) in Fall 2011 to the beds assigned the overwinter treatments, the overwinter cover crop only and the overwinter cover crop and spring compost. The legume was incorporated into the soil in early spring. The beds that were assigned the compost treatments received the compost in early spring (100 lb N acre^{-1} for the compost only treatment and 50 lb N acre^{-1} for the cover crop and compost treatment) and were tilled soon after. Soil samples (0-6", 6-12", and 12-24") were collected for chemical analysis in the fall 2011 and also in the spring and fall of 2012. Sampling in the spring 2012 was done one month after the cover crop was incorporated so that we could access the nitrogen (N) availability from the cover crop and also from the compost. This type of data was not available for high tunnels in SW MN.

TEMPERATURE AND GROWING DEGREE DATA

Growing degree days (GDD) are a method to evaluate the effect of temperatures on plant growth. Long-term outside GDD values for Lamberton average 2528. In 2012 (Table 1) there were 402 more GDDs in the high tunnels, 3209 in the high tunnels versus 2807 outside GDDs. These GDD results are similar to results reported in the Ceres Trust 2nd year report, where the high tunnels averaged 450 more GDD's than the outside. During the growing season the maximum air temperature in the high tunnels averaged 5.5 ^{o}F greater than the outside maximum temperature. In addition, high tunnel minimum air temperatures averaged 2.5 ^{o}F warmer than the outside minimum temperatures (Figure 1). Every crop has three cardinal temperatures (minimum, maximum, and optimum) for plant growth and development. Plants can tolerate temperatures above and below these temperatures but growth is best within the minimum and maximum range and close to optimum. Midway through the growing season, the late morning and afternoon temperatures routinely exceed 90 ^{o}F and can reach 100 ^{o}F in the high tunnels. In attempt to keep high tunnel air temperatures more in-line with optimum temperatures for plant growth we have installed a 30% (percentage of light blocked) black plastic shade covering to all three tunnels the past two years. The shade cloth reduces light intensity and temperature up to 4-8 ^{o}F. The shade cloth is installed in early June as outside temperatures increase and removed in early September after outside air temperatures decrease again.

RESULTS AND DISCUSSION

SOIL TESTS

The most interesting results for soil analysis were found for soil nitrate, soil phosphorus (P), and soil salinity (EC) for the depth of 0 to 6". Samples taken in the fall of 2011, showed that overall, the beds that received compost had higher nitrate left in the soil than the beds that received green manure only (Table 2). The beds that were planted to cucumber had the greatest nitrate residual than any other crop. Although cucumber is a high production crop and can take up high amounts of nutrients from soil, disease pressure in 2011 limited cucumber yield, resulting the high nitrate levels in the soil. The soil samples collected in the spring 2012 after treatments had been added and incorporated showed a significant interaction between soil nitrate levels and previous crop (Table 2). The hairy vetch was able to provide, on average, more than 100 lb N $acre^{-1}$ to the beds that were cropped to determinate tomatoes in the previous year (Table 2). However, beds that had more than 100 lb N $acre^{-1}$ in the soil test collected in fall 2011, showed N immobilization from vetch. This result was also observed for the beds that received compost and compost+vetch treatments, where beds that have more than 100 lb N $acre^{-1}$ in the samples collected in the fall 2011 showed N immobilization from added compost and hairy vetch (Table 2). The 2012 fall soil sampling shows that deep nitrate levels increased on beds that were cropped to spring greens. This can be observed in the 12-24" sampling depth (Table 2). The reasons for this behavior are mostly due to the shallower root system of the spring greens and also the much lower yields compared with the other crops. For the other crops, soil levels seems to have dropped compared with levels from 2011. This indicates that the fertility management adopted in 2012 has helped improve soil fertility in terms of nitrate availability.

The results observed for soil EC were very similar to those observed for soil nitrate (Table 2). Soil EC is a reflection of dissolved salts in the soil solution. Among all nutrients measured in the soil test, nitrate and sodium are the ions that accounted for more than 90% of the dissolved salts in the soil solution, and therefore, are the ions that most affected soil EC. Soil EC was greatest in the beds that were cropped to cucumber in 2011, a result more likely due to the fact that the cucumber crop suffered from severe disease and yield was compromised. The low yield in those beds led to accumulation of salts, which led to the higher soil EC values. For the spring sampling, soil EC was lowered compared to samples taken in the fall 2011. The EC values measured in 2012 showed a much lower EC value, which could be a result of the lower nitrate levels as indicated above.

Soil test P levels were lowest in beds that received the hairy vetch treatment only compared with beds that received compost and compost+vetch (Table 2). However, soil P levels are continuing to increase and there are signs that P is moving to the lower horizons as indicated by the deep sampling (Table 2). Soil test P averaged 44, 66, and 22 ppm in beds receiving vetch in spring, fall 0-6, and fall 12-24, respectively (Table 2). Soil test P was very similar in the compost and compost+vetch treatments and averaged 162, 194, and 60 ppm in beds receiving compost or compost+vetch in spring, fall 0-6, and fall 12-24, respectively (Table 2). This result shows that over application of compost can significantly increase soil nutrient levels above levels which are environmentally safe, also it shows that a better nutrient management plan must be incorporated into high tunnels managed organically to maintain sustainability.

SPRING CROPS

Beginning in March, spring crops were planted on three dates starting on March 7th, then March 21st, and the final planting date was April 5th, in all three tunnels in beds that received all three treatments, vetch only, compost only, and vetch + compost. The species planted were Salad

Bowl a green loose-leaf lettuce, Red Salad Bowl a red loose-leaf lettuce, and Tyee spinach. An internal row cover was used over the spring crops until early May.

Both types of lettuce produced well and gave repeated cuttings into mid-June, which was four weeks shorter than 2011. This was probably due to the hotter spring in 2012, as in mid-June the lettuce started to become bitter. However, the green lettuce produced on average about 37% more lettuce than the red variety (Table 2). There were no clear planting date effects on lettuce yield, though there were some compost treatment effects, unlike 2011 where there was no effect of compost versus no compost on spring crop yield. The treatment that received compost only had the greatest yields for between both varieties, followed by the compost + vetch treatment, and lastly the vetch alone. This was probably because the compost alone treatment was the treatment that had the greatest amounts of nutrient being applied. As reported in the soil section, the compost treatment had the largest amounts of P in the soil; however, other nutrients except N were also higher in the compost treatments. The spring spinach did not produce as well as the lettuce, perhaps due to the warmer spring. There was also a treatment effect, where the combination of compost and vetch resulted in the greatest yields followed by compost alone, and lastly vetch alone (Table 2).

SUMMER CROPS SOIL FERTILITY

Tomato and pepper summer crops were started on February 28, 2012 in the SWROC greenhouse; cucumbers were started on March 9th. Additional summer crop plants were started in March in case of disease or other unforeseen problems that may have occurred before, during or after transplanting the seedlings. Determinate and indeterminate tomatoes were transplanted into the high tunnels on April 23rd, and cucumbers and peppers on April 24th. Soil fertility treatments were not a significant factor controlling total yield for any of the vegetable crops or varieties except cucumbers (Table 4). Socrates yielded greatest with the compost only treatment, sweet success yielded greatest in compost plus cover treatment. These results are similar to 2011 where there was found to be no significant difference in total yield between soil fertility treatments (compost versus no-compost) for any of the spring or summer vegetable crops.

CUCUMBERS

Unlike 2011, where cucumber yield was limited due to an infestation of cucumber beetle's, in 2012 the cucumber beetle was not a significant problem on crop yield. Cucumber beetles were present again in 2012 but were controlled by the use PyGanic™ an Organic Materials Review Institute (OMRI) approved organic pesticide which was applied on average, three times a week during the summer. This has allowed the cucumbers to continue to produce into late August. In late July, spider mites became a severe problem and cucumber yields were limited in one tunnel. Another OMRI approved pesticide (70% Neem Oil) was sprayed and helped maintain yields in the two remaining tunnels. The two varieties planted were Socrates and Sweet Success. There were some interactions between fertility treatment and variety, Socrates yielded greatest (Table 4) with the compost only treatment, while sweet success yielded greatest in compost plus vetch treatment. Yield season totals were greatest for both varieties in July (Table 5). Socrates produced more cucumber fruit than Sweet Success, 1891 versus 1157; however the fruit produced was smaller, on average each cucumber weighed 0.36 pounds for the Socrates and 0.66 pounds for the Sweet Success (Table 5). This year, the total amount of cucumber harvested, 1489 pounds was almost three times higher than 2011 when 508 pounds were harvested. Overall, Sweet Success had a significantly greater yield and fruit size, but Socrates produced more total fruit.

TOMATOES – DETERMINATE AND INDETERMINATE

For the tomatoes, there was no significant damage caused by insects; however, tomatoes did suffer from blossom end rot early in the season and the determinate tomatoes had more severe symptoms than the indeterminate tomatoes. This was more likely caused by hydric stress during the hot days, but it could have also been caused by excessive nutrients in the soil. To prevent the physiological disorder, a solution of calcium chloride at 1.0% was applied twice a week for two weeks during July.

Two varieties of determinate tomatoes were planted, BHN-589 and Scarlet Red. End of season analysis showed there was no fertility treatment effect (Table 4) for either of the varieties. Both determinate tomato varieties had significantly greatest yield totals and number of fruit harvested in October (Table 6). Fruit size was greatest early in the season and decreased as the season continued (Table 6). Total yield weight and fruit harvested was significantly greater with BHN-589, Scarlet Red yielded significantly larger fruit size (Table 6).

For the indeterminate tomatoes, the varieties planted were Cobra and Better Boy. Both varieties resulted in very similar yields; and there was no significant fertility treatment by variety interaction (Table 4). August was the most productive month for total yield for both indeterminate varieties (Table 7), with October having the most fruit harvested. Fruit size was largest in July for both varieties and then decreased as the season progressed (Table 7). Overall, Better Boy had significantly greater total yield weight and fruit size, but had lower total fruit harvested (Table 7).

PEPPERS

No significant damage due to insect or physiological disorder was observed in the peppers in 2012. The two varieties planted were Ace and Carmen. The peppers were harvested when turning to red. There was no significant fertility treatment by variety interaction (Table 4). Yields varied by variety, Ace yielded 302 total lbs and Carmen yielded significantly greater with 330 total lbs for the season (Table 8). Fruit size was significantly greatest during July and August for both varieties (Table 8). Overall Carmen had significantly greater season yield totals and the number of fruit harvested, however Ace had significantly greater fruit size (Table 8).

REMARKS ON VEGETABLE YIELD AND SOIL FERTILITY

It is important to note some of the significant changes from the preliminary report that was submitted late last summer. Other than the cucumbers, which had for the most part reached their season yield totals at the time of the preliminary report, the fertility treatment effects we saw earlier in the season were no longer significant for the determinate and indeterminate tomato varieties along with the pepper varieties.

OUTREACH

On April 4th we held our 3rd annual Extending the Growing Season Day, with speakers from the University of Minnesota SWROC, University of Minnesota Extension, the Rodale Institute, and a local vegetable and herb producer from Iowa. The full-day event had approximately 65 attendees; participants were given an update of the results from the previous season and funded by The Ceres Trust.

The University of Minnesota SWROC annual Organic Field Day was held on July 11th, there were approximately 75 participants. The high tunnels were a stop on the field tour and the participants were able to hear about the 2012 research, ask questions, and share ideas with the faculty and staff at the SWROC.

Results from the trial were presented as a poster presentation February 21-23, at the 2013 Midwest Organic and Sustainable Education Service (MOSES) conference held in La Crosse, Wisconsin which had over 3,300 attendees. On March 11, 2013 a presentation was presented to 22 attendees at the Third Crop Producers meeting in Fairmont, MN. In October 2013, data from this research was presented at the 2013 ASA-CSA-SSSA international meeting in Tampa, FL.

Vegetable produce from the high tunnels was used by the SWROC kitchen during events throughout the summer. Produce was also used by local University of Minnesota Extension Educators for nutrition and cooking classes, and more than 1,500 lbs of vegetables was donated to local area food shelves in the past two years.

CHALLENGES

The 2012 growing season has provided a number of disease, insect and environmental challenges. Included at the end of the report are photos of some of the problems we encountered.

The spring crops had a minor infestation of cabbage looper in the lettuce varieties. Yield damage was minimal, and the looper was controlled with an application of DiPel Pro DF™, a biological insecticide approved for organic production.

Both the determinate and indeterminate tomatoes were affected by physiological leaf roll, cracking, and blossom end rot. We believe the cause of these problems is primarily due to the hot dry summer experienced this year in southwest Minnesota. The leaf roll was temporary and the plants were helped by the addition of a 30% shade cloth to the outside exterior roof of the tunnels. Tomato cracking was more prevalent this year; we feel the heat was the major contributor, although we also monitored our drip irrigation system more closely to make sure the plants weren't being overwatered. Blossom end rot was a problem at the beginning of the season, hot temperatures during flowering, excessive nutrients in the soil not allowing calcium uptake were probably all factors. The foliar addition of calcium chloride and cooler temperatures in August has helped to mitigate this problem.

The cucumber beetle was once again present in 2012. Cucumber beetles can cause bacterial wilt, and in 2011 the entire cucumber crop was infected before we could control it and the cucumber yield was terminated by the end of June. In 2012 we were able to control the cucumber beetle with an aggressive regime of PyGanic™ an OMRI approved broad spectrum contact insecticide. In late July, we started seeing nutrient deficiency symptoms in the cucumbers, what we originally thought might be a nutrient treatment affect was in fact a spider mite infestation. Once the problem was identified we began a weekly 70% Neem oil application regimen which helped to suppress the spider mites.

Overall we have experienced more insect problems than in our previous years growing vegetables in the high tunnels. But our experiences are issues that local producers either have experienced or could experience in the future. Through our outreach program we will be able provide information on our successes and failures to help local high tunnel vegetable producers.

SIGNIFICANCE OF THE RESULTS

There are a number of significant results obtained from this study that will be beneficial to organic high tunnel vegetable producers:

- All soil fertility treatments tested provided similar amounts of nutrients for optimum production. The choice for nutrient sources should be made after performing a detailed observation on the soil fertility status. This can help avoid potential drawbacks due to intense compost based agriculture.
- Crop variety was one of the most significant effects observed in this study. There was a trend in all varieties where the higher the fruit size the lower the total number of fruits produced.
- The results of this research showed that the best choice of variety for a farmer should be based on how the produce will be sold:
  - If produce is to be sold as unit, then varieties that produce the higher number of fruits should be selected;
  - If produce is to be sold by weight, then varieties that result in higher total yields should be selected.
- Air temperature and GDD results from this study showed that high tunnels can provide a positive impact for producers by providing higher GDD per season compared to outside conditions. Maximum air temperatures and light intensity can be moderated through the use of shade cloth during part of the growing season.
- Weed and pest control are issues for all vegetable growers. Plastic mulch placed over the organic vegetable beds controls virtually all weeds and maintains soil moisture for the vegetable crops. OMRI approved contact pesticides, with timely applications can control pests found in high tunnel organic vegetable production.

The soil fertility results from this study have also shown that the nutrient management philosophy of using manure compost to supply a crop's requirement for nitrogen has the potential to negatively affect the sustainability of the high tunnels and lead to soil health problems. High amounts of soluble salts present in manure compost, can lead to salt build up in the soils to levels that are limiting to production of most vegetable crops. And repeated manure compost applications as the main source of nutrients can also cause an imbalance of nutrient uptake by plants leading to physiological disorders and yield reduction. Results from this study led us to request and receive funding from the Ceres Trust to begin new research that will continue to focus on soil fertility, but also look at maintaining soil health through a combination of crop species being grown with different nutrient sources, including cover crop, alfalfa compost, beef manure compost, and commercial organic certified compost (Sustane). During the future three years, the SWROC research team will continue to provide quality research data to local growers during the annual extending the season field day, in addition to that, in the last year the SWROC will host a field school. In the field school farmers will be invited to come to the SWROC and learn by participating on sections that will demonstrate how to replicate at their farms what was learned during the three years of research. For example, the farmers will learn how to make useful interpretation of soil test, how to efficiently compost alfalfa, how to work with potato and sweet potato in the tunnel, and more.

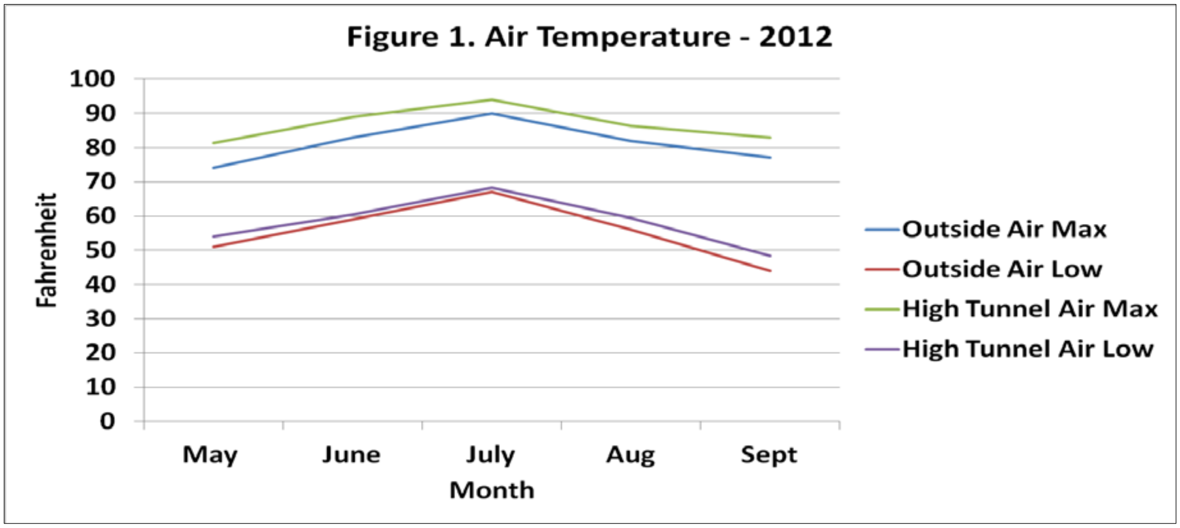

Table 1. 2012 Growing Degree Days

	2012 GDD	
Date	**High Tunnel**	**Outdoor**
May	523	403
June	717	612
July	875	808
August	643	572
September	451	412
Total	3209	2807

+GDD = (Tmax +Tmin)/2 – Tbase. Where Tmax is maximum daily temperature and is set equal to 86°F when temperatures exceed 86°F,Tmin is the minimum daily temperature and is set equal to 50°F when temperatures fall below 50°F, Tbase is the base temperature.

Table 2. Soil properties determined on spring (0-6") and fall (0-6" and 12-24") 2012

2012 Crop	Treatment	Nitrate lb / acre			EC dS / m			Phosphorus ppm		
		Spring	Fall		Spring	Fall		Spring	Fall	
		0-6	0-6	12-24	0-6	0-6	12-24	0-6	0-6	12-24
Green Pepper	Vetch	129	16	61	1.2	0.40	0.40	79	115	31
Spring Greens	Vetch	41	43	108	0.7	0.43	0.43	40	51	19
Indet. Tomatoes	Vetch	24	58	56	0.5	0.53	0.33	20	52	16
Cucumber	Vetch	64	51	41	0.8	0.47	0.33	42	57	19
Det. Tomatoes	Vetch	29	38	75	0.6	0.53	0.40	52	55	24
Green Pepper	Compost	197	31	21	1.7	0.43	0.30	205	152	20
Spring Greens	Compost	59	49	133	1.0	0.53	0.50	177	203	95
Indet. Tomatoes	Compost	128	56	51	1.0	0.67	0.37	150	168	37
Cucumber	Compost	135	51	57	1.2	0.77	0.47	192	203	53
Det. Tomatoes	Compost	93	72	87	1.0	0.63	0.57	146	255	94
Green Pepper	Compost+Vetch	186	20	19	1.9	0.60	0.33	218	178	32
Spring Greens	Compost+Vetch	52	52	137	0.8	0.47	0.50	113	212	68
Indet. Tomatoes	Compost+Vetch	85	65	35	0.9	0.67	0.33	167	162	38
Cucumber	Compost+Vetch	52	57	81	0.9	0.50	0.53	140	189	61
Det. Tomatoes	Compost+Vetch	227	28	45	1.7	0.40	0.37	190	218	101

Table 3. 2012 Spring Crop – Total Season Weight (lbs) by Soil Fertility Treatment

Treatment	Green Lettuce	Red Lettuce	Spinach
		Total lbs summed over all three tunnels	
Compost	4.55	3.32	1.13
Vetch	3.99	2.81	0.63
Compost+Vetch	4.08	3.11	1.49
Total Yield	12.62	9.24	3.25

Table 4. 2012 Vegetable Yield – Total Season Weight (lbs) by Soil Fertility Treatment

Soil Fertility Treatment	Cucumbers		Green Peppers		Indeterminate Tomato		Determinate Tomato	
	Socrates	S. Success	Ace	Carmen	Cobra	B.Boy	BHN-589	S. Red
Compost	254 a	259 b	99 a	108 a	207 a	202 a	323 a	240 a
Hairy Vetch	225 b	201 b	118 a	121 a	186 a	200 a	339 a	301 a
Compost+ Vetch	224 b	326 a	84 a	101 a	214 a	176 a	282 a	174 a

+Means followed by the same letter by column are not significantly different at the 0.05 probability level.

Table 5. Cucumber Yield – Total fruit weight, number of fruit, and fruit size by date

	Total lbs/date		Fruit harvested		Mean lb/fruit	
Date	**Socrates**	**S. Success**	**Socrates**	**S. Success**	**Socrates**	**S. Success**
June	218 b	326 a	585 a	481 a	0.37 a	0.68 a
July	320 a	337 a	823 a	482 a	0.39 a	0.69 a
August	165 b	123 b	483 a	194 a	0.31 a	0.60 a
Total	703 B	786 A	1891 A	1157 A	0.36 B	0.66 A

+Column values followed by the same lower-case letter are not significantly different at P = 0.05. Total values followed by the same capital letter are not significantly different at P = 0.05.

Table 6. Determinate Tomato Yield – Total fruit weight, number of fruit, and fruit size by date

	Total lbs/date		Fruit harvested		Mean lb/fruit	
Date	**BHN-589**	**Scarlet Red**	**BHN-589**	**Scarlet Red**	**BHN-589**	**Scarlet Red**
July	143 c	112 b	277 c	165 c	0.53 a	0.61 a
August	317 b	167 b	630 b	308 b	0.51 ab	0.54 b
September	82 d	139 b	172 d	283 b	0.47 b	0.48 c
October	402 a	297 a	1287 a	953 a	0.31 c	0.31 d
Total	944 A	715 B	2366 A	1709 B	0.45 B	0.52 A

+Column values followed by the same lower case letter are not significantly different at P = 0.05. Total values followed by the same capital letter are not significantly different at P = 0.05.

Table 7. Indeterminate Tomato Yield – Total fruit weight, number of fruit, and fruit size by date

	Total lbs/date		Fruit harvested		Mean lb/fruit	
Date	**Better Boy**	**Cobra**	**Better Boy**	**Cobra**	**Better Boy**	**Cobra**
July	142 b	151 b	193 c	235 c	0.76 a	0.56 a
August	226 a	190 a	398 b	466 b	0.57 b	0.43 b
September	82 c	80 c	160 c	218 c	0.51 b	0.32 c
October	158 b	158 b	467 a	562 a	0.34 c	0.29 d
Total	607 A	578 A	1218 A	1481 A	0.54 A	0.40 B

+Column values followed by the same lower case letter are not significantly different at P = 0.05. Total values followed by the same capital letter are not significantly different at P = 0.05.

Table 8. Pepper Yield – Total fruit weight, number of fruit, and fruit size by date

	Total lbs/date		Fruit harvested		Mean lb/fruit	
Date	**Ace**	**Carmen**	**Ace**	**Carmen**	**Ace**	**Carmen**
June	24 c		109 b		0.22 b	
July	51 b	80 b	161 b	288 c	0.32 a	0.28 a
August	98 a	89 b	349 a	357 b	0.28 a	0.25 a
September	39 b	22 c	169 b	109 d	0.25 b	0.21 b
October	89 a	139 a	390 a	798 a	0.23 b	0.20 b
Total	302 B	330 A	1178 B	1552 A	0.26 A	0.24 B

[+]Column values followed by the same lower case letter are not significantly different at P = 0.05. Total values followed by the same capital letter are not significantly different at P = 0.05.

PHOTOS

Spring and summer crops produced in SWROC high tunnels.

University of Minnesota SWROC High Tunnels

Hairy Vetch cover crop overwinter growth

Summer crops (tomatoes, pepper and cucumbers) after transplanting

Spring greens (green and red loose-leaf lettuce and spinach)

Cucumbers ready to harvest

Trellised cucumber plants

Determinate tomatoes kept separate with cages

Trellised indeterminate tomatoes

Determinate tomatoes

Peppers

Peppers ready for harvest

PHOTOS OF PRODUCTION CHALLENGES

Green loose-leaf lettuce with cabbage looper caterpillar

Determinate tomatoes with physiological leaf roll

Indeterminate tomato with shoulder cracking

Tomato with blossom end rot

Cucumber plant infected with bacterial wilt

Cucumber plant with spider mite damage and a striped cucumber beetle