ORGANIC FARMING RESEARCH FOUNDATION

Project report submitted to the Organic Farming Research Foundation:

Project Title:

Shade-covered high tunnels for summer production of lettuce and leafy greens

FINAL PROJECT REPORT

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Funding provided by OFRF: $5,835, awarded spring 2001

Project period: 2001

Report submitted: April 27, 2005

Project Summary. This project was conducted to test practical methods for extending the production of cool season leafy greens into the hot summer months in Kansas City, where high temperatures normally terminate production of these crops from June through August. We used high tunnels covered with 40% shade cloth, combined with drip irrigation and were able to produce crops of lettuce (10 cultivars) and Asian greens (5 types) throughout the summer. Trials were conducted at three locations, two of them working organic farms, and the other an agricultural experiment station in order to produce statistically valid experimental results. We produced higher yields of marketable quality lettuce and greens over multiple harvests throughout the summer compared to outside plots, which produced lower yields of poorer quality crops. As a result of this project, both growers have continued with summer greens production, recognizing that adapted warm-season vegetables may be more profitable under hot summer conditions. Results of the project have been disseminated through multiple avenues including workshops at the Great Plains Vegetable Growers Conference in January 2002, and a high tunnel construction guide posted on www.hightunnels.org. A video documenting the research project has been developed funded by a subsequent grant from the USDA SARE program (attached) and will also be posted on the high tunnels website. This project contributed significantly to the initiation of a multi-state USDA-funded project on high tunnels for the central Great Plains, which includes a significant component of research and extension related to organic vegetable production and continuing assessment of extension of cool season crop production into to the hot summer months.

Introduction. Most varieties of greens do not grow throughout the market season in the Midwest because of the 85-degree-plus weather, which persists for much of July, August and September. High temperatures (and resulting problems with dormancy and rapid drying of soil) result in poor crop establishment, and bitterness and bolting of lettuce. Other leafy greens are severely affected by high insect populations. The ability to extend the greens season through the summer heat would benefit local growers while meeting a consumer need at peak market times.

During the summer of 2001, we used shade-covered high tunnels, and lettuce and green cultivars with reported heat tolerance, to attempt to grow high quality greens throughout the summer in the Kansas City area. Trials comparing monthly plantings of lettuce and green cultivars inside shade-covered high tunnels and in adjacent open-field were conducted at three locations from early July through late-September.

Objectives.

Objective One: Test 17 varieties of lettuce and six varieties of Asian greens to determine what varieties and types of greens produce the best under hot summer conditions when shade cloth is used. We tested ten varieties of lettuce and five varieties of Asian greens, over four plantings each in 2001.

Objective Two: Test combinations of white shade cloth, mulch, and floating row covers to reduce soil and air temperatures and to control pests. White shade cloth was used, but not floating row cover.

Objective Three: Determine if the capital investment and extra labor involved in growing under shade cloth is justified by the income potential.

Objective Four: To develop a documented, workable and affordable system for growing greens in the Midwestern summer heat that can be used by other growers.

Materials and Methods. Trials were conducted at Full Circle Farm, Kansas City, Kansas, at Bear Creek Farm, Osceola, Missouri, and at the K-State Research and Extension Center, Olathe, Kansas. Full Circle Farm and Bear Creek Farm are certified organic farms, and the plot chosen for trials at the K-State Research and Extension Center had been an "organically-managed" brome grass pasture for 40 years prior to tillage the year before initiation of our study.

High tunnels (or hoop houses), 18' x 30', were constructed at each house using 30' hoops of schedule 40 PVC, spaced 3' apart. Tunnels were covered with standard 6 mil greenhouse poly film with a 4-year life expectancy. Sides were constructed to roll up for ventilation and ends were left open for ventilation. [Details of high tunnel construction are presented in the attached construction guide (Appendix 1), produced as an output of this project.] Tunnels were covered with PAK woven white shade cloth (39% shade), which was removed in late September when day-time high temperatures no longer regularly exceeded 90 F. Total cost of materials for each high tunnel, including shade cloth, was roughly $550.

Ten lettuce and 5 leafy greens cultivars were evaluated in the study (Table 1). To avoid potential problems with thermodormancy, lettuce seedlings were germinated under climate-controlled greenhouse conditions at Kansas State University. Approximately one month prior to field transplant, seedlings were germinated and grown in a peat:vermiculite mix in Speedling trays and fertilized with dilute fish emulsion. Greens were direct seeded. There were four planting dates at each trial site, with date of first planting delayed at the K-State site due to later construction of the high tunnel there. Plots from each planting were harvested over an extended period, beginning as the first cultivars reached harvestable size, and or as re-growth from greens or lettuce was harvested periodically. Planting and harvest dates at each site are presented in Table 2.

At each planting date, variable numbers of lettuce or greens cultivars were planted inside shaded high tunnels and in adjacent outside plots. A minimum of 5 lettuce plants were planted per cultivar, with a spacing of 8" x 12" or closer, and greens were direct-seeded in 1" bands 1' apart and a minimum of 5' long. Numbers of transplants planted or feet of row seeded were recorded. Similar spacing was used for inside and outside plots of the same cultivar on any planting date.

Plots were harvested when deemed to be ready by each grower. Lettuce was harvested once-over as heads, or as cut-and-come-again, and greens were harvested as cut-and-come-again. At harvest, lettuce heads from each plot harvested were counted and graded, marketable quality lettuce was weighed and observations of quality were noted. At harvest of greens, area harvested was noted, and marketable greens were weighed. At each harvest, value of lettuce or greens harvested per plot was calculated as follows: head lettuce priced at $2.25 (anything over 0.33 lb); cutting lettuce priced at $9.00/lb (includes multiple heads and heads 0.33 lb and under); and cutting greens priced at $9.00/lb at Full Circle and Bear Creek Farms, and $2/lb at Olathe.

Because area and number of plants sown was not consistent over plantings or locations, yield data were standardized following the completion of harvest of each plot by dividing the number of lettuce plants harvested or the linear feet of greens harvested, by the number of plants (or linear feet of greens) planted or harvested. This allowed meaningful comparisons of performance of cultivars grown inside shaded tunnels and in the open. Plant survival was also

calculated following final harvest by dividing total number of plants (or area) harvested, by number of plants (or area) planted. The mean value of harvest from each plot was also calculated by dividing total value by number of plants sown. Trial results were analyzed statistically by considering each location to be a replication in the experiment. The experimental design was a split, split, split plot with three replications, with structure (high tunnel versus open) as main plots, planting dates as sub-plots, and cultivars as sub-sub plots. Data for Tatsoi, one of the leafy green cultivars, were not complete over trial sites, so this cultivar was dropped from the statistical analysis.

We attempted to monitor soil and air temperatures inside and outside of high tunnels during the trial. However, our poor quality thermometers malfunctioned early in the experiment, so data were not meaningful. Mean temperatures and precipitation at the K-State Research and Extension Center were collected during the trial, and are presented in Table 3. During 2002, experiments were continued at all locations. This time soil and air temperatures were monitored more carefully using Onset Hobo H8 Pro Temperature/External loggers placed 18" above ground level in standard solar radiation shields. Soil temperatures were monitored at 4" depth using external temperature sensors connected to the dataloggers.

Results and Discussion. The advantages of growing lettuce and leafy greens in shaded high tunnels as compared to the open field were almost immediately obvious to the cooperators at each location. Shade-grown lettuce and greens grew larger, faster than their open-field-grown counterparts, and appeared to have consistently higher quality, being consistently cleaner (due to lack of rain splashing) and more succulent. Table 4 presents an overview of results obtained inside shaded high tunnels and outside at each location by planting date and over planting dates and locations. Information on numbers of plants planted, and numbers, weights and values of harvest are presented. Inspection of Table 4 shows that at Full Circle and Bear Creek Farms, we consistently planted more plants inside tunnels than outside. It also shows that at all locations, a higher proportion of plants was harvested from inside shaded high tunnels than from outside. Total yields from inside shaded high tunnels were consistently higher than from outside, and the overall value of harvests from shaded high tunnels was consistently higher than from outside. At Full Circle Farm, the retail value of the harvest from the high tunnel was greater than the cost of materials to construct the high tunnel. At Bear Creek Farm and the K- State Research and

Extension Center, the value of harvest came close to matching the cost of the tunnels.[1] As these structures have an anticipated life expectancy of several years, it is remarkable that in a single season they come close to paying for themselves.

Results of statistical analysis of standardized results from the trial are presented in Table 5. There were marginally significant effects of environment (high tunnel versus open field). There were also highly significant effects of cultivar and the interaction of cultivar by environment and cultivar by planting date. This means that some cultivars performed better than others, and that the pattern of superiority of performance by some cultivars varied inside shaded high tunnels versus the open field, as well as with planting date.

Overall means for standardized yields, values and survival rates of lettuce and leafy greens grown in shaded high tunnels and in the open field are presented in Table 6. Means for high tunnel-grown plants were higher in each case, indicating the consistent superiority of shaded high tunnels over open fields in our trials. Standardized results for the performance of individual cultivars grown in shaded high tunnels and the open field are presented in Table 7. These results show the consistent superiority of performance of each cultivar grown inside shaded high tunnels compared to the open field. They also show that some cultivars were better able to tolerate open-field conditions, most notably some of the greens, such as Arugula. Results from Table 7 are presented graphically in figures 1, 2 and 3. We also sampled the varieties for taste and bitterness over the season and asked customers for feedback as well, and found that there was no perception of summer bitterness or toughness.

The climatic conditions which occurred during our trial were normal for the Kansas City area (Table 3). Indeed, rains were well-distributed and adequate, probably contributing to better performance of outside plots than might be expected in a drier year (such as 2002). While our monitoring of soil and air temperature was unsuccessful in 2001, we repeated the trials in 2002, and gathered daily soil and air temperature data from inside the shaded high tunnels and adjacent outside plots during the course of the experiment. Figures 4, 5, and 6 present daily graphs of air and soil temperatures at Bear Creek Farm during 3-day periods in early June, July and August. Air temperature highs were either slightly higher inside tunnels than outside (early June), or very similar. Air temperature lows were consistently slightly higher in the tunnels than in the field, probably due to the insulating properties of the plastic tunnels. Soil temperature highs in tunnels were consistently lower than outside soil temperatures, and lows in tunnels were either lower than or similar to outside soil temperatures. Soil temperature highs in the high tunnels were similar to or lower than air temperatures in the tunnels, while soil temperature highs outside frequently exceeded air temperatures. Lower root temperature has been reported to be an important factor for favorable lettuce growth (Thompson et al., 1998)[2], and the consistently

[1] The difference in price reflects our different markets and customer bases and the difference we can charge between baby lettuces and greens (high value) versus head lettuce (which we get less for). The Kansas City customers are more interested in gourmet salad mixes, the Olathe customers are more traditional vegetable consumers, looking for large head lettuce at a lower price. A low price was arbitrarily assigned to greens produced at the K-State Research and Extension Center, since they were generally allowed to get much larger than the "baby" stage prior to harvest, and were not, in fact, sold.

[2] Thompson, H.C., Langhans, R.W., Both, A.. and Albright, L.D. 1998. Shoot and root temperature effects on lettuce growth in a floating hydroponic system. J. Am. Soc. Hortic. Sci. 123, 361-364.

superior performance of lettuce and greens grown in our shaded high tunnels may be at least partially attributed to the cooler soil temperatures in our tunnels compared to adjacent field plots. It is likely that other factors, such as reduced wind, reduced light intensity and modified light quality (reduced ultraviolet) also contributed to the superior performance of shaded high tunnel-grown lettuce and greens compared to those grown in open fields.

Conclusions. We were funded for a second year of research by the USDA SARE program. In the second year, we direct seeded the lettuces and harvested them as baby greens in order to avoid the issue with early bolting and small head size. We also used overhead misting to reduce afternoon heat. In general, we found that direct seeding was more effective and that misting did improve tenderness, taste and yields. The shade cloth was very effective in greens. We have also found additional benefits to the use of shade cloth with other crops such as tomatoes, where sunscald is eliminated by its use.

In the years since conducting this work, we have found that all crops produced in the summer in the high tunnels (with shade cloth and without) are of better quality and yields than field produced crops. Because of limited space in high tunnels, we've dedicated the majority of our high tunnel space to higher-yielding, more profitable heat adapted crops like tomatoes and melons and cucumbers and set aside a smaller amount of space for greens production, primarily in response to customer interest in having some lettuce and greens available throughout the season.

We also found that, while the harvested greens were beautiful when first harvested and brought to the farmers' market, they did not hold up well in the summer heat radiating off the parking lot pavement, and that we lost too much of the product to wilt. Bagging, rather than our traditional bulk sales, helped with this issue some, but the greens often wilted in the bag.

Outreach. In January of 2002, we presented a one-hour workshop at the Midwest Vegetable Growers Conference where we showed a video of photographs and live footage of the project to about 100 people. The information was well-received and was one of the early outreach activities promoting high tunnels and shade cloth for summer vegetable production. Farm tours to Full Circle Farm and the K-State Research Center also took place in 2002 and 2003 specifically looking at high tunnels and the summer greens trials. A video of the project is being posted on www.hightunnels.org. Additionally, as an outcome of this project, Edward Carey has presented talks on the use of shaded high tunnels for season extension of cool season crops.

References.

Jim Hail, Robbins Hail, Katherine Kelly and Ted Carey. Constructing a simple pvc high tunnel. www.hightunnels.org/careyhow-tobuild.htm (see appendix)

E. Carey, K. Kelly, R. Hail and X. Zhao. 2005. Summer production of cool season greens in shaded high tunnels. Proceedings 32nd National Agricultural Plastics Congress, page 125. American Society for Plasticulture, College Park, PA (see appendix)

Table 1. Ten lettuce and 5 leafy green cultivars with reported tolerance to high temperatures were selected for summer production trials as follows.

Species and type	Cultivar	Source
Lettuce (*L. satva*)		
Oakleaf	Berenice	Johnny's Selected Seeds
	Hussarde	Johnny's Selected Seeds
Grand Rapids	Red Sails	Johnny's Selected Seeds
	Simpson Elite	Johnny's Selected Seeds
Butter head	Ermosa	Johnny's Selected Seeds
	Mikola	Johnny's Selected Seeds
Romaine	Kalura	Johnny's Selected Seeds
	Forellenschuss	
Crisphead	Anuenue	Johnny's Selected Seeds
	Demorges Braun	
Brassica juncea	Red Giant mustard	Johnny's Selected Seeds
B. rapa Japonica group	Kyona Mizuna	Johnny's Selected Seeds
B. rapa Narinosa group	Tatsoi	Johnny's Selected Seeds
B. rapa Chinensis group	Mei Qing Choi	Johnny's Selected Seeds
Eruca vesicaria subsp. sativa	Arugula	Johnny's Selected Seeds

Table 2. Planting and harvest dates of lettuce and leafygreen cultivars evaluated at three locations during the summer of 2001.

Location and planting date	Harvest dates
Full Circle Farm	
June 29;July 18*	8/17, 8/20, 8/24, 8/27, 9/7, 9/14, 9/28, 10/1, 10/4
July 30	8/24, 9/7, 9/14, 9/17, 9/28, 10/1, 10/12, 11/17
September 6	10/1, 10/5, 10/10, 10/12, 10/18, 10/22, 10/31, 11/13, 11/17, 11/20, 11/29
September 26	10/18, 10/24, 10/31, 11/2, 11/9, 11/17, 11/26, 11/29
Bear Creek Farm	
July 1	7/26, 7/29, 8/3, 8/6, 8/10, 8/13, 8/17
August 2	9/7, 9/14, 9/17, 10/8, 10/12, 10/15
September 9	9/21, 9/24, 9/28, 10/1, 10/5, 10/8, 10/12, 10/15, 10/19, 10/29
September 26	10/15, 10/19, 10/20, 10/22, 10/29
K-State Center	
July 31	9/1, 9/4, 9/6, 9/7, 9/10, 9/22, 10/14
August 31	9/26, 10/3, 10/14
September 7	10/14, 11/5
September 29	11/26

*Inside and outside plots partially replanted on second date due to slug infestation .

Table 3. Monthly average maximum and minimum temperatures and total precipitation at the K-State Research and Extension Center, Olathe, during the 2001 trial season.

Month	Mean maximum temperature (F)	Mean minimum temperature (F)	Precipitation (inches)
July	92.9	71.5	3.04
August	91.4	65.9	4.46
September	79.3	54.6	3.03
October	69.2	44.8	2.26
November	63.0	39.9	0.32

Table 4. Total lettuce and greens planted and harvested, total harvest weight and value by farm, planting date and whether planted in shaded high tunnels or open field. Trials conducted during the summer of 2001.

Location	Planting	High tunnel	Total planted (# of lettuce plants + linear feet of greens)	Total harvested (# of lettuce plants + linear feet of greens)	Total harvest (lb)	Total value ($)
Full Circle Farm	1	in	66	45	12.01	102.65
		out	69	49	7.38	66.42
	2	in	96	75	28.34	251.66
		out	73	45	7.52	62.90
	3	in	108	96	35.99	269.98
		out	74	17	3.75	26.83
	4	in	160	145	43.39	309.33
		out	92	19	1.86	16.74
	all	**in**	**430**	**361**	**119.73**	**933.62**
		out	**308**	**130**	**20.51**	**172.89**
K-State, Olathe	1	in	65	59	35.19	147.77
		out	67	41	17.61	78.47
	2	in	72	67	33.98	156.28
		out	70	67	20.82	123.65
	3	in	72	69	57.86	188.60
		out	71	65	30.64	140.16
	4	in	51	48	21.50	130.08
		out	50	0	0.00	0.00
	all	**in**	**260**	**243**	**148.53**	**622.84**
		out	**258**	**173**	**69.07**	**342.28**
Bear Creek Farm	1	in	53	52	18.89	130.97
		out	52	33	11.46	78.24
	2	in	97	72	15.09	124.72
		out	38	22	2.87	25.83
	3	in	95	81	25.70	185.65
		out	74	46	13.53	98.10
	4	in	64	43	10.44	71.29
		out	57	9	4.23	24.75
	all	**in**	**309**	**248**	**70.12**	**512.63**
		out	**221**	**110**	**32.09**	**226.92**
All three locations	**all**	**in**	**999**	**852**	**338.38**	**2129.09**
		out	**787**	**413**	**121.67**	**742.09**

Table 5. Analysis of variance of weights and values of shade- and open-field-grown lettuce and leafy green cultivars grown in 4 successive plantings during the summer of 2001.

Source of variation	Df	Mean harvest wt per plant or area planted	Mean harvest wt per plant or area harvested	Mean value per plant or area planted	Mean survival at harvest
		Pr >F			
Environment (Shade vs. Open)	1	0.0604	0.0576	0.0445	0.0601
Planting date	3	0.0845	0.0846	0.1359	0.1487
Environment*Planting date	3	0.8364	0.8457	0.7106	0.0825
Cultivar	13	<.0001	<.0001	0.0594	0.0559
Environment*Cultivar	13	0.0015	0.0065	0.0434	0.1626
Planting date*Cultivar	39	<.0001	<.0001	0.0263	0.3691
Environment*Planting date*Cultivar	39	0.7121	0.9252	0.8129	0.7837

Table 6. Comparison of mean yields, values and survival of lettuce and leafy green cultivars grown in shaded high tunnels or open fields at three locations near Kansas City during the summer of 2001.

	Mean wt per plant sown (lb)	Mean wt per plant harvested (lb)	Mean value per plant ($)	Mean survival at harvest (%)
Shaded high tunnel	0.37	0.41	2.09	82.9
Open field	0.16	0.20	0.93	50.1
Pr > F	0.0604	0.0576	0.0445	0.0601

Table 7. Mean yields, values and survival rates of 10 lettuce and 4 leafy green cultivars grown in 39%-shaded high tunnels or open field, during the summer of 2001.[1]

Cultivar	High tunnel	Mean yield per plant sown (lb)	Mean value per plant sown ($)	Mean survival at harvest (%)
Anuenue	in	0.25	1.80	76.4
	out	0.09	0.70	33.7
Berenice	in	0.23	1.83	76.8
	out	0.15	1.04	46.7
Demorges Braun	in	0.26	1.84	78.1
	out	0.11	0.89	50.0
Ermosa	in	0.30	2.02	85.6
	out	0.13	1.07	54.6
Forellen.	in	0.21	1.32	53.4
	out	0.08	0.68	52.3
Hussarde	in	0.27	1.79	75.0
	out	0.18	1.39	64.6
Kalura	in	0.50	2.19	87.0
	out	0.19	1.10	48.9
Mikola	in	0.23	1.63	70.4
	out	0.12	0.86	40.8
Redsails	in	0.24	1.67	73.5
	out	0.12	1.00	53.4
Simpson	in	0.33	1.94	81.7
	out	0.14	0.97	46.8
Arugula	in	0.58	2.62	95.6
	out	0.48	1.73	57.2
Mizuna	in	0.74	3.32	101.1
	out	0.16	0.61	71.8
Mustard	in	0.56	2.85	101.1
	out	0.15	0.67	50.9
Pakchoi	in	0.42	2.41	104.8
	out	0.11	0.36	30.0
	Pr > F	0.0015	0.0434	0.1626

[1]Least square means.

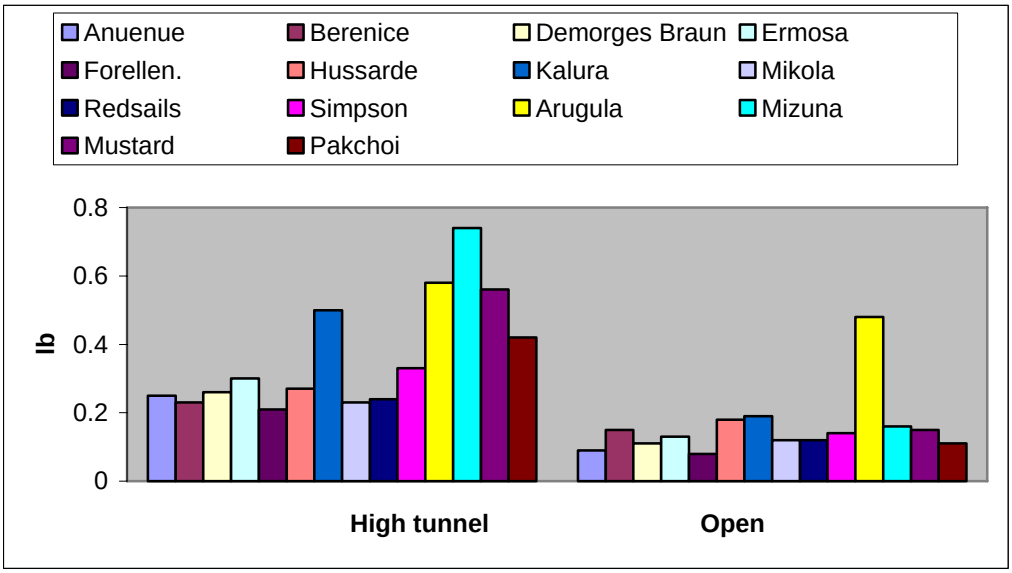

Figure 1. Mean yield of lettuce (per plant) and leafy green cultivars (per ft^2) grown in shaded high tunnels or in the open at three locations near Kansas City during the summer of 2001.

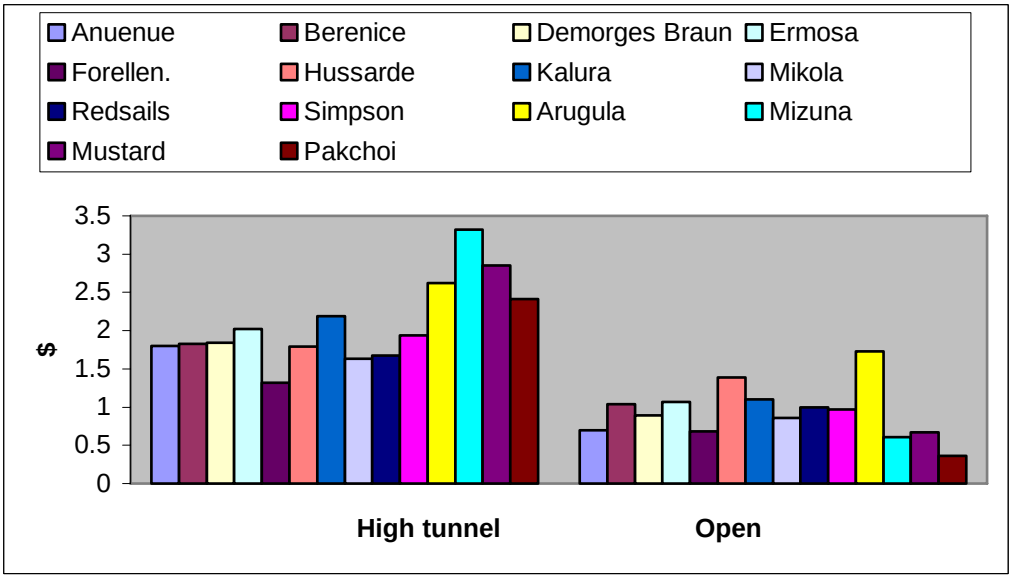

Figure 2. Mean value of lettuce (per plant) and leafy green cultivars (per ft^2) grown in shaded high tunnels or in the open at three locations near Kansas City during the summer of 2001.

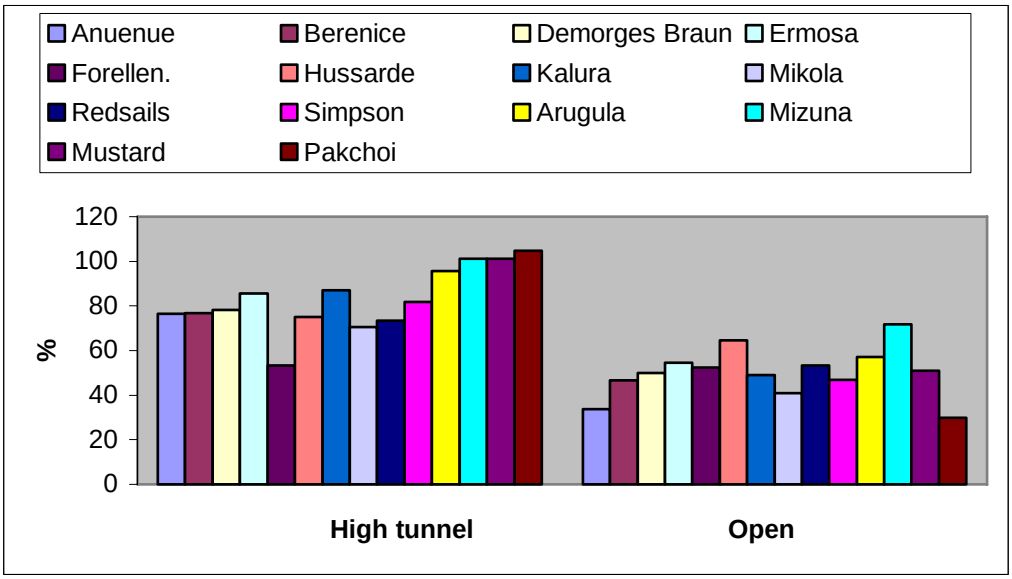

Figure 3. Mean survival rates of lettuce and leafy green cultivars grown in shaded high tunnels or in the open at three locations near Kansas City during the summer of 2001.

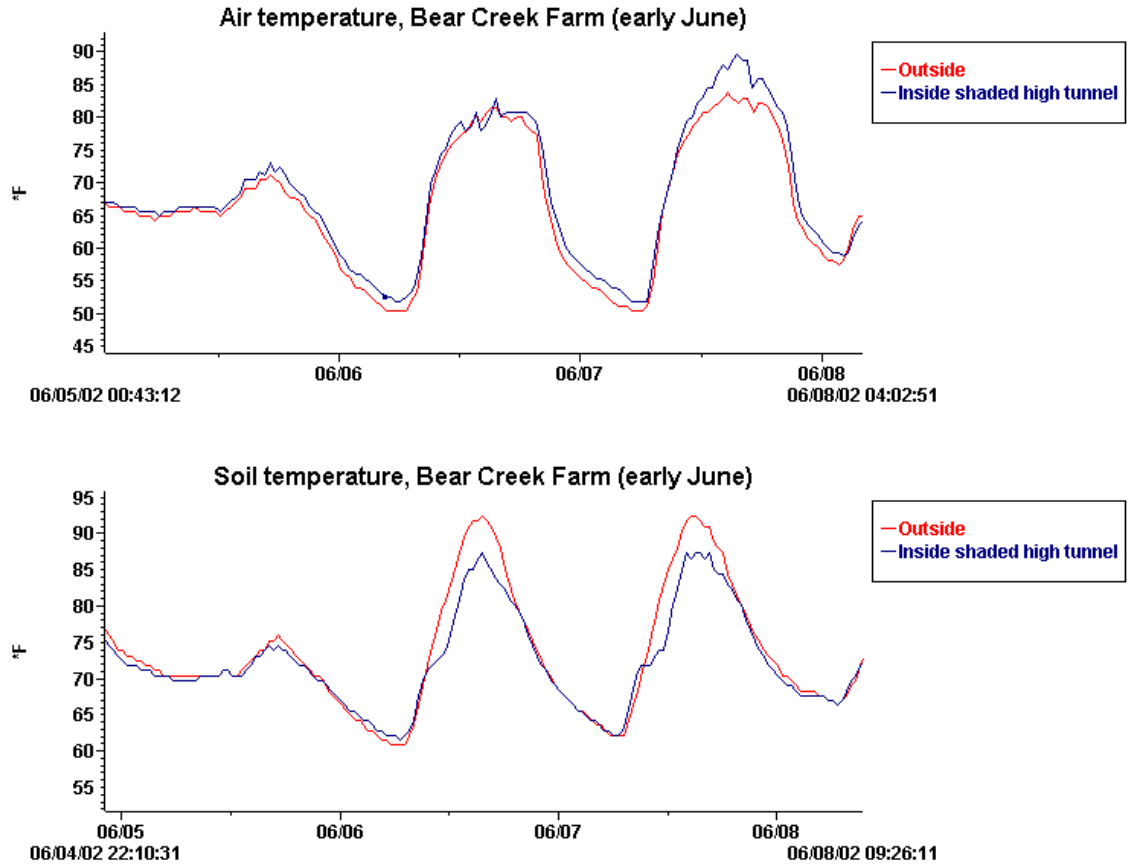

Figure 4. Air (18”) and soil (4”) temperatures inside shaded high tunnels and in adjacent outside plots during a 3-day period in early June, 2002.

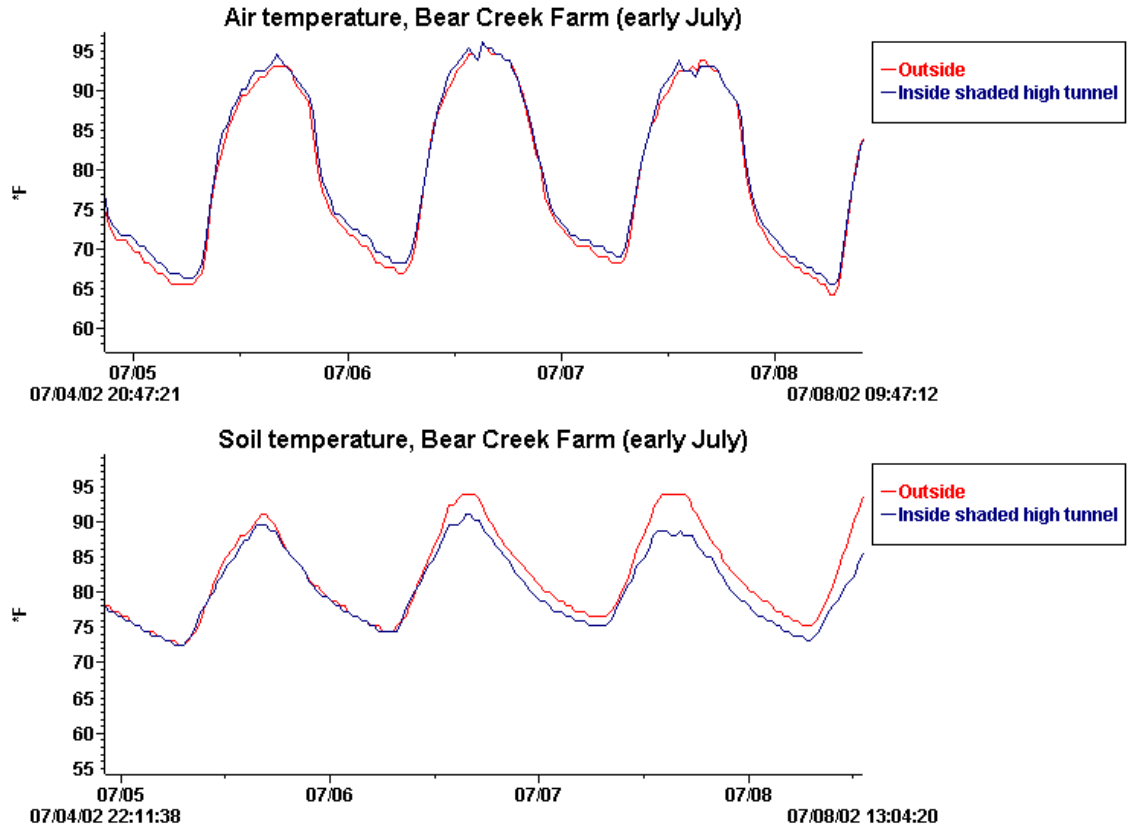

Figure 5. Air (18”) and soil (4”) temperatures inside shaded high tunnels and in adjacent outside plots during a 3-day period in early July, 2002.

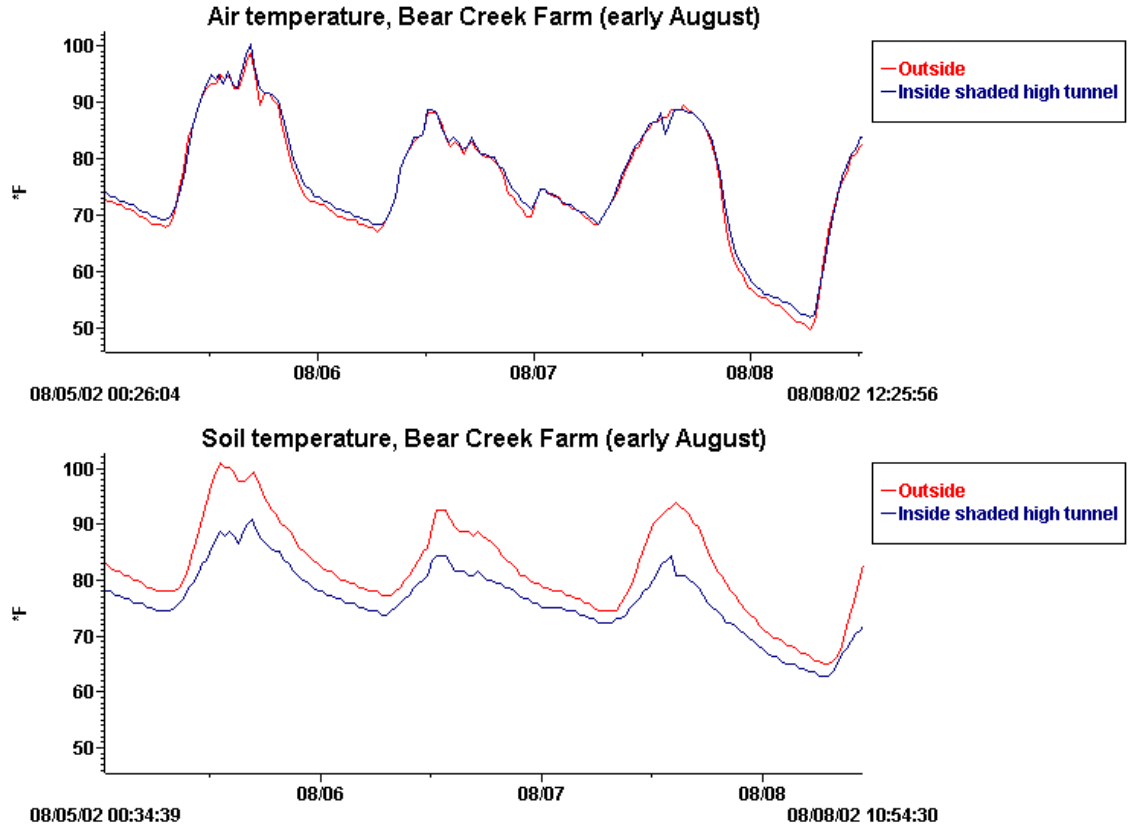

Figure 6. Air (18”) and soil (4”) temperatures inside shaded high tunnels and in adjacent outside plots during a 3-day period in early August, 2002.