ORGANIC FARMING RESEARCH FOUNDATION

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This is a final project report submitted to the Organic Farming Research Foundation.

General topic: Management of insect vectored plant diseases in organic tunnel production.

Project title:
Evaluation of screened high tunnels for production of organic vegetables in Colorado

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Project period: 2006 and 2007. This is a final project report for two seasons of research. This project was originally funded for one year, but the project was extended a year due to poor showing of pest insects in year 1. Data for both years are included.

Report submitted: February 2008

Project note: This project was funded in partnership with EPA Region 8.

Project Summary

During the summers of 2006 and 2007, we evaluated four different high tunnel coverings to see if we could reduce the incidence of insect vectored diseases by excluding the vectors from the crops. We were also interested in seeing how these different coverings would hold up under our weather conditions, and if there would be differences in the microclimate within the tunnels that would impact three different commonly grown vegetable crops.

In Colorado, the most common and problematic disease vectors on organic crops include **western flower thrips (***Frankliniella occidentalis)*, which vectors tomato spotted wilt on tomatoes (as well as a number of other diseases to other crops), **potato psyllid** (*Bactericerca (=Paratrioza) cockerelli*) which is responsible for psyllid yellows on solanaceous crops, **beet leaf hopper (***Circulifer tennelus***)** which vectors curly top virus, and **striped cucumber beetle (***Acalymma trivittatum***)** which causes direct damage and also vectors bacterial wilt to cucurbit crops. Colorado summer conditions are characterized by high light conditions, low relative humidity, and about 120 frost free days; an increase in the use of high tunnels attests to growers' attempts to extend the production season and improve the climatic conditions for high value crops.

The project was originally intended to be completed in one year, however the chance migrations of psyllids failed to materialize in 2006 and beet leaf hopper numbers were also very low, so we were unable to compare severity of insect vectored disease of unprotected crops with those in the screened tunnels. However, the lack of insect pressure allowed us to make crop growth comparisons under the different treatments without having to factor in possible insect impact, which was an unexpected benefit. Another unexpected but very useful event was the occurrence of a microburst of very high wind, which put the different covering materials to the test of extreme weather conditions.

Overall, the crops performed very well under all of the covers in spite of high temperatures in the tunnels. Melon yields were similar to field production; however tomato and spinach yields and quality were superior in the tunnels.

Two of the materials evaluated failed under high winds; the 1.5 oz spun bond polyester (SBP) shredded, and the polyvinyl alcohol (PVA) came apart at the sewn seams. The polyethylene (PE) covers held up to all weather events.

In 2007 the SBP and PVA were replaced with more durable greenhouse insect screening material (LS Econet), which survived very high winds, small hail, and excluded disease vectoring insects.

During 2007 we experienced infestations of western flower thrips, potato psyllid, and cucumber beetle but relatively few beet leaf hoppers, allowing us to evaluate the effectiveness of a stronger insect screening material which also provided some climate attributes.

Introduction

High tunnels are increasingly being used by small farmers across the country to extend the production season of high value crops. These inexpensive structures allow producers to reduce risk of frosts to sensitive crops during the early spring and late fall, and allow production of hardy species through the winter months without supplemental heat. During the summer months protection from wind and small hail further enhance their utility.

High tunnels are commonly covered with polyethylene glazing which requires ventilation; generally side walls are rolled up and end walls are opened or removed. Open ventilation allows free entry of insect pests including important disease vectoring insects such as beet leaf hoppers, potato psyllids, and western flower thrips. Very low densities of any of these insect species may result in significant crop loss due to the diseases they vector. Because organic producers lack effective control options for these pests, exclusion of these insects may be one of the better options available for organic growers producing crops susceptible to these diseases. Exclusion of insects in high tunnels has not been adopted because of the relatively high cost associated with greenhouse insect screening. Insect screening has been developed specifically for the greenhouse industry, with specific mesh sizes which allow ventilation while excluding insects as small as western flower thrips, however these materials are expensive (~$900 for a 6x15m tunnel) and may not be economical for low tech, low cost tunnels. Floating row cover materials (breathable spun bonded polypropylene) may offer an inexpensive alternative (~$30 for a 6x15m tunnel) which would offer insect exclusion and environmental protection with the added advantage of not requiring the daily if not hourly ventilation adjustment required of poly-covered high tunnels. In this project it was proposed to evaluate the utility and performance of two types of floating row cover materials when applied to high tunnels, and compare these to a conventional poly covered high tunnel. Another material was added for evaluation in the following year (the second year follow-up was not originally proposed). The environmental conditions inside the tunnels as well as the level of protection provided against insect pests were evaluated. The project was demonstrated to producers and extension personnel during two summer field days, and results have been presented at producer meetings. Printed and electronic reports will be available from the CSU Specialty Crops Program.

Objectives

The objectives of this study were:

- To evaluate the efficacy of high tunnel structures covered with insect excluding materials to reduce insect vectored diseases in an organic production system.
- To evaluate the effect of different covering materials on the tunnel growing environment (temperature, relative humidity, and radiation).
- To compare costs and benefits of different tunnel covering materials as they apply to plant protection under organic production.
- To provide growers and extension personnel with applied research findings and demonstrable production systems.

In terms of evaluating the covering materials, there were two major problems that we confronted during the first year of the project which ultimately provided some valuable information, but which impacted the study significantly and required us to repeat the trials with some design changes in the following year.

The first problem arose with the availability of reinforced SBP; because it was not available at the time, we proceeded with non-reinforced material. The other material to be evaluated (PVA) was not available in the proper widths, which required custom sewing of the 73” wide strips to fit the tunnels. During an early season microburst much of the SBP was severely damaged and required replacing. Late in the season, the stitching material used to sew the PVA began breaking down, which resulted in some holes forming where insects could have entered and which probably altered the microclimate inside the tunnel.

The second major setback in terms of addressing the objectives of the study was the uncharacteristically low occurrence of potato psyllids (none observed), and beet leaf hoppers (few individuals sighted late in the season) in 2006. Thrips were present but in relatively low numbers and no disease incidence was associated with any of these pests.

As a result, the first year evaluation focused primarily on material performance, climate inside the tunnels, and crop performance in the tunnels.

Materials and Methods

Location

The trials were conducted on certified organic land at the Colorado State University Horticulture Field Research Center (HFRC), Fort Collins, Colorado. The land has been certified organic since 2002 by the Colorado Dept. of Agriculture.

Design

Treatments 2006

a) The “Frost Guard” brand tunnels were manufactured by Nexus Greenhouse Corp. and measure 48 feet (14.6 m) long, 20 feet (6 m) wide, and 9 ft (2.7 m) tall. They were covered with either:

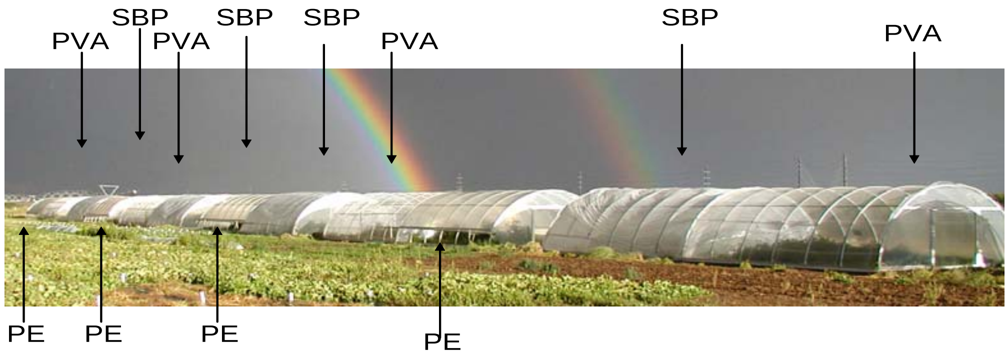
- i) polyvinyl alcohol (Tufbell) (Peaceful Valley Farm Supply, Grass Valley, CA)
- ii) spun-bonded polypropylene (Agribon 19) (Peaceful Valley Farm Supply, Grass Valley, CA)
- iii) 6 mil polyethylene greenhouse film (Klerks K50 Clear, American Clay Works, Denver, CO) with a conventional roll-up side ventilation system.

b) Each covering represented a treatment and was replicated four times.

c) Each tunnel was split in half, providing two treatments per tunnel, with a vertical plastic wall between the treatments (see addendum 1).

d) Each treatment consisted of a half tunnel (each half tunnel was designated 1-12) covered with either SBP, PVA or PE (see figure 1).

Figure 1. Experimental treatments. Most tunnels are covered with two different materials.



PVA = polyvinyl alcohol; Tuffbell
SBP = spunbonded polyester; Agribon 19
PE = polyethylene; Klerks 4yr greenhouse poly
Each tunnel is split into two treatments
There are 4 replications of each treatment

e) Within each treatment randomized blocks of 2 varieties each of tomato (Celebrity, Brandywine), melon (Honey Orange, Swan Lake) and spinach (Springer) were grown. Melons and tomatoes were grown on black plastic mulch and spinach was grown on bare soil.
f) Tomatoes and melons were transplanted on May 1, having been started in greenhouses at CSU and grown using organic methods. The tomatoes were grown in 72-cell trays and the melons were grown in 2-inch round peat pots.
g) The soil in the tunnels was tested for fertility and amended with composted chicken manure equivalent to 5 ton/ac, which was tilled into the soil before planting.
h) Drip tape (8 mil, 100 gal/min/100 ft delivery rate, Chapin Watermatics Inc.) supplied irrigation water which was monitored using watermark sensors placed in each bed at two locations. Soil tension was monitored and maintained between -30 to -70 centibars.
i) Tomatoes were trellised to a height of 4 feet on a Florida weave system. Melons were not trellised.
j) All production practices adhered to NOP standards.

Insect and disease monitoring
a) Yellow sticky traps on stakes were placed inside and outside of the tunnels to monitor insect activity. Whole plant monitoring for psyllids and leafhoppers was done weekly on specified plants and thrips were to be collected from flowers of tomato and melon for identification and determination of population density. Plants exhibiting disease symptoms were submitted to CSU's Plant Diagnostic Laboratory for disease identification.

Tunnel climate measurements
a) Temperature and humidity were recorded at three positions in each treatment representing microclimates affecting the different species. HOBO® U10 Data Loggers were used to continuously monitor temperature and relative humidity.
b) A Quantum light meter was used to measure photosynthetically active radiation (PAR) on two dates.

Evaluation of production and quality
a) Yield data were collected from the crops as they reach marketable age.
b) Observations of plant habit, relative vigor, and general plant responses were also made and recorded.

Durability and other field observations of the covering materials were made. A cost benefit analysis of the different treatments was made.

Treatments 2007

a) In 2007, much of the same work was repeated hoping that pests which were absent in 2006 would be present in 2007. The materials which failed to withstand the high winds were replaced with more durable greenhouse screening (LS Econet, US Global Resources, Seattle), in spite of its higher cost.

i) Each treatment consisted of an entire tunnel covered with either greenhouse screening (GS) or polyethylene (PE).

Tunnel	1	2	3	4	5	6
Treatment	GS	PE	GS	PE	GS	PE

b) Within the treatment randomized blocks of 2 varieties each of tomato, cucumber, salad mix (lettuce, arugula, mizuna) were grown. Cucumbers and tomatoes were grown on black plastic mulch, and salad mix was grown on bare soil. Drip tape supplied irrigation water which was monitored using watermark sensors. Soil moisture was maintained at 30-70 KPa (1 KPa = 1 centibar).

c) Tomatoes and cucumbers were pruned to two stems and clipped to hanging twine per common greenhouse trellising systems.

d) All other practices were the same as the 2006 trials.

Project Results

<u>Summary of Results 2006</u>

Insect exclusion

Absence of potato psyllids and very low numbers of beet leaf hoppers and western flower thrips in 2006 failed to provide a gauge by which we could compare the efficacy of the different tunnel covers for insect exclusion and associated transmission of disease.

Covering performance, durability and tunnel climate

Damaging winds enable us to gauge the durability and suitability of light weight floating row cover (Agribon19) which performed well until extremely high winds ripped the material, and PVA (Tufbell) which performed well until stitched seams broke down; presumably from UV degradation of the thread used for sewing the seams.

The tunnel microclimates in all of the tunnels were hotter and more humid than ambient conditions and resulted in comparable or better production than field production, but very similar production between the treatments. Vegetative growth was greatest in the SBP treatment.

Crop production

Production results of the tunnels were all comparable or better than field production of the same cultivars. Better quality of fruit was especially evident in the greens and spinach due to reduced pressure from flea beetles (which were not a target of study). Surprisingly, even with high daytime temperatures, spinach performed well in all of the treatments. Relatively low melon production was surmised to be a result of reduced pollinator presence in the SBP and PVA treatments; however pollinators managed to find their way into these tunnels even though they appeared to be well enclosed.

Summary of Results 2007

Insect exclusion

Psyllids were observed in field plantings relatively late in the season but early enough to cause measurable impacts; however they did not significantly impact yields. Successful exclusion of psyllids from the screened houses and very rapid population increases and subsequent crop decline in the open ventilated PE covered tunnels proved the efficacy of the screened tunnels in excluding psyllids. Beet leaf hoppers and thrips failed to present problems in any of the treatments, but were not especially abundant in 2007. Flea beetle damage to the salad crops was low in the screened tunnels and high in the PE tunnels.

Covering performance, durability and tunnel climate

Microclimatic differences between the screened and PE treatments were measurable but did not result in yield or quality differences (see Figs. 4 and 5). The durability of the LS Econet screen was excellent, holding up well to high wind and light hail.

Crop production

Psyllids arrived after fruit set but before fruit maturation, so they did not reduce crop yields. Crop production between treatments was not different, however the quality and earliness of peppers and tomatoes was enhanced over field production at the same site. It was observed, but not measured, that flowers and basil grown in the screened tunnel had markedly taller stems and larger leaves respectively than field grown counterparts.

Results 2006

Tunnel climate

Temperature and relative humidity were logged during the entire growing season in all of the tunnels as well as outside of the tunnels. Minimum, maximum and average temperatures and relative humidity (RH) were higher in all of the tunnels than ambient conditions (see Figs. 2 and 3). Among the treatments, the SBP consistently had higher RH and lower average and maximum temperatures than the other treatments. Average low temperatures were only slightly higher in the SBP and PVA than the PE or ambient conditions. The following figures summarize the average, average maximum, and average minimum temperatures and relative humidities recorded from June 30-Oct. 26, 2006.

Figure 2. Averages of daily maximum, minimum and average temperatures of three different tunnel coverings (SBP, PVA, and PE) and ambient temperatures in ºF, 6/30/06 -10/26/2006.

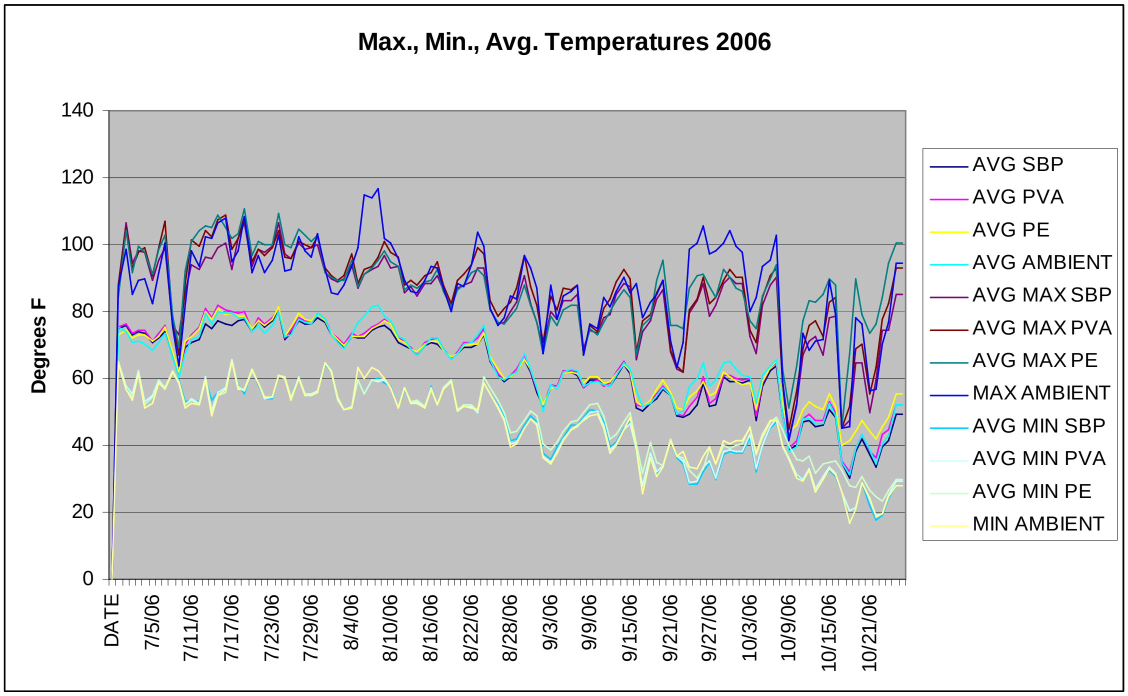


Figure 3. Relative humidities recorded in tunnels with SBP, PVA, and PE covers 6/30-10/26/2006. Daily minimum, maximum and average %RH.

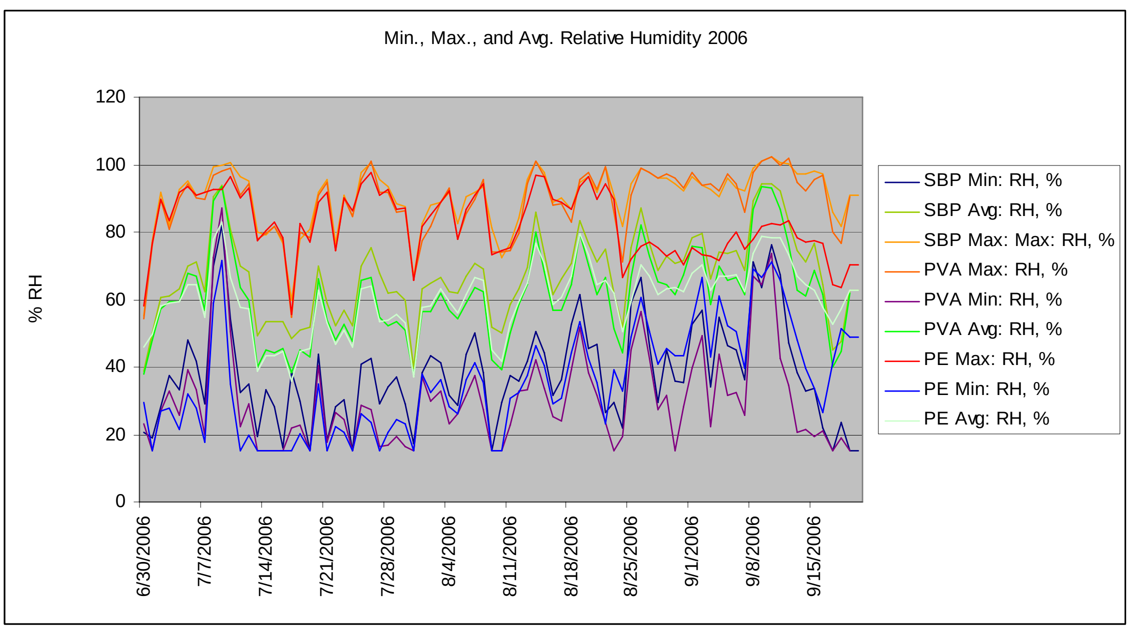


Figure 4. Average, maximum, and minimum temperatures in tunnels covered with greenhouse screening (IS) and polyethylene (PE), 6/15/07 to 11/2/07.

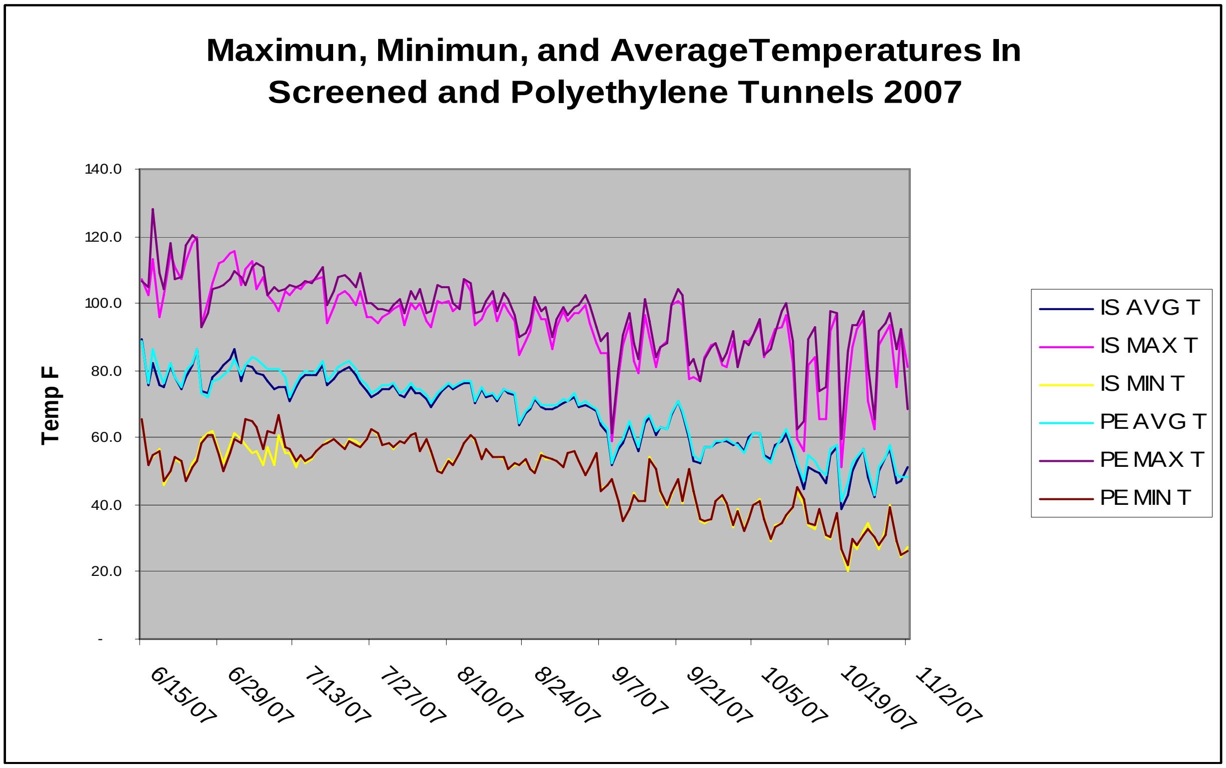
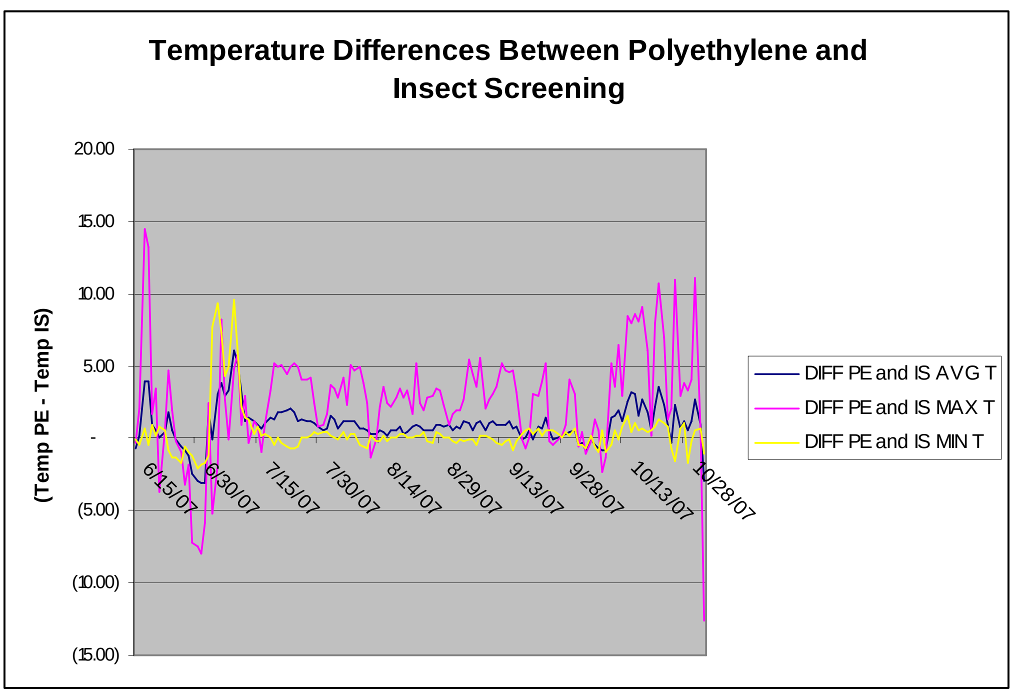


Figure 5. Temperature differences between polyethylene and insect screening.



Crop performance

All of the crops grew well in all of the treatments; however high temperatures at the time of transplanting stressed the tomatoes and melons considerably at that time, which was probably a result of insufficiently hardened plants. After recovering, the crops performed well and did not show stress at any point during the season.

Yields of melons, tomatoes and spinach were measured and are summarized in the following figures.

Figure 6. Yield of Honey Orange melon in tunnels covered with polyethylene (PE), polyvinyl alcohol, (PVA), and spun bonded polyester (SBP). 2006.

Figure 7. Yield of Swan Lake melon in tunnels covered with polyethylene (PE), polyvinyl alcohol, (PVA), and spun bonded polyester (SBP). 2006.

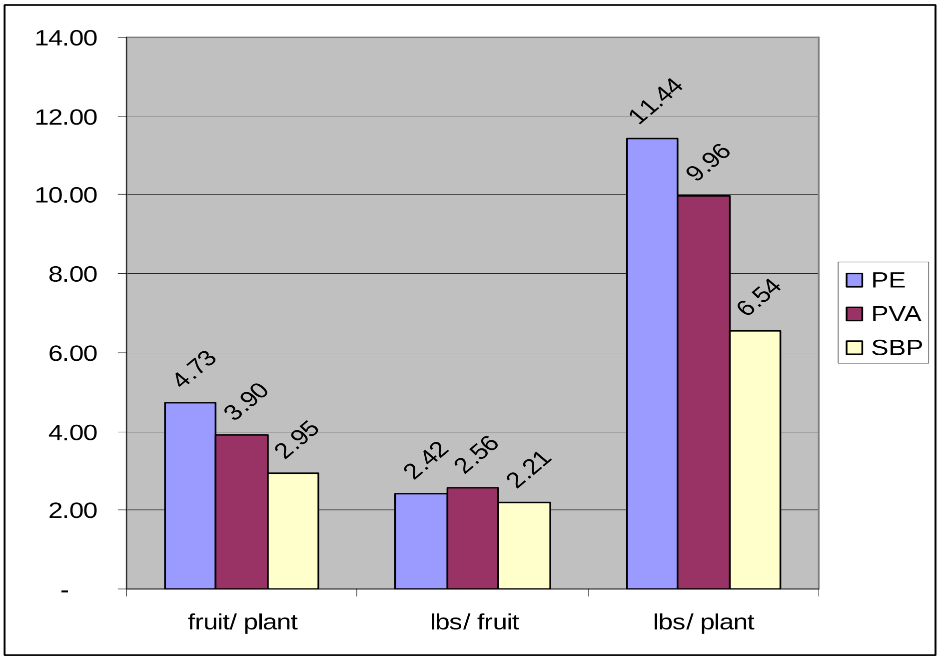


Figure 8. Spinach yields (single whole plant harvest) of Springer variety in tunnels covered with polyethylene (PE), polyvinyl alcohol, (PVA), and spun bonded polyester (SBP). (3 reps only, 4^{th} reps were omitted due to poor stands). 2006.

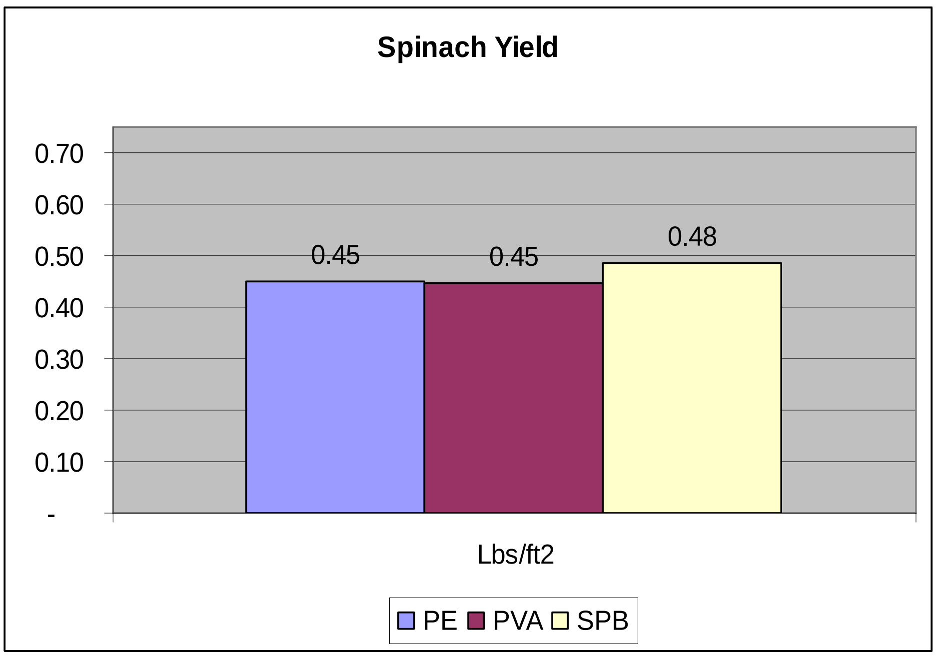
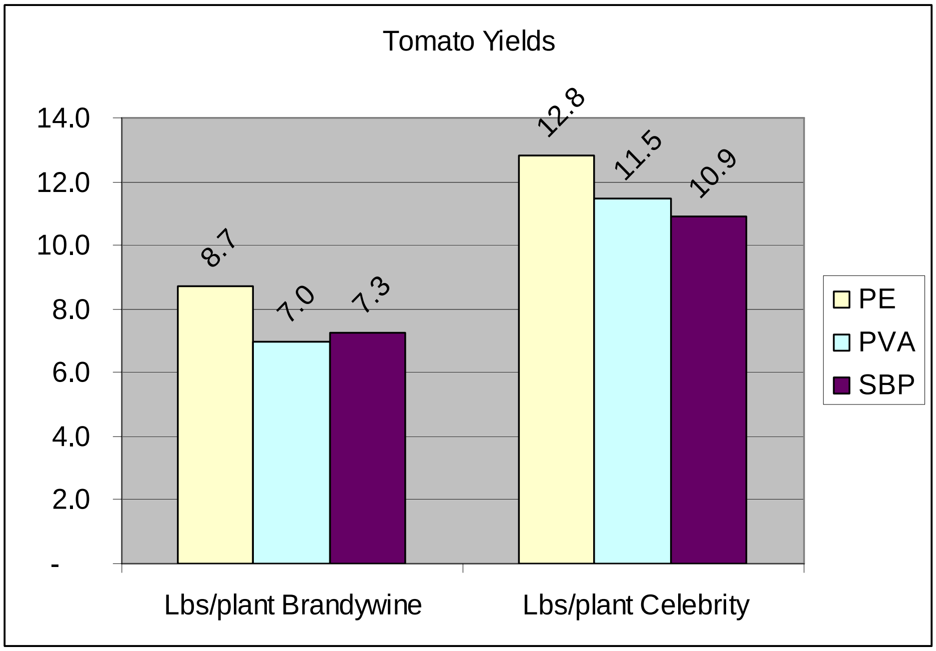


Figure 9. Tomato yields per plant of Celebrity and Brandywine varieties in tunnels covered with polyethylene (PE), polyvinyl alcohol, (PVA), and spun bonded polyester (SBP). 2006.



Gross revenue from sale of crops produced in high tunnels was estimated by multiplying the yields obtained by prices charged for similar products at a local farmers' market. From this analysis it is evident that tomatoes would return the highest average revenue per square foot of production, however variety had greater impact on return than any of the treatments. Melons returned the least per square foot, and would probably not be justified as a tunnel crop because of low yields. Gross returns on spinach were relatively low, however the opportunity to produce multiple crops of greens or other quick maturing crops should allow returns to approach that of tomatoes. The gross returns reported only represent sales and tunnel cost; no other operational or capital costs are included in this analysis.

Figure 10. Tomato yield and gross return per square foot in 2006 using experimental yield data and local farmers' market prices for similar products. The following assumptions are used: Plant density= 0.25 plants per square foot, Sales price = $ 3.00/lb.

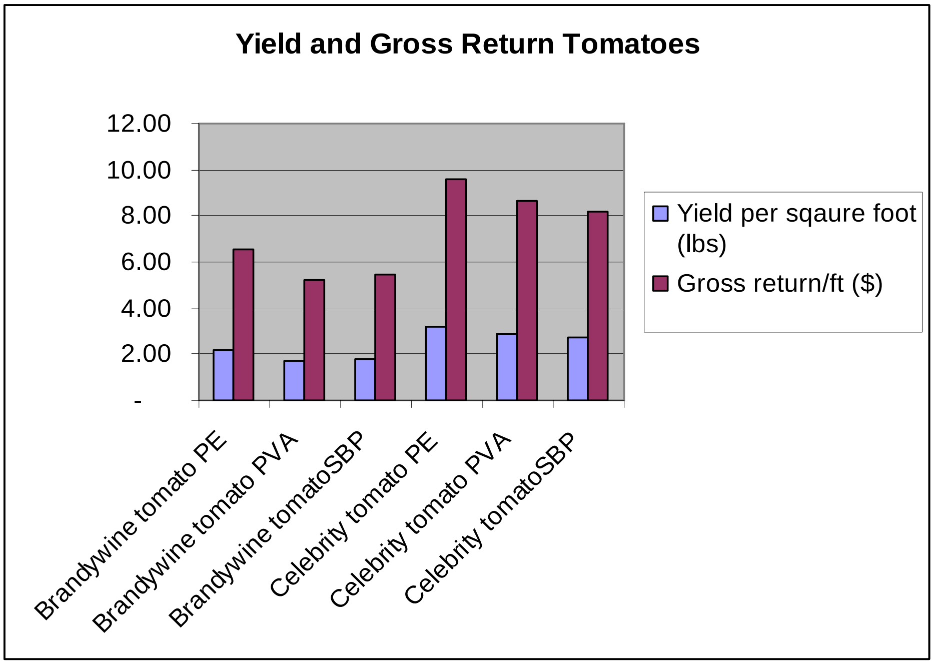


Figure 11. Melon yield and gross return per square foot in 2006 using experimental yield data and local farmer's market prices for similar products. The following assumptions are used: Plant density = 0.11 plants per square foot, Sales price = $ 1.25 /lb.

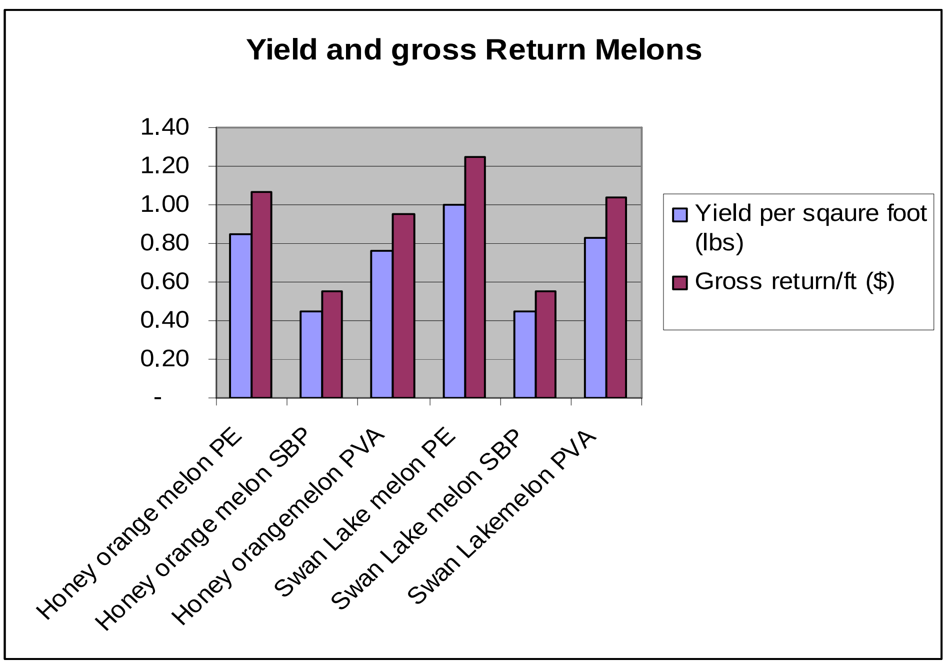
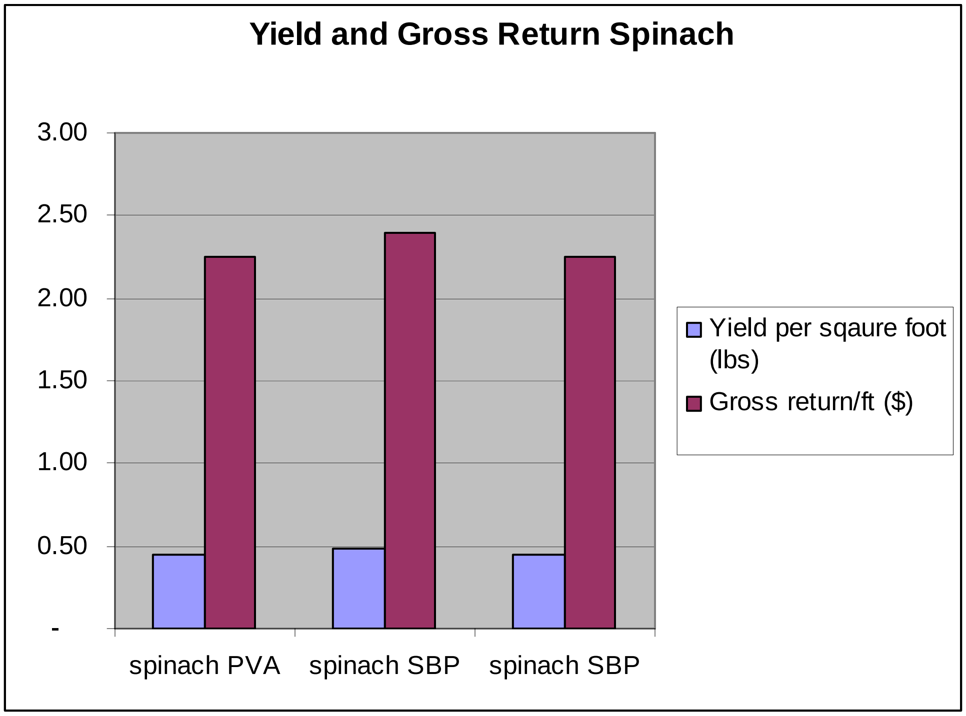


Figure 12. Spinach yield and gross return per square foot in 2006 using experimental yield data and local farmer's market prices for similar products. The following assumptions are used: Single harvest of spinach. Sales price = $ 1.25 /lb.



Cost comparisons

Table 1. Costs of materials for the construction of high tunnels using PE, SBP, PVA, and LS Econet.

Covering material	Structure plus covering	Cost per square foot of production area
4 year greenhouse polyethylene	$ 1,961	$ 2.04
Polyvinyl alcohol	$ 1,898	$ 1.98
Spun bond polyester	$ 1,547	$ 1.61
LS Econet	$ 2,350	$ 2.45

Table 2. Amortized cost of tunnels with PE, PVA, SBP, or LS Econet coverings.

	Cost of covering materials			Cost of structure			
Covering material	Initial cost/ ft sq	expected life, years	amortized cost/yr	structural cost	expected life, years	amortized cost/yr	total cost of tunnel/yr/sq ft
4 year greenhouse polyethylene	$ 0.15	4	$ 0.04	$ 1.78	10	$ 0.18	$ 0.22
Polyvinyl alcohol	$ 0.23	3	$ 0.08	$ 1.78	10	$ 0.18	$ 0.25
Spun bond polyester	$ 0.02	1	$ 0.02	$ 1.78	10	$ 0.18	$ 0.20
LS Econet	$ 0.50	5	$ 0.10	$1.78	10	$ 0.18	$ 0.28

Conclusions and Discussion

The benefits of using insect-excluding coverings on high tunnels were made apparent in the second season of this study when potato psyllids were successfully excluded from the screened high tunnels while the conventional roll-up sided tunnels experienced severe crop damage due to psyllid yellows; however the crop damage came too late in the season to affect yields. Had beet leaf hopper populations been higher, it is probable that similar results would have been seen. Thrips pressure too, was light, and no thrips vectored diseases were observed, even though some thrips were found on the crops. Flea beetle and cucumber beetle were reduced to such a degree that very little direct feeding damage was observed on susceptible crops; however complete exclusion was not accomplished and the insects somehow found their way into the tunnels, albeit at very low numbers relative to field conditions. Surprisingly, even some pollinators (*Bombus* spp.) were found in the screened tunnels.

The choice of which screening or other porous covering material to use was shown to be very important, primarily in the context of durability. The climatic performance of the SPB was excellent prior to its destruction in high winds which suggests that a similar material with reinforcement or slightly heavier grade may provide the benefits of insect exclusion, enhanced climate, and low price while still being strong enough to withstand occasional high winds. This is an area that would merit continued evaluation.

All of the materials evaluated produced high temperatures in excess of what is considered to be tolerable limits of the crops grown; however neither stress nor reduced crop quality were observed. The relatively low vapor deficit (high relative humidity) in the enclosed tunnels was probably the reason for this. The number of days in excess of 100ºF in the PE tunnels was nearly double that of the porous materials, which illustrates the value of self-ventilating porous materials. Frost damage resulting from radiation frost (cold clear nights with temperatures hovering around freezing) was more pronounced in the screened tunnels, even though recorded temperatures were within 1-2 degrees F.

Amortized costs of tunnels with any of the coverings are very similar so performance of the material should be the guide for determining which cover to use. Yield and gross return trends collected in 2006 suggest that PE coverings will offer the best economic return; however in years where disease vectoring insects may result in significant crop loss, the benefit from using any of the screening materials would be better choices. Consideration of labor requirements for installation or replacement of short lived covering materials should also be considered, suggesting that LS Econet or PVA, both of which are presumed to last several years, may be better choices.

Outreach

This study has been highlighted during three CSU Specialty Crops Program Field Days, and preliminary results were presented at two Colorado Big and Small Farm conferences. The study has also been highlighted in two classes taught in the CSU Interdisciplinary Organic program (Diagnostics of Organic Farm Systems and Organic Greenhouse Management). The CSU Rocky Mountain Small Organic Farm Project also has a steady stream of visitors from the region as well as from out of state and abroad that are very interested in high tunnel production methods and the work being done here.

This project has helped showcase our more comprehensive organic research and education program, and the infrastructure and working experience gained from the project will continue to be a great asset.

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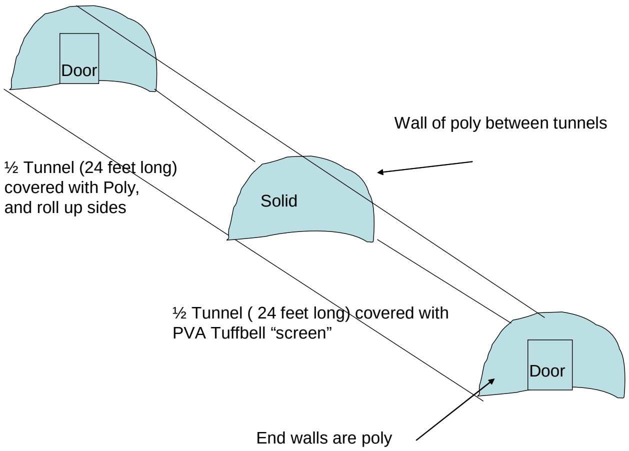
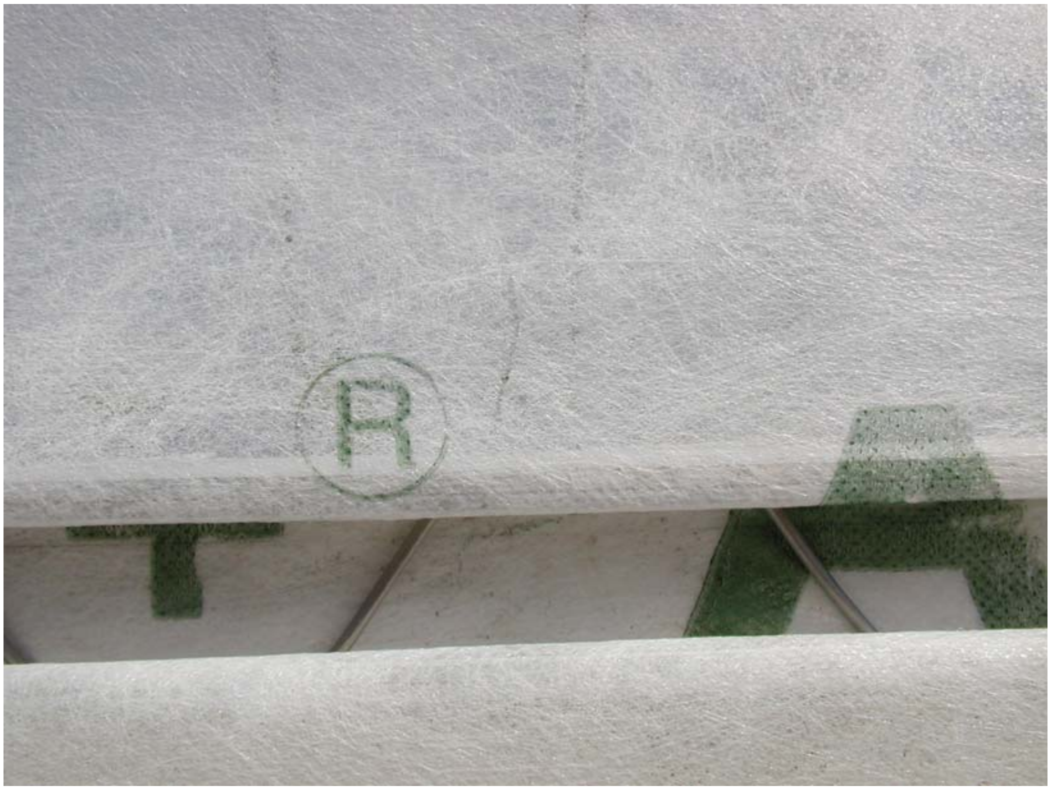
Dr. Whitney Cranshaw, (Co PI)

And technical advisors:
Rosie Carter and Chuck Barry, Cortez, CO
John Cooley, Delta CO
Dr. Ron Godin, CSU, Rogers Mesa
Dr. Greg Vlaming, CSU, Durango, CO

Addendum 1: View of tunnel with division to provide 2 treatments per tunnel




View of division wall in screened high tunnel OFRF trial . CSU 5/2006.



Wiggle-wire holding SBP to frame of high tunnels. CSU 5/2006.


Construction of OFRF screened tunnel project. CSU 5/2006.


Melons and tomatoes in SBP covered tunnel.

CSU summer interns preparing to plant OFRF trials, May 2006. CSU Rocky Mountain Small Organic Farm Project.