2009 Farm Walk Education Series

WSU Organic Farm Field Day, Thursday July 30, 2009

Presented by
Tilth Producers of Washington and the WSU Small Farms Team
Farm Walk Logistics - Complete details at www.tilthproducers.org
More information also at http://smallfarms.wsu.edu
FARMER-TO-FARMER: PASSING ON THE WISDOM

2009 Farm Walk Education Series
Sponsored by the WSU Small Farms Team
(smallfarms.wsu.edu)
and Tilth Producers of Washington
(www.tilthproducers.org)

**WSU Organic Farm Field Day**
and Farm Walk, Pullman, WA

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Farm Walk Evaluation Form…Please fill out and leave at the site
THANK YOU!!!
Mission

The WSU Organic Farm is committed to education, research, and extension. As a teaching farm, the primary goal is to pass on the skills necessary to grow organic fruits and vegetables in an intensive, small-scale environment. The farm is available to the WSU scientific community to conduct organic research projects. In addition, the farm strives to provide fresh produce to the community, local food banks and non-profits.

Farm History

Ground was broken at the farm in the fall of 2003 under the direction of Dr. John Reganold, WSU soil scientist and professor, and Kathi Colen-Peck, WSU graduate student. Initial farm funding came as grants from Small Planet Foods and the Kellogg Foundation. These funds were used to acquire the first farm structures, basic hand tools, irrigation supplies, seeds, and payroll support for the first season.

The first field course was offered at the farm in 2004. In the fall of 2004, Brad Jaeckel became farm manager and instructor. Brad owns and operates his own small farm in Moscow, ID. The initial grant funding ended in 2004, and in 2005 the farm began an 85-member CSA (Community Supported Agriculture) to generate funds for farm expenses. A harvest shed was built that year and more perennial crops were planted.

Following the success of the 2005 season, the CSA increased to 100 members in 2006. The remainder of operational funding currently comes from the Department of Crop and Soil Sciences, WSU Small Farms Team, and WSU Center for Sustaining Agriculture and Natural Resources.

In 2006, WSU approved the first organic agriculture major in the nation as part of its new Food Systems degree program. The farm's summer field course, Soils 480 – Practicum in Organic Agriculture, became a requirement for the new major.
WSU Organic Farm story, continued

Farm Operations

Farm structures include a small tool shed, a 24'x24' harvest shed/shade structure, two 20'x48' hoophouses, a vermiculture bin, a large area for composting, and an educational soil pit. As well as growing 30+ annual crops, the farm is also home to a culinary herb garden, medicinal herb garden, asparagus, Italian plums, rhubarb, and raspberries. Irrigation water is supplied by WSU and an efficient drip system is utilized for almost all crops.

CSA Program (Community Supported Agriculture, see following brochure)

Currently the farm enjoys a 25 week harvest season extending from mid-May to the end of October, with approximately 120 frost free days. The farm manager/instructor and assistant manager are the only paid employees with the remainder of labor coming from students and volunteers. By working with the Palouse Food Project and the WSU Community Service Learning Center, the farm addresses local food security issues and provides a location for volunteer participation.
CROPS AND VARIETIES

- **Onions**: Red: Ruby Ring; Yellow: Cortland; Sweet: Walla Walla; Button: Borrettana Cippollini, Red Marble; Bunching: Lisbon White; Shallot: Red Prisma; Leek: King Sieg

- **Corn**: Sweet: Luscious, Sugar Pearl; Dry: Painted Mountain

- **Peas**: Snap: Sugarsnap; Shelling: Pioneer

- **Beans**: Pole: Fortex; Bush: Provider; Fava: Windsor

- **Cucumbers**: Field: Lemon, Market More; Hoophouse: Tasty Jade, Sohyu Long

- **Summer Squash**: Yellow: Meteor; Green: Cashflow

- **Winter Squash**: Delicata, Butternut, Spaghetti, Sunshine, Carnival (Sweet Dumpling), Acorn

- **Pumpkin**: Baby Pam, Howden, Jarrahdale, Rouge Vif D’Etampes, Valenciano

- **Carrot**: Early: Nelson; Main season: Scarlet Nantes, Ya Ya, Yellowstone

- **Radish**: Cherry Belle Turnip: Purple Top Globe, Hakurei, Oasis

- **Spinach**: Space, Tyee Beets: Early Wonder Tall Top

- **Lettuce**: Mix: Gourmet Mix + Blackhawk, Outrageous; Head: Jericho, Cracoviensis, Waldman’s

- **Tomato**: Determinate: Valley Girl, Taxi; Indeterminate: Moscovich, New Girl; Cherry: Sungold, Sweet 100, Washington Cherry

- **Chard**: Bright Lights Kale: Winterbor, Red Russian, Ripbor

- **Brassicas**: Pac Choi: Black Summer; Broccoli: Arcadia, Gypsy; Cabbage: Farao, Nikko, Minuet; Kohlrabi: Early White Vienna, Purple

- **Peppers**: Sweet: New Ace; Green: Anaheim; Spicy: Matchbox

- **Herbs**: Parsley: Italian Flat Leaf, Moss Curled; Cilantro: Santo; Basil: Genovese, Nufar; Fennel: Perfection

- **Eggplant**: Orient Express Artichokes: Imperial Star

- **Watermelon**: Blacktail Mt, Sugar Baby, Quetzali, Sorbet Swirl, Sweet Eat’n
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About the
WSU Organic Farm

The Organic Farm was established in 2004 primarily as an organic teaching farm. We offer an intensive 22-week course for college credit or continuing education units.

In order to cover our expenses, the produce we grow is sold through this CSA, a local farmer’s market, and to on-campus hospitality and dining services.

The 4 acre farm was certified organic in the fall of 2004 and is committed to using sustainable growing methods. Farm partners include Community Food Bank, BackYard Harvest, Harvest House, Pullman Child Welfare Food Bank and WSU Center for Civic Engagement.

WSU Organic Farm
C/O Brad Jaeckel
291 Johnson Hall
Washington State University
Pullman, WA 99164-6420

Phone: (509) 335-5893
E-mail: jaeckel@wsu.edu
www.css.wsu.edu/organicfarm

This year our harvest season will be 24 weeks: May 20–October 30

Share Options:
Full Share (4-6 people)
☐ $525

Half Share (2-3 people)
☐ $325

Pick-Up Options: (Please Choose One)
☐ Wednesday pickups will be at the new Pullman Fresh Food Market in downtown Pullman between 4:30 and 6:30.

☐ Friday pickups will be at the farm harvest shed between 3 and 6.

Email Options:
☐ Receive newsletter via email

☐ Receive weekly harvest list on Mondays via email

*A letter will be sent to all members by May 1st with CSA start dates, pickup locations, and directions to the farm and the Pullman market.
Welcome! The WSU Organic Farm invites you to become a member of our Community Supported Agriculture (CSA) program. By participating in a CSA, you will be bridging the gap between farmer and consumer.

As a member, you will receive a weekly box of in-season local produce. Each box will include a weekly newsletter highlighting farm activities, unusual vegetables, and offering recipes to inspire.

Imagine being able to eat healthy organic garden fresh food without the worries of keeping your own garden. As a shareholder in a CSA, you provide the farm monetary security for operating costs throughout the growing season. You also provide a guaranteed market for the vegetables, fruit, and herbs we will grow. Imagine being able to eat healthy, organic garden fresh food without the worries of keeping your own garden.

Shareholder Agreement

I/We understand the purchase conditions and agree to the payment schedule. I/we also understand that, although the WSU Organic Farm strives to raise a large variety of quality produce, timing quality and quantity can vary according to weather, pests, and other factors. I/we understand the purchase conditions and agree to the payment schedule. I/we also understand that:

Signature(s)                                                                                                  Date

Name(s) PRINT                                                                                              Phone #: 

Address                                                                                                           e-mail: 

Amount Enclosed: $                               Thank You!

*Please make checks payable to WSU Organic Farm and send with Sign-up Form to address on back.

The four-acre organically certified farm is located within the Tukey Horticultural Orchard between the Moscow/Pullman airport and the WSU Organic Farm and sent with Sign-up Form to address on back.

Spring Box Sample
Salad mix, baby spinach, radishes, snap peas, arugula, shallot greens

Summer Box Sample
Broccoli, beets, kale, bunching onions, strawberries, summer squash, basil, green beans, cucumbers

Fall Box Sample
Potatoes, pumpkins, carrots, cabbage, apples, garlic, tomatoes, storage onions, salad mix, snap peas, carrots, squash, kale, spinach, beets, radishes, green beans, cucumbers

Each sample represents one week out of the whole season. Expect to receive a diverse variety throughout the season!
This past week the farm had its annual organic inspection to determine if it is in compliance with state and national organic regulations. The farm’s original three acres have been certified by the Washington State Department of Agriculture since 2004 and continues to remain certified. I thought this would be a good time to talk about the process and what it means for the farm to have this designation.

Each year I’m required to reapply for our organic certification, which first involves filing an application in January. This is nice because we have had some time to take a break from the growing season and sit down with the paper work that has accumulated over the season. The first section requires details on the farm’s gross sales for the year. This is important because the state charges an annual fee based on those sales and will do a minor audit of the farm’s books during the annual inspection. The next section has to do with how much did we grow last year. This basically equates to number of CSA shares as that is the majority of our sales. Then I have to report any changes we may be making in the upcoming year to our management plan. The management plan is a lengthier piece that was submitted with our first application back in 2004. I don’t have to rewrite it, just update.

The annual inspection first consists of an audit of the farm’s sales, seed orders, and material applications. The inspector is interested in seeing an easy to follow record keeping system for all of these areas. I keep all the sales information on spreadsheets so that is easy, the seed orders are all on detailed printed receipts, and our fertilizer and compost applications are all documented in a notebook kept at the farm. Our inspector told us this process is easy to check with small farms but can be challenging with larger industrial size ones where sales don’t always match production data. So these audits are the first line in determining if a farm may be reporting false information.

After the audit section we take a walk around the farm with our most recent farm map. Luckily we have an updated version that I hope to get posted to the website for you all to see. The inspector is interested in seeing any new structures, buffers with other farms or research plots, and any new crops that will be listed under the certificate. An example would be the blueberries we planted this spring were listed on our certificate last year but hadn’t been planted yet.

Another important point that you all should be aware of it our forth acre is not certified or organic and will not be until next year. This acre came under our management only last year and while we do manage it exactly like the rest of the farm it is in a three year transition period before it will be included in our certificate. This is because it was not managed organically before we took it over. The crops being grown there (spring cabbage crops, potatoes, and pumpkins) are being managed organically but are not certified.

— Brad Jaeckel
I must confess, like many of us in the United States, I have not spent much time getting to know the fava bean. Although widely known in other parts of the world like Asia and the Middle East, the fava bean, also known as broad bean, is less well known here. When you find favas in your box, experiment with one of the recipes I found below. Basic instructions for cooking the beans are in the first recipe (in the second recipe the beans are cooked on the grill). Once cooked you can add them to salads, in a side with vegetables, or in a stir-fry. Enjoy!

—Marcia Gossard

**FRESH FAVA BEAN AND PECORINO SALAD**


*Makes 8 to 12 servings*

- 2 pounds fresh unshelled fava beans (about 2 cups shelled beans)
- 3 tablespoons extra-virgin olive oil
- 1 tablespoon freshly squeezed lemon juice
- 1 teaspoon dried leaf oregano
- 3 tablespoons fresh flat-leaf parsley leaves, snipped with scissors
- 1/8 teaspoon crushed red peppers (hot red pepper flakes), or to taste
- 8 ounces soft sheep's milk cheese such as a pecorino or a soft fresh goat's milk cheese, cut in small cubes
- Salt and freshly ground black pepper to taste

To shell the beans, pull on the stem of the pod and unzip them, on both sides. Take the shelled beans and drop them in boiling water for 30 seconds. Remove and plunge into ice water, and peel off the beans' waxy outer covering. Drain. Now, they are ready for use in this or any other recipe.

In a medium bowl, combine all ingredients, and toss to blend. Taste for seasoning.

**GRILLED FAVA BEANS**


- 1 pound of fresh fava beans, still in their pods
- olive oil
- salt
- crushed red pepper flakes, lemon zest, and or chopped fresh herbs (optional)

In a large bowl toss the fava bean pods with olive oil and salt. Arrange them in a single layer on a grill over medium-high heat. Grill until blistered on one side, about 4 to 5 minutes, then flip and grill for a few minutes more on the other side. To test for doneness take a pod off the grill, open and taste one of the beans. The fava beans to be smooth and creamy when you pop them out of their skins—not undercooked. But keep in mind that they'll keep steaming in their pods for a few minutes after they come off the grill. Season the grilled favas with a bit more salt (if needed) and any herbs or lemon zest if you like. To eat: tear open the puffy green pods, take a fava bean, pinch the skin and slide the bright green fava from its outer covering. Eat one at a time and be sure to lick your fingers.

Newsletter by Marcia Hill Gossard — [www.nasw.org/users/mgossard](http://www.nasw.org/users/mgossard)
Brassicaceous Seed Meals as Soil Amendments
Lynne Carpenter-Boggs, Stewart Higgins, Hector Saez, Chad Kruger
BIOAg Program, Center for Sustaining Agriculture and Natural Resources, Washington State University

Introduction
The extraction of oil from seed of brassicaceous crops such as canola and mustards leaves brassicaceous seed meal (BSM) as a by-product. As the production of oil seed for biodiesel increases, so will the production of BSM. Currently BSM is used primarily for livestock feed, but it has higher value as an organic nitrogen fertilizer, organic herbicide, or organic fungal disease suppressant.

Sources and quantities of BSM:
- Washington State in 2007 produced 10,300 tons of canola (Brassica napus) and mustard seed (B. juncea, Sinapis alba, etc).
- After oil extraction, 52-60% of material remains as BSM
- = approx. 6,000 tons BSM currently available annually
- Volumes could increase.
- WA state govt uses 20% biodiesel => 20,000 tons BSM
- Public and private use in WA at 20% => 1 million tons BSM
- Custom crushers are available to produce BSM on contract.

Justification:
- Value-added sale of BSM is necessary to economically produce oilseed biodiesel.
- BSM contains plant nutrients (6-2-0), has weed control and pest control activities.
- BSM as a pesticide improves worker safety (GRAS)
- BSM from non-GMO varieties can be approved for use in certified organic production as fertilizer or pesticide.

Refined product potential:
- 100% of BSM produced could be used, with no waste
- As fertilizer or biocontrol, 1-2 tons/acre = 3,000 - 6,000 acres can now be treated.
- With >100,000 certiﬁed organic acres in WA, demand could outstrip supply

System requirements & competition for raw materials:
- Oilseed crushers are available from several sources in US for about $40,000, used, up to $140,000 or more.
- The primary competing use for BSM is as livestock feed. BSM and mustard seed are also used for condiment mustard and for the production of essential oil of mustard.

Key Research Findings

Jobs/economic development:
- BSM potentially more valuable than the oil
- Other organic fertilizers near 6% N cost $3 - $70 per lb N, making BSM fertilizer worth approx. $7.35 / lb N or $894/ton
- Jobs created in farming, crushing, transporting, marketing

Additional environmental benefits:
- BSM could reduce/ replace methyl bromide
- BSM adds organic matter to the soil
- N bound in organic forms is less likely to leach or pollute water.
- Possible nitrification inhibition ~3 wks further reduces leaching

Closest commercial example:
- Corn gluten as weed & feed
- B. carinata seed meal as fertilizer
- Only two organic fungicides for Pythium control in greenhouse: Terramaster 4EC and Previcur Flex

Development stage and timeline to commercial success:
- Registration as a fertilizer takes a matter of months
- Use of BSM for pesticide requires more R & D to improve consistency of results
- Incubation with Pythium may be needed
- B. juncea is now registered for limited uses; adding more uses requires relatively little research and cost.

This research was funded through the BioWa’s Feedstock Research Program (aka “Appendix A”), a partnership between WSU Ag Research Center and the Washington State Department of Agriculture.

[Graphs and tables showing nitrate release, ammonium release, pythium population, and spinach biomass over time with different treatments.]
Leafy Greens as a Winter Crop in Washington State

Kristy Ott1 Rich Koenig1 Carol Miles2 John Reganold1 Joe Powers3 and Brad Jaeckel1

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Abstract: Production of leafy greens in protective season extension structures, like hoophouses, can provide residents of colder regions with fresh vegetables all year while simultaneously supporting local economies. This study examined how harvest date, variety, and location could impact yield of several varieties of organically managed leafy greens grown in an unheated, unlit hoophouse during winter in Pullman and Vancouver, WA. A total of 24 varieties of Asian greens, spinach and lettuce were grown the first winter and a subset of 12 of those varieties were selected for cultivation the second winter to make experimentation simpler. Plants were started in a greenhouse approximately 6 weeks prior to transplanting them into the hoophouse. Soil was amended with compost and a solution of liquid fish and kelp fertilizer was applied to plants every three weeks. Plants were watered as necessary. On average, the greens took 11 weeks to mature in the hoophouse to an appropriate size for a gourmet salad mix. Propagation of all cultivars was successful but variable. In general, Asian greens had the highest yields followed by spinach and then lettuce. Our research showed that plants had higher yields on later harvest dates as light and temperature conditions increased. Also, starting the plants in the greenhouse earlier in Autumn the second year, appeared to increase yields. In the first year, plant yields were incomparable based on location but in the second year, plants grown in Vancouver had higher yields. Winter production of leafy greens was successful in this experiment and is a well-suited option for vegetable producers in Washington State. A continuation of this study is currently being conducted to examine better management practices that may shorten length of time of growth and improve yield of leafy greens in winter production.

Seeding, transplant, and harvest dates for three trials in Pullman and Vancouver in winter 2005-2006 and 2006-2007

<table>
<thead>
<tr>
<th>Planting Year</th>
<th>Seeding Date</th>
<th>Transplant Date</th>
<th>Harvest Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005-2006</td>
<td>1</td>
<td>9-Nov 14-Dec</td>
<td>15-Mar</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>23-Nov 4-Jan</td>
<td>28-Feb</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7-Dec 18-Jan</td>
<td>30-Mar</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>17-Oct 1-Dec</td>
<td>15-Feb</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>31-Oct 12-Dec</td>
<td>1-Mar</td>
</tr>
</tbody>
</table>

Average air and soil temperatures (°F) inside and outside of the hoophouse in Pullman and Vancouver, WA over both year’s growing season

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature Type</th>
<th>Pullman Average</th>
<th>Pullman Range</th>
<th>Vancouver Average</th>
<th>Vancouver Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air inside</td>
<td>37</td>
<td>4 to 89</td>
<td>46</td>
<td>25 to 68</td>
</tr>
<tr>
<td></td>
<td>Air outside</td>
<td>33</td>
<td>-7 to 68</td>
<td>42</td>
<td>25 to 76</td>
</tr>
<tr>
<td></td>
<td>Soil inside</td>
<td>40</td>
<td>27 to 71</td>
<td>46</td>
<td>40 to 57</td>
</tr>
<tr>
<td></td>
<td>Soil outside</td>
<td>34</td>
<td>18 to 65</td>
<td>44</td>
<td>34 to 55</td>
</tr>
</tbody>
</table>

When air temperatures were below freezing, cloches were constructed by covering bent wire with Agribon Remay ™ fabric (AG-30 26 g m⁻²) over the beds to create a warmer environment for the plants. Continuous use of cloches could possibly be one way to increase yield.

Hoophouses used in this experiment were large and ranged in size from (807 to 1076 ft²). All were constructed of wood and metal or PVC pipe, and covered in a single layer of 6 mil UV treated greenhouse plastic. The floors were open and plants were planted directly into the soil.

Twenty-four varieties of lettuce, Asian greens and spinach grown in Pullman and Vancouver in winter 2005-06 and 2006-07 plantings.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Seed Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian Greens</td>
<td></td>
</tr>
<tr>
<td>Arugula</td>
<td>New Dimension Seed</td>
</tr>
<tr>
<td>China Express Cabbage</td>
<td>Territorial Seed Company</td>
</tr>
<tr>
<td>China Jade</td>
<td>New Dimension Seed</td>
</tr>
<tr>
<td>*Ching-Chiang</td>
<td>Territorial Seed Company</td>
</tr>
<tr>
<td>*Komatsuna</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>Melissa Cabbage</td>
<td>Territorial Seed Company</td>
</tr>
<tr>
<td>*Mizuna</td>
<td>New Dimension Seed</td>
</tr>
<tr>
<td>Napa Cabbage</td>
<td>Nichols Garden Nursery</td>
</tr>
<tr>
<td>Shanghai Pak Choy</td>
<td></td>
</tr>
<tr>
<td>*Tat Soi</td>
<td></td>
</tr>
<tr>
<td>Lettuce</td>
<td></td>
</tr>
<tr>
<td>Blushed Butter Oak</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>*Bronze Arrowhead</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>*Brown Golding</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>*Cardinale</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>*Crescentesia</td>
<td>Wild Garden Seeds</td>
</tr>
<tr>
<td>Emerald Oak</td>
<td>Wild Garden Seeds</td>
</tr>
<tr>
<td>Jack Ice</td>
<td>Wild Garden Seeds</td>
</tr>
<tr>
<td>Kwiek</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>*Oscarde</td>
<td>Wild Garden Seeds</td>
</tr>
<tr>
<td>*Yugoslavian Red</td>
<td>Abundant Life Seeds</td>
</tr>
<tr>
<td>Spinach</td>
<td></td>
</tr>
<tr>
<td>*Giant Winter Spinach</td>
<td>Territorial Seed Company</td>
</tr>
<tr>
<td>*Tyee Spinach</td>
<td>Johnny’s Seeds</td>
</tr>
</tbody>
</table>

* Indicates those varieties planted both years

Bold green text indicates the varieties that had the highest yields

Gourmet Salad Mix at harvest

Leaky Greens at harvest in March in Pullman

Leafy Greens at harvest in March in Pullman
Abstract: Market gardeners can grow crops year-round with season extension techniques. Cultural practices, plastic mulches, row covers, and low tunnels provide growers with earlier, later, and higher-quality produce that can capture more markets and demand higher prices. High tunnels or hoop houses, which are essentially unheated greenhouses, have gained increased interest around the country in the past 10 years. Many growers now consider hoop houses essential to the success of their market gardens; they are the focus of research projects, workshops, and new manuals. This publication describes these season extension techniques and provides sources for equipment, supplies, and further information.

Revised by Janet Bachmann
NCAT Agriculture Specialist
January 2005
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Introduction

Market gardeners use a variety of techniques to extend the growing season. Since season extension has a long history, current techniques involve both rediscovery and innovation. Gardeners through the centuries have learned to use available materials to produce earlier crops in the spring, grow cool-season crops in summer, maintain production well into the fall, and even harvest crops through the winter. Time-honored methods include cold frames heated with manure, masonry walls or stone mulch as heat sinks, and cloches (glass bell jars) to protect individual plants. Improvements in glass quality were big news for season extenders of the 18th and 19th centuries. (Ashton, 1994) More recently, plasticulture (use of plastics in agriculture) has greatly extended the possibilities for year-round production. Plastic film mulches, drip irrigation, row covers, low tunnels, and high tunnels protect high value crops. Photo by Janet Bachmann

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or hoophouses, help to protect crops from the weather. The use of plastic in horticultural crop production has increased dramatically in the past decade. High tunnels are springing up around the country, as more and more market gardeners see them as essential to their operations.

Benefits from year-round production include year-round income, retention of old customers, gain in new customers, and higher prices at times of the year when other local growers (who have only unprotected field crops) do not have produce. Other potential benefits of season extension technologies are higher yields and better quality. In addition, with year-round production you can provide extended or year-round employment for skilled employees whom you might otherwise lose to other jobs at the end of the outdoor growing season. Disadvantages include no break in the yearly work schedule, increased management demands, higher production costs, and plastic disposal problems.

Eliot Coleman, a market gardener in Maine who uses various techniques to grow vegetables year-round, summarizes the contribution season extension makes to sustainability.

... to make a real difference in creating a local food system, local growers need to be able to continue supplying “fresh” food through the winter months...[and] to do that without markedly increasing our expenses or our consumption of non-renewable resources.(Coleman, 1995)

The information in this publication and in the materials listed as Further Resources can help you analyze the benefits and costs of season extension techniques on your farm.

**Cultural Practices**

Almost all plants benefit from increased early- and late-season warmth. Many cultural techniques can modify the microclimate in which a crop is grown, without using structures or covers, though some of these techniques require long-term planning.

**Site Selection**

Garden site selection is very important for extended-season crop production. Cold air, which is heavier than warm air, tends to settle into valleys on cold nights, limiting the growing season there. In areas of relatively low elevation, a higher-elevation site only a few miles away can easily have a 4- to 6-week longer growing season. A site on the brow of a hill, with unimpeded air drainage to the valley below, would be ideal where season extension is an important consideration. (In more mountainous areas, temperatures drop as elevation increases.)

In northern states, land with a southern aspect is the best choice for early crops, as south-facing slopes warm up sooner in the spring. Furthermore, the closer to perpendicular the southern slope is to the angle of sunlight, the more quickly it warms.

South-facing slopes may not be advantageous in the southern U.S., where soil is likely to be relatively shallow, poor in soil fertility, and low in accumulated organic matter. If there has to be a choice between a sunnier aspect and native soil quality, the latter wins out, especially in the South, where winters and early springs are not as cold as in the North.

**Soils and Moisture Content**

Soils can affect temperature because their heat storage capacity and conductivity vary, depending partly on soil texture. Generally, when they are dry, sandy and peat soils do not store or conduct heat as readily as loam and clay soils. The result is that there is a greater daily temperature range at the surface for light soils than for heavier
soils, and the minimum surface temperature is lower. Darker soils often absorb more sunlight than light-colored soils and store more heat. Consequently, areas with lighter-colored soils (and no ground cover) are more prone to frost damage. (Snyder, 2000)

Bare soil absorbs and radiates more heat than soil covered with vegetation. Although the radiated heat helps protect against frost, cover crops provide many other benefits. Mowing to keep the ground cover short provides a compromise.

In addition, moist soil absorbs and radiates more heat than dry soil, because water stores considerable heat. To maximize this effect, water content in the upper one foot of soil where most of the change in temperature occurs must be kept near field capacity. (Snyder, 2000)

**Irrigation**

Overhead sprinklers, furrow, and drip irrigation can be used to protect crops from frost. Sprinklers are turned on when the temperature hits 33°F. When the water comes in contact with plants, it begins to freeze and release heat. As ice forms around branches, vines, leaves, or buds, it acts as an insulator. Although the level of protection is high, and the cost is reasonable, there are several disadvantages. If the system fails in the middle of the night, the risk of damage can be quite high. Some plants are not able to support the ice loads. Large amounts of water, large pipelines, and big pumps are required. Water delivered to a field via drip and furrow irrigation, however, can keep temperatures high enough to prevent frost damage without the same risks. (Evans, 1999; Snyder, 2000)

**Smudge Pots and Wind Machines**

Smudge pots that burn kerosene or other fuels are placed throughout vineyards or orchards to produce smoke. The smoke acts like a blanket to keep warm air from moving away from the ground. The smoke is also a significant source of air pollution, and smudge pots are rarely used anymore. (Atwood and Kelly, 1997) Today, using oil and gas heaters for frost control in orchards is usually in conjunction with other methods, such as wind machines, or as border heat (two or three rows on the upwind side) with undertree sprinkler systems. (Evans, 1999; Geisel and Unruh, 2003; Snyder, 2000)

Specialty cut flower growers Pamela and Frank Arnosky in Texas have a lot of experience dealing with wide fluctuations in temperature, and in a recent article they describe various methods for protecting high-value crops. They give this description of wind machines.

Cold air is heavier than warm air, and on a still night, the cold air will sink below the warm air and actually flow downhill. This is what happens when people say you have a “frost pocket.” As cold air flows downhill, it gets trapped in valleys and low spots. Even a row of trees can hold cold air in a pocket. Unless your farm is perfectly flat, you probably have a frost pocket somewhere, and you can avoid trouble by planting that spot later in the spring, or with hardy plants.

As the cool air sinks, the warm air is pushed up, and settles in a layer just above the field as an “inversion layer.” This is a pretty neat phenomenon

Orchard-Rite Ltd. wind machines protect crops from frost, and with added Agri-Cool™ System protects apple crops from hot weather. Photo courtesy of Orchard-Rite, Ltd.
that occurs on perfectly still nights. The inversion layer can be quite warm, and often is not very far off the ground. 

In big orchard operations, you will often see giant fans on towers among the trees. These fans are there to take advantage of the trapped inversion zone. They mix the warm air above and prevent the cold air from settling among the trees. They are super-expensive, but so is losing a crop. Fans like this only work in a still, radiational frost. (Arnosky, 2004)

More information about wind machines is available from contacts listed under **Further Resources**.

**Windbreaks**

Windbreaks decrease evaporation, wind damage, and soil erosion, and provide habitat for natural enemies of crop pests. They are also an important part of season extension, helping to create protected microclimates for early crops. Windbreaks should run perpendicular to (across) the prevailing direction of early-season winds. (Hodges and Brandle, 1996) Existing stands of trees can be used, but choose trees for windbreaks carefully, so that shading, competition for water and nutrients, and refugia for plant pests do not become problems.

Fall-planted cover crops of small grains (rye, barley, winter wheat) can serve as windbreaks the following spring; at plow-down, strips are left standing every 30 to 40 feet and cut or tilled under when no longer needed. Each strip should be the width of a small-grain drill (10 to 12 feet). However, small winter-grains may be too short to constitute an effective windbreak for early spring crops. Top-dressing with compost will help ensure a good stand. Another option is to plant perennial grass windbreaks that will maintain protection through winter and early spring.

These are only general guidelines; experimentation and adaptation are necessary to find the best solution for a particular situation. Other windbreaks include snow fences, commercial windbreak materials, brush piles, stone walls, old fencерows or hedges, shrubs, berry brambles, and even overgrown ditches. In any case, wind-breaks should not be allowed to interfere with down-slope air drainage and should allow for some circulation to prevent air stagnation and frost pockets. (Lamont, 1996; Hodges and Brandle, 1996)

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**Cultivar Selection**

Cultivar selection is important for early crop production. The number of days from planting to maturity varies from cultivar to cultivar, and some cultivars germinate better in cool soil than others. Staggered planting dates can be combined with the use of cultivars spanning a range of maturity dates to greatly extend the harvest season for any one crop. Early-maturing cultivars are very important in going for the early season, though in many cases the produce will be smaller. Some later-maturing cultivars also have better eating qualities and yields than earlier cultivars. Information on varieties adapted to your area is available from local growers, seed catalogues, trade magazines, Cooperative Extension, and resources listed at the end of this publication.

**Shade**

Although season extension usually brings to mind an image of protecting plants from the cold, modifying temperatures in mid-summer can also be important. Shade over a bed can create a cool microclimate that will help prevent bolting and bitterness in heat-sensitive crops such as lettuce and spinach, make it possible to grow warm-weather crops in areas with very hot summers, and hasten germination of cool-weather fall crops. Some growers provide cooling shade by growing vines such as gourds on cattle panels or similar frames placed over the beds. Shade fabrics, available from greenhouse- and garden-supply companies, can be fastened over hoops in summer to lower soil temperatures and protect crops from wind damage, sunscald, and drying. Placing plants under 30 to 50% shade in mid-summer can lower the leaf temperature by 10°F or more. (Bartok, 2004)

Commercial shade fabrics are differentiated by how much sunlight they block. For vegetables like tomatoes and peppers, use 30% shade cloth in areas with very hot summers. For lettuce, spinach, and cole crops, use 47% in hot areas, 30% in northern or coastal climates. Use 63% for shade-
loving plants. (The maximum shade density—80%—is often used over patios and decks to cool people as well as plants). (Peaceful Valley, 2004) See the ATTRA publication *Specialty Lettuce and Greens: Organic Production* for more on growing lettuce in hot weather. Shade houses can also provide frost protection for perennials and herbs during winter. Temperatures inside can be as much as 20°F higher than outdoors. (Bartok, 2004)

Silver Tufbell from Peaceful Valley Farm Supply is a specially developed alternative to woven shade fabric. It is impregnated with silver-finish aluminum for very high light as well as infra-red (heat) reflection. This, combined with a close weave, gives 45% shading during the day, but reflects heat back to the crop at night. Silver Tufbell is especially suited for sun- and heat-sensitive crops. The reflective surface also deters many pests, especially whiteflies and aphids, from approaching the crop. (Peaceful Valley, 2004)

Steve Upson, who has been working with hoop-houses at the Noble Foundation in Oklahoma, began installing Kool-Lite Plus brand poly film, in attempts to keep the houses cooler in the summer. He says this film, which blocks solar infra-red radiation, has kept temperatures up to 12°F cooler during the afternoon and evening. He says although you can expect to pay 75% more for Kool-Lite Plus, the additional cost can be justified, considering the costs associated with the use of shade fabric. (Upson, 2002)

**Transplants**

Use of transplants (versus direct seeding) is another key season-extension technique. Some crops have traditionally been transplanted, and recent improvements in techniques have expanded the range of crops suited to transplant culture. Transplants provide earlier harvests by being planted in a greenhouse several weeks before it is safe to direct-seed the same crop outdoors. If a grower uses succession planting or multiple cropping (i.e., follows one crop with another in the same spot), transplants provide extra time for maturing successive crops. Transplants hit the ground running, with a 3 to 4 week head start on the season. Transplanting aids in weed control by getting a jump on the weeds and by quickly forming a leaf canopy to shade out germinating weed seedlings. Transplants also avoid other pests that attack germinating seeds and young seedlings, such as fungal diseases, birds, and insects.

**Multiple Cropping**

Planting more than one crop on the same bed or row in one year intensifies the cropping schedule. Immediately after one crop is harvested, another is planted. Dr. Charles Marr and Dr. William Lamont (1992) list the following advantages of multiple cropping, and conclude “if you can’t triple crop, then you certainly can consider double cropping.”

- Cost savings. Money spent on plastic mulch, drip irrigation lines, and other equipment covers three crops instead of one.
- Higher gross per acre. In his triple cropping field trials, Lamont realized gross returns of $13,000 to 15,000 per acre.
- Improved cash flow. Multiple harvests throughout the season can provide income at critical times and distribute returns more evenly over a longer period.
- Risk management. Multiple cropping provides a hedge against the loss of a crop to freezes, hailstorms, and other crises.
- Increased productivity. Small areas of land are thus made more productive, a great boon in areas where cropland is scarce or costly.
Table 1. Spring-Fall Planting Sequences for North Carolina

Please note that crops in the same family never follow each other in the same field or bed in the same year. The same rule applies to triple cropping sequences.

<table>
<thead>
<tr>
<th>Spring</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peppers</td>
<td>Summer squash, cucumbers, or cole crops</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Summer squash, cucumbers, or cole crops</td>
</tr>
<tr>
<td>Summer squash</td>
<td>Tomatoes or cole crops</td>
</tr>
<tr>
<td>Eggplant</td>
<td>Summer squash</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>Tomatoes</td>
</tr>
<tr>
<td>Muskmelons</td>
<td>Tomatoes</td>
</tr>
<tr>
<td>Watermelons</td>
<td>Tomatoes</td>
</tr>
<tr>
<td>Honeydews</td>
<td>Tomatoes</td>
</tr>
<tr>
<td>Cole crops</td>
<td>Summer squash, pumpkins, muskmelons, or tomatoes</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>Summer squash, pumpkins, muskmelons, or tomatoes</td>
</tr>
<tr>
<td>Snap beans</td>
<td>Summer squash, pumpkins, muskmelons, or tomatoes</td>
</tr>
<tr>
<td>Southern peas</td>
<td>Summer squash, pumpkins, muskmelons, or tomatoes</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Summer squash, pumpkins, muskmelons, or tomatoes</td>
</tr>
<tr>
<td>Sweet corn</td>
<td>Summer squash, tomatoes, or cucumbers</td>
</tr>
<tr>
<td>Strawberries</td>
<td>Tomatoes, summer squash, cucumbers, or pumpkins</td>
</tr>
</tbody>
</table>

(Sanders, 2001)

Table 2 shows examples of double cropping sequences from North Carolina. (Sanders, 2001)

Table 2 shows examples of triple cropping sequences suitable for plasticulture in Kansas. (Marr and Lamont, 1992) For related information, see the ATTRA publication Scheduling Vegetable Plantings for Continuous Harvest.

<table>
<thead>
<tr>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cole crops</td>
<td>Summer squash</td>
<td>Tomatoes</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Cucumbers</td>
<td>Tomatoes</td>
</tr>
<tr>
<td>Sweet corn</td>
<td>Cucumbers</td>
<td>Tomatoes</td>
</tr>
</tbody>
</table>

(Marr and Lamont, 1992)

Plasticulture for Season Extension

During the past 10 years there has been an explosion in the use of plastics in agriculture. The term “plasticulture” is used to describe an integrated system that includes—but is not limited to—plastic film mulches, drip irrigation tape, row covers, low tunnels, and high tunnels. Some benefits of a comprehensive plasticulture system include:

- Earlier crop production (7 to 21 days earlier)
- Higher yields per acre (2 to 3 times higher)
- Cleaner, higher-quality produce
- More efficient use of water resources
- More efficient use of fertilizers
- Reduced soil and wind erosion (though erosion may increase in un-mulched paths between rows)
- Potential decrease in disease
- Better management of certain insect pests
- Fewer weeds
- Reduced soil compaction and elimination of root pruning
- The opportunity for efficient double or triple cropping (Lamont, 1996)
Disadvantages of Plasticulture:
The Disposal Dilemma

Costs and management time will both increase with the use of plasticulture, but if it’s done well, the higher productivity and profit should more than compensate. The most serious problems associated with plasticulture have to do with removal from the field and disposal. Machines are commercially available to remove plastic mulch from the field (Zimmerman, 2004; Holland, 2004) and to roll and pack it into bales, but for smaller-scale growers this is probably not an option. Other obstacles to recycling include dirt on the plastic, UV degradation, the high cost of collecting and sorting, and a lack of reliable end-use markets. But recycling technologies and initiatives are evolving. Dr. William Lamont, an advocate of plasticulture, envisions a future when growers will remove, chop, and pelletize field plastics for use as a fuel. Lamont and others at The Penn State Center for Plasticulture are currently testing a heater manufactured in Korea that burns plastic pellets made from waste plastics of all types. Dennis DeMatte, Jr., who as manager of the Cumberland County (New Jersey) Improvement Authority works with New Jersey’s greenhouse plastic film recycling program, stated that since the program was initiated in 1997, the CCIA has recycled approximately 80 percent of the film collected. From 1997 through 2002, the state collected about 1,120 tons of film. (Kuack, 2003) Web sites for more information about recycling agricultural or greenhouse-related plastic products include:

- The Penn State Center for Plasticulture
  www.plasticulture.org/newsletters/ASP_April04.pdf

- Cumberland County Improvement Authority
  www.ccia-net.com

- Agriculture Container Recycling Council
  www.acrecycle.org

- USAg Recycling Inc.
  www.usagrecycling.com

- Cornell University Environmental Risk Analysis Program
  http://environmentalrisk.cornell.edu/C&ER/PlasticsDisposal/AgPlasticsRecycling/

Plastic Mulches

Plastic mulches have been used commercially on vegetables since the early 1960s. Muskmelons, tomatoes, peppers, cucumbers, squash, eggplant, watermelons, sweet corn, snap beans, southern peas, pumpkins, and okra will all ripen earlier and produce better yields and fruit quality when grown on plastic mulch.

Plastic mulches have helped growers in extreme northern and high-altitude climates harvest heat-loving crops that were previously impossible for them to grow. In the northeastern U.S. small acreages of sweet corn are established by transplanting into plastic mulch for an early crop. Broccoli, cauliflower, pumpkin, and winter squash can also be established as transplants into plastic, if earliness and reduced environmental stress are required. In the Southwest, spring melons are direct seeded then covered with plastic strips to accelerate germination and development. At the three to four leaf stage, the plastic is removed. (Guerena, 2004)

Small-scale market gardeners will probably lay down plastic mulch by hand. Tim King, market gardener near Long Prairie, Minnesota, has been using a system of raised beds, drip irrigation, plastic mulch, and fabric row-cover tunnels since 1986. He says that although doing everything by hand is very labor intensive, they are very pleased with the flexibility this gives them to “hybridize” the parts of the system in various ways. It also al-
allows them to reuse much of the material a second and even a third season. (King, 2002)

Mechanical application can save time. Many growers have found that a simple tractor-pulled mulch layer will reduce overall costs and help ensure a uniform installation that will resist wind damage. Plans are available for a mulch layer that can be built in a farm shop (Thompson et al., 2004), and the machines are also commercially available. They can also be designed to install a drip irrigation line at the same time. (Zimmerman, 2004; Holland, 2004) Plants or seeds can be set through slits or holes in the plastic by hand or with a mechanical transplanter. Labor savings from mechanical transplanters are significant, even on limited acreages.

For successful plant establishment with plastic mulch, it is important that beds be level, the plastic is tightly laid, drip irrigation tape is placed in a straight line in the center of the bed, and water is applied through the irrigation system immediately after transplanting. Never use plastic mulch without irrigation.

Certified organic producers should be aware that organic standards place certain restrictions on the use of plastic mulches. For example, PVC plastics may not be used as mulches or row covers. Also, plastic mulches must be removed from the field before they begin decomposing—which would seem to eliminate photodegradable films from organic production.

Plastic mulches are available in a number of colors, weights, and sizes for various needs. Many come as 3- to 5-foot wide rolls that can be laid over soil beds with a tractor and mechanical mulch layer. Extensive research with colored mulches has been conducted at the Horticulture Research Farm, Rock Springs, Pennsylvania, by staff of The Pennsylvania State University Center for Plasticulture. (See Further Resources for contact information.)

Black plastic mulch is the most commonly used. It suppresses weed growth, reduces soil water loss, increases soil temperature, and can improve vegetable yield. Soil temperatures under black plastic mulch during the day are generally 5°F higher at a depth of 2 inches and 3°F higher at a depth of 4 inches compared with bare soil. (Sanders, 2001) Black plastic embossed film has a diamond-shaped pattern. It has the same advantages as smooth black plastic. The pattern helps to keep the mulch fitted tightly to the bed. For plastic mulch to be most effective, it is important that it be in contact with the soil that it covers. Air pockets act as insulation that reduces heat transfer.

Clear plastic mulch will allow for greater soil warming than colored plastic. It is generally used in the cooler regions of the United States, such as New England. Clear plastic increases soil temperatures by 8 to 14°F at a depth of 2 inches, and by 6 to 9°F at a depth of 4 inches. (Orzolek and Lamont, no date) A disadvantage is that weeds can grow under the clear mulch, while black mulch shades them out. Therefore, clear plastic is generally used in conjunction with herbicides, fumigants, or soil solarization. Organic growers may want to experiment with clear plastic to find out whether weeds become a real problem. The mulch’s benefit to the crop may outweigh the competition from weeds. (Coleman, 1995)

White, coextruded white-on-black, or silver reflecting mulches can result in a slight decrease in soil temperature. They can be used to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial.

Infrared-transmitting (IRT) mulches provide the weed control properties of black mulch, but they are intermediate between black and clear mulch in warming the soil. IRT mulch is available in brown or blue-green.

Red mulch performs like black mulch, warming the soil, controlling weeds, and conserving moisture, with one important difference. In Pennsylvania experiments, tomato crops responded with an average 12% increase in marketable fruit yield over a 3-year period. There appears to be a reduction in the incidence of early blight in plants grown on red mulch, compared with plants grown on black mulch. When environmental conditions for plant growth are ideal, tomato response to red mulch is minimal. Other crops that may respond with higher yields include eggplant, peppers, melons, and strawberries. (Bergholtz, 2004) (Red mulch also suppresses nematodes. See the ATTRA publication Alternative Nematode Control.)

Additional colors that have been investigated include blue, yellow, silver, and orange. Each reflects different radiation patterns into the canopy of a crop, thereby affecting plant growth and development. Increased yield was recorded for peppers grown on silver mulch, cantaloupe on green IRT or dark blue mulch, and cucumbers and summer squash on dark blue mulch,
compared with black. Insect activity can also be affected: yellow, red, and blue mulches increase peach aphid populations; silver repels certain aphid species and whiteflies and reduces or delays the incidence of aphid-borne viruses in crops. (Orzolek and Lamont, no date)

Photodegradable film has much the same qualities as other black or clear plastic film, but is formulated to break down after a certain number of days of exposure to sunlight. The actual rate of breakdown depends on temperature, the amount of shading from the crop, and the amount of sunlight received during the growing season. Buried edges of the film must be uncovered and exposed to sunlight. Use of photodegradable film eliminates some of the disposal problems associated with regular plastic, but is not without problems, and its availability has decreased rather than expanded during the past five years. A representative of one company that no longer offers photodegradable mulch says they discontinued the product because the breakdown was not consistent. Photodegradable mulch is not allowed for use in organic production.

Biodegradable Mulches

Biodegradable plastics are made with starches from plants such as corn, wheat, and potatoes. They are broken down by microbes. Biodegradable plastics currently on the market are more expensive than traditional plastics, but the lower price of traditional plastics does not reflect their true environmental cost. Field trials in Australia using biodegradable mulch on tomato and pepper crops have shown it performs just as well as polyethylene film, and it can simply be plowed into the ground after harvest. (Anon, 2002) Researchers with Cornell University also found that biodegradable mulches supported good yields, but the films they used are not yet commercially available in the U.S. (Rangarajan et al, 2003) Bio-Film is the first gardening film for the U.S. market. Made from cornstarch and other renewable resources, it is 100% biodegradable. Bio-Film is certified for use in organic agriculture by DEBIO, the Norwegian control and certification body for organic and biodynamic agricultural production, and is available from Dirt Works in Vermont. (See Further Resources.)

Paper mulch can provide benefits similar to plastic and is also biodegradable. An innovative group in Virginia carried out on-farm experiments to explore alternatives to plastic. They compared soil temperatures and tomato growth using various mulches, including black plastic, Planters Paper, and recycled kraft paper. Plastic, paper, and organic mulches all improved total yields of tomatoes grown in the trials, when compared with tomatoes grown on bare soil. (Schonbeck, 1995; Anderson, 1995)

Recycled kraft paper is available in large rolls at low cost. Participants in the experiment were concerned that it would break down too quickly. To retard degradation, they oiled the paper. This resulted in rather transparent mulch and, as with clear plastic, soil temperatures were higher than under black plastic. Weeds also grew well under the transparent mulch. To reduce weed growth and to keep the soil from becoming too hot, the experimenters put hay over the oiled paper several weeks after it was laid.

Planters Paper is a commercially available paper mulch designed as an alternative to plastic. It comprises most of the benefits of black plastic film and has other advantages. It is porous to water. Left in the soil, or tilled in after the growing season, it will degrade. Tomatoes grown with this mulch showed yields and earliness similar to tomatoes grown in black polyethylene mulch, even though the latter resulted in slightly higher soil temperatures. Planters Paper, however, is considerably more expensive than black plastic. It does not have the stretchability of plastic, and it tends to degrade prematurely along the edges where it is secured with a layer of soil. The paper is then subject to being lifted by the wind. Rebar, old pipe, or stones — rather than soil — can be used to secure the edges. (Bergholtz, 2004)

Penn State Center for Plasticulture trial of potatoes grown with colored plastic mulch, drip irrigation, and floating row covers. Photo courtesy Penn State Center for Plasticulture.
Melons, more and earlier

One study, based on three years of field trials in Utah, found that clear plastic mulch increased watermelon yield by 20%, while using the mulch and a row cover increased the yield by 44%, in comparison with melons raised without plasticulture. The mulch also allows for earlier planting. Dr. Alvin Hamson, the primary author of the study, recommends covering the cultivated beds with clear plastic a week or two before transplanting. Then set the transplants into slits cut into the plastic. The mulch will trap enough heat to protect the melon plants down to an air temperature of 27ºF.

Some further tips from Dr. Hamson: Transplant three-week-old seedlings into the field (harden them off first) about the same time apple blossoms open in your area. If you plan to use a floating row cover in addition to the mulch, you can set out transplants a week before apple bloom. Be sure to remove the row cover a week before the melons begin to flower, so that bees can pollinate them, and remove it gradually—leave the cover off for a few more hours each day for a week. Dr. Hamson recommends the same early planting technique for summer squash. (Long, 1996)

Another study, done at an experiment station in Connecticut, involved multiple cropping of specialty melon transplants using black plastic mulch and floating row covers. Yields from these beds were up to three times higher than yields from beds planted in plastic mulch without the row cover. The earliest-yielding cultivars in this study were Passport (galia) and Acor (charentais), both developed with shorter days to maturity for use in northern climates. These specialty melons are larger than cantaloupe and fetch a higher price. Accounting for the added expense of row covers, the researchers concluded that “row covers not only increased early fruit and total fruit, but profitability is about 6-fold greater when melons are grown for retail or wholesale.” (Hill, 1997)

Floating Row Covers

Floating row covers are made of spun-bonded polyester and spun-bonded polypropylene and are so lightweight that they “float” over most crops without support. (Crops with tender, exposed growing points, such as tomatoes and peppers, are exceptions. To prevent damage from wind abrasion, the cover should be supported with wire hoops.) The spun-bonded fabric is permeable to sunlight, water, and air, and provides a microclimate similar to the interior of a greenhouse. Plants are protected from drying winds by what amounts to a horizontal windbreak, and the covers give 2 to 8ºF of frost protection. In addition to season extension, advantages include greater yields, higher-quality produce, and exclusion of insect pests.

Floating row covers are available in various weights ranging from 0.3 to 2 ounces per square yard. The heavier the cover, the more degrees of frost protection it affords. Sizes range from widths of 3 to 60 feet and lengths of 20 to 2,550 feet. Wider covers are more labor-efficient, as there is less edge to bury per covered area. Durability is related to weight, type of material, and the additives used.

The lightest covers are used primarily as insect barriers. They can protect crops such as cabbage and broccoli from looper eggs and cabbage worms by excluding the egg-laying moths. Eggplant, radishes, and other favorites of the flea beetle are easily protected by floating row covers. Be sure to rotate crops in fields or beds planted under row covers, since overwintering insects from a previous crop can emerge under the cover. (Hazzard, 1999) Various diseases spread by insect vectors such as aphids and leaf hoppers are prevented as long as the cover remains in place. Disadvantages to the lighter covers are that they are easily damaged by animals and are seldom reusable. The lightest covers have a negligible effect on temperature and light transmission.

Medium-weight covers are the most commonly available. They are used to enhance early maturity, increase early yields and total yields, improve quality, and extend the season or make possible the production of crops in areas where they could not otherwise be grown. They also serve as insect barriers. Crops commonly grown with protection of medium-weight covers include melons, cucumbers, squash, lettuce, edible-pod peas, carrots, radishes, potatoes, sweet corn, strawberries, raspberries, and cut flowers.

Heavier covers, those exceeding 1 ounce per square yard, are used primarily for frost and freeze protection and where extra mechanical strength and durability are required for extended-season use. The microclimate created by heavier covers is similar to that created by...
medium-weight covers, but they can be reused for three to four seasons or more.

Floating row covers can be installed manually or mechanically. Immediately after transplanting or direct seeding, lay the covers over the area and weigh down or bury the edges. Small-diameter concrete reinforcing bar (rebar), cut to manageable lengths, is excellent for weighting the edges. Enough slack should be left in the cover to allow the crop to grow. Row covers placed over crops growing on bare soil create a favorable environment for weed germination and growth. Periodic removal of the cover for hand cultivation is not practical. Weed control can be a significant problem under row covers, unless they are used in combination with plastic or other mulches.

In self-pollinated crops, or leafy vegetables such as lettuce or cabbage, the covers can be left on for most of the production period. One caution when growing tomatoes or peppers under covers is in regard to heat — temperatures that rise above 86°F for more than a few hours may cause blossom drop. With insect-pollinated crops, such as melons, squash, or cucumbers, the covers must be removed at flowering to allow for insect pollination. The covers may, however, be replaced after the crop has been pollinated. Removing the covers should be considered a hardening-off procedure. Over the course of a few days, keep the covers off for longer and longer periods. Final removal is best done on a cloudy day, preferably just before a rain. Plants will suffer more transition shock if exposed to sun and wind.

Row covers should be stored away from sunlight as soon as they are removed from the field. Many have been treated to resist degradation by UV light; whether or not that is the case, they will last longer if stored carefully in a dark, dry place. Fold or roll the covers in a systematic way to make them easy to unfurl for the next season’s use.

Hoop-Supported Row Covers (Low Tunnels)

Row covers made of clear or white polyethylene are too heavy to float above the crop, so they are supported by hoops. Dimensions vary, but a typical structure is 14 to 18 inches high at the apex and wide enough to cover one bed. They are commonly used in combination with black plastic mulch for weed control. Hoop-supported row covers are often called low tunnels. They offer many of the same benefits as floating row covers, but are not permeable to air or water and are more labor-intensive. There are several types of low tunnels.

Slitted row covers have pre-cut slits that provide a way for excessive hot air to escape. At night the slits remain closed, reducing the rate of convective heat loss and helping to maintain higher temperatures inside the tunnel.

Punched row covers have small holes punched
about 4 inches apart to ventilate hot air. The punched covers trap more heat than the slitted tunnels. They are best for northern areas and must be managed carefully to avoid overheating crops on bright days. They are useful for peppers, tomatoes, eggplant, most cucurbits, and other warm-season crops that grow upright.

Tunnels that use two 3-foot wide plastic sheets stapled together at the top are commonly used by farmers growing trellised crops such as cherry tomatoes, long beans, and bitter melons. These tunnels are more expensive to put up, but they require little equipment investment. Most of the work to put them up is done by hand. (Ilic, 2004)

Hoops for supporting slitted or punched row covers are often made from 10-gauge galvanized wire. The pieces are cut to 65 to 75 inches long. Each end is inserted about 6 to 12 inches deep on each side of a row or bed to form a hoop over it. Hoops are spaced 5 to 8 feet apart—or less. Tim King, a market gardener in Minnesota, cuts hoops 3 to 4 feet long and spaces them 2 feet apart in the beds. (King, 2002) The covers are anchored on each edge with soil. Tunnels can be set by hand or with machines that resemble plastic mulch layers.

High Tunnels

High tunnels, also called hoop houses, have been attracting a lot of attention in the past few years, as more and more market gardeners have come to consider high tunnels essential tools in their operations. A high tunnel is basically an arched or hoop-shaped frame covered with clear plastic and high enough to stand in or drive a tractor through. Traditional high tunnels are completely solar heated, without electricity for automated ventilation or heating systems. Crops are grown in the ground, usually with drip irrigation. Compared to greenhouses, high tunnels are relatively inexpensive, ranging in price from $1.50 to $3.00 per square foot—and even less for the Haygrove multibay tunnels discussed below.

High tunnels are used extensively in Europe, Asia, and the Middle East. Although high tunnels are not used as much in the United States as in other parts of the world, interest here is growing rapidly. Universities and agricultural organizations around the country are conducting high-tunnel research, market growers are hosting workshops on their farms and at conferences, and more articles are appearing in trade journals and newsletters.

Cold Frames

Traditional low structures such as cold frames and cloches are continually being modified by innovative gardeners and garden supply manufacturers. Although cold frames work well in protecting crops in cold weather, construction costs are high compared to plasticulture systems. For special situations, many publications contain plans for cold frames, solar pods, and other small portable structures. Solar Gardening, by Leandre and Gretchen Poisson, listed under Further Resources, is one such publication. A more recent article on cold frames can be found in the November 2004 issue of Fine Gardening magazine. (Vargo, 2004)
Universities and Foundations Conducting High Tunnel Research (Lamont, 2003)

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Right: The most critical components of hoop house strength are the end walls. Below: At the Noble Foundation, wood end-posts fabricated from two 2- by 6-inch boards, corrugated fiberglass. Photos courtesy of Noble Foundation.
Several manuals on hoophouses have been published recently. They give details on construction, crop production, economics, and sources for supplies, equipment, and additional information. Some of these were written by market gardeners who have built and are using hoophouses. Others were published as a result of research done at universities and private foundations. Titles and ordering information for these are provided under Further Resources.

High tunnels have had a tremendous impact on season extension. Market gardeners say the structures pay for themselves in one season.

- Crops grown in hoophouses have higher quality and are larger than those grown in the field.
- Crops grown in hoophouses can hit the market early when prices are high and help to capture loyal customers for the entire season.
- Hoophouses allow certain crops to be grown throughout the winter, providing a continuous supply to markets (and tables) the entire year.

Crops that have been grown in high tunnels include specialty cut flowers, lettuce and other greens, carrots, tomatoes, peppers, squash, melons, raspberries, strawberries, blueberries, and cherries. Although high tunnels provide a measure of protection from low temperatures, they are not frost protection systems in the same sense that greenhouses are. On average, tunnels permit planting about three weeks earlier than outdoor planting of warm season crops. They also can extend the season for about a month in the fall. Earlier plantings and later harvests would require a supplemental heating system.

Location and Site Preparation

Alison and Paul Wiediger of Au Naturel Farm in south-central Kentucky grow winter vegetables in 8,500 square feet of high tunnels. In regard to locating a hoophouse, they advise other growers to put it close to the house. Especially on cold days, the shorter the walk from the house to the hoophouse, the more pleasant the trip will be—and the more likely you will be to make it. The Wiedigers advise other growers to prepare the site so that the ground is level from side to side, and has no more than 3% slope from end to end. Avoid wet or shady areas and obstructions to ventilation. Make sure drainage around the site is good. You don’t want water running through the house every time it rains. (Wiediger, 2003)
Orientation

Dan Nagengast of Wild Onion Farm in eastern Kansas says the orientation (east-west or north-south) depends on your location. Manufacturers recommend orienting the house to capture the most light in winter. For locations north of 40° latitude, the ridge should run east to west. For locations south of 40° latitude, the ridge should run north to south. At any latitude, gutter-connected or closely spaced multiple greenhouses will get more light if they are aligned north-south because they avoid the shadow cast by structures to the south.(Byczynski, 2003) Dr. Lewis Jett, in Columbia, Missouri, says that a high tunnel should be oriented perpendicular to prevailing winds: in regard to orientation of a high tunnel, sunlight is less important than ventilation.(Jett, 2004)

Design and construction

A high tunnel is not difficult to build. The most common design uses galvanized metal bows attached to metal posts driven into the ground 4 feet apart—a traditional quonset style structure. Carol A. Miles and Pat Labine in Washington offer construction details for a 10-foot by 42-foot structure that can be built for $350.(Miles and Labine, 1997) See Appendix I.

The High Tunnel Production Manual, published by The Pennsylvania State University Center for Plasticulture, details the construction and use of 17- by 36-foot tunnels using a gothic arch design developed by Penn State. (They chose this smaller size for research purposes.) The center section of the end walls can be opened up for easy access by machinery.(Lamont, 2003) Construction details only are shown in Appendix II, Design and Construction of the Penn State High Tunnel.

The Hoop House Construction Guide, by Steve Upson of the Noble Foundation, provides details for three designs: quonset, straight wall, and triple side-vent. Upson says the quonset structure is generally the least expensive to purchase. While satisfactory for producing low growing crops, trellised crops can’t be grown close to the sides. Straight wall designs provide unhindered internal access along the sides of the house, while permitting plenty of vertical growing space, but because of the additional pipe required, expect to pay more for materials and to spend more time on construction. The triple side-vent has vents on both ends of the tunnel; one side of the house is taller than the other, and the third vent is at the top of the tall side. This is the most expensive of these three designs. See Further Resources for information.

Strength is important. Heavy-gauge galvanized steel pipe is best for hoops. Setting the hoops four feet rather than any further apart is also recommended. Growers in snowy climates might choose a peaked-roof structure instead of the quonset style.(Bartok, 2002) The most critical components of a hoop house for strength are the end walls.(Upson, 2004) At the Noble Foundation, wood end-posts fabricated from two 2- by 6-inch boards, corrugated fiberglass panels for end-wall glazing, and industrial steel frame doors with heavy-duty latches, provide long-lasting end walls.

The most economical covering is 6-mil greenhouse grade, UV-treated polyethylene, which should last three to five years. Do not use plastic that is not UV-treated—"It will fall apart after half a season.”(Mattern, 1994)

Roll-up sides used on many high tunnels provide a simple and effective way to manage ventilation and control temperature. The edge of the plastic is taped to a one-inch pipe that runs the length of the tunnel. A sliding “T” handle is attached to the end of the pipe so that the plastic can be rolled up as high as the hip board. Ventilation is controlled by rolling up the sides to dispel the heat. Depending on temperature and wind factors, the two sides may be rolled up to different heights.

Coleman (1995) gives the following advice for dealing with wind.

Wind whipping and abrasion can be a serious problem. No matter how carefully the cover is tightened when it is first put on, it always seems to loosen. There are two ways to deal with this. The simplest is to run stretch cord over the top of the plastic from one side to the other…. One cord between every fourth rib is usually sufficient. The tension of the stretch cord will compensate for the expansion and contraction of the plastic due to temperature change and will keep the cover taut at all times. The second solution is to cover the tunnel with two layers of plastic and inflate the space between them with a small squirrel cage fan. This creates a taut outer surface that resists wind and helps shed snow.
Missouri cut flower grower builds a solar-powered hoop house

When Bryan Boeckmann of Westphalia, Missouri, decided to start cultivating cut flowers, a high tunnel seemed like the natural choice. But he had a problem: He couldn’t always be in Westphalia to make the required adjustments. Temperatures in such a structure can easily get too high on a sunny day, and the grower must be on hand to open the vents.

“I work full time for the fire department in Jefferson City, and the temperature in a high tunnel can change a lot in a 24-hour period,” he said. “I had to have something I could rely on. Fortunately, necessity is where most good ideas come from.” Boeckmann’s good idea was to use solar power to automatically raise and lower the side curtains on his tunnel. His project was funded by a grant from the Missouri Department of Agriculture.

Jim Quinn, the MU extension researcher who helped with the project, said Boeckmann was inspired by existing technology in poultry barns. “He had seen how poultry curtains work, and he thought, ‘Why can’t I do the same thing with a high tunnel and use solar power?’” The curtains are made of white, woven, tarp-like material. They are pulled up to close the sides and lowered to open the sides of the tunnel. Quinn said the innovation “is really a nice fit. The times when you need to adjust the curtains are when there’s a lot of sunny weather, and that’s also when the solar power is available.”

Boeckmann initially hoped to drive the side curtains with conventional electric power, but hooking into the grid was “cost-prohibitive,” he said. He called on Missouri Valley Renewable Energy (MOVRE), a firm in Hermann, Missouri, to design and build a solar unit. Using mostly used parts, MOVRE owner Henry Rentz constructed a small building with two solar panels on the roof and an inverter, batteries, and control panel within.

“I found some used stuff for Bryan because I wanted him to succeed in what he was doing,” said Rentz. “Those batteries alone would have cost $1,600 new. I basically did it to show people something that already works.”

The system succeeded beyond their expectations. “In June, when we had that extended period of rain, that system ran for 11 days without sun,” Rentz said.

“It’s fairly simple,” Boeckmann said. “Once you’ve initially set it up, typically you don’t have to mess with it. You just have to set the thermostat.” The thermostat in the hoop house senses temperature and, at a set point, triggers a mechanism that very slowly raises or lowers the plastic side curtains. “The reason it moves so slowly is to give the temperature in the building a chance to adjust,” he said. “It takes it 15 minutes to go all the way up. You can do it manually really fast, if a storm is coming.”

Boeckmann also uses solar power to drive his irrigation pump—“a little bitty pond pump that doesn’t eat up a lot of juice.”

He believes his innovations could boost the already growing interest in high tunnel construction. “There’s good reason for the interest,” he said. “The difference they make is phenomenal, considering it’s just a sheet of plastic stretched over a frame. They just keep improving them.”

For more information, contact Jim Quinn at 573-882-7514 or by e-mail at quinnja@missouri.edu. (Rose, 2004)
Irrigation is essential for adequate and timely watering. Watering can be done by hand, through a trickle or drip system, or by overhead emitters. The Pennsylvania State Center for Plasticulture High Tunnel Production Manual discusses the advantages of drip irrigation from water being delivered directly to the soil around the crops.

- Efficient water and fertilizer use
- Reduced weed competition in areas outside the beds
- Ability to simultaneously irrigate and work inside tunnels
- Reduction in disease potential because water doesn’t get on the leaves

If you choose trickle irrigation, use one line per row, or depending on the crop, one line per double row. If the soil is adequately fortified with nutrients, supplemental feeding might not be necessary; however, nitrogen can be applied through the trickle system.

The manual also discusses overhead irrigation and provides details on how to construct an overhead system. This allows irrigation water to be applied evenly to the entire soil surface. It can be used to leach salts from tunnel soils or to establish and grow cover crops within the tunnel.

A floor covering of a single sheet of 6-mil black plastic or landscape fabric provides several advantages. It warms the soil, controls weeds, greatly reduces evaporation of soil moisture, and serves as a barrier against diseases in the soil that could infect plant parts above ground. Secure the edges (sides and ends) of the plastic to prevent wind from blowing the plastic over the plants.

Temperature management using the roll-up sides is critical. On sunny mornings, the sides must be rolled up to prevent a rapid rise in temperature. Tomato blossoms, as mentioned earlier, will be damaged when temperatures go above 86°F for a few hours. Even on cloudy days, rolling up the sides provides ventilation to help reduce humidity that could lead to disease problems. The sides should be rolled down in the evening until night temperatures reach 65°F. A maximum/minimum thermometer is a great aid in keeping tabs on temperature.

Twenty feet by 96 feet is a size commonly used by market growers. This size allows efficient heating and cooling, efficient growing space, and adequate natural ventilation. Lynn Byczynski and Dan Nagengast who grow specialty cut flowers and vegetables in Zone 5 near Lawrence, Kansas, have five hoop houses, each 20 by 96 feet. They purchased Polar Cub cold frames from Stuppy Greenhouse Company. They chose Stuppy not because it was the only greenhouse manufacturer, but because it was the closest, so shipping costs were least expensive. The cost for two houses was $3,250, including the metal frames, four-year poly covering, wiggle wire to attach the poly to the frames, and shipping. Lumber to install the roll-up sides and poly-covered endwalls cost an additional $1,600. They also paid a neighbor $300 to prepare the site with a bulldozer and laser leveling device. In their first year, the hoop houses produced more than twice what they cost. The record of crops grown, planting and harvest dates, and revenue per square foot is shown in Table 3. (Byczynski, 2003) Additional details, including photos that show the construction of a Stuppy’s Polar Cub cold frame at Wild Onion Farm, can be found in The Hoophouse Manual: Growing Produce and Flowers in Hoophouses and High Tunnels. See Further Resources.

Alison and Paul Wiediger also use a commercially available 20- by 96-foot high tunnel, in
addition to two 21- by 60-foot tunnels. They think there is value in building as large a structure as is practical. (Wiediger, 2003)

Most of the growing in this tunnel will be in spring, fall, and winter when outside temperatures are cooler/colder. We believe that both the earth and the air within the tunnel act as heat sinks when the sun shines. At night, they give up that heat, and keep the plants safe. The smaller the structure, the smaller that temperature “flywheel” is, and the cooler the inside temperatures will be.

They also find that plants close to the walls do not grow as well as the plants further from them. The larger the frame, the larger the percentage of effective growing area. And most growers want more, rather than less, space at the end of one growing season.

Twenty feet wide, however, may be as wide as you can get with the inexpensive cold frame type hoophouses without interior bracing. Longer than 100 feet or so may be too long for effective natural ventilation.

The Wiedigers use a double layer of 6-mil, 4-year poly to cover their tunnels. A small fan blows air between the two layers to create an insulating barrier against the cold. Construction and management details can be found in their manual, Walking to Spring: Using High Tunnels to Grow Produce 52 Weeks a Year. See Further Resources for ordering information.

### Haygrove Multibay Tunnel Systems

With Haygrove tunnels, innovative growers are literally covering their fields to protect high-value crops from early and late frost, heavy rain, wind, hail, and disease. The frames also provide support for shade cloth and bird netting. (DeVault, 2004) The British company Haygrove was started in 1988 with a little more than two acres of strawberries in hoophouses. By 2002, Haygrove had expanded to nearly 250 acres of soft fruits, includ-
ing strawberries, blackberries, red currants, and cherries, grown under plastic in England and eastern Europe. They also came up with a new design for multibay tunnels and sold 3,000 acres of tunnels throughout Europe. Haygrove tunnels are now being distributed and used in the U.S. Haygrove sells tunnels from 18 to 28 feet wide per bay, with a three bay minimum. There are no walls between bays. The total length and width can be whatever the grower desires. Company representative Ralph Cramer in Lancaster County, Pennsylvania, says he has seen tunnels as short as 65 feet and as long as 1,100 feet. They have been used to cover from 1/3 acre to 100 acres (of blueberries in California). Unlike greenhouses, Haygrove tunnels don’t need to be built on flat ground, but can be built on slopes. Cramer says advantages of the systems include lower cost and better ventilation. (Cramer, 2004) One acre of Haygrove tunnels costs about 55 cents per square foot, or about $24,000.(Byczynski, 2002)

North Carolina market gardeners Alex and Betsy Hitt covered two quarter-acre blocks with Haygroves in 2004. One block was planted to specialty cut flowers, the other to organically grown heirloom tomatoes. Heirlooms have not been bred to resist foliar diseases, and growing organically limits fungicide options. Alex was pleased with the resulting decrease in plant disease: “We have very severe foliar disease

Full production in early March at Au Naturel Farm, lettuces and spinach. Photo courtesy of Au Naturel Farm.

Haygrove tunnels covering large area. Photo courtesy of Haygrove Tunnels.
problems on our tomatoes in the field and traditionally would pick a crop for about five weeks, and then it would be dead. With the Haygroves, we picked from the same number of plants for almost 10 weeks and picked and sold 35% more fruit than last year.” (Hitt, 2004) Hitt also noticed less disease in the Haygroves, compared with single bay tunnels with roll-up sides. He attributes the difference to better ventilation in the Haygroves, since they vent so high, resulting in less humidity. (Cramer, 2004)

Pennsylvania grower Steve Groff of Cedar Meadow Farm agrees. In 2004, despite the early arrival of late blight in the eastern United States and Canada, Groff’s six inter-connected bays yielded more than 3,000 25-pound boxes of tomatoes (by October 11), with seventy percent of them grading out at No. 1. His unprotected fields yielded only about 25 to 60 percent percent No. 1s. Groff says 2004 was an extremely unusual year, with a lot of wet weather. Tunnels allowed him to reduce fungicide use by more than 50 percent and allowed tomato harvest to begin two to three weeks earlier. They also extended the season: On October 11, Groff was still picking from tomatoes planted in April, and expected to harvest 100 to 200 more 25-pound boxes. (DeVault, 2004, Groff, 2004)

Leitz Farms in Sodus, Michigan, covered 10 acres of tomatoes this year to help control growing conditions. Fred Leitz, one of four brothers who run the family farm, said the plants look healthier than the ones outside and show no sign of disease. Their operation was featured on the front page of Vegetable Growers News. (Morris, 2004)

Haygrove tunnels, unlike single bay hoophouses, are not designed to carry a snow load, so they cannot be covered with poly during the winter in areas that have snow. John Berry, director of Haygrove, says “Haygrove tunnels are designed to be temporary low-cost structures that can be moved with the crop. The key management task is venting. Unlike conventional single hoop houses, multibay tunnels can be completely opened to ensure the crop is not stressed by heat or humidity.” Strawberries grown with this system can be picked two to three weeks earlier in the spring; yields of raspberries, blueberries, and strawberries have consistently been 30 percent higher in tunnels, compared with field grown berries; and the grade-out percentage for soft fruit under the tunnels runs about 90:10 Class A to B, compared with 75:25 for conventional outdoor production. (Otten, 2003)
The mobile high tunnel

The “salad days” of season extension were arguably in the second half of the 19th century, on the outskirts of Paris, where 2,000 or so market gardens employed cloches and cold frames to produce 100,000 tons of out-of-season produce per year. Many of these growers built small trackways on which to move the heavy glass cloches and frames to different parts of the garden. (Poisson, 1994) For the past century, European horticulturists have put railcar wheels on greenhouses and rolled them on iron rails. The rails extend two or more times the length of the greenhouse, making multiple sites available for one house. Eliot Coleman describes a sample cropping sequence for a mobile greenhouse or high tunnel.

An early crop of lettuce is started in the greenhouse on Site 1. When the spring climate is warm enough for the lettuce to finish its growth out-of-doors, the ends are raised and the house is wheeled to Site 2. Early tomato transplants, which need protection at that time of the year, are set out in the greenhouse on Site 2. When summer comes and the tomatoes are safe out-of-doors, the house is rolled to Site 3 to provide tropical conditions during the summer for transplants of exotic melons or greenhouse cucumbers.

At the end of the summer, the sequence is reversed. Following the melon and cucumber harvest, the house is returned to Site 2 to protect the tomatoes against fall frosts. Later on, it is moved to Site 1 to cover a late celery crop that was planted after the early lettuce was harvested. Then Site 1 is planted to early lettuce again, and the year begins anew. (Coleman, 1992)

Coleman has adapted these practices to his own garden, replacing the heavy and costly iron with more practical wooden rails. He provides plans for his mobile high tunnel, and year-round cropping plans, in his book Four-Season Harvest. See Further Resources.

Economics of Season Extension

One method for determining whether season extension techniques can be a profitable addition to a farming operation is called partial budgeting. (Illic, 2004) A partial budget requires assessment of changes in income and expenses that would result from changing to a different practice. It is called a partial budget because it is not necessary to calculate the expenses that would be the same for either practice. Steps to follow in the analysis include:

- Decide what crop will be grown using a season extension technique.
- Decide what season extension technique will be used.
- Calculate costs of the new technique, including supplies, rent or purchase of specialized equipment, labor, water, pest management. Allow for extra hours of labor due to inexperience in the first year.
- Calculate the added gross income from the new technique. Gross income is simply the price per unit of produce sold multiplied by the number of units sold. Income changes as a result of a change in the price received per unit, a change in the number of units sold, or both.
- Calculate any reduced expenses associated with the change. For example, use of black plastic or paper mulch will reduce the need for cultivation or herbicides. Use of floating row covers will reduce the need for other insect pest management operations.
- Add up all the increases and decreases of expense and income and calculate the total change in profit.

Specific information on costs of materials and supplies is available from the companies and in the manuals listed under Further Resources. The High Tunnel Production Manual, High-Tunnel Tomato Production, The Hoophouse Handbook and several Noble Foundation bulletins contain sample budgets for a number of fruits, vegetables, and cut flowers.

It must be remembered that any sample budget is just that—a sample. All market gardeners bring their own mix of skills, values, and resources together to build a unique system. According to Coleman(1992):

The secret to success in lengthening the season without problems or failures is to find the point at which the extent of climate modification is in balance with the extra amount of time, money, and management skill involved in attaining it. When planning for a longer season, remember the farmer’s need for a vacation period during the year. The dark days of December and January, being the most difficult
months in which to produce crops, are probably worth designating for rest, reorganization, and planning for the new season to come.

References


www.ken-bar.com


www.newfarm.org/columns/george_devault/0804haygrove.shtml


Guerena, Martín. 2004. Personal communication.


Hitt, Alex. 2004. Personal communication.


www.sfc.ucdavis.edu

Line drawings show key features of plastic tunnel and mulch laying machine. A list of materials needed to construct one in a farm shop is included.


Further Resources

Publications


The Hoophouse Handbook: Growing Produce and Flowers in Hoophouses and High Tunnels. 2003. By Lynn Byczynski (ed.). Fairplain Publications, Inc. 60 p. Includes information on construction and management, including crops to grow and sources of supplies. To order, send $15 plus $4 shipping to:

GFM
P.O. Box 3747
Lawrence, KS 66046
800-307-8949 (toll-free)

Extending the Season: Six Strategies for Improving Cash Flow Year-Round on the Market Farm. 2004. Edited by Lynn Byczynski, Fairplain Publications. 60 p. Includes articles about protected early and late crops; winter crops in the field and unheated hoophouse; high-dollar crops for the heated greenhouse; storage crops to sell months after harvest; value-added products to sell year-round; creating year-round markets. $15 plus $4 shipping from GFM.

Walking to Spring. 2003. By Paul and Alison Wiediger. Au Naturel Farm. 94 p. The Wiedigers tell how they use high tunnels to grow produce 52 weeks a year. Includes information on construction, crops grown, record-keeping, and additional resources. The price is $15 plus $3.50 shipping and handling. Order from:

Au Naturel Farm
3298 Fairview Church Road
Smiths Grove, KY 42171
270-748-4600
wiediger@msn.com
http://aunaturelfarm.homestead.com/

High Tunnel Production Manual. 2003. By William J. Lamont et al. The Pennsylvania State University. 164 p. Covers construction, production, and economics for vegetables, berries, sweet cherries, and flowers. Includes additional resources. To order, send a $25 check made out to The Pennsylvania State University to:

Dr. Bill Lamont
Department of Horticulture
206 Tyson Building
The Pennsylvania State University
University Park, PA 16802
Extension Publications
University of Missouri
2800 Maguire Blvd.
Columbia, MO 65211
573-882-7216
800-292-0969 (toll-free)

Hoop House Construction Guide. 2004. By Steve Upson. Samuel Roberts Noble Foundation Agricultural Division. 46 p. Excellent photos show all construction details from preparing the site to attaching the poly covering. The resulting hoophouse is sturdy enough to withstand the extremes of Oklahoma weather. Contact:
Steve Upson
The Samuel Roberts Noble Foundation, Inc.
P.O. Box 2180
Ardmore, OK 73402
580-223-5810
sdupson@noble.org

Four-Season Harvest: Organic Vegetables from Your Home Garden All Year Long. 1999. By Eliot Coleman. Chelsea Green Publishing. 234 p. Inspired by Scott and Helen Nearing’s garden in the late ’60s and based on the author’s success with harvesting fresh vegetables year-round in New England, this book contains details on design, construction, and management of the outdoor garden, cold frames, mobile high tunnels, and root cellars. Also includes growing tips for 50 vegetable crops, a planting schedule for extended harvests for all locations in the U.S., and sources of tools and supplies. Written primarily with the home gardener in mind, but much of the material can be applied to a commercial operation. Available from bookstores, on-line booksellers, or directly from the publisher:
Chelsea Green Publishing
P.O. Box 428
Gates-Briggs Building #205
White River Junction, VT 05001
800-639-4099 (toll-free)
www.chelseagreen.com


The Winter-Harvest Manual: Farming the Back Side of the Calendar. 1998. By Eliot Coleman. Four Season Farm. 62 p. This manual describes what Coleman and his wife Barbara Damrosch have learned since the above book was written. It includes their reasons for “farming the back side of the calendar” and details about how they do it, as well as a list of seed, tool, and supply companies. Available for $15 including postage from:
Four Season Farm
609 Weir Cove Road
Harborside, ME 04642


Two articles describe the passive solar production system used by Steve and Carol Moore in Spring Grove, Pennsylvania.

The article provides instructions for making your own waste oil heater from an old water heater tank. It is said to burn used crankcase oil both cleanly and without any detectable odor, and put out a lot of heat. The heater is designed for use in a shop or garage rather than in an open field.

Organizations

American Society for Plasticulture
Since 1990, the plastics industry, as individual companies and through organizations such as APC, has invested more than $1 billion to support increased recycling and educate communities in the United States. The Association of Postconsumer Plastic Recyclers hosts a Website as a service to the plastic packaging industry to promote the most efficient use of the nation’s plastics recycling infrastructure and to enhance the quality and quantity of recycled post-consumer plastics.

Manufacturers and Suppliers

NOTE: This list is intended to be neither comprehensive nor exclusive. Endorsement of any particular product or company is not implied. Additional suppliers, both wholesale and retail, are listed in the manuals and on the High Tunnel Web site described above. Many resources are also listed in the American Vegetable Grower magazine’s annual Source Book (July issue) and the Greenhouse Grower. Contact:

Meister Publishing Co.
3773 Euclid Ave.
Willoughby, OH 44094
440-942-2000

Good Fruit Grower is another trade magazine that lists suppliers. Contact:

Good Fruit Grower
105 South 18th Street, Suite 217

Yakima, WA 98901
509-575-2315
www.goodfruit.com/buyers/

A.M. Leonard
P.O. Box 816
Piqua, OH 45356
800-543-8955 (toll-free)
www.amleo.com

General tools, also landscape fabric, plastic film, shade cloth.

American Plant Products & Supplies
9200 N.W. 10th
Oklahoma City, OK 73127
405-787-4833
800-522-3376 (toll-free)
www.americanplant.com

Source of greenhouse frames, films and glazing, shade cloth, row covers, mulch film.

Atlas Greenhouse Systems, Inc.
P.O. Box 558
Alapaha, GA 31622
800-346-9902 (toll-free)
service@atlasgreenhouse.com
www.AtlasGreenhouse.com

Structures. Highly recommended by growers in the South and Midwest.

CropKing, Inc.
5050 Greenwich Rd.
Seville, OH 44273
330-769-2002
cropking@cropking.com
www.cropking.com

Offers grower-training workshops in hydroponic production.

Dirt Works
6 Dog Team Rd.
New Haven, VT 05472-4000
800-769-3856 (toll-free)
admin@dirtworks.net
www.dirtworks.net/

Source of Bio-Film 100 biodegradable mulch.

FEDCO Seeds
P.O. Box 520A
Waterville, ME 04903
207-426-9005
www.fedcoseeds.com

Floating row covers, plastic film mulches.

Frost Boss Wind Machine
Hawkes Bay Wind Machines, Ltd.
Hastings, New Zealand
www.frostboss.com.nz/
Source of wind machines for frost protection.

Griffin Greenhouse & Nursery Supplies
1619 Main Street
P.O. Box 36
Tewksbury, MA 01876
978-851-4346
www.griffins.com
Wholesale distributor of a range of plastic culture products.

Harmony Farm Supply & Nursery
3244 Hwy. 116 North
Sebastopol, CA 95472
707-823-9125
info@harmonyfarm.com
www.harmonyfarm.com
Floating row covers, frost blankets, landscape fabric, cold frames, greenhouse poly.

Haygrove Tunnels
Ralph Cramer
116 Trail Road North
Elizabethtown, PA 17022
866-HAYGROVE (toll-free)
Ralph.cramer@haygrove.com
www.haygrove.co.uk

Holland Transplanter Co.
P.O. Box 1527
Holland, MI 49422-1527
800-275-4482 (toll-free)
www.transplanter.com
Manufacturer of mechanical transplanters, bed shapers, mulch layers, mulch lifters, and related equipment.

Hummert International
4500 Earth City Expressway
Earth City, MO 63045
800-325-3055 (toll-free)
www.hummert.com
Drip irrigation, landscape fabric, greenhouse frames, poly covering, floating row cover, other supplies.

Jaderloon
P.O. Box 685
Irmo, SC 29063
800-258-7171 (toll-free)
jaderloon@jaderloon.com
www.jaderloon.com
Offers a complete line of structures and wide selection of accessories including film fastening systems, inflation blowers, polycarbonate sheets, and poly patch.

Johnny’s Selected Seeds
955 Benton Ave.
Winslow, ME 04901
207-861-3900
www.johnnyseeds.com
Floating row covers, slitted row covers, black poly mulch, IRT-100 green poly mulch, landscape fabric, tacks and staples, cold frames, seeds for hoop house/greenhouse production and for hot weather lettuces.

KEN-BAR, Inc.
25 Walkers Brook Drive
Reading, MA 01867-0704
800-336-8882 (toll-free)
info@ken-bar.com
www.ken-bar.com
Suppliers of Dupont AG-06, Typar, Custom-Cover 5131, clear polyethylene slitted and punched row covers, Insolar slitted/punched row covers or tunnels, wire for hoops, embossed and smooth black plastic mulch, Planters Paper mulch, SRM-Red plastic mulch, IRT plastic mulch, and clear polyethylene tubes.

Ledgewood Farm Greenhouse Frames
Route 171
Moultonboro, NH 03254
603-476-8829
Manufacturer of Penn State type Gothic-arch design frames.

Mechanical Transplanter Co.
1150 Central Ave.
Holland, MI 49423
800-757-5268 (toll-free)
mtc@mechanicaltransplanter.com
www.mechanicaltransplanter.com
Mechanical transplanters, bed shapers, mulch layers, mulch lifters, low tunnel layers, floating row covers, colored film mulches, and photodegradable mulch.

Orchard-Rite, Ltd.
P.O. Box 9308
Yakima, WA 98909
509-457-9196
www.orchard-rite.com
Source of wind machines and orchard heaters.

Peaceful Valley Farm Supply
P.O. Box 2209
Grass Valley, CA 95945
888-784-1722 (toll-free)
www.groworganic.com
- Agribon and Tufbell floating row covers,
- slitted row covers, shade cloth, IRT mulch,
- Planters Paper, black embossed polyethylene
  mulch film, repair tape, clips, hoops, Wall-
  O’-Water.

Plastitech, Inc.
478 Notre Dame
St. Remi, Quebec
Canada J0L 2L0
450-454-3961
800-667-6279 (toll-free)
info@plastitech.com
www.plastitech.com
- Plastic mulch, floating row covers, tunnels,
  irrigation, artificial windbreak material,
  mechanical mulch layers.

Rain-Flo Irrigation
884 Center Church Rd.
East Earl, PA 17519
717-445-6976
- On-farm family-owned and -operated busi-
  ness. Manufactures vegetable growing ma-
  chinery and supplies and carries almost all
  brands of irrigation equipment, specializing
  in drip irrigation. Floating row covers,
  plastic film mulches, mulch layers, trans-
  planters, mulch lifters.

ReflecTek Foils, Inc.
P.O. Box 310
Lake Zurich, IL 60047
888-439-6121 (toll-free)
www.repelgro.com
- Metalized UV reflective and other plastic
  film mulches.

Stuppy Greenhouse Mfg.
1212 Clay
North Kansas City, MO 64116
800-733-5025 (toll-free)
greenhouse@stuppy.com
www.stuppy.com
- Offers a variety of both coldframes and
  greenhouses.

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liam J. Lamont, Dr. Carol Miles, Lynn Byczynski
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Ralph Cramer, Steve Groff, Alex Hitt, Bryan
Boeckmann, and Steve Upson.
When constructing a greenhouse would be unwieldy and too expensive, a plastic-enclosed house—the hoophouse—fulfills most of a small farmer's or home gardener's needs. So named because of the arched or "hoop" structure that supports the plastic "skin," hoophouses are available in many lengths.

If you have a small farm business and are looking for ways to increase crop diversity or earliness, this portable field hoophouse may help. Some crops that are well suited to this type of hoophouse include tomatoes, peppers, eggplants, and melons—crops that need to be planted after danger of frost and that generally mature late in the season west of the Cascade Mountains. The hoophouse effectively allows a grower to produce early yields of crops that require more heat units than the environment may otherwise provide.

The hoophouse rests directly over the soil in the field, using no benches or special growing media. Two people can easily dismantle and reassemble the lightweight structure in a different section of the field each year or within a growing season. An advantage to moving the hoophouse around the field is crop rotation, which avoids pest buildup. Another is the low cost, approximately $350 for a 10' X 42' hoophouse.

The following hoophouse design will result in a structure approximately 10' wide at the base, 6 1/2' high at the center, and 42' long (Figure 1). Growers can easily adjust the length by adding or taking away support hoops and altering the length of the polyethylene plastic appropriately. The maximum length of polyethylene plastic available on the market is 100', which governs the maximum length for constructing a hoophouse. While initial construction of the hoophouse will take a day, two people can later put it up and take it down in only 2 hours. Storing the hoophouse out of the field during the winter months spares it from some of the worst weather and makes it last many years. Using wood treated with water-based preservatives also increases the longevity of the structure.
Polyethylene plastic is available in many grades. A 6 mil weight is recommended for greenhouses. Selecting a lighter weight (4 mil) is not recommended. Untreated polyethylene will cost less initially; however, the lifespan of the material is significantly less, and the material will likely degrade after one year of use. When treated with a UV inhibitor, 6 mil plastic generally is guaranteed for 3 years.

Gases that escape from the PVC (polyvinyl chloride) pipes contribute to the deterioration of the polyethylene plastic. To prevent "off-gasing," paint the PVC pipes with white latex paint. Use wood treated with water-based preservatives for the base of the door frame, where the wood comes into contact with the soil. Untreated wood used for the remainder of the frame will not severely affect its longevity. Choose a mid-weight (4 oz to 5 oz) corrugated plastic for the ends. A clear plastic generally will darken over the years, whereas a colored plastic will lighten with time. The color of the plastic will not affect the usability of the hoophouse. Most light will enter through the polyethylene sides.

The choice of nylon twine for tying the hoops in place is broad. Twisted twine is susceptible to unraveling, while braided twine is more durable. Natural fiber twine (jute or cotton) is not recommended due to the stretching these materials experience. Baling twine is inexpensive and durable.

**Materials**

- 9 ea. 2" X 4" X 12' boards, treated with water-based preservatives
- 4 ea. 2' X 8' sheets of 4 oz greenhouse-grade corrugated plastic
- 30 ea. 1/2" X 18" lengths of reinforcing rod (rebar)
- 17 ea. 18' lengths of 1" rigid white schedule 40 PVC (20' lengths cut down)
- 430' good quality nylon twine (minimum tensile strength 210 lbs.)
- 1 piece of 6mil polyethylene plastic sheeting, 50' long x 20' wide
- 38 ea. 3" galvanized self-tapping screws with rubber washers
- 30 ea. 1" galvanized self-tapping screws with rubber washers
- 10 ea. 1/4" X 4" bolts and matching wing nuts
Building the Ends

Two of the two-by-four boards will become the bottoms of the door frames. Construct both door ends in the same fashion. For each door frame, place an 11-foot length of two-by-four down with a 4-inch side facing up. Mark the center of the 11-foot board, then mark 14 1/2" on each side of the center. These marks frame a 29" length in the middle of the board, which will become the bottom of the doorway. At each end of the framing board, measure 6" and drill two 1-inch holes next to each other into the bottom piece, placing the holes as close together as possible (Figure 2).

![Diagram of door frame construction](http://cru.cahe.wsu.edu/CEpublications/eb1825/eb1825.html)

**FIGURE 2.**
Top view of bottom piece with two holes drilled 6" from each end and door uprights marked, and front view of the hoophouse end frame.

Turn the bottom piece on its side and insert a PVC length into holes at opposite ends, to form a hoop. This will be the outermost hoop. The corrugated plastic and door frame will attach to it. Cut two 6-foot lengths of two-by-four for the door uprights, along with one 32-inch piece for the top (header) of the door. Screw the header into the uprights, using the 3-inch self-tapping screws, so that the door frame is 2" wide and 4" deep. The door frame is then screwed to the bottom piece at the marked position using 3-inch self-tapping screws. Brace each side of the doorway with a two-by-four cut 72" long with the ends appropriately angled. Screw braces in place with 3-inch self-tapping screws.

Cut the corrugated plastic, lining up the ridges horizontally, to fit the ends of the hoophouse. Fitting the corrugated plastic horizontally gives added strength to the ends. Overlap the top piece of corrugated plastic a few inches over the bottom piece to keep the ends weatherproof. Use 1-inch self-tapping screws with rubber washers to attach the corrugated plastic to the door frame and the hoop. The rubber washer is helpful to keep the corrugated plastic from cracking.

Attaching the ends to the hoop structure with bolts makes the hoophouse quite easy to take apart and reassemble.
In the field, mark an area 10' wide by 42' long for the hoophouse site. At each of the four corners hammer an 18-inch piece of reinforcing bar (rebar) 12" into the ground, leaving 6" above the surface. The aboveground portion of the rebar will hold the PVC hoops of the hoophouse in place. Place a door frame upright at one end, inserting the PVC hoop onto the rebar. In what will be the inside of the hoophouse, attach a support leg to each door upright (Figure 3). Using 3-inch self-tapping screws, attach the support legs to the side of each door frame that will face the polyethylene plastic. Attach a support "foot" to the end of each leg and pound them into the ground. The support legs will keep the hoophouse frame from shifting, losing its shape, or straining the plastic. Place the second door frame at the opposite end of the area marked for the hoophouse. Insert the PVC hoop over the rebar and secure with support legs in the same fashion.

At 3-foot intervals along each of the 42-foot sides, hammer rebar into the ground, always leaving 6" above the surface. Gently bend an 18-foot length of PVC, positioning each end directly above the rebar, and carefully slide the PVC ends onto the rebar to form an arch (Figure 4). Repeat this procedure until you have formed 13 PVC hoops. It is not necessary to insert rebar into the two remaining holes in the bottom of each of the door frames. Simply insert the PVC into the holes, forming a double hoop at each end. When the polyethylene plastic is in place, bolt the double hoops together.
Starting at one end of the hoophouse, attach one end of the twine to the top center of the second hoop—the hoop immediately next to the door frame end. Pass the twine over to the next hoop, pulling it tight and looping it around the hoop. Continue on to each successive hoop until all hoops are attached together. When you reach the last hoop, reverse the process until you are back where you started. Connecting the hoops with twine helps to stabilize the hoop frame and will support the polyethylene plastic that will lie on top of it. It is important to keep the twine tight to prevent the plastic from sagging and collecting water when it rains. This would cause stress on the plastic and on the PVC framework.

Measure and cut a 5-foot strip off the 50-foot length of polyethylene plastic. This will leave a piece 45' long by 20' wide to be used for the hoophouse body. Use the piece 5' long by 20' wide for the doors. Spread the 45-foot length of polyethylene plastic across the hoop structure, pulling it tight, and insert the ends of the plastic between the double-hoops at each end. Bolt the corrugated plastic to the double-hoop ends, keeping the polyethylene plastic sandwiched between. To bolt the ends together, drill five holes through the corrugated plastic, the double-hoop ends, and the polyethylene plastic. Space the bolts so that one is at the top center, and two are on each side spaced 2' apart (Figure 2). Place a rubber washer over the hole on the corrugated plastic side, insert the bolt, and secure the wing nut on the inside of the hoophouse.

Secure the polyethylene plastic in place with twine tied over every hoop except the double hoop ends. To attach the twine to the hoops, lift the PVC hoop up slightly, tie a 20-foot length of twine to the rebar, and slip the PVC hoop back in place. Throw the twine over the hoophouse to the other side and tie it in the same fashion to the rebar supporting the other end of the PVC hoop. The twine should be just loose enough to allow slipping the polyethylene plastic up when raising the sides of the hoophouse for ventilation. Tying the plastic down at each hoop prevents the plastic from blowing out due to wind pressure.

**Finishing Touches**

The doors are simply polyethylene plastic sheeting, weighted on the bottom and hung on hooks at the top of the doorways. Cut the remaining piece of 5' X 20' polyethylene plastic to form two pieces 5' wide and 6' long. Attach a narrow piece of scrap wood at each end of the 6-foot length of polyethylene plastic. You can roll the plastic doors up on warm days to allow a breeze through the hoophouse, lowering the temperature. The polyethylene plastic along the 42-foot sides of the hoophouse also can be rolled up and attached with twine to the hoops (Figure 5). This additional ventilation is necessary during the hot summer months in most climates. To use the hoophouse, form two soil beds, one running down each side of the hoophouse, and install drip tape in each bed for easy watering (Figure 6). Transplant or direct seed crops into the soil.

![View of the side of the hoophouse, showing polyethylene plastic secured by twine. A side of the hoophouse has been raised for ventilation and tied in place with twine.](http://cru.cahe.wsu.edu/CEpublications/eb1825/eb1825.html)
Transplant crops into the soil inside the hoophouse. Lay drip tape down the center of each bed.