Season Extension: Introduction and Basic Principles

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What exactly is season extension?

In agriculture, season extension refers to anything that allows a crop to be cultivated beyond its normal outdoor growing season.

Advantages

- Possible year-round income
- Retention of old customers
- Gain in new customers
- Higher prices
- Higher yields
- Better quality
- Extended employment for workers

Disadvantages

- No break in yearly work schedule
- Increased management demands
- Higher production costs
- Plastic disposal problems

How does season extension contribute 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".

– Eliot Coleman, The New Organic Grower

Thermodynamics and Properties of Plants

We can extend the growing and harvest season for crops through techniques that evolve from two primary strategic goals:

1. Protecting crops from damage from extremes of heat or cold
2. Enhancing the growth of crops for quicker maturity and higher quality under adverse weather conditions

Often one technique will affect more than one strategy. For example, a raised bed will dry faster and warm up sooner in spring, but will therefore require more attention to irrigation needs, and may develop higher-than-desirable soil temperatures sooner than flat ground when summer arrives. It can also cool faster than flat ground. Another example: A row cover may protect a crop from a frost, but can also prevent the crop from developing as much hardiness as an uncovered crop, due to the artificial mild climate under the cover.

Growers are much more likely to succeed in their efforts to extend the growing season for crops if they understand some basic principles about heat and cold, about how plants respond to thermal changes, and how various landscape features and protective materials influence the thermal environment of plants.

Controlling the flow of heat

- The ground is a huge reservoir of heat. It's the heat radiating from the soil that

protects crops at night when you cover them, or protects the lower part of plants that have a good canopy of leaves. As the ground gets colder in late fall, it radiates less heat. Thus the leaf canopy or added row covers will give less protection as the ground cools. The reverse is true as the soil temperature increases in spring. Wet ground conducts and radiates more heat than dry ground.

- Lighter, sandier soils and any soil in a raised bed will dry out, warm up, and become workable earlier in the spring. Adding organic matter to clay soils can improve drainage; this will also darken any soil so it will absorb more heat. Dark mulches, such as black plastic, also raise soil temps. Mulches will insulate the ground and allow less heat out at night; thus crops will be colder on mulched ground.

- Clouds form a "blanket" that slows radiant heat loss from the earth. Temperatures can drop as much as 5-10° F within an hour after the sky clears at night. The arrival of cloud cover will often raise temperatures and save crops on a frosty night.

- Water can store a lot of heat and can give it up relatively quickly. This enables overhead irrigation to protect a crop from frost. It also creates warmer microclimates near ponds or other bodies of water.

- Water also absorbs heat quickly, and evaporating water removes heat from its environment. Thus, overhead irrigation on a hot day can cool heat-sensitive crops or aid germination of heat sensitive seeds.

- Land sloping to the south will stay warmer in the late fall and warm up sooner in the early spring. Land sloping east will warm sooner in the morning; to the west it stays warmer in the evening.

- Cold air is heavier than warm air, and will slide down slopes to settle in flat areas or hollows, often referred to as "frost pockets". On a calm night, the warmest "microclimate" in a given area will often be near the top of a slope. Objects in a landscape, such as buildings or created windbreaks, can influence the movement of cold air. Windbreaks uphill from a crop can protect from frost; downhill from a crop may cause trapping of cold air. A forest surrounding a smaller, level field on several sides may also keep cold air from reaching the crops.

- Windbreaks, such as buildings, hedges, fencerows, or woods, can influence microclimates in other ways. They can create a useful "microclimate", where solar

gain can accumulate in daytime; wind can stress plants by accelerating evaporation from leaves; it can also push cold air deeper into the canopy of the crop or through a row cover. The "wind chill factor" means: moving air extracts heat from objects faster than still air.

- Remember: Weather forecasts are usually for urban areas; temperatures on clear nights can be as much as 10 degrees lower in rural frost pockets than what is stated in the media for a general local area.

Hardiness: Which Crops Have How Much, and Under What Conditions?

- If the weather gets colder gradually, plants will develop hardiness, and be less damaged by extreme cold. If extreme cold immediately follows a warm spell, it will do much more damage to most crops.
- Moderate wind also helps to harden crops, both in the field and in seed flats. "Soft" transplants, freshly transplanted to the field, are more vulnerable to frost damage than hardened plants.
- Higher nitrogen levels will keep plants soft, less hardy. Various stresses and health conditions can also lessen hardiness.
- Each crop, when thoroughly hardened, has a typical threshold temperature, below which it will usually be damaged. Within each crop, varieties will vary in their hardiness, hence the range of temperatures given in the following table. Consult seed catalog variety descriptions for mention of degree of hardiness. The table below is based on Doug Jones' personal experience.

Threshold Damage Temperatures for Common Crops

TENDER CROPS (crops originally from the tropics): All are damaged at 31-32° F. These include all the nightshades – tomatoes, peppers, etc. (young potatoes can recover from moderate frost), cucurbits (squashes, cukes, melons, etc), beans, basil, sweet potatoes, and corn (can also recover).

COOL SEASON CROPS: Most crops below will survive at temperatures lower than the indicated range. If winter survival is the main goal, some damage is acceptable; the plants will usually recover as the weather warms up.

VERY HARDY

Leeks (5-20° F)

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Parsnips (28° F, tops 15° F, roots 0° F)
Spinach (8-12°)

HARDY
Cabbage (12-20° F)
Broccoli (18-22° F)
Brussels Sprouts (15-20° F)
Rutabaga (10-15° F)
Kale (10-15° F)
Mustard (10-15° F)

SEMI-HARDY
Lettuce (20-25° F)
Cauliflower (25-28° F)
Carrot (tops 10° F, roots 30° F)
Beets, Chard (15-25° F)
Peas (18-25° F, blossoms 30° F)

Slow-Growing Cool Season Crops – a Special Challenge in the Piedmont

In the Piedmont, we have two seasons of moderate weather enjoyed by cool weather crops (60-75° days): spring and fall. These seasons are often less than 60 days long. The quick-maturing crops are relatively easy to fit into this window: lettuce, spinach, mustard greens, radishes, spring peas, fall carrots. Using transplants helps to fit the cole crops into spring and fall, though the fall seedlings need to be started in a shaded location, and the spring crop in a greenhouse or cold frame. Very slow crops, like parsnips, Brussels sprouts, and celery are more difficult. Row covers can help to get these crops started extra early in spring, so they can finish before hot weather degrades them. Covers can help the fall crop mature without damage.

Temperature Extremes Affecting Germination and Seedling Vigor

One limitation of early spring planting is the negative effect of cold soil on germination. **Seedlings that emerge slowly are much more vulnerable** to attack by soil pathogens. Clear plastic laid directly on a seedbed can help seeds germinate quickly, provided the soil doesn't overheat.

Conversely, hot soil inhibits germination of some fall crops, particularly spinach, lettuce, parsnips, beets. Use mulches, shading, and/or micro sprinklers to cool

lettuce, parsnips, beets. Use mulches, shading, and/or micro-sprinklers to cool the soil and crop.

Days required for vegetable seedling emergence at various soil temperatures for seeds planted ½ inch deep

	Soil Temperature (° F)					
Crop	41	50	60	68	77	86
Cool Season						
Broccoli	28	20	10	7	5	4
Cabbage	24	15	9	6	5	4
Cauliflower	30	20	10	6	5	5
Onion	31	13	7	5	4	4
Pea	36	14	9	8	6	6
Spinach	23	12	7	6	5	6
Warm Season						
Snap Beans	NG	NG	16	11	8	6
Eggplant	–	–	27	13	8	5
Muskmelon	–	–	NG	8	4	3
Pepper	NG	NG	25	13	8	8
Sweet Corn	NG	22	12	7	4	4
Tomato	NG	43	14	8	6	6

NG = No Germination; – = Not Tested
Source: California Agricultural Extension Leaflet

Cultural Practices for Season Extension

Cultural Practices for Modifying Micro-climate

There are lots of things you can do to modify the crop microclimate that do not involve covers or structures. Some of these strategies require long-term planning.

Site Selection

Land with a south-facing slope will stay warmer in the late fall and warm up sooner in the early spring. A site at the top of the slope, with unimpeded air drainage down the hill, would be ideal for maximizing season extension.

Soil and Moisture Management

Adding organic matter, tillage, raised beds, improve drainage

Cultivar Selection

- Cultivar selection is an important strategy for achieving season extension. 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.

- Heat-tolerant varieties can help extend the season of certain crops.

- See ATTRA publication Scheduling Vegetable Plantings for Continuous Harvest

Transplants

Use of transplants is a key season extension technique. They can provide a 3-4 week head start on the season.

Irrigation

- Increasing or decreasing soil water content can enable tillage operations, prevent waterlogging of the root zone and/or aid germination.

- Overhead irrigation can be used to protect crops from frost. Micro-sprinklers can be used to cool them.

Windbreaks

- Use of windbreaks can result in increased yield and earlier crop production by providing wind protection. Young plants are most susceptible to wind damage and "sand blasting". Rye strips between rows can provide protection from wind and wind-borne sand. Windbreaks can improve early plant growth and earlier crop production, particularly with melons, cucumbers, squash, peppers, eggplant, tomatoes, and okra.

- The major benefit of a windbreak is improved use of moisture. Reducing the wind speed reaching the crop reduces both the direct evaporation from the soil and the moisture transpired from the crop. This moisture advantage also improves conditions for seed germination. Seeds germinate more rapidly and young plants put down roots more quickly. Improved moisture conditions continue to enhance crop growth and development throughout the growing season.

- The type and height of the windbreak determine its effectiveness. Windbreaks can be living or non-living. Rye strips are suggested for intensive vegetable production based on economics. In general, the windbreak has a significant effect on the crop at a distance of 8 times the height of the windbreak. A rye strip 3 feet tall will protect vegetables up to 24 feet away. The windbreak should be planted perpendicular to the prevailing wind direction. Rye strips should be planted from September through October to obtain good plant establishment and to provide adequate time for plant growth prior to beginning the next production season.

Fabrics and Structures for Season Extension

Plastic Mulch

- Plastic mulches have been used commercially for the production of vegetables since the early 1960s. Plastic mulches provide many positive advantages for the user, such as increased yields, earlier maturing crops, crops of higher quality, enhanced insect management, and weed control. They also allow other components, such as drip irrigation, to achieve maximum efficiency. Although a variety of vegetables can be grown successfully using plastic mulches, muskmelons, tomatoes, peppers, cucumbers, squash, eggplant, watermelons, and okra have shown the most significant responses. Production of strawberries and cut flowers is also greatly improved by the use of plastic mulch.

- Plastic mulches directly impact the microclimate around the plant by modifying the radiation budget (absorbitivity vs. reflectivity) of the surface and decreasing the soil water loss. The **color** of a mulch largely **determines its energy-radiating behavior** and its influence on the microclimate around a vegetable plant. Color affects the surface temperature of the mulch and the underlying soil temperature. Another important factor is the **degree of contact between the mulch and soil** or by not being taut, often quantified as a thermal contact resistance, will greatly influence the performance of a mulch. If an air space is created between the plastic mulch and the soil by a rough soil surface, soil warming can be less effective than would be expected from a particular mulch.

- **Black plastic mulch** – the predominant color used in vegetable production is an opaque blackbody absorber and radiator. Much of the solar energy absorbed by black plastic mulch is lost to the atmosphere through radiation and forced convection. The efficiency with which black mulch increases soil temperature can be improved by optimizing conditions for transferring heat from the mulch to the soil. Because thermal conductivity of the soil is high relative to that of air, much of the energy absorbed by black plastic can be transferred to the soil by conduction if contact is good between the plastic mulch and the soil surface. Soil temperatures under black plastic mulch during the daytime are generally 5° F higher at a 2-inch depth and 3° F higher at a 4-inch depth compared to those of bare soil.

- **Clear plastic mulch** – absorbs little solar radiation but transmits 85% to 95%, with relative transmission depending on the thickness and degree of opacity of the polyethylene. The undersurface of clear plastic mulch usually is covered with condensed water droplets. This water is transparent to incoming shortwave radiation but is opaque to outgoing longwave infrared radiation, so much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch. Thus, daytime soil temperatures under clear plastic mulch are generally 8 to 14° F higher at a 2-inch depth and 6 to 9° F higher at a 4-inch depth compared to those of bare soil. Clear plastic mulches generally are used in the cooler regions of the United States, such as the New England states. Weeds can be a big problem under clear mulch.

- **White, white-on-black, or silver reflecting mulch** – can result in a slight decrease in soil temperature (-2° F at 1-inch depth or -0.7° F at a 4-inch depth) compared to bare soil, because they reflect back into the plant canopy most of the incoming solar radiation. These mulches can be used to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial.

- Infrared-transmitting mulch – These mulches provide the weed control properties of black mulch but are intermediate between black and clear mulch in terms of increasing soil temperature. The color of these mulches can be blue-green or brown. These mulches warm up the soil like clear mulch but without the accompanying weed problem.

- 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.

Source: Center for Plasticulture at Penn State

Biodegradable mulch

- 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. 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. 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 available from Dirt Works in Vermont.

- 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.

- 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.

Source: ATTRA Season Extension Techniques for Market Gardeners

Row Covers

Two main types of row covers:

1. floating row covers – lie directly over the crop and may cover multiple rows
2. Hoop-supported row covers – sometimes referred to as low tunnels, they generally cover a single row

There are also two basic types of row cover materials:

1. clear polyethylene
2. spunbonded polyester or polypropylene

All of these are available in varying thicknesses, weights, widths, and lengths.

- Crop distinctions such as temperature sensitivity, pollination methods, and growth habit dictate the type of row cover that is best to use.

- Spunbonded covers are comprised of a thin mesh of white synthetic fibers which entrap heat and serve as a barrier to wind, insects, and varmints. Water from rain or overhead irrigation freely passes through. The weight of these covers ranges from 0.3 to about 2.0 oz/sq yd. The **lightest covers** are used primarily for **insect exclusion** while the **heaviest** of the covers are used for **frost protection.** The most common **medium weights** are 0.5 to 1.25 oz/sq yd and are best for **season extension** for such crops as melons, cucumbers, squash, lettuces, peas, carrots, radishes, potatoes, sweet corn, strawberries, and cut flowers. With covers under 0.5 oz there is minimal heat retention at night; and over 1.75 oz, there is a significant reduction in light transmission. The heavy covers are used for nighttime frost protection only since they do not transmit sufficient light for optimum crop growth.

- Spunbonded row covers in the 0.5 to 1.25 oz range provide 2-4° F frost protection in the spring. In the fall, there is more protection because there is a larger reservoir of heat in the soil in the fall than in the spring.

Floating row covers

- Floating covers require much less installation labor than hoop supported covers. The wider and longer the covers, the less labor required per unit area since only the edges are secured. These covers vary in width from 3 to 60 feet and up to over 2,000 feet long. Even though most crops can be grown without damage under floating covers, tomatoes and pepper are an exception. If the spunbonded material is not supported with wire hoops for these crops, flapping of the cover in the wind will damage the growing points of young plants. Also, with summer squash under windy conditions, many of the leaves might be broken by the cover. For these three crops, a series of strategically placed wire hoops will prevent crop damage.

- Weed control can be a significant problem under row covers unless they are used in combination with plastic or some other type of mulch.

Hoop-supported row covers

- 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.

Additional Observations by Doug Jones:

- In the protected, wind-free, slightly warmer environment under the cover, crops will grow faster during cold weather. Ironically, this effect also prevents plants from developing as much hardiness as equivalent crops with no protection! To deal with this, I add a second cover when extreme cold is forecast.

- In the Piedmont, many cool-season crops can be brought through the winter under an adequate thickness of fabric (medium weight fabric: add a second layer). Crops actually grow a little during winter warm spells.

- High (hoophouse) or low tunnels with a single layer of clear plastic get much warmer on sunny winter days than fabric covered beds, so crops will grow faster. But it gets about as cold at night in the hoop house as under the fabric covers. In the coldest weather I like to add a row cover to beds of semi-hardy crops inside the hoophouse. Clear plastic must be ventilated on calm, sunny days when ambient temperatures are above 50-60° F. Otherwise, the crop will be overheated.

- Plant leaves that touch the fabric usually get more damaged from extreme cold, and from strong winds whipping the cover back and forth. A tunnel structure of heavy (9 gauge) wire hoops will help to keep the fabric from touching the leaves of the crop. Concrete block wire ("ladder wire") makes a more stable tunnel structure. It's important to stretch the fabric very tight end-to-end, and use lots of pins, soil, or rocks to keep big winds from blowing your covers into the trees. Red plastic "Repins™" are very effective for pinning, as well as easy to pull up for access to the crop.

- Wire hoops are not sufficient to prevent heavy snow from collapsing the cover. Sometimes I just take the cover off when a big snow is forecast, and actually get less damage than under the collapsed tunnels. Powdery snow itself is a good insulator.

High Tunnels

- A high tunnel, or hoophouse, 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.

- High tunnels have been used for many years throughout Europe, Asia, and the Middle East and they are rapidly gaining in popularity here. Several universities are now conducting high tunnel research.

- Benefits of high tunnels:
- 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 the entire year.

- . The most critical components of a hoop house for strength are the end walls.

- 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.

- Hoophouses are 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. 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.

- 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". Some growers use a double layer of plastic.
- 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.

- 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.

- Alison and Paul Wiediger of Au Naturel Farm in Kentucky 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. 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.

  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.

- 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 Resources handout).

Source: ATTRA Season Extension Techniques for Market Gardeners

- Eliot Coleman popularized the concept of the mobile high tunnel in the U.S. The tunnels sit on railroad wheels and roll on wooden rails so they can be moved from one site to another. For example, the tunnel might be used to start a lettuce crop, and once the spring warmed up enough for the lettuce to thrive outdoors, the tunnel is moved to the second site where tomatoes are planted. Coleman's book Four-Season Harvest provides details on the mobile tunnel model.

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. 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, including 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. One acre of Haygrove tunnels costs about 55 cents per square foot, or about $24,000.

Local Example of Haygrove Tunnel System: Peregrine Farm

- Locally, Alex and Betsy Hitt of Peregrine Farm purchased a half an acre (two ¼ acre blocks) of Haygrove tunnels and first used them for the 2004 growing season. They had actually gotten a quote before the 2003 season began and the price scared them so they walked away. But then the summer of 2003 yielded a horrible tomato crop due to all the rain and disease so they decided to go for it. They had seen the Haygroves being used for cut flower production in California and Pennsylvania. They wanted them mainly as "dry houses" to keep the tomatoes dry and also for certain flowers that don't like their blooms getting wet (lisianthus, poppies, campanula, delphinium, etc.). Alex and Betsy already had 6 mobile high tunnels that worked great for tomatoes but they

wanted something that could be moved with the rotation, cover lots of ground, and be well-suited for cover crops.

- They contacted Ralph Cramer of Cramer's Posie Patch , the east coast distributor for Haygrove. They ordered two ¼ acre blocks because that was the size of their rotation plots. Each bay is 24 feet wide. The Haygrove tunnels are shipped over from England. It takes about 8 weeks. The shipping cost alone is $4,000, whether the cargo container is full or not. If growers did a cooperative purchase they could reduce shipping costs. The total cost, including shipping, was $0.85/square foot. The plastic is supposed to last for at least two years; Alex will get at least three years.

- Construction of Haygroves: You have to be prepared for the delivery. You have to unload everything within two hours or you get charged Alex received over 5 tons of stuff! The roll of plastic itself weighed one ton. Need to have appropriate equipment ready for off-loading. The Hitts constructed the tunnels in October and covered them with plastic the following April. Haygrove sends someone to advise you on construction. They won't do any of the actual work but they are there to tell you how to do it. The Hitt's Haygrove rep spent an entire day with them and showed them how to lay out the field. It took two people 80 hours total to construct ½ acre of Haygroves. It took 4 people an additional hour to cover each bay in plastic.

- The Hitts use one ¼ acre block for cut flowers and one for heirloom tomatoes.

- *Advantages of Haygroves*

- Disease protection – Alex has a mysterious strain of anthracnose disease that attacks his tomatoes. This disease has even left our plant pathologists stumped. Under the Haygroves, the disease comes 3-4 weeks later, so instead of 5 weeks of production, he gets 8-9 weeks, and a 35% increase in income. At this rate, it will take three years to pay off the tunnels. They are still trying to work out which crops are best suited for the Haygroves. For some crops, it may increase disease. Dahlias had powdery mildew under the Haygroves.

- Improved quality – Alex believes they would be great for producing a superior quality melon since they would control the amount of rain which often dilutes the sugars and causes splitting. They grew melons in the Haygroves the first year and they did great until the plastic had to be removed for an impending hurricane and then the melons all exploded!

- Provides season extension – doesn't just affect temperature but also wind and moisture. The multiple huge bays means there's a large area of air under there

that cools off slower at night. The Haygroves were originally designed in England to keep strawberries dry, so they are designed more for controlling rainfall rather than temperature. However, the Hitts did have a surprise frost hot after planting their tomatoes – the ground outside was totally white and the tomatoes inside the tunnels were fine.

- *Disadvantages of Haygroves*
- They are very difficult to construct if you have rocky soil, as the Hitts do. The legs are sunk 30 inches, and Alex had to use a jackhammer! This causes problems not only with initial installation but also makes it difficult to move them. To get around this problem, the Hitts are going to install another set of permanent legs, which the Haygroves can be moved to. This will allow them to have a three year rotation with the Haygroves.

- The Haygroves present a huge sail out in the field so you have to be prepared to vent them by pushing the plastic up very high. They are designed to withstand 70 mph winds. They were designed for England conditions where they don't get thunderstorms like we do that bring wind and rain at the same time. The Hitts have already had some bows bend due to a downdraft thunderstorm. They learned that come the first of May, they vent the tunnels, using ladders to push the plastic as high as they can. They make sure to roll the plastic up inside so it doesn't wrinkle and collect water running off the top – this would soon weigh it down and cause bending.

- They are not designed to take a snow load. They must be uncovered in winter. They can be used with sidewalls and end walls but they still are not designed for overwintering crops.

- Like any greenhouse, there will be a lot of water running off so you need to prepare for this when preparing the site. Make sure that when the water pours down the sides, it can run off between the rows and not across them. Alex digs a little trench in the leg row and seeds it with a cover crop to direct water out into the field.

- Would they do it again, knowing what they know now? Alex said they would. For them, it was a specific answer to a specific problem, and tomatoes were 16% of their business so it was worth solving that problem. For people who want to grow lettuce all season, a Haygrove is not for them. They should just

get a high tunnel. The Haygroves are pretty labor-intensive, and it takes a couple of years to learn how to best manage them.

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 midsummer can lower the leaf temperature by 10° F or more.

- 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). 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.

Source: ATTRA Season Extension Techniques for Market Gardeners

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