

# Selecting Your Structure

Setting out to build a high tunnel is no different from any other capital project. The steps prior to construction—planning, financing and funding, and ordering—are often the most difficult. The actual building project is relatively simple and can be exciting. The completion of any project has rewards of satisfaction and future profit.

In shopping for a high tunnel, and here we focus on single-bay structures, a grower will need to select from an array of designs, sizes, and special features. Different materials and construction methods can also be used. Experienced farmers have weighed the advantages and disadvantages of these options for their climate, markets, production aims, and bottom line.

## Quonset or Gothic-shaped Structures?

The shape of a tunnel affects its performance. It will have an effect on lighting (and shading), energy gain, growing space, and ventilation.

Single-bay high tunnels come in two primary shapes: Quonset and Gothic arch (*see diagram below*). The Quonset shape is relatively short and squat with a rounded roof and sloped sides, while the Gothic, like a cathedral, has a high pointed peak and straight sidewalls. Unheated Quonset structures can also serve as cold frames for overwintering nursery stock. Multi-bay high tunnels, including the Haygrove structure described in this manual, are usually a series of interconnected Quonset-shaped tunnels. Gothic type tunnels have several advantages compared to Quonset models. In many circumstances, these advantages easily offset their greater cost.

A Gothic-shaped structure readily sheds snow because of the steep pitch of its roof. Quonsets, especially those with PVC bows, need to be swept free of snow to prevent collapse. When snow threatens, some growers set up 2" x 4"s as temporary props under the ridge pole, purlins, or bows of their Quonset-shaped high tunnels. PVC

tunnel owners are wise to remove their plastic for the duration of the snowy season.

Match your structure's design load to local conditions of snow and wind. Some greenhouse suppliers can select design specifications appropriate to your county. In the first winter, one northern farmer's high tunnel—purchased from a southern supplier—was destroyed in a snowstorm, along with the perennial plant material inside.

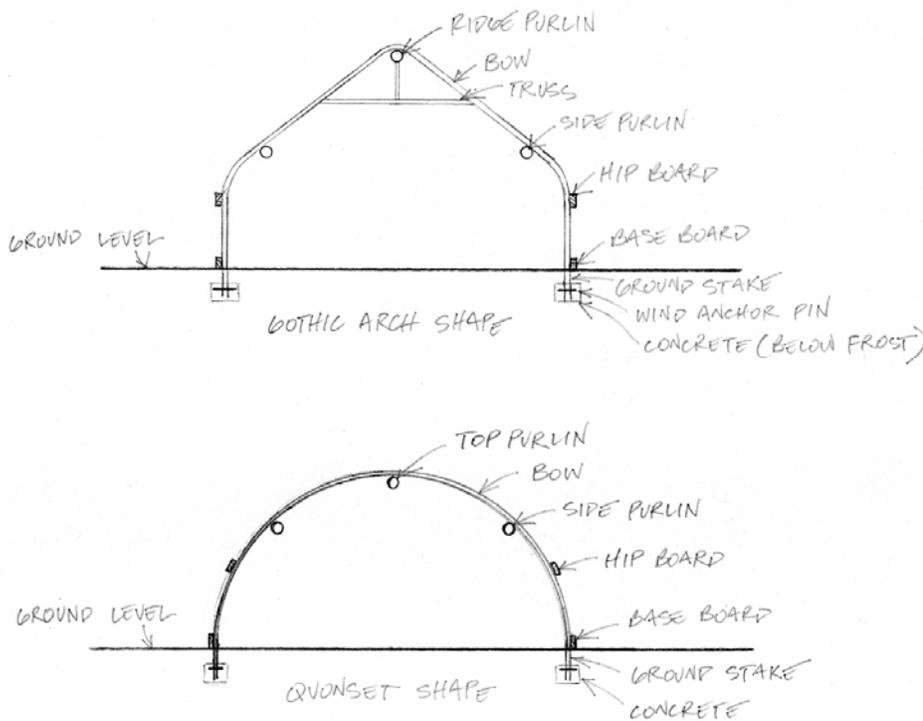
The taller sidewalls of Gothic tunnels offer more usable space along the sides for crop production and growth and for working comfort. For trellised crops like tomatoes, Gothic-style tunnels provide adequate height both for the interior and perimeter rows. The headroom over the edge beds in a Quonset tunnel may be so low that even a short person is uncomfortable when using a walk-behind seeder, for instance.

The Gothic shape also contributes to better air exchange and moisture control, and thus a superior growing environment. The greater height of Gothic tunnels allows for better ventilation through higher gable-end vents. Gothic arch roofs tend to have enough of an angle to help shed water that condenses on the interior, instead of dripping on the plants below.

In Quonset tunnels, since the whole structure is curved, opened roll-up sides expose some of the crops growing along the side to precipitation and other adverse weather conditions. This defect can be partially alleviated by purchasing extended ground posts.

## Footprint

High tunnels come in many sizes, in widths from 14' to over 40' and in incremental lengths. A width to length ratio of 1:2 is ideal for passive solar



gain (See Mazria's "The Passive Solar Energy Book"). However, you get more for your money with a 30' x 96' high tunnel than a 30' x 60' structure.

Narrower tunnels will experience more heat loss than wider tunnels because of their perimeter to growing area ratio. A 10' x 90' tunnel has a 200' lineal perimeter and a 900 square foot growing area, whereas a 30' x 70' tunnel also has a 200' lineal perimeter and 2,100 square foot growing area. The second structure has 133% more growing area, and less than half the ratio of perimeter (or heat loss potential) to growing area. Wider tunnels also tend to be taller and provide improved ventilation and interior air circulation.

Under northern growing conditions, even 30' wide high tunnels can be sufficiently ventilated with roll-up sides and large gable-end vents and doors. In warmer climates, in tunnels with tall, dense crops like tomatoes, narrower tunnels (20' to 26') may more effectively reduce stale air in the middle of the structure without mechanical ventilation.

### **Size**

How big should your high tunnel be? Consider not just how much growing space you expect to use now, but also what you'll want a few years into the future. A well-built tunnel will last at least 20 years.

Another important factor in determining the size of high tunnel to purchase is the amount of additional workload you are prepared to take on. Steve Moore estimates that a 30' x 96' high tunnel that is intensively planted with multiple crops can take 10 hours or more of labor each week after initial set up and skill development. Marketing time is additional. When a farm uses a simple cropping pattern, like Slack Hollow Farm's winter spinach system, regular management time can be greatly reduced.

To get the most from your investment, it might make more sense to start with a short, wide house (i.e., 30' x 48') and add on later than to buy a 16' x 96' high tunnel that may quickly outgrow its usefulness.

Also when determining the size of tunnel to build, take into account how the structure will fit on your property. What are the site possibilities? How much land is available and what is its topography? It is critical to have enough room around the tunnel for easy access with vehicles and equipment, snow removal, water drainage, and ventilation; to avoid shading; and to allow for future expansion (See "Site Considerations" on page 26).

## **Selecting Materials**

### **The Frame**

Historically, wood was commonly used to frame greenhouses, but it has gone out of fashion because of its relatively high maintenance cost and the availability of steel greenhouses. Pete Johnson, a year round grower in North-central Vermont, is an exception. He is currently growing tomatoes and salad crops in a very large high tunnel which he framed with Eastern white cedar and other local trees. For most growers, steel is the best material for a high tunnel frame. The best greenhouse structures are made of high tensile strength steel covered with a very good galvanized coating to prevent rust.

An alternative to steel for the structural members of a high tunnel is polyvinyl chloride (PVC) pipe. Price is PVC's only real advantage compared to steel. Mainly it is used in farmer-built tunnels. Tunnels whose bows are made of PVC pipe are more prone to collapse under snow load and wind. Only narrow high tunnels with a Quonset-shape and smaller walk-in or

caterpillar tunnels can be constructed of this weaker material. It should be noted that PVC is a persistent poison that harms human and animal health and pollutes the environment during manufacture and disposal (See "The Trouble with PVC" on page 31).

Bow spacing will depend upon the overall design of the tunnel, the anticipated snow load, and the strength and capacity of its component steel. Although a 4' bow spacing is used fairly commonly, with trusses placed on every other bow, growers are increasingly turning to 5' bows that utilize trusses on every bow.

(See "Bending your Own Frames" on page 43.)

### **Baseboards and Gable-ends**

Most high tunnels use wood for baseboards, hip boards and gable-end framing. For the gable-end, another option is steel. While more costly, it will not need to be replaced and is easy to work with. For the baseboard, recycled plastic lumber, that is rot and insect resistant, is another comparatively expensive alternative.

In selecting the type of lumber to be used for the baseboard and hip board, consider their rates of decay. Finding lumber that is affordable, durable, and sustainably harvested is a challenge and trade-offs are inevitable. For example, redwood is very expensive and unsustainable.

Other more accessible choices, (depending on location) include rot-resistant wood species such as the cedars, cypress, black locust, and Osage Orange. White oak can also be used, though it will need to be replaced after about eight years, the second time you replace the tunnel's polyethylene film. Cheaper but less attractive options are hemlock, pine, and spruce, listed from most to least rot-resistant.

## **The Trouble with PVC: A Cheap but Unsustainable Material**

Polyvinyl chloride (a.k.a. vinyl or PVC) is a chlorinated hydrocarbon, like DDT and dioxin. During PVC production and disposal, very large quantities of hazardous organochlorine chemicals are produced unintentionally and released into the environment. As a result of its intrinsic hazards, PVC is under intense scrutiny in many countries, by governments as well as environmental and health advocates.

PVC is virtually impossible to recycle because each PVC product contains a unique mix of additives. Even in Europe, where PVC recycling is more advanced than in the U.S., less than 3% of post-consumer PVC is recycled. And even most of this tiny fraction of PVC is merely “down-cycled” into other products, so the amount of virgin PVC produced is not reduced.

The production of chlorine for PVC uses as much energy as 80 medium-sized nuclear power plants would generate. Chlorine production is an extremely energy-intensive process that consumes about 1% of the world’s total electrical output.

Among the toxic chemicals produced during the PVC lifecycle are chlorinated dioxins, chlorinated furans, PCBs, hexachlorobenzene, and octachlorostyrene. Workers and communities are exposed to high levels of the toxic substances released into water, air, and soil due to PVC production. These toxic substances are also released when PVC is incinerated.

As a group, toxic by-products of PVC production are highly persistent. These chemicals do not degrade in nature, so they build up in the environment. Transported by wind currents and water, their presence has been documented even in the most remote regions of the globe.

Since these chemicals are fat-soluble, they build up in the tissues of living organisms. In species high on the food chain (like humans), the levels of these chemicals can be millions of times greater than in the environment. In mammals, these chemicals easily cross the placenta and concentrate in breast milk.

Some of the toxic chemicals produced when PVC is made are dangerous even at extremely low doses. For instance, at doses in the low parts per trillion, dioxin causes damage to fetal development, and the immune and endocrine systems, and impairs reproduction. Cancer and brain and nervous system damage are also associated with exposure to these organochlorines.

In its pure form, PVC is rigid and brittle. To make flexible vinyl products, large quantities of plasticizers called “phthalates” are added. Phthalates cause cancer, infertility, testicular damage, reduced sperm count, suppressed ovulation, and abnormal development of male reproductive tract in lab animals. Like the organochlorine byproducts of PVC production, phthalates are pollutants that bioaccumulate (i.e., persist in the environment) and are found in the tissues and fluids of the human population. As they are not chemically bonded to PVC, but merely mixed in when the vinyl is formulated, they eventually leach out into air, water, and other substances with which the vinyl comes in contact.

Pure PVC is not stable, so lead, cadmium, and organotin are added to stabilize vinyl used in construction and for other extended-life applications. These stabilizers, which are toxic and persistent in the environment, are released when vinyl is formulated, used, and disposed.

*(Source: Thorton, PhD, Joe. Environmental Impacts of Polyvinyl Chloride Building Materials. A Healthy Building Network Report.)*

Due to the dangers of exposure to human and animal health, CCA (chromated copper arsenate) pressure-treated wood has not been produced for most residential and general consumer uses since 2004. Two Canadian government agencies, Environment Canada and Health and Welfare Canada, consider arsenic to be a “non-threshold toxicant” (i.e., a substance for which there is believed to be some chance of adverse health effects at any level of exposure). Arsenic leaches out into soil and is taken up by plants. Organic farmers are prohibited from using arsenic-containing pressure-treated lumber.

Borates are one of the arsenic-free wood treatment alternatives already on the market. Treating oak with approved borate products may lengthen its lifespan to 12 years. Steve Moore has treated oak with sodium tetraborate and sodium octaborate, both of which may meet organic standards if from mined sources. He uses these food grade borate products as they can be readily and inexpensively obtained from local chemical suppliers. Borate wood preservatives such as Boracare can be purchased from pesticide distributors. They penetrate into the wood much more effectively than the food grade materials dissolved in water.

End walls can be made of plywood (painted is best), twin wall polycarbonate sheets (\$1.50/ft<sup>2</sup>), other structured sheets, or just polyethylene film (\$0.10/ft<sup>2</sup>). Of course, opaque materials like plywood prevent light transmission.

Twinwall polycarbonate is an extruded ribbed high-tech plastic with double walls for added insulation. It is sold as structural sheeting. For high tunnels, it has an application for the gable-end walls. As a hoop house covering, it compares favorably with both polyethylene and glass. It transmits up to 83% of light (more than two layers of polyethylene film),

and insulates 40% better than glass, but weighs one-sixteenth as much and won't shatter. It is very durable and cuts easily with a saw. It is far more expensive than poly but costs less than glass.

## Plastic Film

By far the most common covers for high tunnels of all types are made of polyethylene. UV resistant greenhouse-quality polyethylene is far superior to common construction-grade polyethylene. It transmits light better; is more resistant to wind, heat, and yellowing; and has a longer life.

It is important to replace poly film as recommended. For instance, after four years, standard 6-mil plastic loses about 15% of its ability to transmit light. This is particularly significant during winter production, especially in cloudy climates.

Greenhouse film treated with anti-condensate additives prevents condensation drips. Infrared re-radiant (IR) materials are added to film to reduce overnight heat loss. In the U.S., metal halides are typically used to treat the film, while in Europe phosphorous and boron compounds fill this function.

Chris Wien, at Cornell University, points out that "films that lack an additive which blocks infrared radiation can allow so much heat to escape on cold clear nights that temperatures in high tunnels are lower than they are outside the tunnel. You can have instances in which the plants inside freeze before plants just outside the greenhouse. It is very important that polyethylene films used on high tunnels have an infrared blocker added to prevent such a problem."

Anecdotal evidence suggests that the frost forming on the inside of the plastic on a high tunnel is an excellent reflector of infrared radiation. Steve Moore thinks that it may be equal in value to special infrared AC plastic in

unheated structures. In heated structures (where the interior frost is not present), infrared AC plastics undoubtedly retain heat better.

New designer greenhouse films are now entering the market. When the Cramers replaced the film on their Haygrove multi-bay tunnel, they chose *Luminance THB* (thermal heat barrier) poly which costs 10% more than ordinary greenhouse film (*See [www.bpiagri.com/hort-luminance.htm](http://www.bpiagri.com/hort-luminance.htm)*). Using infrared blockers, this enhanced poly reduces excess daytime heat and scorching while also helping to minimize heat loss at night. It also increases light diffusion, making more light available to plants to increase photosynthesis and yields. In particular, it is recommended for ornamentals and nursery stock and has been shown to improve tomato yields. However, the manufacturer cautions that it is not the best choice for early spring growth.

Steve Moore experimented with several types of plastic film over a multi-year period on two adjacent high tunnels. He compared double layers (inflated) of the standard 6-mil 4-year film with infrared re-reflectants and anticondensate to single layer *Coeava*, a 7.8 mil film with reportedly an 8-year useful life.

In south central Pennsylvania, a high tunnel with two layers of 6-mil, 4-year standard poly was warmer by an average of over 6°F during the winter, and had superior plant growth compared to high tunnels with a single layer of 7.8 mil high performance plastic. Steve suspects that this difference in thermal performance between the two types of film would be less significant in a warmer climate or under late fall or early spring conditions.

In carrying out this experiment, Steve had thought that the lower insulating ability of a single layer of poly could be offset by using more layers of row

cover inside the structure. He also hoped to gain the benefit of enhanced light transmission and save money by not using another layer of high tunnel covering. But neither of these theories proved correct. In the dead of winter, the double walled tunnel stayed warmer and outperformed the single layered tunnel.

## Double Versus Single Layers

A double layer of poly film with inflation between the layers provides insulation and reduces heat loss by 40% according to Aldrich and Bartok (see NRAES publication, "Greenhouse Engineering,"). Along with increasing heat retention, the second poly layer reduces the light level by about 10% so a balance must be reached. Low light levels cause plants to become weak and leggy, and slow down growth. As an alternative to double poly layers with an inflation fan, some farmers use multiple layers of floating row covers, which more drastically decrease light transmission. Unless these covers are removed during the day, crop production may suffer.

Many farmers have found it sufficient to use a single layer of polyethylene on their high tunnels. However, in the winter, these high tunnels will have greater heat loss and will be colder than tunnels with a double layer of poly. And where a heating system is used, significantly more fuel will be needed if just a single layer of poly film is employed. Using a double layer requires electricity to run a small blower fan. An alternative to being connected to the electrical grid is a modest solar power system. (*See "Photovoltaic Inflation Systems" on page 48 and "Getting the Right Pressure on Your Inflation" on page 46.*)

## Disposal and Recycling of Agricultural Plastic Films

Plastic film must be disposed of when its useful life is over, presenting the

farmer with a disposal problem. Polyethylene covers on high tunnels and greenhouses make a significant contribution to the growing problem of waste plastics. Polyethylene film has rapidly replaced more durable materials in many farm applications. Plastic bags and covers are used to store hay and ferment animal feeds such as silage and haylage, and palletized goods are shrink-wrapped. Most of these plastic films are produced from low-density polyethylene (LDPE #4) resins.

The most environmentally sound disposal option for these plastics is recycling, which is discussed below. Most agricultural plastics are not recycled, however, in part because recycling opportunities are few and far between. Surveys in New York and Pennsylvania suggest that about half of agricultural plastics are burned and the remainder are buried or dumped on-farm. These states, like many others, do not restrict the on-farm disposal of plastics. Therefore, farmers have no economic or legal incentive to transport these materials to a regional transfer station or other central collection facility for recycling or controlled disposal (at a landfill or incinerator).

Burning agricultural plastics in open fires or burn barrels is a burdensome and unpleasant job. It is also highly polluting and carries short- and long-term health risks. A chemical fact sheet cautions firefighters to wear a self-contained breathing apparatus where there is a risk of exposure to burning polyethylene and states that fumes from molten or burning polyethylene can cause respiratory irritation, headache, and nausea.

Low temperature combustion of plastic film that occurs in on-farm burning produces soot and other noxious emissions and also leaves toxic residues. These emissions are far in excess of those released by municipal waste incinerators that burn

at very high temperatures and are equipped with mandatory pollution control devices. An early 1990s study for the US EPA reported that 20 times as much dioxin, 40 times as much particulate matter, and many times more metal emissions resulted from open burning of household waste in barrels compared to municipal waste incinerators.

Since that study, the gap in emissions from open burning versus incineration has grown exponentially due to stricter pollution control standards for incinerators imposed since 1995. Between 1990 and 2000 emissions of toxic compounds called dioxins and furans declined by about 99% and heavy metals by more than 90% in 66 large municipal waste incinerators.

On-farm burial removes refuse from sight, but decomposition is extremely slow and the potential exists for movement of water-soluble breakdown products into groundwater. Leaving discarded plastic lying around is unsightly and gives a negative impression about agriculture. Pools of water that form in the plastic film serve as mosquito breeding grounds.

Municipal disposal in landfills or incineration is a better alternative for disposing of waste plastics than on-farm burning, burial, or non-disposal. Farmers often reject this option because of the expense, time, and logistics involved.

Another disposal method—pelletizing waste agricultural plastic into fuel nuggets—has been under investigation by at Pennsylvania State University researchers since 1995. The “densified” fuel pellets would generate energy when burned with coal in boilers. These pellets would also eliminate the problem of densely compacted plastic bales causing “hot spots” that damage incinerator equipment.

When highly contaminated plastics are used to make the pellets, more toxic emissions result, sometimes exceeding regulatory limits. One hypothesis is that dirt and debris limit air movement to the combustible materials—a problem that increases when plastic mulches are wet.

Originally researchers envisioned “co-firing” small burners with these waste plastic pellets and coal for heating greenhouses and for other farm applications. But pollution concerns may require that the pellets be burned as a tiny portion of the total mix in a large industry or municipal incinerator. The toxicity of ash from burning plastic fuel pellets on the farm is another area of concern.

Recycling is a superior way to dispose of agricultural plastics. Recycling programs are underway in the Northeast US and Canada for handling most types of plastic resins used in agriculture, though their geographic coverage is spotty. In the absence of such a program, some farmers are stockpiling their waste plastic film until they have access to a recycling program. A trip to purchase equipment or supplies may serve as an occasion to bring waste plastic to a distant recycling program.

In the Northeast, two successful agricultural plastic recycling programs stand out as models for government initiatives and individual entrepreneurs. A polyethylene nursery film collection program was started in New Jersey around 1997. This state-run collection program collects “clean” bundles of nursery and greenhouse films. Its Mt. Holly site accepts film from out-of-state growers. In its first five years, with 100 to 125 growers participating, almost 1.8 million pounds of nursery film was recycled. The \$20 to \$25 per ton fee is substantially less than the \$60 per ton landfill tipping fee.

With an initial aim of reducing farmers' tipping fees, Lancaster County farmer Daniel Zook started a viable agricultural polyethylene collection business that is now actually paying \$80 to \$100 a ton for waste polyethylene. In 2005 (its fifth year), Zook Plastic Recovery sold 500,000 pounds of plastics. Zook set up the program with Trex, a company that reprocesses the material into plastic lumber for decking. Besides guaranteeing a market, this firm guided Zook through start-up and helped him purchase a cardboard baler. Zook holds month-long waste plastic collection drives each spring and fall and for a couple weeks in the summer. He also accepts plastic at other times. After he bales this plastic, he has it hauled to a Trex factory in Virginia.

A 2003 Cornell report lists several other agricultural plastic recycling efforts. A plastic lumber re-processing facility based in Prince Edward Island, Canada, is capable of handling "dirty" LDPE plastics used in dairying. A nationwide, industry-sponsored network collects high-density polyethylene pesticide containers. In the US and Canada, an industry-sponsored program based in Ontario, Canada, picks up, pays for, and re-processes polystyrene nursery flats and trays.

The recycling of agricultural plastics lags behind other types of recycling due to several barriers. Municipal waste transfer stations cannot easily accommodate loose plastic film, which is bulky and difficult to handle. Any collection site must be equipped to bale the material separately.

The quality of agricultural plastic film is often compromised by contamination of dirt, moisture, or debris. Contamination reduces the marketability and/or the price paid. For example, the Trex Company pays less than one-fifth its standard rate for plastics that require pre-cleaning. This

company has installed a \$10 million wash line to clean dirty plastics and also has a pick line to remove debris.

The black and white agricultural films used for mulch bags and wrapping are not much in demand by plastic recyclers as the pigments must be greatly diluted to manufacture marketable plastic lumber. This is relevant to high tunnel growers because, in many regions, the bulk of agricultural film is used by dairy farms and feed producers, and greenhouse film alone might not be abundant enough to support a collection program.

Agricultural plastics are also more costly and inefficient to collect than urban plastics, because they are dispersed across the countryside and farmers dispose of these plastics sporadically and seasonally. Since concentrated quantities of agricultural plastics are more attractive to recycling markets, recycling programs may need to be organized into regional or statewide programs.

Farmers are more likely to participate in recycling where there is a nearby collection system, where burning and dumping are prohibited, and where tipping fees for solid waste disposal are significantly higher than for recyclables. Regional and statewide recycling programs may be most appropriate given the capital costs for recycling equipment, the sporadic and seasonal nature of plastic removal, the dispersed feedstock for recycling, and the critical mass of materials needed to attract industry.

Despite these challenges, opportunities for new private and public recycling efforts abound. While greater farm use of polyethylene is increasing the magnitude of the disposal challenge, high oil prices are also creating greater demand for waste plastics. Farmers who use agricultural plastics should consider taking an active role in making recycling an

easier choice for other farmers in their region.

*This section was adapted in part from Levitan, Lois, and Barros, Ana. "Recycling Agricultural Plastics in New York State." March 11, 2003. 2nd ed. Environmental Risk Analysis Program. Cornell University. <http://environmentalrisk.cornell.edu/C&ER/PlasticsDisposal/AgPlasticsRecycling/>. Personal communications with plastic recyclers and reports from Penn State provided additional background.*

## Multi-Bay Tunnels

Multi-bay high tunnels are a special category of tunnel. The most prominent manufacturer of this type of tunnel is the British company, Haygrove Ltd. As fruit farmers in Herefordshire, England, Haygrove found single bay tunnels inadequate for field-scale crop protection. With multi-bay tunnels in Spain as an inspiration, it developed its own model.

In Spain, where the climate is mild, multi-bay tunnel frames can be rather weak. Haygrove tunnels improved on the original Spanish tunnel concept by making them appropriate for use in the U.K. Since they were first introduced in 1996, their use has spread to 30 countries, from Norway to Australia, and by 2006, they were protecting over 7,000 acres of crops.

Like other high tunnels, Haygroves enable the farmer to extend both ends of the growing season. They also prevent rain, wind, and hail damage, reduce pesticide use, and avoid the loss of harvest days due to precipitation.

In terms of environmental management, Haygroves vent more fully than typical single-bay high

tunnels. Haygrove's lacing system holds the polyethylene cover securely in place while allowing a grower to vent the tunnels up to 8' or 10' high. This design feature virtually eliminates the problem of excess tunnel heat and humidity.

Haygroves are three-season structures. They are not designed to support a heavy snow load. In temperate regions, the polyethylene film should be removed for the period of time during which snowfall is possible. The film is "hibernated" by pulling it off the hoops, down onto the Y of the legs, and covering it with black plastic that is secured with twine. This eliminates any chance of snow damage to the tunnel and protects the film from UV exposure when not in use. At the beginning of the next growing season, the film is remounted on the hoops and secured with the rope lacing.

Haygroves can withstand relatively high winds. Each Haygrove leg and anchor has an auger welded to it, and these are drilled 30" into the soil; cement is not used. This keeps Haygrove tunnels from lifting out of the soil, something that can happen with single bay tunnels that are not cemented into the ground. During high winds, Haygroves should be left fully vented. This decreases pressure on the tunnel by allowing some of the wind to move through the tunnel while still shielding the crops from its full force.

Most growers in temperate climates vent (open) and close their tunnels every day for the first six weeks or so of the season and then leave them completely vented for the majority of the growing season. No special attention to venting is required during the period when severe thunderstorms are most likely. Daily venting and closing is again practiced during the fall.

Haygrove tunnels concentrate the runoff in the leg rows between the bays, and this water must be controlled. Prior to construction, most growers form shallow swales that are covered with weed barrier cloth. The legs are then drilled into the soil through small slits in the cloth.

Haygroves are sold in various bay widths and heights to accommodate a range of needs. The structures are tall enough for tractor access and dwarf tree-fruit production. The Haygrove design allows adjacent bays to be managed for different microclimates, with curtains dividing bays with cool and warm crops. The configuration of these tunnels provides for easy expansion of growing area to the sides or ends.

These tunnels retail for about half the cost of traditional, single-bay high tunnels. The minimum Haygrove purchase is a half-acre; however, a full trailer load contains two acres and the delivery cost is the same whether the trailer is full or not.

Construction time is faster for these multi-bay structures than for traditional high tunnels. Typically, growers report 250 to 300 man-hours to construct an acre-sized Haygrove compared to 75 or 100 hours for a 30' x 96' tunnel (1/12th acre).

Construction involves relatively few tools and no lumber. Along with delivery, Haygrove provides on site hoop bending and construction training for customers. Since these tunnels follow the natural contours of the land, there is no need for heavy equipment to prepare a level site.

### **Inferior Multi-Bay High Tunnels**

One farmer decided to buy a less expensive multi-bay structure to save money, and regrets his purchase. Rob Hastings, the owner-operator of Rivermede Farm in Keene Valley, New York (in the Adirondacks), may be one of the most Northern-most

farmers in the Eastern U.S. to grow crops in a multi-bay high tunnel. He grows fall raspberries, everbearing strawberries, and cut flowers (for October weddings) in the structure and also has five heated and unheated single bay high tunnels.

After going on the Haygrove grower tour in England, he was sold on this type of high tunnel. Based solely on economic considerations, he opted to buy a cheaper model from another company (which we will refer to as "Brand X"), instead of a Haygrove, which it superficially resembled. He purchased a four-bay structure that covers a quarter acre for under \$7,000; each bay measured 26' x 100'. A Haygrove covering a third acre would cost \$12,000, in part because the shipping is the same whether one buys an acre or a fraction of an acre.

"There are many subtle differences that you can't see in the catalogue," says Rob, explaining his disappointment at the weaknesses of the structure he selected. He has had to modify and reinforce the high tunnel in order for it to function. Contrasting the two companies, he characterizes Haygrove as "farmers turned metal benders" and Brand X as "metal benders who happen to make products for farmers."

While on the tour in England, he watched how quickly the Haygrove went up. The Brand X structure took much longer to assemble and construction was far from smooth. "There is no comparison," Rob observes. A major difference is that Haygroves can be constructed out of extra-long pieces because they are shipped from the United Kingdom in a container and then delivered as a unit to the customer. Haygrove personnel come and bend the hoops on the farm.

Brand X's multi-bay high tunnel consists of multiple pieces that need to be bolted or screwed together. For

instance, there are five pieces in each Brand X hoop while a Haygrove hoop comes as a single piece. “I had to find a flat surface on the farm to assemble the hoops so they would not be twisted.” Each of these joints presents a weak spot, and Rob has experienced a plethora of failures around these joints. “I had to double screw every hoop where it joins the Y post,” he says. “It either tore out the tek screw or bent them.”

Rob has identified various annoying design flaws in the Brand X. In a Haygrove the hoops rest on the Y post and no water can get in and freeze. The Brand X structure allows water to enter and freeze. Haygroves have a peg at the top of each Y post for tying the rope to that keeps the plastic film on. The Brand X lacks the peg and there is nothing to tie to.

The Haygrove has an effective way to finish off the end walls and simultaneously provide wind bracing. The Brand X structure comes with a reinforced plastic end wall which has not been satisfactory. “The flopping plastic acts like a gigantic sail tied down with an anchor,” observes Rob. He plans to do some cross bracing to shore up the plastic.

The lack of technical support is another major frustration. “Brand X barely knew I had bought one,” he says. “When I called, I was talking to someone who was clueless and who was not a farmer.” Rob recommends other farmers learn from his mistakes and “invest in the best.” “I’m sorry I didn’t ask questions,” he concludes.

### Single-Bay Tunnels in the Haygrove Style

Haygrove’s newest product is the “Solo” single bay tunnel. It comes in sizes appropriate for the smaller grower. Typical dimensions are 24' x 200' and 28' x 200", though various widths and lengths are available. This Quonset-shaped structure is built of 14 gauge galvanized steel hoops. Its

poly cover is secured to the framework with the same rope lacing system used on Haygrove’s multi-bay tunnels and therefore provides excellent venting. With a minimum 10' height at the peak, it has a large air volume for its size. Being a single-bay tunnel, the Solo seals well for maximum season extension. Like other Haygroves, it is sold as a three-season structure and is not engineered for snowload.

Solos can be erected on hills or uneven sites and compared to other single-bay tunnels, much less construction time is required. As with Haygrove’s multi-bay high tunnels, no carpentry or extra materials are required. While Solos are single-bay tunnels, they can be built on double prong anchors (8" between bays) to cover large areas.

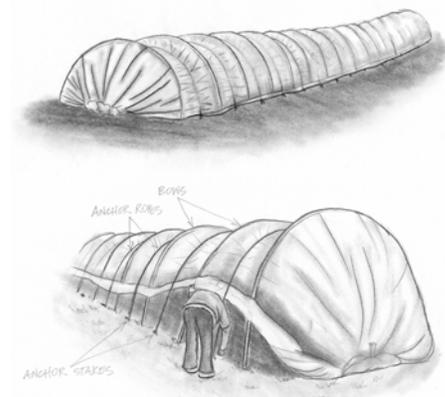
A Solo package, including the poly film cover and 12 mil roll-up doors for both ends, costs about \$1 per square foot, or about half the cost of a more conventional high tunnel.

## Walk-in Tunnels (Caterpillars)

Walk-in tunnels are inexpensive alternatives to the greenhouse-like structures that come to mind when thinking about high tunnels. For an equivalent area under cover, they cost less than a quarter of the price of a more traditional high tunnel. With respect to environmental modification, they are intermediate between traditional high tunnels and the low tunnels commonly used by vegetable growers. (See “Low Tunnels” on page 38.)

Due to their segmented appearance, some growers call these structures “caterpillar tunnels” (see diagram). They have been used to grow

vegetables, cut flowers, greens, and herbs.



The size of walk-in tunnels is variable. They range from 8' to 18' in width and cover two to four beds. Their length may be from 24' to 300' or more, depending on the length of beds they are intended to cover and limits to the sizes of available covers. The flexible tunnel length enables a grower to construct a walk-in tunnel virtually anywhere on the farm because it can be sized to fit into a farm’s existing bed system. The tunnels are tall enough to walk in and are accessed by ducking under the sides anywhere along their length (hence their name).

Bows for walk-in tunnels may be made from PVC, electrical conduit, or galvanized steel hoops. To erect the tunnel, the bows are either slipped over ground stakes made of rebar or tubular steel, or the bows are set directly into the ground about a foot deep. Bows are spaced six to ten feet apart, depending on the site’s wind exposure. It is best not to construct the tunnel broadside to the wind, but if that is unavoidable, the tunnel will serve as an effective windbreak for crops planted on its lea side.

A 1/4" rope tied from hoop to hoop is used to form a ridge purlin. The purlin is attached to heavy-duty ground stakes at both gable ends. The structure is quite “loose” when uncovered; much of the tunnel’s structural integrity comes from the

cover and the way it is secured to the ground.

Walk-in tunnels may be covered with greenhouse plastics, heavy spun-bonded fabrics such as Typar, or shade cloth. The cover should be matched to the intended use of the structure. The less expensive Typar might be the better choice, for example, if the goal is to give a boost (or provide insect protection) to cool-season crops such as spring greens. Greenhouse plastic would be the better choice for an early planting of tomatoes. And shade cloth might be selected for rooting strawberry tip cuttings.

The covering is held fast by 1/4" ropes that are drawn over the top of the structure (Canastoga wagon-style) and are secured to stakes or earth anchors in the ground. These ropes give the structure its segmented, caterpillar-like appearance. The edges of the plastic are left loose, but the covering should be sized so that there are at least two feet of extra material on each side. In particularly windy locations, the covering may be secured by placing rocks or small sand bags on the edges of the plastic. At the gables ends, the plastic is bunched together using rope, and the rope is tied to a secure stake. The tunnel's dimensions should be configured to fit commonly available greenhouse films or floating row covers.

While they have many advantages, starting with their cost, walk-in tunnels are really three-season structures. The wide bow spacing that keeps them cost-effective greatly reduces their snow load capacity, so the covering should be removed before winter. However, walk-in tunnels with a bow-to-bow spacing of 4' and a width of 10' have reliably withstood snow.

Walk-in tunnels must be ventilated manually to avoid excessive

temperatures. During the coldest periods of the year, sections of the sides (the cover) are propped up with short "Y" shaped props or branches cut for the purpose. When temperatures warm, the sides may be rolled up along the entire length of the tunnel. Clamps or tall "Y" props can help hold the rolled up plastic in place. The sides must be rolled down when high winds threaten.

These tunnels are highly portable. They may be erected and dismantled relatively quickly. For example, two 200' long units built to cover three beds of lettuces were erected by Ted and Jan Blomgren and a co-worker over the course of a morning.

One way to reduce the annual costs of construction and dismantling is to leave the caterpillar tunnel in place from year to year, and to develop a list of tunnel crops around which a crop rotation plan might be developed.

Walk-ins are highly adaptable structures. They may be built over existing crops, or over bare ground for a later planting. They may be built in the fall, left uncovered during the winter, and then covered in the spring for an early planting. Or they may be used to cover tomatoes during the spring and summer, and then taken down and reconstructed over an existing fall spinach crop.

### **Caterpillar Tunnels at Windflower Farm**

Ted and Jan Blomgren have found many uses for walk-in tunnels to produce vegetables and cut flowers. On Windflower Farm in Easton, New York, they construct some of their caterpillars with metal bows spaced 10' apart, and others using PVC bows spaced 6' to 8' apart. At any given time in the growing season, the Blomgrens may have as many as 9,000 to 12,000 ft<sup>2</sup> of walk-in tunnels on their farm, with the typical tunnel 200' long. Most are covered in 6 mil greenhouse plastic obtained from

Farm Tek, "the only source of very long plastic" of which they are aware. Their other walk-ins are skinned in Typar.

Caterpillars have become important on Windflower Farm because they are easy to construct and cover, and are inexpensive, while providing many of the benefits of a multi-bay structure like a Haygrove. Steel hoops and plastic film for one of their 16' x 200' tunnels cost them about \$1,500, about one-third the cost of a Haygrove multi-bay high tunnel. In addition, air flow in caterpillars is excellent—better than in a more expensive, conventional high tunnel—as caterpillars open fully like a Haygrove. (But unlike a Haygrove, management of high winds in a caterpillar requires closing the sides.)

To get high quality fruit early from their first planting, Ted and Jan transplant zucchinis and cucumbers into walk-in tunnels on May 1. These tunnels span three beds that are six feet on center. Early harvests of both of these vegetables are important in meeting their goal of delivering a diversity of "real vegetables" (as opposed to salad greens) to their New York City-based CSA membership.

Cucumbers, planted two rows per bed into black plastic (or six rows across a tunnel), start yielding a substantial harvest by the end of June. The zucchinis go into bare ground, with one row running in the middle of each of the three raised beds. Each row of zucchini is sandwiched between rows of quick Asian greens. These greens will be harvested by the middle of June just as the zucchinis are filling out the space. By the end of the first week of July, the zucchini harvest is going strong.

On May 1, tomato transplants are planted into three beds in walk-in tunnels for first harvest in July. Using the hybrid variety 'Mountain Spring' as their mainstay, Windflower Farm

gets a high quality fruit that bears well over a long period of time. In 2005, they harvested from their May 1 planting until late October. They have also produced eggplants and bell peppers in walk-in tunnels.

The Blomgrens initially experimented with walk-in tunnels to protect China asters from aster yellows, a disease transmitted by leafhoppers. The alfalfa fields that surround Windflower Farm are leafhopper habitat. Ted says they skinned these tunnels with Typar because “We thought we could get away without rolling up the sides,” something that wouldn’t be possible for plastic-covered tunnels which trap heat more effectively. “Now, tarnished plant bug is our only insect problem,” says Ted.

Besides preventing aster yellows, the tunnel environment produced China asters with stems three feet long. Short-stemmed cut flowers are not desirable and Ted and Jan realized that the extended stem length was a benefit that tunnels could provide other cut flowers. The absence of wind and reduction of light in the walk-in tunnels are two factors associated with longer stems.

Windflower Farm currently grows stock, snapdragons, godetia, larkspur, Bells of Ireland, and lisianthus in walk-in tunnels to achieve much earlier blooms and longer stems. They have come to prefer walk-in tunnels to regular high tunnels. They are also convinced that plastic film is superior as a tunnel cover to Typar except for mid-summer production. In the summer, they use Typar to protect against insects, diffuse the brightness of the sun, and shelter the flowers from wind.

Though they are moving away from Typar, Ted stresses that it has two virtues. It costs about half as much as plastic, and its light weight makes it easy to use. “I can cover a 200-foot tunnel myself,” he said. It takes a

minimum of two people to install a plastic cover.

On walk-in tunnels built for fall lettuce and salad mix, they may still use Typar as the cover. Ted and Jan sometimes build tunnels over beds where they have already set transplants. Using a marking rod, they pound in stakes at 10' intervals and then lower hoops over the stakes. For an inside cover, they use a midweight fabric, such as 0.9 ounce Covertan, suspended over low wire hoops. They harvest mature lettuce from these unheated tunnels as late as Thanksgiving. Ted cautions that this design has no capacity to bear snow.

### **Caterpillar Tunnels at New Minglewood Farm**

In 2004, Chris Lincoln grew half his tomato crop at New Minglewood Farm in walk-in tunnels. Better yields and a higher percentage of #1s have convinced him to raise his entire tomato crop in these tunnels. This year, he used four 100' long tunnels to grow 800 row feet of heirloom tomatoes for retail sale at a farmers' market and to restaurants.

Chris notes higher yields, higher quality, a longer harvest season, and cleaner fruit as benefits of growing fresh market tomatoes in these tunnels. He also counts the low cost of the tunnels and the ease of moving them to different sites on the farm as advantages to walk-in tunnels when compared to more permanent, stationary high tunnels.

Getting earlier tomatoes was not the overriding factor in adopting this growing environment. New Minglewood's typical tomato schedule (reported for 2005) is as follows: Seed on March 28, transplant on May 16, begin picking on July 23, last harvest on October 18, first killing frost on October 21.

In 2005, they sold 5,885 pounds of tomatoes with an average of 11.8

pounds per plant on their 500 plants. (Production varies considerably among the diverse heirloom varieties grown at this farm.) At \$3/lb. for #1 fruit, and \$2/lb. for seconds, Chris and his wife, Tammara Van Ryn, grossed almost \$16,000 on this crop, produced in one-eighth of an acre of caterpillar tunnels.

Chris used 1-1/2" diameter Schedule 40 PVC pipe, rather than steel, for bows. The bows are spaced every 6' and placed on rebar stakes, with a rope and another pair of stakes in between. His tunnels are 10' wide, which allows just two rows of tomatoes per tunnel.

Ideally, he said, the tunnel would be 2' wider, with a corresponding increase in height to accommodate the indeterminate varieties that he grows. As it is, when the plants fill out, they are a bit crowded and grow into the sides and roof of the tunnel. The actual size is perfect for determinate tomatoes, which he does not grow.

Wind is the biggest threat to the walk-in tunnel design, but built properly, they seem to hold up adequately. Unlike a more conventional high tunnel, where the plastic is attached directly to a steel frame, walk-in tunnel plastic is held down by ropes secured to the earth by means of rebar stakes or earth screws. Like the Blomgren's structures, Chris uses ropes over top of the plastic and secured to long rebar stakes driven deep into the ground. If these ropes are not secure, wind can cause damage. To prevent wind damage, it is critical that these anchors are long and stout enough to hold the ropes.

Chris believes that walk-in tunnels have been more time-consuming for New Minglewood Farm than regular hoop houses would be. This is mainly due to the labor involved with setting up and covering these tunnels before tomato planting and disassembling

them later in the year after the plants have been removed.

Another regular task during the spring and fall is opening and closing the sides, depending on sun, rain, and temperature. To vent, Chris rolls up the plastic and clips it to a rope. Once the weather warms, the sides stay up all summer.

In 2006, Chris mulched with black landscape fabric. He used a weed barrier fabric to accelerate tomato development, suppress weeds, and prevent soil splash on the plants. He chose a 6' wide fabric and covered the 2' wide space between tunnels as well as all the ground inside of the tunnels, enabling him to locate the tomato rows at the intersection of two pieces of the fabric. This arrangement eliminated the need to burn or cut plant holes into the fabric.

## Low Tunnels: An Alternative to High Tunnels

In some climates, low tunnels can be an inexpensive alternative to high tunnels for cold weather season extension. Low tunnels are simple, protective structures consisting of wire hoops covered with polyethylene or fabric row covers. Though more labor intensive, with well-planned beds, they can be assembled with just a small investment.

On Tobacco Road Farm in Lebanon, Connecticut (about an hour east of Hartford), organic market growers Bryan and Anita O'Hara have over an acre of low tunnels for extending fall vegetable production and growing a variety of baby and braising greens and other vegetables throughout the colder months. The low tunnels are removed in late spring to allow for

easier field production. The O'Haras complement their low tunnels with two small 14' and 16' wide high tunnels used for seedling production.

The couple markets their mixed vegetables and maple syrup cooperatively with Bryan's father. Their stand always sells out at the two Saturday farmers' markets their family attends from early May through Thanksgiving. The nearby Willimantic Food Co-op, which just tripled its store area, is their other major outlet and has a standing order with them.

Several factors, including southern exposure and wind protection, help make low tunnels feasible for impressive season extension at Tobacco Road Farm. The low tunnels at the farm are situated on a sloping, southwest facing field. Conifer windbreaks mitigate the prevailing west wind. A third environmental advantage to this site is a large dammed river the size of a small lake located beyond a grove of trees next to the field.

But this is not a snow-free environment. While most snowfall is light, the O'Haras may receive as much as 8" or 10" of snow at a time. And though snow usually melts in a few days, their low tunnels have been covered by snow for a month, without harmful effects on the plants inside. However, when the tunnels are covered in snow, harvest is impossible.

The O'Haras have been using these inexpensive tunnels for about 10 years at an annual cost of about 7.5 cents per square foot (\$3,000/acre) to extend their growing and harvest season. At first, their goal was to push fall production later. Driven by strong customer demand for the good-tasting, cold weather-grown greens and their need for farm income, they just kept on expanding their off season production. Bryan said, "We realized

that these plants are winter annuals. They have no disease and insect pests when we grow them out of season."

The seeding dates for their winter and spring low tunnel crops are astonishing late. They continue planting through the beginning of December and start up again in February. All these crops—which include lettuces, Asian greens, spinach, kales, Claytonia, scallions, beets, carrots, dandelions, parsley, and arugula—are direct seeded with an Earthway seeder. Normally, harvest continues until Christmas and then resumes in March. The mild winter of 2005-06 allowed them to harvest at intervals in January and February as well.

At Tobacco Road Farm, beds are standardized at 3' wide, separated by 8" wheel tracks. For this bed width, the wire hoops must be at least 80" long. The hoops are about 24" high at center. The minimum hoop size is 3/16" round stock. Either steel or galvanized will do. Wire hoops are spaced 2' to 2.5' apart. The tunnels are covered with two layers of plastic at frost, usually in early October. In March, the warming sun prompts the removal of the plastic film and its replacement with Agribon. This spun polyester row cover breathes and lets water pass through. Both the plastic and the fabric row cover are held down with up to a dozen 6 ml black plastic sand bags.

Bryan buys 20' lengths of steel wire at a local metal shop and has them chop it in thirds, precisely the length he needs. Bryan has used the same steel wire for over 10 years. Chafing from surface rust only occasionally causes rips in the Agribon row cover, while also helping to stick the cover onto the hoops. Galvanized steel is much more expensive.

For ease of operation, the beds are covered in 40' sections. Wind build up makes longer sections unmanageable,

and with the length of this low tunnel, two people working together can uncover a whole field in little time. Bryan uses two layers of cheap 1.5 mil construction grade plastic. A 200' length of this film will suffice for two 40' sections. To close the ends, 50' of plastic is needed to skin 40' long low tunnels. The ends are bunched up and pulled tight to create tension over the top of the hoops.

Bryan is an enthusiastic missionary for the environmental control provided by low tunnels. They prevent excess precipitation from damaging germination and ruining crops, and protect crops from wind and cold. Bryan has measured a 35°F gain on sunny days. The low tunnels should be vented if the outside temperature reaches about 70°F and opened to catch precipitation if excessively dry. In 2005, Bryan kept the beds uncovered until the extremely late first frost on October 21, a lapse he came to regret since 20" of rain that month broke all records. If the beds had been covered, the crops would not have been devastated and it would have been more possible to control chickweed with cultivation.

Irrigation is rarely required until later in winter. The plants seem to like it drier in winter, Bryan explained, noting two mechanisms that plants use to withstand cold temperatures: desiccation and mineralization of their sap to reduce their freezing point. These mechanisms make these crops extremely sweet-tasting in the winter.

In the central Connecticut climate, snow build up has not been a problem for the low tunnels. The hoops are pushed down by snow load, but pop up, pushing off the snow, as soon as the sun begins melting it. Snow accumulation on the wheel tracks insulates the low tunnels, provides a windbreak, and also holds down the row cover.

For several years, Bryan has been selecting Asian greens and arugula for cold hardiness. This breeding has yielded quick results, boosting winter survival from 10% to 100% in arugula just by collecting seed from planted that made it through the winter. For his first breeding experiments, Bryan seeded three adjacent beds of Mizuna, Tatsoi, and Miruba. He replanted the next year from the seed he harvested from the Mizuna mother plants which successfully over-wintered. Each year he collects seed from subsequent generations of plants interbred from the three cultivars that survive the winter. The hybrid seed selected from a large gene pool produces very vigorous plants with much greater cold tolerance. He can stagger seed production by altering when he harvests for salad mix.

Chickweed is the biggest weed problem in winter low tunnel production. Before they grew year round, the O'Haras used to tolerate chickweed in their fields over the winter so now they are grappling with a huge seed bank. Seeding crops very late in the fall allows late tillage, reducing chickweed germination, and the Asian greens sown on December 2 were their cleanest over-wintered crop.

At Tobacco Road Farm low tunnels have a variety of advantages:

- Low tunnels are very inexpensive and quick to install. Bryan estimated that two people could cover over an acre in two days.
- In the spring, low tunnels are more easily cooled than high tunnels to prevent bolting.
- Low tunnels are easily converted from plastic to cloth covers.
- Low tunnels allow farmers to manage water, protecting crops and soil from excess rain and wind. A slight slope allows water to run off the tunnels.

- Low tunnels allow farmers to grow without insect and disease pressure.
- Since low tunnels are closer to the earth, they provide more heat to the plants in the day. Bryan said they are 3° to 5°F warmer than ambient temperature on cold nights, similar to their high tunnels.
- Cold growing conditions enhance the taste of the crops.
- Low tunnels convert readily for regular summer production, allowing triple cropping.
- Soil preparation and other tractor operations can be carried out in the field prior to quick installation of the low tunnels.
- As they are easily removable, low tunnels reduce soil salt build up.

The O'Haras also recognize that low tunnels have the following disadvantages, some of which are common to high tunnels as well:

- The biggest issue is that low tunnels are more labor intensive. To hoe, harvest, or irrigate, the coverings must be removed.
- Low tunnels cannot be automated and require a lot of bending to manage the cover, causing worker discomfort.
- Low tunnels restrict access compared to high tunnels. One can't harvest on a cold, windy day.
- Cut lettuce grown under plastic film-covered low tunnels (or high tunnels) is very delicate and wilts quickly. This is one reason to convert to a fabric covering like Agribon.
- Low tunnels provide a perfect environment for chickweed, the ultimate winter weed.
- The plastic cover on low tunnels must be vented during warm sunny late fall and winter days.

*(An earlier version of this profile appeared in "Growing for Market.")*