Design and Construction of High Tunnels in West Virginia

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High tunnels are passively vented, solar greenhouses that are used to lengthen the production and marketing season of vegetable and fruit crops (*Figure 1*). No artificial heating/cooling or ventilation system is used within the high tunnel, and the only external connection is water for drip or micro-irrigation. Most high tunnels are covered with a single or double layer of polyethylene plastic (6-mil; greenhouse-grade) and have a useful life of 20 years if properly constructed and maintained. Crops within high tunnels are usually grown directly in the soil rather than artificial growing media, but soil-less substrates (perlite, compost, water) can be used for crop production within high tunnels.

High tunnels are very effective in collecting radiant energy from sunlight and using this energy to increase air and soil temperature to accelerate crop growth. Thus, in areas with abundant sunlight, high tunnels will be very effective for early-season harvest and lengthening the growing season.

High tunnels facilitate intensive crop production on a small land area and are conducive to sustainable farming practices such as intercropping, cover cropping, compost application and biological pest management. Crops within the high tunnels are protected from environmental stresses such as drought, wind, hail, rain and intense sunlight. Heavy rainfall prevents soil erosion within the high tunnel. The dry environment within the high tunnel keeps the plant canopy dry and reduces diseases and weed growth. High tunnels also physically exclude many pests from attacking the crop including insects and wildlife. As a result, many growers use high tunnels for organic production of fruits and vegetables. High tunnels have significantly lower investment costs and annual operating costs than standard greenhouses.


Figure 1. High tunnels are passively vented, solar greenhouse structures covered with a single or double layer of polyethylene plastic.

The first step in high tunnel crop production is choosing a suitable site for the structure (*Figure 2*). Most high tunnels are permanent structures, so the site chosen will be the area for crop production for several seasons. Depending on location, building permits may be required. The site should have no history of perennial weeds or diseases and be well-drained and free of large stones. A soil test should be conducted in advance of choosing the site for the high tunnel. Since high tunnels are manually vented, they should be accessible. Water is an essential input for high tunnels, so access to water (surface or well) is necessary. While most high tunnels do not require electrical inputs,

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some growers choose to have electric fans which circulate air or inflate air between double layers of polyethylene.

High tunnels do not have to be constructed on perfectly level land, but a building pad or terrace can be made prior to constructing the high tunnel. Slope along the length of the high tunnel will facilitate water movement but should not be greater than 3%. Slope across the width of the high tunnel can be compensated by adjusting the height of the ground posts on either side. The construction pad can have sloping sides to channel water and snow runoff from the high tunnel structure.

The site should have full sun and good air flow since these are essential inputs to how well a high tunnel functions. Low areas that accumulate cold air (frost pockets) and water or sites close to a tree line or other structures which may cast a shadow on the high tunnel structure should be avoided. Also, areas with strong wind should have a wind break to prevent excessive wind stress or snow accumulation against the structure.

Figure 2. The site for construction of a high tunnel should be accessible, well-drained with abundant sunlight. (Photo Credit: E. Coleman)

Orientation or positioning of the high tunnel is site dependent. The primary criterion should be maximizing passive ventilation. Therefore, for suitable ventilation, the high tunnel should be oriented so the length of the structure is perpendicular (i.e., at right angles) to prevailing winds at the site. In West Virginia, a north-south orientation is optimal for cross ventilation. Above the 40° latitude, most high tunnels are oriented in an east-west direction for maximum light interception particularly during low light months of winter. Most of West Virginia is below 40° latitude, so orientation is based on maximizing cross ventilation. Generally, the strongest winds which can damage the structure occur from the north-northwest in West Virginia, so a north-south orientation allows this potentially damaging wind to hit the smallest surface area of the structure (i.e., the end wall).

High tunnels vary in length, width and shape. Ideally, the high tunnel should be at least tall enough to walk in with ease (> 7 ft.) or for equipment to be taken into the structure to till the soil, apply compost or create raised beds. Most high tunnels are 15-30 feet wide; 9-15 feet high and up to 200 feet in length (*Figure 3*). Optimal length for an individual structure with roll-up sides is approximately 100 feet. Many growers will start with a short, wide structure (e.g., 30 ft x 48 ft) and add on to the length in subsequent years. A shorter, wider structure is superior to a longer, narrower structure since the former will have less area exposed to the outside environment.

Larger high tunnel structures tend to store more heat during the day and are less likely to overheat. At night, when maintaining a stable temperature is crucial, larger high tunnels are less likely to cool down as rapidly. In addition, a taller high tunnel allows warm, buoyant air to rise in the structure facilitating ventilation.

Figure 3. Quonset- (**A**) and Gothic- (**B**) shaped high tunnels.

There are two main structural designs for high tunnels: Quonset and Gothic. Quonset structures have a round roof with slightly shorter and curved sidewalls (*Figure 3A*), while Gothic structures has a pointed peak (A-frame) with straight sidewalls (*Figure 3B*). Gothic structures tend to shed snow and ice better than Quonset structures. Gothic structures also allow for a peak or gable vent to be added to the structure which facilitates air movement and ventilation.

Sidewalls on the high tunnel structure are usually rolled-up to facilitate cross ventilation (*Figure 4*). Therefore sidewalls should be at least 5 feet in height to maximize ventilation. During inclement weather, the sidewalls are closed.

Figure 4. Sidewalls are rolled-up to facilitate cross-ventilation within the high tunnel.

If the site for high tunnel construction encounters significant snow or wind stress throughout the year, cross-braces (bracing of the bows) or other supplemental bracing of the frame may be necessary to strengthen the structure. Frames for high tunnels are usually galvanized steel but other materials can be used. Wood frames have been used as framing material for high tunnels. However, there is more blockage of sunlight from the wood frame than by other framing materials. Polyvinyl chloride (PVC) has also been used as a framing material for high tunnels (*Figure 5*). Most PVC-framed high tunnels are smaller in width than steel-framed structures. While PVC high tunnels can be lower in costs, they tend to be vulnerable to damage from wind, snow and ice unless they are properly braced.

Figure 5. PVC-framed high tunnels are functional high tunnels.

After the site and general design of the high tunnel has been chosen, the structure can be constructed. Both spring and fall are excellent times of the year to build a high tunnel. The soil is amenable to construction, and the air temperature is suitable for pulling and stretching plastic over the structure. If building on a site which is presently in sod, the sod can be tilled after most of the high tunnel has been constructed.

The next step is to place the corner ground posts of the high tunnel so that the structure is ultimately square. The Pythagorean Theorem can be used to establish a 90°angle at each corner. The Pythagorean Theorem states the square of the hypotenuse of a 90° triangle is equal to the sum of the squares of the other two sides. Once one corner is square, the other three corner posts can be set so that the diagonals (length from one corner post to the opposite end corner post) are equal (*Figure 6*). For example, a 30 ft x 96 ft high tunnel will have a 100.5 ft length diagonal ($30^2 + 96^2$) if the structure is square.

After the corner posts have been squared, they can be backfilled with cement to provide support for the structure (*Figure 7*). Obviously cement makes the structure permanent, so if there are plans to move the structure in the future, this step may be avoided. The remaining high tunnel ground posts are driven into the soil as straight as possible to various depths (usually no less than 18 inches) with a sledge hammer or post driver. A post level will be very useful in making sure each post is plumb. Also a leveling line (mason twine) connected to the bolt holes of each corner post can be used to drive each post to a depth which is level. A positioning or spacing jig can be used to evenly space the ground posts. Most ground posts are placed 4, 5 or 6 feet apart, with 4 feet the recommended spacing for high tunnels in West Virginia.

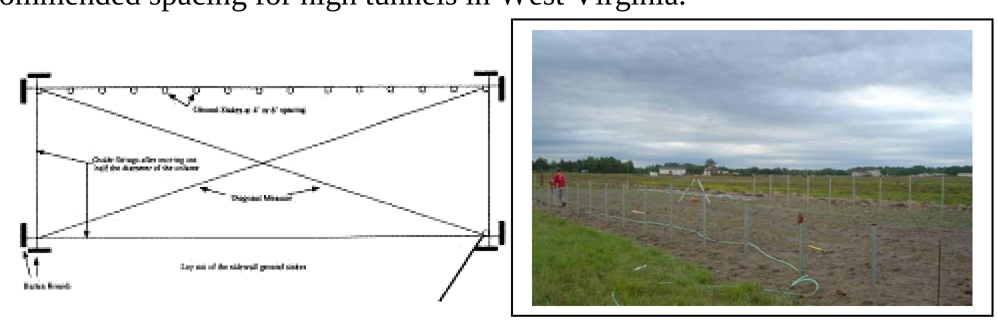


Figure 6. The high tunnel structure must be square at each corner post.

Figure 7. Corner posts can be set in cement to provide strength for the high tunnel structure. A leveling line is used to ensure each ground post is level. (Photo credit: A. Montri)

The bows of the structure typically are 2-3 pieces and can be loosely assembled on the ground. Each bow is then inserted into the ground post and secured with 1-2 carriage bolts. Placing each bow in the ground post will require approximately 3 workers. After the bows are secured in place, the purlins should be attached to the bows. Purlins are smaller diameter pipes which are bolted (or clamped) to the bows to provide stability to the structure (*Figure 8*). Each high tunnel frame should have 1-3 purlins. Cross-braces can be attached to provide increased strength to the high tunnel frame.

Figure 8. Purlins, cross braces, base boards and hip boards are attached to each bow to provide stability to the high tunnel frame.

After the purlins have been added to the structure, the baseboards and hipboards can be placed on the high tunnel. Baseboards and hip boards add strength to the base of the frame (*Figure 8*). For most high tunnel frames, 2 inches x 6 inches x 10 feet wood (or recycled plastic) boards are suitable. Pressure treated wood can be used for both hipboards and baseboards. Each section of baseboard is bolted onto the ground post or secured with a pipe strap (*Figure 9*). The baseboard and hipboard must be level across the length of the high tunnel. Each joint between sections can be spliced with a small segment of board.

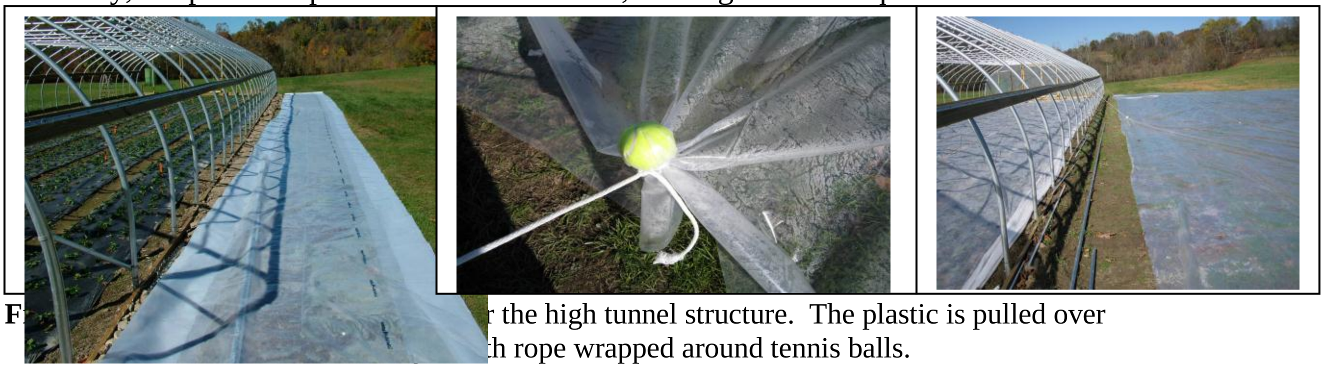
Hipboards are attached 5-8 feet above the baseboards (*Figure 8*). Hipboards provide additional strength to the structure and are the boards in which the plastic covering the high tunnel structure is attached. Aluminum channel lock can be secured to the hipboard to provide a location for securing the plastic (*Figure 9*).

Figure 9. Pipe straps are used to secure the baseboards and hipboards to the high tunnel frame. Aluminum channel lock is used to secure the plastic to the frame.

After the frame has been assembled, the end walls can be constructed. End walls vary in design from a simple fabric curtain to a wood-framed structure with doors (*Figure 10*). End walls provide strength to the high tunnel and should be built to provide easy access of people and machinery. End walls can be covered with polyethylene plastic, polycarbonate or plywood. The north-facing end wall can be covered with double layer of polyethylene plastic to provide greater protection from the north wind. Some growers will completely remove the end wall coverings during warm weather.

Figure 10. There is a diversity of end wall designs for high tunnel structures.

The plastic covering can be placed over the high tunnel structure after construction of the frame and end walls has been completed. There are many types of greenhouse plastics, but the plastic should be a UV- (ultraviolet light) treated plastic, 6 mil in thickness, with a useful life of approximately 4 years. IR (infrared) blocking plastic is also available and will provide better heat retention. A calm day with moderate temperatures will be optimal for covering the structure. Plastic should not be pulled over the structure if temperatures are lower than 60°F since it will be difficult to obtain a good stretch on the plastic. Ideally, the plastic should be taut and not flap against the bows. At least 4-5 people will be needed to pull the plastic over the high tunnel. The plastic comes in a roll which is unrolled along the length of the house (*Figure 11*). After unrolling the plastic, a handful of the plastic can be folded around a tennis ball at various distances. Rope is then tied to this ball and thrown over the frame (*Figure 11*). Carefully, the plastic is pulled over the structure, making sure it is square with the frame.



F[illegible] r the high tunnel structure. The plastic is pulled over [illegible] h rope wrapped around tennis balls.

The plastic is attached to the frame with wiggle wire or polylock placed in each aluminum channel lock on the hip board (*Figure 12*). One side should be completely secured first then any slack in the plastic can be pulled and the other side wired. The plastic should be as taut as possible. The channel lock on the end bows are used to hold the plastic to the end walls of the high tunnel. The plastic is clamped on to a metal roll bar (purlin pipe) which serves as the bar for rolling the plastic up or down on each side wall. A "T- or L"- shaped handle can be made to serve as a hand crank which makes rolling the pipe up easier (*Figure 13*). Rope can be laced on the sidewalls to hold the plastic sidewall closer to the frame and prevent flapping in wind (*Figure 12*).

Figure 12. Plastic is secured to the frame with wiggle wire within each channel lock. Rope can be laced along the sidewall for tightening the roll-up sides. Water runoff from the high tunnel can be collected and used for irrigation.

To prevent excessive water movement into the high tunnel, a drainage ditch should be dug to channel water away from the high tunnel. A woven landscape fabric can also be used to divert excess runoff water and prevent weeds from growing close to the high tunnel. Rain gutters can also be secured to the hipboard and used to channel water into a storage tank that can be used to irrigate crops within the high tunnel (*Figure 12*). Batten tape can be used to secure the plastic to the end wall frame. Batten tape is applied over the plastic and stapled into place (*Figure 14*).

Figure 13. A L-shaped handle for rolling the sidewalls up or down.

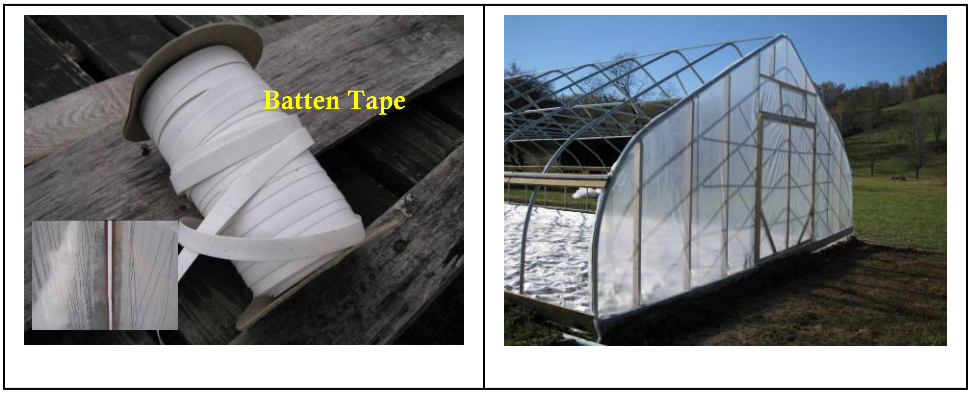


Figure 14. Batten tape is used to secure the plastic to the end wall frame.

Additional High Tunnel Construction Resource Material:

The Hoophouse Handbook. 2003. Growing for Market. L. Byczynski (ed.).

The Winter Harvest Handbook. 2009. E. Coleman. Chelsea Green Publishing Co., White River Junction, VT

High Tunnel Production Manual. 2008. Penn State Center for Plasticulture.

Walking to Spring. 2003. Paul and Alison Weidiger.