Energy and Capital Costs of
High Tunnel Construction
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Introduction

Commercial vegetable growers in Kentucky have been using unheated high tunnels for year-round production for more than a decade. Proponents of high tunnel production claim it is a more energy-efficient and economical means of supplying off-season vegetables than trucking field-grown produce from warmer climates. Increasing energy-efficiency can contribute to both environmental and economic sustainability.

In 2005 we constructed a high tunnel at the Kentucky State University Research Farm as part of an organic vegetable production demonstration. We set out to measure the economic and energy efficiency of using this structure for season extension.

Materials and Methods

A 9 x 12 m high tunnel was constructed on organic land at the Kentucky State University Research Farm. Two layers of 6 mil poly were supported by 11 hoops, spaced 1.2 m apart. Wood-framed walls at either end continued a screen door and two windows for passive ventilation. Hoops and end walls were supported by steel pipes, driven 0.6 m into the soil. Poly was attached to the frame with aluminum ‘wiggle wire’ fastener tracks. A 60 W blow fan was used to maintain an insulating pocket of air between the plastic layers.

The cost and weight of construction materials was recorded, and the energy used to manufacture and transport these materials to the site was estimated.

Cool-season crops were transplanted and direct-seeded in the house beginning in late January. These were gradually replaced with warm-season crops, beginning in April (Fig 1). Temperatures were recorded at half-hour intervals 3 cm above the soil surface, 2 m inside and outside the north wall of the tunnel.

Windows were opened on most winter and spring mornings to allow passive ventilation. They were closed in the evening to retain heat through the night. At the end of May windows were opened permanently, and sides were rolled up to 1 m above the soil surface.

Results

Table 1. Embodied energy and cost of high tunnel construction materials.

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Weight (kg)</th>
<th>Life (y)</th>
<th>E intensity (MJ/kg)</th>
<th>Embodied E (GJ)</th>
<th>Cost ($)</th>
<th>Amortized ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 hoops</td>
<td>steel</td>
<td>543</td>
<td>20</td>
<td>31</td>
<td>16.8</td>
<td>842</td>
<td>1,020</td>
</tr>
<tr>
<td>Poly fasteners</td>
<td>aluminum</td>
<td>45</td>
<td>20</td>
<td>241</td>
<td>10.8</td>
<td>546</td>
<td>310</td>
</tr>
<tr>
<td>Cladding</td>
<td>6 mil poly</td>
<td>184</td>
<td>4</td>
<td>86</td>
<td>15.8</td>
<td>3950</td>
<td>660</td>
</tr>
<tr>
<td>Framing</td>
<td>pine</td>
<td>250</td>
<td>10</td>
<td>12</td>
<td>30.0</td>
<td>300</td>
<td>160</td>
</tr>
<tr>
<td>Toe boards</td>
<td>plastic lumber</td>
<td>150</td>
<td>10</td>
<td>12</td>
<td>18.0</td>
<td>180</td>
<td>100</td>
</tr>
<tr>
<td>Screen doors</td>
<td>steel</td>
<td>18</td>
<td>10</td>
<td>31</td>
<td>5.6</td>
<td>56</td>
<td>25</td>
</tr>
<tr>
<td>Blower fan</td>
<td>steel</td>
<td>1</td>
<td>10</td>
<td>151</td>
<td>0.1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1,191</td>
<td></td>
<td></td>
<td>97.1</td>
<td>5,876</td>
<td>2,800</td>
</tr>
</tbody>
</table>

Fig. 2. Average daily temperature outside (top) and inside the KSU high tunnel. Vertical bars show temperature range for each day.

Discussion

The materials used to construct our high tunnel required an energy investment of approximately 6 GJ per year over the life of the tunnel (Table 1). Operating the blow fan continuously demands another 6 GJ per year. 12 GJ could be used to truck approximately 4,000 heads of lettuce to Kentucky from California - five times as much as the tunnel produces in a single harvest.

High tunnels can be part of an economically sustainable operation. Our materials cost ~$3,000 (Table 1). The value of the harvest will cover the cost of construction materials in the first year, and we will fall well below the amortized annual cost of $328.

The tunnel buffered temperature fluctuations during the transition from winter to summer by boosting winter highs and moderating winter lows (Fig. 2). Differences between inside and outside temperatures became less pronounced when the sides were rolled up, and windows were left open for summer ventilation.

We found linear relationships between inside and outside temperatures for the KSU tunnel, with differences that pronounced as cold temperatures (Fig. 3). Such relationships could be used to measure high tunnel effectiveness.

Our energy analysis raises questions about the environmental sustainability of even unheated houses using the double layer inflated poly system. This is just one of the systems used by the growing number of producers using high tunnels for season extension in Kentucky. Single layer houses, and double layers separated by stretched lines of T-tape are also used. These should be more energy efficient, as these smaller houses using the inflated poly system. We plan to evaluate alternative systems in future studies.

Conclusion

1. High tunnels can allow year-round vegetable production in Kentucky.
2. The double layer inflated poly system is affordable, but energy intensive at the scale tested.
3. Daily minimum and mean temperatures inside a high tunnel are linearly related to outside temperatures.

Fig. 3. Relationships between inside and outside temperatures.

Fig. 1. Stages in construction of the KSU high tunnel. A summer cover crop of cowpea was incorporated at the tunnel site (top left). End walls were prepared off-site (top middle). Steel pipes were pounded into the soil to anchor the structure (top right). Visitors to the KSU field day attached the bows to the anchor pipes (center left). Two layers of plastic were stretched over the frame (center middle) and attached with wiggle wire (center right). Cool-season crops planted in late January (bottom left) were ready for harvest by March (bottom middle). Warm season crops planted in April were harvested in June and July (bottom right).