Apple Tree Trellis Redesign

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Client: Anna Wallis  Faculty Advisors: Dr. Dan Guyer & Mr. Phil Hill

Background

Trellis systems support apple trees using wire and support posts. Purpose of a trellis is to provide support for fruit-bearing trees by balancing above ground forces with below ground forces through a desired material. Typically, the support posts are made of red pine (Figure 1). Increasing demand for red pine in housing and power industries has caused availability issues. Red pine prices have increased $3.50/post since 2019. Growers are not planting due to high trellis costs. Modern orchard layouts make trellises a necessity.

Constraints

- Withstand 100 mph winds (Dyer, 2021)
- Aligns with typical orchard parameters:
  - 3 ft in-row tree spacing
  - 11 ft between-row spacing
  - 12 ft tree height
  - 1 row = 175 ft
- Trellis height ≥ 12 ft

Design Alternatives

Modern orchard layouts make trellises a necessity. Increasing demand for red pine in housing and power industries has caused availability issues. Red pine prices have increased $3.50/post since 2019. Growers are not planting due to high trellis costs. Modern orchard layouts make trellises a necessity.

Material Testing

A four-point bend test (Figure 5) was conducted at the MSU Civil Infrastructure Lab to determine the strength of our trellis members.

- MTS software was utilized with a deformation rate set at 0.01 in/s.
- Trellis members were judged based on their stiffness.
- Stiffness coefficient was calculated by taking the slope of the elastic, linear portion of a force vs. displacement graph (Figure 6).

Material Testing

- Red Pine
  - Withstands 6,000 lb of force
  - Costs $144 per row

- Steel
  - Withstands 3,550 lb of force
  - Costs $483 per row

Discussion

After considering the cost, strength, ease of installation, and ability to be considered organic for each material, red pine was chosen as the optimal design.

Red Pine

- Withstands 6,000 lb of force
- Costs $144 per row

In the case that red pine is not available in the location of the orchard, 3.74 in steel posts are the next best option.

- 3.74 in Steel
  - Withstands 3,550 lb of force
  - Costs $483 per row

Both fiberglass options are not optimal due to their reduced ability to support weight. They easily deformed during material testing. To provide sufficient strength, the posts would need to have a maximum spacing of 4 ft, which is not practical for an apple orchard.

Standards and Regulations

- Standard Test Methods for Bend Testing of Material for Ductility (ASTM E290-14)
- 100 mph Wind Rating (ASCE 7-16)
- Organic Certification (7 CFR 205.602)
- Arsenic (prohibited) is used to treat lumber used for trellises

Select References


Economics

Material costs include cost of posts and to deliver to Michigan. It does not include attachments, wire, or labor needed for installation.

- Red Pine
  - $21.96
  - $2.36
- Steel
  - $209.16
- Fiberglass
  - $24.14

We were given a $1,000 budget for this project. To track expenses and the existing budget remaining, Table 5 was used. The total budget used was $343.

Acknowledgments

Thank you to the following staff and faculty who guided us through the design project:

- Ms. Ceren Aydin, Mr. Brian Gietzel, Dr. Dan Guyer, Mr. Phil Hill, Dr. Mark De Kleine, Dr. Dana Kirk, Dr. Emily Lavely, Dr. Wei Yi Lu, Dr. Luke Reese, and Dr. Anna Wallis

Table 1: Summary of criteria used to select optimal design.

<table>
<thead>
<tr>
<th>Trellis Material</th>
<th>Cost ($/row)</th>
<th>Stiffness Coefficient (kN/m)</th>
<th>Installation (%)</th>
<th>Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Pine</td>
<td>$144</td>
<td>4,534</td>
<td>5</td>
<td>No</td>
</tr>
<tr>
<td>65 mm (3.74 in)</td>
<td>$500</td>
<td>7,734</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Steel</td>
<td>$500</td>
<td>1,354</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>Foam Fiberglass</td>
<td>$453</td>
<td>264</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Cement Fiberglass</td>
<td>$585</td>
<td>185</td>
<td>1</td>
<td>No</td>
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</table>

Table 2: Stiffness coefficient and elastic deformation comparison.

<table>
<thead>
<tr>
<th>Trellis Material</th>
<th>Stiffness Coefficient (kN/m)</th>
<th>Elastic Deformation Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Pine</td>
<td>4,534</td>
<td>1-030</td>
</tr>
<tr>
<td>65 mm (3.74 in)</td>
<td>7,734</td>
<td>0-780</td>
</tr>
<tr>
<td>Foam Fiberglass</td>
<td>264</td>
<td>0-25</td>
</tr>
<tr>
<td>Cement Fiberglass</td>
<td>185</td>
<td>0-1,005</td>
</tr>
</tbody>
</table>

Table 3: Decision matrix for design alternatives.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Red Pine</th>
<th>Steel</th>
<th>Foam-filled Fiberglass</th>
<th>Cement-filled Fiberglass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Strength</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>6.48%</td>
<td>4.8%</td>
<td>3.8%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

Table 4: Material costs as of July 2022.

<table>
<thead>
<tr>
<th>Material</th>
<th>Max. Spacing</th>
<th>Cost/Unit</th>
<th>Cost/Row</th>
<th>Posts/Row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Pine</td>
<td>$21.96</td>
<td>$2.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>$209.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiberglass</td>
<td>$24.14</td>
<td></td>
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</tbody>
</table>

Table 5: Total project cost and remaining balance from $1,000 budget.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost ($)</th>
<th>Quantity</th>
<th>Total Cost ($)</th>
<th>Balance ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>$100</td>
<td>144</td>
<td>$10,100</td>
<td>$243</td>
</tr>
<tr>
<td>Fuel</td>
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<td>Steel</td>
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<td>1</td>
<td>$44.00</td>
<td>$199</td>
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</tbody>
</table>

Figure 1: Depicts a red pine trellis post at Clarksville Research Center.

Figure 2: Free body diagram with forces applied during 100 mph wind.

Figure 4: Steel 95 mm (3.74 in) trellis member at Clarksville.

Figure 3: Cement filled fiberglass post (left), unfilled fiberglass post (center) and foam filled with fiberglass red fiberglass post (right).

Figure 5: Bend test machine at MSU Civil Infrastructure Lab.

Figure 6: Material comparison force vs. displacement graph.