Greenhouse Vegetable Production

Tuesday afternoon 2:00 pm

Where: Gallery Overlook (upper level) Room E & F
MI Recertification credits: 1 (1B, COMM CORE, PRIV CORE)
CCA Credits: NM(0.5) CM(1.5)
Moderator: Marissa Schuh, Vegetable Educator, MSU Extension, Adrian, MI

2:00 pm  Grafting; True Benefits and False Hype; Yield, Diseases, Economics
  • Judson Reid, Cornell Cooperative Extension, Penn Yan, NY

2:30 pm  Greenhouse Lighting 101
  • Roberto Lopez, Horticulture Dept., MSU

3:00 pm  Alternatives to In-Ground Production
  • Judson Reid, Cornell Cooperative Extension, Penn Yan, NY

3:30 pm  Recognizing Tomato Nutrient Disorders
  • Brian Whipker, Horticultural Science Dept., North Carolina State Univ.

4:00 pm  Session Ends
Grafting High Tunnel Tomatoes
yield, rootstock and price influence profitability

Judson Reid and Cordelia Hall, Cornell Vegetable Program
Email: jer11@cornell.edu, phone: 585.313.8912

Introduction

Tomatoes grown in soil based greenhouse and high tunnel systems have proven profitable in wholesale auction settings as well as farmer’s markets and CSA’s. However, as production continues in the same soil, risk of root-zone diseases, nematodes and soil nutrient deficiencies increase. Grafting, the combination of two separate cultivars into one plant, is one management approach to these challenges. Previous Cornell research has demonstrated the ability of grafted plants to increase tomato yields by 5 lbs per plant compared with ungrafted control plots. This can increase net revenue by $1.50/sq ft of greenhouse space; or $62,500 per acre. However, does grafting make sense horticulturally and/or economically in all situations?

Materials and Methods

On February 21, 2012 seeds of tomato scion varieties Big Dena and Panzer (no longer commercially available) and rootstock varieties Maxifort and Arnold were sown in a soilless potting mix (Promix, Premier Horticulture) at a cooperating greenhouse in Penn Yan, NY. Seeds of rootstock variety Colossus were sown on February 22. All varieties were transplanted to 50-cell flats at first true leaf stage, on March 6. On March 23 grafts were made with the three root stock varieties and two scions, for a total of 6 combinations, 40 finished plants per combination. Cuts were made with a double-edged razor blade on a 45º-angle across the stem of both varieties, immediately above the cotyledons, the union was then joined with 2 mm silicon grafting clips. Grafted plants in 50-cell trays were placed immediately in a darkened healing-chamber with 100% relative humidity and temperature of 80-84 ºF. Grafted plants were gradually re-acclimated to greenhouse bench conditions, with increasing intervals of time out of the healing chamber, until complete acclimation, approximately 12 days post-grafting. Grafted plants were transplanted into an unheated high tunnel with a Lima Silt Loam soil on April 18. Conventional fertilization was carried out per grower standards. Plants were grown on a vertical trellis and pruned to a single growing point. Graft survival was recorded with viable plants available on April 18. Number of fruit per block and total weight per block was recorded at each harvest, beginning June 6 and ending October 30. Data were analyzed using statistical software Analysis of Variance (ANOVA) procedure, and treatment means were separated using Fisher’s Least Significant Difference (p<0.05).

Results

Survival of grafted plants was highest with Colossus rootstock, with an average of 94%, followed by Maxifort with 84% and Arnold 73% (Chart1). When examining graft survival based on scion, Big Dena had an average 86% survival across the two rootstocks and Panzer 79%. Grafting significantly increased yield of both scion cultivars (Table 1). The highest yielding combination as measured by pounds per plant was Big Dena X Maxifort with a value of 30.6. Panzer X Maxifort followed with 29.16 lbs per plant.

Discussion

Graft survival rate is not likely related to cultivar compatibility. Two people conducted the grafting process and differences in technique may account for variability in survival. It is critical however, to
match the scion stem diameter as best as possible to root stock stem diameter. Vigorous scions such as Panzer could be started several days after all of the root stock used here. Grafting of Panzer scions onto all rootstock trialed here offered significantly higher production than the ungrafted controls. Big Dena yield was higher on all rootstock, but only significantly separate from ungrafted when grafted to Maxifort. It should be noted this trial took place in ‘fresh’ tunnel soil that had not seen vegetable production for several years. In other work by the Cornell Vegetable Program it has been noted that yield response to grafting is greater at sites that have a recent history of intensive tomato production.

Yield as measured by pounds per plant, is perhaps the most important metric in this trial, however it is not the only one needed for selecting a scion/rootstock combination. The grower noted a preference for Panzer fruit, based on color and shape. The three rootstock X Big Dena combinations gave the significantly heaviest fruit weight, creating their own grouping. Fruit size may be an important attribute for some markets. Unfortunately Panzer is no longer commercially available in the US. Yield precocity is also important for tomato marketing, as a price differential exists for early season fruit.

Conclusions

Is grafting always the right decision? This depends on:

- scion and rootstock combination
- transplant cost
- soil conditions
- market value of tomatoes

For example economics of grafting Panzer onto Maxifort are very favorable based on the yield increase in this trial. The grower estimated cost of a Maxifort X Panzer is $1.50/plant vs. ungrafted Panzer at $0.36/plant. With a mean increase of 4.7 lbs per plant, the break-even price required is $0.24 per lb. Indeed, all of the Panzer/rootstock combinations were significantly higher in yield than the ungrafted treatment at a level that justifies the investment. However, Big Dena when grafted onto Arnold and Colossus shared a statistical grouping with the ungrafted treatment. This could indicate an economic negative performance, by increasing the cost of the transplant, without significant yield increase. Big Dena grafted onto Maxifort yielded significantly higher to justify the investment.

If commercial grafted transplants cost $3.00/plant, additional revenue of $2.64 per plant is required (based on grower estimate). The lowest performing combination in this trial would have to be marketed at nearly $1.00 per pound to justify the grafting investment. Current USDA terminal price points are often below $0.5/lb.

These comments do not consider the impact of rootzone disease, which was not detected in this trial. Growers with infested soils would face greater losses from ungrafted production further justifying the investment. As many tunnels have soil further compromised than this site, yield differences between grafted and non-grafted will likely be higher.

In the future our program plans to publish data on the relationship between grafting, spacing and economic returns.
Table 1. Yield in fruit and lbs for 8 tomato rootstock/scion combinations.

<table>
<thead>
<tr>
<th></th>
<th>Mean Fruit Weight (lbs)</th>
<th>Total Fruit per Plant</th>
<th>Mean Plant Yield (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Big Dena</strong></td>
<td>0.64 bc</td>
<td>38.31 c</td>
<td>24.54 cd</td>
</tr>
<tr>
<td><strong>Big Dena X Maxifort</strong></td>
<td>0.70 a</td>
<td>43.69 ab</td>
<td>30.60 a</td>
</tr>
<tr>
<td><strong>Big Dena X Collosus</strong></td>
<td>0.68 ab</td>
<td>39.69 bc</td>
<td>26.80 bcd</td>
</tr>
<tr>
<td><strong>Big Dena X Arnold</strong></td>
<td>0.72 a</td>
<td>37.56 c</td>
<td>26.85 bc</td>
</tr>
<tr>
<td><strong>Panzer</strong></td>
<td>0.55 e</td>
<td>44.58 a</td>
<td>24.42 d</td>
</tr>
<tr>
<td><strong>Panzer X Maxifort</strong></td>
<td>0.62 cd</td>
<td>47.19 a</td>
<td>29.16 ab</td>
</tr>
<tr>
<td><strong>Panzer X Collosus</strong></td>
<td>0.60 cde</td>
<td>47.00 a</td>
<td>28.11 b</td>
</tr>
<tr>
<td><strong>Panzer X Arnold</strong></td>
<td>0.58 de</td>
<td>47.88 a</td>
<td>27.61 b</td>
</tr>
</tbody>
</table>

*p value* | 0 | 0.0001 | 0.0003

*Chart 1. Survival rates out of 40 plants per six rootstock/scion combinations.*
Greenhouse Lighting 101

Roberto G. Lopez
Department of Horticulture
Michigan State University
rglopez@msu.edu

Quantity of Light

- The term daily light integral (DLI) describes this cumulative amount of light (photons of light) that an area or location receives during one day.
- DLI is the cumulative amount of photosynthetic light received in 1 square meter of area (10.8 sq. ft.) each day, or mol·m⁻²·d⁻¹.

DAILY LIGHT INTEGRAL (DLI)

- DLI cannot be determined from an instantaneous reading
- DLI is similar to a rain gauge
- A rain gauge is used to measure the total amount of rain that was received in a particular area during a 24-hour period

DAILY LIGHT INTEGRAL (DLI)

- Values from sunlight outdoors vary from 5 (winter in the North) to 60 mol·m⁻²·d⁻¹ (in the Southwest in summer)
- In a greenhouse, values seldom exceed 30 mol·m⁻²·d⁻¹ because of shading and structures which can reduce light by 40 to 70%
- Target DLI of 15 mol·m⁻²·d⁻¹ for most greenhouse vegetables

DLI OUTDOORS

http://flor.hrt.msu.edu/production-info

DAILY LIGHT INTEGRAL (DLI)

Varies due to factors that influence light intensity and duration:
- Time of the year (sun’s angle)
- Location and cloud cover
- Day length (photoperiod)
- Greenhouse glazing/covering(s)
- Structure and obstructions
- Hanging baskets
- Supplemental lights
PLANT RESPONSES TO INCREASED DLI

- Leaves (smaller and thicker)
- Time to flower (faster, due partly to temperature)
- Branching (increased)
- Stem diameter (increased)
- Plant height (sometimes reduced)
- Root growth (increased)

METHODS TO INCREASE DLI

- Minimize overhead obstructions such as hanging baskets
- Make sure your glazing is properly cleaned (ie. whitewash, dust, algae removed)
- Provide supplemental lighting from High Pressure Sodium Lamps (HPS), Metal Halide or Light Emitting Diodes (LEDs)

SHADING INCREASES AS PLANTS GROW

Without plants With plants

25% shading 42% shading

SUPPLEMENTAL LIGHTING DURING VEGETABLE, LEAFY GREEN AND HERB PRODUCTION

VEGETABLE DLI REQUIREMENTS

- 100 to 200 µmol·m⁻²·s⁻¹ of PAR from HPS lamps and LEDs is typically delivered to vegetables and cut flowers
- Target DLI of 15 mol·m⁻²·d⁻¹ for most greenhouse vegetables

VEGETABLE DLI REQUIREMENTS

- **Lettuce.** A DLI of 12 to 13 mol·m⁻²·d⁻¹ or higher is generally recommended
  - Optimal DLI of 15 to 20 mol·m⁻²·d⁻¹
  - Supplemental PPF of 50 to 100 µmol·m⁻²·s⁻¹
  - SL can also improve lettuce quality (such as heart firmness) but increase tip-burn incidence
  - Photoperiod of 10 to 16 hours
LETTUCE TARGET DLI

• 17 mol·m⁻²·d⁻¹ target
  • Assumes good air flow (paddle fans)
• If >17 mol·m⁻²·d⁻¹ for 3 days in a row → leaf tip burn
• If poor air flow or concerned about tip burn, set a lower target
• Days to harvest at:
  • 17 mol·m⁻²·d⁻¹ 35 days
  • 10 mol·m⁻²·d⁻¹ 60 days
  • 5 mol·m⁻²·d⁻¹ 119 days

LETTUCE GROWTH IS DIRECTLY PROPORTIONAL TO LIGHT

Linear relationship between lettuce (cultivar Ostinata) final shoot dry mass and total accumulated light levels.

Adapted from Both et al., 1997, Acta Horticulturae 418:45-51

WITHIN BOUNDS – PLANT BIOMASS ACCUMULATES LINEARLY WITH INCREASED LIGHT

Leaf Tip Burn (Calcium deficiency at high light)

Neil Mattson, Cornell Univ.

END OF PRODUCTION
SUPPLEMENTAL LIGHTING OF LETTUCE

• Under low-light greenhouse conditions, foliage of red leaf lettuce is:
  • Often pale green to light purple
  • Not as aesthetically appealing to consumers
**END OF PRODUCTION**

**SUPPLEMENTAL LIGHTING OF LETTUCE**

- Color is a key component
  - Influences and registers with consumer’s initial perception of product quality
  - Appeal
- Lettuce crops
  - Leaf color
    - Intensity
    - Distribution

**END OF PRODUCTION**

**SUPPLEMENTAL LIGHTING OF LETTUCE**

- Anthocyanins are responsible for the red pigmentation in leaves
- Anthocyanin concentration
  - Dependent on environmental conditions
    - Light quality
    - Light intensity
    - Temperature

**SUPPLEMENTAL LIGHTING OF LETTUCE**

- Finishing stage of crop cycle
- Proposed practice to enhance color
  - Increase product quality and aesthetic value

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**Light source**

<table>
<thead>
<tr>
<th>Light source</th>
<th>Light type</th>
<th>Spectral ratio (Red:Blue)</th>
<th>Intensity (μmol m⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Photoperiodic</td>
<td>---</td>
<td>4.1</td>
</tr>
<tr>
<td>HPS</td>
<td>Supplemental</td>
<td>100:0</td>
<td>70.0</td>
</tr>
<tr>
<td></td>
<td>Light-emitting</td>
<td>50:50</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>diodes (LEDs)</td>
<td>0:100</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0:100</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0:100</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**LETUCE ‘CHEROKEE’**

<table>
<thead>
<tr>
<th>Light source</th>
<th>Red LED</th>
<th>R:B LED</th>
<th>Blue LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>HPS</td>
<td>5 days of EOP</td>
<td>7 days of EOP</td>
<td>14 days of EOP</td>
</tr>
</tbody>
</table>
CONCLUSIONS – LETTUCE
• Five to 7 days of EOP SL of 100 µmol·m⁻²·s⁻¹ red:blue, red or blue LED light
• Promotes enhanced red pigmentation of lettuce ‘Cherokee’, ‘Ruby Sky’ and ‘Vulcan’ foliage when grown under a low greenhouse DLI

VEGETABLE DLI REQUIREMENTS
• **Cucumber.** A DLI of 12 to 19 mol·m⁻²·d⁻¹ or higher is generally recommended
  • Optimal DLI ≥30 mol·m⁻²·d⁻¹
  • SL increases fruit relative growth rate, fruit number and weight, and fewer fruits are aborted
  • Supplemental PPF of 180 to 220 µmol·m⁻²·s⁻¹
  • Photoperiod of 16 to 20 hours

Source: Lighting Up Profits
**Vegetable DLI Requirements**

- **Sweet pepper.** Fruit quality and yield are highest when average DLI is 30 mol·m⁻²·d⁻¹ or higher.
  - Supplemental PPF of 95 to 160 µmol·m⁻²·s⁻¹
  - Photoperiod of 16 to 20 hours

- **Tomato.** Fruit quality and yield are highest when average DLI is 30 mol·m⁻²·d⁻¹ or higher.
  - Requires a daily dark period of at least four hours, as plants under continuous light become stressed and chlorotic, and fruit yield is reduced.
  - Supplemental PPF of 145 to 210 µmol·m⁻²·s⁻¹
  - Photoperiod of 16 to 18 hours

**Tomato Yield**

<table>
<thead>
<tr>
<th>DLI (mol·m⁻²·d⁻¹)</th>
<th>Rule of thumb: 1% more light → 1% greater yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

**Light Control Strategies**

- Time clock
- Instantaneous thresholds light/shade
- Target daily light integral
**Greenhouse Lighting 101**

### TIME CLOCK

- Lights on for set time each day, often from:
  - October to March (North)
  - November to February (South)
- Manually turn off during sunny days

**Example:**
- Lights on 12 hours/day (6 to 10 am, 4 pm to 12 am)
- $100 \, \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \times 12 \, \text{hrs} \rightarrow 4.3 \, \text{mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$

### INSTANTANEOUS THRESHOLDS FOR LIGHT AND SHADE

- Computer control system
- Light sensor

**Example:**
- $< 300 \, \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ for 10 mins → Lights on
- $> 300 \, \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ for 10 mins → Lights off
- $> 600 \, \mu\text{mol m}^{-2} \cdot \text{s}^{-1}$ for 10 mins → Shade retracted

Continue light in evening until DLI target met

### TARGET DAILY LIGHT INTEGRAL

- Light and Shade System Implementation (LASSI)
- Lou Albright, Cornell University
- Light/shade decisions made at 1 hour time steps
  - Uses solar DLI predictions
  - Delays shading when possible to avoid over shading
  - Lighting to take advantage of nighttime off-peak electricity rates when possible

### SUPPLEMENTAL LIGHTING GUIDELINES

- The high-pressure sodium lamp is the most economical lamp type for many seasonal greenhouse applications
- Lamps should turn on/off automatically by an environmental control computer based on light conditions, for example:
  - On: Light intensity less than 200 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ for more than 5 minutes
  - Off: Light intensity more than 400 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ for more than 10 minutes
**Supplemental Lighting Guidelines**

- Light intensity and duration are both important.
- Common recommendation is to provide 50 to 75 μmol·m⁻²·s⁻¹ of photosynthetic light (PAR) at plant level, which adds 0.18 to 0.27 mol·m⁻² each hour lamps are on. For example:

<table>
<thead>
<tr>
<th>Hours per day</th>
<th>PAR intensity (μmol·m⁻²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1.4 mol 2.2 mol 2.9 mol</td>
</tr>
<tr>
<td>12</td>
<td>2.2 mol 3.2 mol 4.3 mol</td>
</tr>
<tr>
<td>16</td>
<td>2.9 mol 4.3 mol 5.8 mol</td>
</tr>
<tr>
<td>20</td>
<td>3.6 mol 5.4 mol 7.2 mol</td>
</tr>
</tbody>
</table>

**DLI Calc (Google: DLICALC)**

- Allows you to estimate the supplemental DLI from your supplemental light source.
- Allows you to estimate the hours of lamp operation to achieve a target supplemental DLI.

**Greatest Benefit from Supplemental Lighting**

- From October to March (North)
- From November to February (South)
- During non-sunny conditions (during the night and on cloudy days)

**Supplemental Lighting Guidelines**

- Choose lamps based on:
  - Efficiency: Photons per watt (μmol/W)
  - Greenhouse dimensions, especially hanging height
  - Reliability: Use trusted brands with warranties
  - Purchase and installation costs and return on investment
  - Light spectrum for desired plant responses
### LEDs for Photosynthetic Lighting

- Potential challenges with LEDs:
  - Investment cost
  - Don’t emit heat to plants below; crops under HPS lamps can be 2–4 °F warmer than with LEDs
  - Durability and reliability
  - Light emission pattern (often directional light)
  - Shading of fixtures

### Operation Costs

- Operation costs are primarily electrical
- At 10.3 cents per KWH and a lighting level of 500 fc (65 µmol), the electrical costs in cents per ft² week are shown below:

<table>
<thead>
<tr>
<th>Situation</th>
<th>12 hr/d</th>
<th>15 hr/d</th>
<th>18 hr/d</th>
<th>21 hr/d</th>
<th>24 hr/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 W lamp</td>
<td>4.6</td>
<td>5.8</td>
<td>7.0</td>
<td>8.2</td>
<td>9.3</td>
</tr>
<tr>
<td>600 W lamp</td>
<td>4.1</td>
<td>5.1</td>
<td>6.1</td>
<td>7.1</td>
<td>8.1</td>
</tr>
</tbody>
</table>

### High-Intensity Lighting Efficiency

For LEDs, the efficiencies are rapidly improving

<table>
<thead>
<tr>
<th>Lamp type</th>
<th>PPF efficiency (µmol/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS, magnetic, 400 W</td>
<td>0.94</td>
</tr>
<tr>
<td>HPS, magnetic, 1000 W</td>
<td>1.16</td>
</tr>
<tr>
<td>HPS, electronic, 1000 W</td>
<td>1.30</td>
</tr>
<tr>
<td>HPS, electronic, 1000 W, double ended</td>
<td>1.70</td>
</tr>
<tr>
<td>Ceramic metal halide, 315 W</td>
<td>1.34–1.44</td>
</tr>
<tr>
<td>Red + Blue LED fixtures</td>
<td>0.89–1.70</td>
</tr>
</tbody>
</table>

ACKNOWLEDGMENTS

• We thank former graduate student research assistants and technicians who have performed experiments to generate this information.

• We also thank the USDA, private horticulture and lighting companies that support our lighting research including:

Questions?

Roberto Lopez
rglopez@msu.edu
Container Grown Tomatoes
An alternative to in-ground for high tunnels

Judson Reid and Cordelia Hall, Cornell Vegetable Program
Email: jer11@cornell.edu
Phone: 585.313.8912

Intro

A common question in our high tunnel classes is “what can I do to keep my soil healthy if I want to grow tomatoes every year”? The unstated problem is that soil health in tunnels degrades over time as pH, alkalinity, salinity, nutrients and diseases enter unsustainable levels. The balancing act of adding compost, cover crops and fertilizers is like juggling chain saws while walking a tight rope. With considerable skill it can be done. Otherwise a falling chainsaw may cut the rope.

An alternative to the slow motion juggling act of growing tomatoes in the same ground year-after-year is to grow in containers. This allows the use of fresh potting soil every year to preclude alkalinity, salinity and nematodes. How do yield and inputs compare to growing in the ground? To find out we conducted a container trial to analyze the labor, water, and nutrition inputs of tomatoes grown in several different sizes of containers as well as in the ground.

Research Objective:
Evaluate the potential of 3 container types and 3 container sizes for high tunnel tomato production as an alternative to in-ground production.

Trial Design:
A trial to evaluate the potential of container production of tomatoes was established in a cooperating high tunnel in Penn Yan, NY in March 2014. Grown on-farm from seed, tomato transplants (var. ‘Primo Red’ Harris Seeds) in 3” pots were set in 3 types of containers: poly bags, soft felt pots and rigid plastic; each with 3 volumes (or container size); 5, 7 and 10 gallons; creating a total of 9 treatments. Plots were laid out in a randomized complete-block design, with 3 plants per plot, replicated 3 times. A single plot of in-ground tomatoes (9 plants total) was established to compare yield data. All plants were arranged in a single row with a 16” spacing. High tunnel soil was a Lima Silt Loam with two previous year’s history of tomatoes. Potting soil was a peat/perlite blend with an organic starter nutrient charge (“Jeff’s Organic”, Lambert). Cultural practices including trellis, pruning, irrigation, fertility and pest management were to grower standards. Single point temperature readings were taken from the center of one container for each treatment on June 25 and August 4. Tomatoes were harvested multiple times per week from June 7 to October 2. Total weight of and number of fruit per block was recorded at each harvest. Data analysis was conducted using statistical software Analysis of Variance (ANOVA) procedure, with significance groupings determined using Fisher’s Protected Least Significant Difference test.

Results:
Yield as measured by both fruit number and total lbs per plant were not significantly different between any of the treatments (table 1). Larger containers within each type yielded both more fruit and lbs per plant when compared to the 5 gallon containers. The highest yielding treatment in weight was the 7 gallon poly bag with 29.8 lbs. The highest number of fruit came from the 10 gallon rigid plastic, with 65.1. All treatments were superior to in-ground production which averaged 24.3 lbs per plant and 43.4 fruit.
Table 1. Tomato yield in 9 container types.

<table>
<thead>
<tr>
<th>Container</th>
<th>Mean lbs per plot</th>
<th>Mean fruit number per plot</th>
<th>Mean lbs per plant</th>
<th>Mean fruit number per plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid Plastic 5 gal</td>
<td>76.99</td>
<td>152.33</td>
<td>25.666</td>
<td>50.778</td>
</tr>
<tr>
<td>Rigid Plastic 7 gal</td>
<td>76.47</td>
<td>153.33</td>
<td>25.49</td>
<td>51.111</td>
</tr>
<tr>
<td>Rigid Plastic 10 gal</td>
<td>88.687</td>
<td>195.33</td>
<td>29.562</td>
<td>65.111</td>
</tr>
<tr>
<td>S P 5 gal</td>
<td>64.897</td>
<td>129.33</td>
<td>21.632</td>
<td>43.111</td>
</tr>
<tr>
<td>S P 7 gal</td>
<td>83.973</td>
<td>163.67</td>
<td>27.991</td>
<td>54.556</td>
</tr>
<tr>
<td>S P 10 gal</td>
<td>86.683</td>
<td>164.33</td>
<td>28.894</td>
<td>54.778</td>
</tr>
<tr>
<td>Poly Bag 5 gal</td>
<td>76.737</td>
<td>145.33</td>
<td>25.579</td>
<td>48.444</td>
</tr>
<tr>
<td>Poly Bag 7 gal</td>
<td>89.473</td>
<td>186.33</td>
<td>29.824</td>
<td>62.111</td>
</tr>
<tr>
<td>Poly Bag 10 gal</td>
<td>79.403</td>
<td>153</td>
<td>26.468</td>
<td>51</td>
</tr>
<tr>
<td>p value (.05)</td>
<td>NS (.3678)</td>
<td>NS (.0705)</td>
<td>NS (.3678)</td>
<td>NS (.2214)</td>
</tr>
</tbody>
</table>

In-ground* 72.8 130.3 24.3 43.4

*In-ground production was not replicated and not included within statistical analysis of containers. Listed here for reference.

Container type did not significantly impact yield when averaged across container size (Table 2).

Table 2. Mean yield across container type, averaged across size.

<table>
<thead>
<tr>
<th>Container</th>
<th>Lbs/plot</th>
<th>#/plot</th>
<th>Lbs/plant</th>
<th>#/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bag</td>
<td>81.9</td>
<td>161.6</td>
<td>27.3</td>
<td>53.9</td>
</tr>
<tr>
<td>Felt</td>
<td>78.5</td>
<td>152.4</td>
<td>26.2</td>
<td>50.8</td>
</tr>
<tr>
<td>Hard</td>
<td>80.7</td>
<td>167.0</td>
<td>26.9</td>
<td>55.7</td>
</tr>
<tr>
<td>In-ground</td>
<td>72.8</td>
<td>130.3</td>
<td>24.3</td>
<td>43.4</td>
</tr>
<tr>
<td>p value (.05)</td>
<td>NS (.7339)</td>
<td>NS (.2214)</td>
<td>NS (.7339)</td>
<td>NS (.2214)</td>
</tr>
</tbody>
</table>
When container size is averaged across type however, we see that 10 gallon consistently increased yield in fruit number and weight in lbs over 5 gallon containers (Table 3).

Table 3. Yield as affected by container size.

<table>
<thead>
<tr>
<th>Container Size</th>
<th>Lbs/plot</th>
<th>Fruit/plot</th>
<th>Lbs/plant</th>
<th>Fruit/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 gal</td>
<td>51.0 B</td>
<td>91.3 B</td>
<td>17.0 B</td>
<td>47.4 B</td>
</tr>
<tr>
<td>7 gal</td>
<td>57.9 AB</td>
<td>107.3 A</td>
<td>19.3 AB</td>
<td>55.9 A</td>
</tr>
<tr>
<td>10 gal</td>
<td>60.6 A</td>
<td>113.8 A</td>
<td>20.2 A</td>
<td>57.0 A</td>
</tr>
<tr>
<td>p value (.05)</td>
<td>NS (.0902)</td>
<td>0.0475</td>
<td>NS (.0902)</td>
<td>0.0475</td>
</tr>
</tbody>
</table>

Discussion

Yield as measured by weight was similar across all treatments while fruit number varied. A clear trend was significantly higher yield in larger volume containers. However, yield does not always translate to profitability. Given the increased input costs of potting soil, containers, ground cover, etc., we found that in-ground production still had the highest return-on-investment when compared to all but one of the container treatments (Table 4). The 7 gallon poly bag exceeded the economic performance of in-ground tomatoes through the combination of higher yields and the lowest container cost. This represents an opportunity for high tunnel growers to continue in the same site over longer periods of time. However, the container treatments required greater fertility inputs due to the low nutrient holding capacity and limited volume of the media. They also require increased management than growing in the soil. Finding the balance between increased inputs with container culture and the limitations of growing in a poor soil becomes an economic and risk management question.

Table 4. Input cost and yield of 9 different containers compared to in-ground high tunnel tomatoes.
Reading the Signs

Overall Yellowing: -S

Interveinal Chlorosis: -N
Curling: -B, -Cu
Necrosis: -Ca, -Zn

Overall Yellowing: -N
Interveinal Chlorosis: -Mg or -K
Purpling: -P
Necrosis: +B, -P, +Fe/+Mn

Excellent online photo resource: Haifa Chemical
http://www.haifa-group.com/knowledge_center/crop_guides/tomato/plant_nutrition/nutrient_deficiency_symptoms/