crop and farm outcomes

- location
- typical weather
- tunnel (+ other?)
- decisions
- microclimate in tunnel
- crop genetics
Liebig’s Law of the Minimum
One factor most limits growth.

... the factor varies
... may be possible to identify and alter

Microclimate Management/
Season Extension

... limit “governors” of growth
... raise stave height, barrel capacity

http://en.wikipedia.org/wiki/Liebig%27s_law_of_the_minimum
Farms and crop plants are manufacturing sites with required inputs, expected outputs and conditions that affect performance.
• photosynthesis (+)
• respiration (-)
• partitioning or allocation (distribution of what remains)
plant factory: triumph of engineering; much greater yield and C footprint than field production (Japan tripling its investment in plant factories)
indoor and soil-less
indoor, soil-less, vertical
• data-driven
• predictable outcomes
Plant factories and fully climate-controlled greenhouses lead to a loss of control, predictability; increase in risk.
(High) Tunnel Systems

- design, components for, and use of are not fully set (may never be)
- additional options (materials, other inputs) and resources are needed

... foundation for some are available today
track yield and quality
Canopy analysis

Sept 25, 2015

20.39% canopy cover
Canopy analysis

Oct. 6, 2015

63.98% canopy cover
Outrageous Lettuce seeded 10/16/14

top row (unheated soil); bottom row (heated soil)
Average Daily Solar Radiation Per Month

OCTOBER

30-yr avg

East-West Axis Tracking Concentrator

Average Daily Solar Radiation Per Month

MARCH

30-yr avg
East-West Axis Tracking Concentrator

solar radiation effects on avg. daily air temperature inside a 21 ft x 48 ft gothic-style high tunnel March 1-May18 (avg. of 2005-06)
approx. elevation (°) of sun at noon on 15th of each month

<table>
<thead>
<tr>
<th>Month</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>49.2</td>
<td>38.8</td>
<td>29.2</td>
<td>24.0</td>
<td>25.2</td>
<td>33.0</td>
<td>43.3</td>
</tr>
</tbody>
</table>
Thermal Time
Growing Degree Days (GDD)
Heat Units

\[ GDD = \frac{T_{\text{max}} + T_{\text{min}}}{2} - T_{\text{base}} \]
average cumulative growing degree days in- and outside a 21ft x 48 ft gothic-style high tunnel Oct. 14 - Jan. 1 (avg. of 2003-05)

High Tunnel vs. Open Field
GDD Accumulation

day October 14 - January 1
# Correlation: Yield by Average Temperature and GDD

<table>
<thead>
<tr>
<th>High Tunnel</th>
<th>r (probability value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T above</td>
<td>0.60 (0.015)</td>
</tr>
<tr>
<td>T below</td>
<td>0.47 (0.068)</td>
</tr>
<tr>
<td>GDD above</td>
<td>0.68 (0.034)</td>
</tr>
<tr>
<td>GDD below</td>
<td>0.53 (0.033)</td>
</tr>
<tr>
<td>GDD total</td>
<td>0.64 (0.008)</td>
</tr>
</tbody>
</table>
Outredgeous Lettuce

Cumulative Growing Degree Days vs. Total leaf FW in 1ft² (g)

R² = 0.7628
Outrageous lettuce

Total leaf FW in 1ft² (g)

Cumulative Solar Radiation (Langley)

\[ R^2 = 0.6343 \]
https://www.nrel.gov/
ABOUT THE MIDWEST CLIMATE HUB

Our goal is to provide information that will help producers cope with climate change through linkages of research, education and extension partnerships. Encompassing Michigan, Ohio, Wisconsin, Minnesota, Iowa, Missouri, Indiana and Illinois, this region represents one of the most intense areas of agricultural production in the world with a wide array of products.

https://www.climatehubs.oce.usda.gov/hubs/midwest
https://mrcc.illinois.edu/
http://agebb.missouri.edu/weather/realTime/maps/index.php
# Duration of Daylight for 2019

|-----|------|------|------|------|-----|------|------|------|------|-----|-----|-----|

‘Next’ Level Tunnel Production

Devices to Monitor:
- temperature
- relative humidity
- light levels
- crop condition

... in the tunnel.

Some have useful features (e.g., record automatically, send notices).
temperature readings:
• 15- or 30-min intervals seeding-harvest
• 20 cm above, 4 cm below surface

shielded sensor and datalogger in each plot
New! HOBOnet™ Field Monitoring System
real-time, historical, georeferenced weather data

crop microclimates

crop status, outcomes

analysis, synthesis, resource development

better management and outcomes

conditions in nearby tunnels
• farmers
• crop physiologists
• pathologists
• sociologists
• forecasters
• engineers
• economists

• entomologists
• entomologists
• climatologists
• statisticians
• educators

From Idea to Practice
• increase real-time control
• increase predictability
• increase productivity and efficiency
• decrease risk
• increase success
There is no routine cancer. Just as no two people are exactly the same, neither are their cancers.

No two farms are alike.

What’s different? The medical community has systems for developing, communicating, and implementing standards of care. Winter production needs a system for establishing and meeting minimum cropping expectations.
SUMMARY
QUESTIONS?

THANK-YOU and GOOD LUCK!

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College of Food, Agricultural, and Environmental Sciences
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The OSU-OARDC

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Use of trade names does not imply endorsement of the products named nor criticism of similar ones not named.
Growth Rates and Quality of Baby-sized Greens Grown in High Tunnels during Fall and Spring
30’ x 80’ high tunnels covered with single layer of 6-mil poly film
Each high tunnel contains twenty 4’ x 12’ raised beds
Each covered with low tunnel of Agribon as needed
## Seeding dates

<table>
<thead>
<tr>
<th>February</th>
<th>March</th>
<th>April</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31</td>
</tr>
</tbody>
</table>
Targeted Seeding Rates

Lettuce & mesclun mix - 360 seed/ft²

Swiss chard - 240 seed/ft²
Soil heating cables used to raise soil temperature. Cables ran at 74F.

Heated soil vs unheated soil

October 16, 2014
October 23, 2014
March 11, 2015
March 18, 2015

Seeding dates
Harvested 1ft$^2$ areas

Each seeding date harvested 2-3 times
Canopy cover for 'Fordhook' Swiss chard in Spring*

- Feb 11
- Feb 24
- Mar 11
- Mar 18
- Mar 25
- Mar 31
- Apr 14

*Unheated soil
Outredgeous lettuce leaf wt 4 and 5 weeks after seeding

- **Heated-28 DAS**
- **Unheated-28 DAS**
- **Heated-35 DAS**
- **Unheated-35 DAS**

### Data Points:
- **Oct 16**
- **Oct 23**
- **Mar 11**
- **Mar 18**

The graph compares the total leaf FW in 1ft² (g) for different seeding dates and treatments.