Technology-Enabled, Rapid-Response Fresh Food Supply Chains (TERRa-Fresh) Complementary Regions

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Background

Possible Objectives:
- Maximize Profits
- Reduce CO2/water footprint
- Maximize Local Produce

Model Inputs:
Specific parameters that help modelling the planning process

Model Outputs:
Results that can be used to assist the planning process, depending on the desired objective
Analytics: A SIMPLE Crop Model

- Simple generic crop model (SIMPLE) developed by Zhao et al. (2019) is used to predict crop yield.
- Inputs for SIMPLE model includes crop-specific parameters, daily weather data, and water availability.
- Following Zhao et al. (2019), daily biomass growth rate ($\text{Biomass}_{\text{rate}}$) is estimated as:

$$
\text{Biomass}_{\text{rate}} = \text{Radition} \times f_{\text{Solar}} \times \text{RUE} \times f(CO_2) \times f(\text{Temp}) \times \min(f(\text{Heat}), f(\text{Water}))
$$

- $f_{\text{Solar}}$ is the fraction of solar radiation ($\text{Radition}$) intercepted by a crop canopy.
- $\text{RUE}$ is the radiation use efficiency. $[=1]$
- $f(CO_2)$ measures the CO2 impact on biomass growth. $[=1]$
- $f(\text{Temp})$ measures the temperature impact on biomass growth.
- $f(\text{Heat})$ measures the heat stress on biomass growth.
- $f(\text{Water})$ measures the heat stress on biomass growth. $[=1]$
SIMPLE Model Parameters and Inputs

\[ \text{Biomass}_{\text{rate}} = \text{Radition} \times f_{\text{Solar}} \times \text{RUE} \times f(\text{CO}_2) \times f(\text{Temp}) \times \min(f(\text{Heat}), f(\text{Water})) \]

- \( I_{50A} \) is the cumulative temperature required to intercept 50% of solar radiation during canopy closure [=520].
- \( I_{50A} \) is the cumulative temperature required to 50% of radiation interception during canopy senescence [=400].

\[ \text{Solar} = \begin{cases} \frac{f_{\text{Solar}} \times \text{max}}{1 + e^{-0.01 \times (T - I_{50A})}}, & \text{leaf growth period} \\ \frac{f_{\text{Solar}} \times \text{max}}{1 + e^{0.01 \times (T - I_{50A})}}, & \text{leaf senescence period} \end{cases} \]

\[ f(\text{Temp}) = \begin{cases} 0 & T < T_{\text{base}} \\ \frac{T - T_{\text{base}}}{T_{\text{opt}} - T_{\text{base}}} & T_{\text{base}} \leq T < T_{\text{opt}} \\ 1 & T \geq T_{\text{opt}} \end{cases} \]

\[ f(\text{heat}) = \begin{cases} 1 & T_{\text{max}} \leq T_{\text{heat}} \\ 1 - \frac{T_{\text{max}} - T_{\text{heat}}}{T_{\text{extreme}} - T_{\text{heat}}} & T_{\text{heat}} < T_{\text{max}} \leq T_{\text{extreme}} \\ 0 & T_{\text{max}} > T_{\text{extreme}} \end{cases} \]

- \( T_{\text{base}} \) and \( T_{\text{opt}} \) are the base and optimal temperature for biomass growth.
- \( T_{\text{max}}, T_{\text{heat}} \) and \( T_{\text{extreme}} \) respectively represents daily maximum temperature, temperature threshold when biomass growth rate starts to reduced by heat stress, and temperature threshold when biomass growth rate rate reaches 0 due to heat stress.

<table>
<thead>
<tr>
<th>Crop Name</th>
<th>Harvest Index</th>
<th>T_base</th>
<th>T_opt</th>
<th>T_heat</th>
<th>T_extreme</th>
<th>Dry Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>0.68</td>
<td>6</td>
<td>26</td>
<td>32</td>
<td>45</td>
<td>6%</td>
</tr>
<tr>
<td>Lettuce</td>
<td>0.68</td>
<td>6</td>
<td>26</td>
<td>32</td>
<td>45</td>
<td>10%</td>
</tr>
<tr>
<td>Celery</td>
<td>0.68</td>
<td>11</td>
<td>31</td>
<td>37</td>
<td>50</td>
<td>6%</td>
</tr>
<tr>
<td>Bell Pepper</td>
<td>0.68</td>
<td>11</td>
<td>31</td>
<td>37</td>
<td>50</td>
<td>8%</td>
</tr>
<tr>
<td>Carrot</td>
<td>0.7</td>
<td>6</td>
<td>26</td>
<td>32</td>
<td>45</td>
<td>12%</td>
</tr>
<tr>
<td>Cucumber</td>
<td>0.68</td>
<td>11</td>
<td>31</td>
<td>37</td>
<td>50</td>
<td>4%</td>
</tr>
<tr>
<td>Onion</td>
<td>0.85</td>
<td>6</td>
<td>26</td>
<td>32</td>
<td>45</td>
<td>10%</td>
</tr>
<tr>
<td>Green Bean</td>
<td>0.4</td>
<td>11</td>
<td>31</td>
<td>37</td>
<td>50</td>
<td>10%</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>0.68</td>
<td>6</td>
<td>26</td>
<td>32</td>
<td>45</td>
<td>8%</td>
</tr>
</tbody>
</table>
Estimating Yield using SIMPLE Crop Model

- The cumulative biomass until \(i^{th}\) day becomes:
  \[
  Biomass_{cum_{i+1}} = Biomass_{cum_i} + Biomass_{rate}
  \]
- Finally, the total crop yield can be predicted as:
  \[
  Yield = Biomass_{cum_{maturity}} \times Harvest\ Index
  \]

<table>
<thead>
<tr>
<th>Predicted Yields for Tomato in Las Cruces</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planting Date</strong>: Feb 5 (Total Yield: 34,500)</td>
</tr>
</tbody>
</table>

![Graph showing predicted yields for different planting dates]
The unique weather patterns of different areas can be an advantage as it can enable a continuous supply of a crop throughout the year.
Due to current temperature and radiation conditions, it is not favorable to plant tomatoes in certain weeks of the year in Phoenix.

When temperatures increase, the harvesting gap in Phoenix increases, making it an area with less agronomic potential.

Conversely, if temperatures decrease, Phoenix can harvest tomatoes all year long.
Expansion to 5-Digit Zip Code Regions

These tools can be expanded to any region where agricultural production is conducted.
Future Work

- Modify the yield model to consider crops that have only one harvest
- Expand yield model results to other states
- Validate some of the model parameters for each region
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Questions? Comments?
Additional Material
Prescriptive Analytics

Yield Prediction
Usage of biological models to predict the total yield and its harvest distribution for each possible planting week.

Planning Unit Definition
Identify yield homogeneous regions.

Farm Planning
Usage of predicted prices and yields as inputs for agricultural planning optimization models.