Busting Food Sustainability Myths: Climate Adaptation & Mitigation Opportunities in Fruit & Vegetable Supply Chains

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Kaiyu Guan (University of Illinois)
Greg Thoma (University of Arkansas)

Sustainable Ag Summit, Indianapolis IN
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Program

- ‘Myth or Truth’ hand-outs (Dave)
- Crop modeling findings (Kaiyu)
- Life Cycle Assessment (LCA) findings (Greg)
- Q & A
Multi-Disciplinary Project Team

Crop Modeling

Economic Modeling

LCA Modeling

Stakeholders & Extension
The 32 F&V Crop Modeling Counties are Located in 9 of the 14 Major Drainage Basins of the Contiguous US

These are the highest target crop acreage counties in the 31 CRD’s that collectively include 80% of US area planted to the 8 target crops (St. Johns FL added to better represent potatoes)
Climate change is expected to reduce future potato yields in current US production regions, lowering them by an average of \(~10\%\) as we reach the 2050’s.
'Fact' Number 2

• By the 2050’s, the lack of irrigation water availability will severely constrain future processing tomato production capacity throughout most of California.
'Fact' Number 3

• The nutritional value of potatoes & tomatoes will not be detectably impacted by atmospheric and climatic conditions in future environments.
The most cost-effective climate adaptation measure likely to be employed by future potato & tomato growers will be to increase the amount of applied irrigation water.
'Fact' Number 5

- The land area needed to produce potatoes & tomatoes will expand and shift northward as climate change intensifies, with very little production in California, Florida, or Texas.
'Fact' Number 6

- Nitrogen fertilizer use is responsible for around half the carbon footprint of the key foods derived from potatoes & tomatoes (e.g. chips, fries, pasta sauce, ketchup, etc.).
'Fact’ Number 7

• Water footprints for potatoes & tomatoes will increase as temperatures continue to rise in current production areas, forcing farmers to apply more irrigation water.
'Fact' Number 8

• The choice of oil used for frying is far more important than supply-chain packaging considerations with respect to the carbon footprint of consumed French fries.
‘Fact’ Number 9

• The use of renewable energy as a power source can nearly halve the carbon footprint of processed tomato products, such as pasta sauce and ketchup.

☐ MYTH ☐ TRUTH
Decisions on the method of potato and tomato food preparation have far larger impacts on both carbon & water footprints than any farmer decisions.
Program

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• Q & A
Use mechanistic and statistical crop modeling to determine current and future climate and water availability impacts on yield and quality of selected fruit and vegetable crops in current and potential future production states, including land use change resulting from relocation to new production regions.

UF: Senthold Asseng, Gerrit Hoogenboom, Chuang Zhao; WSU: Claudio Stöckle, Stewart Higgins, Tina Karimi, Roger Nelson; UIUC: Kaiyu Guan, Yan Li, Genghong Wu
<table>
<thead>
<tr>
<th>Year 1</th>
<th>Potatoes, Tomatoes, Sweet Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 2</td>
<td>Carrots, Green Beans, Spinach</td>
</tr>
<tr>
<td>Year 3</td>
<td>Oranges, Strawberries, Grapes*</td>
</tr>
<tr>
<td>Year 4</td>
<td>Broccoli*, Melons*, Onions*</td>
</tr>
</tbody>
</table>

* Inclusion of Broccoli, Grapes, Melons, & Onions all contingent on additional funding
Current Status

- 2030s & 2050s impacts/adaptation
- Potatoes: 6 models
- Tomatoes: 3 models
- Sweet corn: 3; Green beans: 2
- Next crops: 2/3 models

Relatively modest climate effects observed through the 2050s, thus climate itself does not appear to be a major direct factor in expected land use change for vegetables.
Crop models used for US potato simulations

<table>
<thead>
<tr>
<th>No.</th>
<th>Crop model</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SIMPLE</td>
<td>Zhao et al. (2019)</td>
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<td>2</td>
<td>CropSyst</td>
<td>Stöckle et al. (1994)</td>
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<td>3</td>
<td>LINTUL-POTATO-DSS</td>
<td>Haverkort et al. (2015)</td>
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<td>4</td>
<td>EPIC</td>
<td>Williams et al. (1989)</td>
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<td>5</td>
<td>DSSAT-Substore</td>
<td>Raymundo et al. (2017)</td>
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<tr>
<td>6</td>
<td>Statistical model</td>
<td>Li et al. (2019)</td>
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</table>
General circulation models (GCM) & future scenarios

<table>
<thead>
<tr>
<th>No</th>
<th>GCM</th>
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<tbody>
<tr>
<td>1</td>
<td>HadGEM2-ES</td>
</tr>
<tr>
<td>2</td>
<td>IPSL-CM5A-LR</td>
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<tr>
<td>3</td>
<td>GFDL-ESM2M</td>
</tr>
<tr>
<td>4</td>
<td>MIROC-ESM-CHEM</td>
</tr>
<tr>
<td>5</td>
<td>NorESM1-M</td>
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</tbody>
</table>

- RCP8.5
- historical period (1981-2010) - 360 ppm atmospheric CO$_2$
  AgMERRA Climate Forcing Dataset
- 2030’s (2021-2050) - 445 ppm
- 2050’s (2041-2070) - 571 ppm
## Future scenarios

<table>
<thead>
<tr>
<th>No.</th>
<th>Scenarios</th>
<th>Time Period</th>
<th>Planting Dates</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Baseline</td>
<td>1981-2010</td>
<td>Based on T</td>
</tr>
<tr>
<td>2</td>
<td>2030s No Adaptation without elevated CO$_2$</td>
<td>2021-2050</td>
<td>Same as baseline</td>
</tr>
<tr>
<td>3</td>
<td>2050s No Adaptation without elevated CO$_2$</td>
<td>2041-2070</td>
<td>Same as baseline</td>
</tr>
<tr>
<td>4</td>
<td>2030s No Adaptation with elevated CO$_2$</td>
<td>2021-2050</td>
<td>Same as baseline</td>
</tr>
<tr>
<td>5</td>
<td>2050s No Adaptation with elevated CO$_2$</td>
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<tr>
<td>6</td>
<td>2030s Adaptation with elevated CO$_2$</td>
<td>2021-2050</td>
<td>Based on future T</td>
</tr>
<tr>
<td>7</td>
<td>2050s Adaptation with elevated CO$_2$</td>
<td>2041-2070</td>
<td>Based on future T</td>
</tr>
</tbody>
</table>
1. Predictor selection. Which climate variables and at what time scale should be used?

2. Fitting function selection. Which fitting functions (e.g., linear, polynomial, spline) should be used?

3. Benefit of other data. How much benefit can satellite data (e.g., EVI and LST) bring to the statistical model's performance?

4. At which spatial level should we build the model (state-specific model or a global national model)?
Yield response to different predictors

- Red line is the fitted line by Locally Weighted Scatterplot Smoothing (LOWESS)
- Determining knots for spline function

source: Li et al., 2019. “Modeling rain-fed corn in the US”
Scatter plot of the "Best climate + EVI" model

source: Li et al., 2019. “Modeling rain-fed corn in the US”

The leave-one-year-out test from 2003 to 2016
Processing Potato Yields by CRD (Baseline and Future)
Program

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- Q & A
Use Life Cycle Assessment (LCA) modeling of current and potential future fruit and vegetable supply chains to identify and evaluate cost-effective adaptation and mitigation opportunities (as informed by crop modeling linked with economic models).

**U ARK:** Marty Matlock, Greg Thoma, Ranjan Parajuli
source: Stratton et al., “Opportunities and tradeoffs as global fruit and vegetable systems expand to meet dietary recommendations,” manuscript in preparation.
Data Sources: EcoInvent (GHG); USDA (crop yields, nutrient density, percent market uses); Institute of Medicine (EAR); Medellín-Azuara et al., 2015 (water use).

All footprints are at harvest and based on edible mass fraction: potatoes (75%), tomatoes (91%).
* All nutrient density footprints multiplied by 0.1 in order to share the same scales.
* This industry term is not the same “tomato paste” available at retail.
Materials and Methods

Integrated modeling framework

Integrated-F&V Supply Chain LCA Model

- Warehouse-cold storage and Processor
- Retail
- Consumer

Biowaste-handling Model

- Waste to animal feed model
- Waste to energy model
- Compost model

Farming-system Model

CRDs level: Farm inputs
- Crop nutrients
- Agro-chemicals
- Fuel
- Irrigation
- Farm operations
- Farm emission

Postharvest-system Model

Product level: raw material inputs
- Electricity
- Heat
- Fuel
- Water
- Chemicals
- Packaging materials
Environmental profiles of Tomato-pasta sauce

System boundary

Background system: supply of raw materials and emissions

Agricultural Production (Farm) → Packaging

Transport → Processors Packaging

Retail/Supermarket → Transport → Packaging waste-treatments

Final consumer → Biowaste

Avoided impacts include biowaste management:
Consumer bio-waste = composting
Bio-waste from other stages = animal feed

Functional Unit (FU) = 1 kg tomato sauce
Biowaste treatment facilities: accounted avoided impacts (consequential modeling)

**Consumer bio-waste** = composting (substitution of synth-NPK)

Bio-waste from other stages = animal feed

Starch (from processing lines) = substitution of conventional starch (maize starch).
A schematic processing steps description
Environmental profiles of Tomato-pasta sauce (CA51)

Contributions from supply chain stages-baseline

CA 51 = California, Fresno County (CRD 51)

<table>
<thead>
<tr>
<th>Contribution</th>
<th>GWP 100 (kg CO₂ eq per FU)</th>
<th>Land use (m² a. crop eq per FU)</th>
<th>Water consumption (m³ per FU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total impact</td>
<td>2.0</td>
<td>1.31</td>
<td>2.41*10⁻¹</td>
</tr>
<tr>
<td>On-farm</td>
<td>6.95*10⁻¹</td>
<td>1.02</td>
<td>2.31*10⁻¹</td>
</tr>
<tr>
<td>Processor</td>
<td>1.16</td>
<td>3.21*10⁻¹</td>
<td>2.06*10⁻²</td>
</tr>
<tr>
<td>Retail</td>
<td>1.45*10⁻¹</td>
<td>1.24*10⁻²</td>
<td>8.44*10⁻⁴</td>
</tr>
<tr>
<td>Consumer</td>
<td>7.56*10⁻²</td>
<td>9.77*10⁻⁴</td>
<td>3.29*10⁻⁶</td>
</tr>
<tr>
<td>Avoided impact</td>
<td>-7.78*10⁻²</td>
<td>-4.71*10⁻²</td>
<td>-1.17*10⁻²</td>
</tr>
</tbody>
</table>
Environmental profiles of Potato-frozen fries

Contribution of the supply chain stages to the total impact of the entire supply chain

<table>
<thead>
<tr>
<th>ID90</th>
<th>Yields (t/ha)</th>
<th>N-inputs (kg/ha)</th>
<th>Irrigation (m³/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
<td>410</td>
<td>7947</td>
</tr>
</tbody>
</table>

**Potato-frozen fries (FU = 1 kg products)**

<table>
<thead>
<tr>
<th></th>
<th>GWP 100 (kg Co2 eq per FU)</th>
<th>Land Use (m² a-crop eq per FU)</th>
<th>Water consumption (m³ per FU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total impact</td>
<td>1.62</td>
<td>1.05</td>
<td>3.30*10⁻¹</td>
</tr>
<tr>
<td>On-farm</td>
<td>2.84*10⁻¹</td>
<td>6.0*10⁻¹</td>
<td>3.02*10⁻¹</td>
</tr>
<tr>
<td>Processor (with packaging unit)</td>
<td>4.7*10⁻¹</td>
<td>1.11*10⁻¹</td>
<td>6.9*10⁻³</td>
</tr>
<tr>
<td>Retail</td>
<td>7.74*10⁻²</td>
<td>-3.98*10⁻²</td>
<td>-1.72*10⁻³</td>
</tr>
<tr>
<td>Consumer</td>
<td>8.16*10⁻¹</td>
<td>4.04*10⁻¹</td>
<td>2.40*10⁻²</td>
</tr>
<tr>
<td>Avoided impact</td>
<td>-2.59*10⁻²</td>
<td>-3.07*10⁻²</td>
<td>-7.28*10⁻⁴</td>
</tr>
</tbody>
</table>
Environmental (GHGs) Hotspots for French Fries

On-Farm Emissions

- On-farm transport
- On-farm emissions (N₂O, and during land transformations)
- Irrigation-water
- Farm implements (fuel + implement operations)
- Pesticides
- Pesticides and other chemicals
- NPK
- Seeds

Processing Emissions

- Waste water treatments
- Waste oil treatments
- Packaging materials treatments
- Transport-train
- Other chemicals (anti-oxidants etc.)
- Packaging materials
- Water
- Vegetable oil
- Heat
- Electricity
Environmental (GHGs) Hotspots for Pasta Sauce

On-Farm Emissions

- On-farm transport
- Mulching
- On-farm emissions (N2O, and during land transformations)
- Irrigation
- Farm implements (fuel)
- Pesticides
- Other chemicals
- NPK
- Seedlings

Processing Emissions

- Waste water treatments
- Waste packaging materials treatments (bins, pallets)
- Transport-train
- Transport-road
- Other chemicals (CaCl, Citric acid, NaOH etc)
- Packaging materials
- Water
- Fuels
- Heat
- Electricity
Example LCA Results

4 oz French Fries

1 oz Ketchup

Supply Chain Step
F = On-Farm
P = Processor
R = Retail
C = Consumer

BaselineGHG (g CO₂e)

<table>
<thead>
<tr>
<th>Supply Chain Step</th>
<th>Baseline</th>
<th>GHG (g CO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>R</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>P</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
</tbody>
</table>

BaselineLand (sq ft)

<table>
<thead>
<tr>
<th>Supply Chain Step</th>
<th>Baseline</th>
<th>Land (sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td>R</td>
<td>F</td>
<td>P</td>
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<td>P</td>
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<td>P</td>
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<tr>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
</tbody>
</table>

BaselineH₂O (gal)

<table>
<thead>
<tr>
<th>Supply Chain Step</th>
<th>Baseline</th>
<th>H₂O (gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td>R</td>
<td>F</td>
<td>P</td>
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<tr>
<td>P</td>
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<td>P</td>
</tr>
<tr>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
</tbody>
</table>
Available Irrigation Water by Basin (per IMPACT)

Does not account for reductions mandated by SGMA

- California
- Colorado
- Columbia
- Great Lakes
- Mississippi
- Northeast
- Red Winnipeg
- Rio Grande
- Southeast
THANK YOU!

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Greg Thoma (gthoma@uark.edu, 479-445-5277)