ASSESSING REGIONAL FOOD SECURITY IN THE U.S. USING CROP MODELS

D.H. Fleisher¹, J.P. Resop², D. Mutiibwa¹, D.J. Timlin¹, and V.R. Reddy¹

¹ USDA-ARS CSGCL, Beltsville, Maryland, USA
² University of Maryland, College Park, Maryland, USA
BACKGROUND
U.S. NORTHEASTERN SEABOARD REGION & FOOD SECURITY

Location: U.S. Northeastern Seaboard Region (NSR)
- 13 state region on east coast from Maine to Virginia
- Imports 65 – 80% fresh fruits & vegetables

Food Security
- Ability of region to satisfy its own consumption needs via regional/localized production
- NSR ‘Self-sufficiency’ or ‘Self-reliance’ metric: 24%

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central &amp; Distant Production</td>
<td>Monocultures, increased vulnerability</td>
</tr>
<tr>
<td>High Food Miles</td>
<td>Costs (price shocks) ; Quality</td>
</tr>
<tr>
<td>Population Growth &amp; Demographics</td>
<td>Food availability ; Diversity</td>
</tr>
<tr>
<td>Land and farm ‘availability’</td>
<td>Limited agricultural land and production infrastructure</td>
</tr>
<tr>
<td>Changing Climate</td>
<td>Warming T; Extreme events</td>
</tr>
</tbody>
</table>
Hypothesis:
- Food security (food quality, rural economies, and etc) will be enhanced with increased emphasis on regional production.

Specific Goal:
- Quantitatively assess production capacity based on knowledge of abiotic limiting factors using explanatory crop models

Outcome:
- Framework to evaluate spatial and temporal components of production for specific crops given constraints including land-use, soil quality, climate, and management
- Geospatial map of production potential in food security context
METHODOLOGY
**GEOSPATIAL DATA & ASSOCIATED MODELS**

Land use / Land availability (USGS, 2011; NASS, 2011; FSA, 2011)

- National Land Cover Dataset (NLCD), 30-m
  - Remotely sensed land cover categories
- Cropland Data Layer (CDL), 30-m
  - Composite representation of annual crop cover maps
- Common Land Unit (CLU), field-scale
  - Delineation of field boundaries via photography

**Soils (NRCS, 2012)**

- Physical characteristics, 1:24,000 scale polygons for ‘soil map-units’
  - Dominant soil type selected per map-unit
  - Soil texture and other physical properties for each soil layer
  - Hydraulic information via ROSETTA model (Schaap et al., 2001)

[Map showing current land use for commodity versus potential land use for commodity]
Climate

- **Historical (NOAA-NCDC), annual-daily-monthly**
  - 378 Weather Stations (monthly norms, 30+ years)
  - Inter-annual variability and daily values generated with CLIGEN (Nicks et al., 1995)
- **Mid-Century Projections (IPCC AR4 basis, Pope et al., 2000), annual-daily-monthly**
  - Statistically downscaled spatially and temporally to CLIGEN parameters
  - A2 Scenario: 2050-2080 High CO₂ ~600 ppmv; +2.3°C→4.3°C; +6↑16% Rainfall

Management (USGS, 2011; NASS, 2010)

- Planting and Harvesting Dates (State-level)
- Management practice (state-level) including irrigation
- Historical ‘farm-gate’ yields / silage
CROP MODELS & SCRIPTS

Current Models
- **SPUDSIM** *(potato)* - leaf-level energy balance approach with coupled stomatal conductance / C3-biochemical approach (Fleisher et al., 2010)
- **MAIZSIM** *(maize)* - leaf-level energy balance approach with coupled stomatal conductance / C4-biochemical approach (Kim et al., 2012)
- **CERES** – Wheat - *RUE* basis with Priestly-Taylor (Jones et al., 2003)

Scenarios
- Current and Potential land-base
- Irrigated and Rain-fed Management
- Historical and Mid-Century Climate

Metrics
- Yield (silage)
- Regional self-reliance
1. Input data layers (weather, soil, management, land use) georeferenced and organized in ArcGIS.
2. 30 independent growing seasons were simulated at each unique modeling unit combination.
3. Output is spatially linked and aggregated to the **county level** for reporting purposes.

---

**SCRIPTING INTERFACE**

- **ArcGIS Interface**
  - Weather - NOAA Management - NASS
  - Soil - SSURGO
  - Land Use 2006 NLCD, 2010 CDL
  - Modeling Units (MUs)

- **Python Interface**
  - Weather Model CLIGEN

- **Input Variables**
  - Daily Weather Data
  - Soil Profile Data
  - Management Data

- **Crop Models**
  - SPUDSIM
  - MAIZSIM
  - Soil Model 2D SOIL

- **Output Variables**
  - Plant Dry Mass
  - Water Uptake
  - Nitrogen Uptake

---

from Resop et al. (2012)
RESULTS & DISCUSSION
LAND-USE & CALIBRATION

Current land-use amount (2.85 million ha total cropland in NSR)

<table>
<thead>
<tr>
<th>Crop</th>
<th>2011 Land base (ha)</th>
<th>Percent of Total Ag Land</th>
<th>Self-reliance metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIZE</td>
<td>1,659,847</td>
<td>59%</td>
<td>64%</td>
</tr>
<tr>
<td>POTATO</td>
<td>43,936</td>
<td>2%</td>
<td>24%</td>
</tr>
</tbody>
</table>

Calibration

- County-level comparisons between 30-year averaged model runs versus 20+year observed yields (silage)

<table>
<thead>
<tr>
<th>Number of Counties</th>
<th>Crop</th>
<th>% yield within 2 stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>276</td>
<td>Maize</td>
<td>80</td>
</tr>
<tr>
<td>203</td>
<td>Potato</td>
<td>76 (94% adjusted)</td>
</tr>
</tbody>
</table>

Irrigation

- Potato: 82% South; ≈ 0% North
- Maize: 2% across NSR

- Predictions outside confidence limits were higher than observed-means reflecting ‘potential’ yields
POTATO YIELDS UNDER HISTORICAL CLIMATE

Rainfed (left) and Irrigated (right) Simulated 30-year Potato Yields Aggregated to County Level on Potential Agricultural Landbase

Water-limited Potato Yield (Mg ha\(^{-1}\))
- Not Modeled
- 0 - 12
- 13 - 16
- 17 - 21
- 22 - 25
- 26 - 29
- 30 - 36
- 37 - 42

Non-limited Potato Yield (Mg ha\(^{-1}\))
- Not Modeled
- 0 - 12
- 13 - 16
- 17 - 21
- 22 - 25
- 26 - 29
- 30 - 36
- 37 - 42

from Resop et al. (2013)
POTATO YIELDS UNDER HISTORICAL CLIMATE

Average Yields
- Similar production (< 3%) on current- versus potential-land
- Yield gap of 46% between rain-fed versus irrigated production

Geospatial Trends
- Latitudinal dependency
  - Yield increase of 2.8 or 2.6 Mg ha\(^{-1}\) degree-latitude\(^{-1}\) for rainfed or irrigated production
  - Primarily due to: T (1 to 2°C); Photoperiod; Soil characteristics (clay, bulk density)

Food Security Context
- Self-reliability Metric
  - 6.6% of all cropland (increase from 2%) required to achieve 100% if rainfed
  - 4.6% of all cropland (increase from 2%) required to achieve 100% if irrigated
MAIZE SILAGE UNDER HISTORICAL CLIMATE

Rainfed (left) and Irrigated (right) Simulated 30-year silage Aggregated to County Level on Potential Agricultural Landbase

Water-limited Corn Yield (Mg ha⁻¹)
- Not Modeled
- 0 - 14
- 15 - 22
- 23 - 29
- 30 - 35
- 36 - 41
- 42 - 50
- 51 - 58

Non-limited Corn Yield (Mg ha⁻¹)
- Not Modeled
- 0 - 14
- 15 - 22
- 23 - 29
- 30 - 35
- 36 - 41
- 42 - 50
- 51 - 58

from Resop et al. (submitted, 2016)
MAIZE SILAGE UNDER HISTORICAL CLIMATE

Average Silage
- Similar production (< 1% difference) for current- versus potential-land
- Smaller yield gap (29%) between rain-fed versus irrigated production

Geospatial Trends
- Latitudinal dependency
  - Silage increase of 0.99 or 1.67 Mg ha\(^{-1}\) degree-latitude\(^{-1}\) for rainfed or irrigated production
  - Differences associated with T; Soil; Photoperiod

Food Security Context
- Self-reliability
  - 89% of all cropland (increase from 59%) required to achieve 100% if rainfed
  - 69% of all cropland required to achieve 100% if irrigated
POTATO YIELDS UNDER FUTURE CLIMATE

Simulated 30-year Yields on Potential Agricultural Landbase

Percent Yield Change

<table>
<thead>
<tr>
<th>State</th>
<th>WL</th>
<th>NL</th>
<th>***</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME</td>
<td>-45</td>
<td>-7</td>
<td>-45</td>
</tr>
<tr>
<td>VT</td>
<td>-54</td>
<td>-10</td>
<td>-54</td>
</tr>
<tr>
<td>RI</td>
<td>-79</td>
<td>-19</td>
<td>-79</td>
</tr>
<tr>
<td>NH</td>
<td>-54</td>
<td>-9</td>
<td>-54</td>
</tr>
<tr>
<td>MA</td>
<td>-74</td>
<td>-16</td>
<td>-74</td>
</tr>
<tr>
<td>CT</td>
<td>-76</td>
<td>-21</td>
<td>-76</td>
</tr>
<tr>
<td>NY</td>
<td>-75</td>
<td>-9</td>
<td>-75</td>
</tr>
<tr>
<td>PA</td>
<td>-78</td>
<td>-22</td>
<td>-78</td>
</tr>
<tr>
<td>NJ</td>
<td>-91</td>
<td>-27</td>
<td>-27</td>
</tr>
<tr>
<td>MD</td>
<td>-90</td>
<td>-21</td>
<td>-21</td>
</tr>
<tr>
<td>DE</td>
<td>-92</td>
<td>-21</td>
<td>-21</td>
</tr>
<tr>
<td>WV</td>
<td>-81</td>
<td>-20</td>
<td>-20</td>
</tr>
<tr>
<td>VA</td>
<td>-87</td>
<td>-20</td>
<td>-20</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td><strong>-75%</strong></td>
<td><strong>-18%</strong></td>
<td><strong>-50%</strong></td>
</tr>
</tbody>
</table>

from Resop et al. (submitted, 2016)
MAIZE SILAGE UNDER FUTURE CLIMATE
Simulated 30-year Silage on Potential Agricultural Landbase

Percent Yield Change

<table>
<thead>
<tr>
<th>State</th>
<th>WL</th>
<th>NL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME</td>
<td>-23</td>
<td>-19</td>
</tr>
<tr>
<td>VT</td>
<td>-23</td>
<td>-19</td>
</tr>
<tr>
<td>RI</td>
<td>-19</td>
<td>-15</td>
</tr>
<tr>
<td>NH</td>
<td>-19</td>
<td>-16</td>
</tr>
<tr>
<td>MA</td>
<td>-18</td>
<td>-18</td>
</tr>
<tr>
<td>CT</td>
<td>-19</td>
<td>-18</td>
</tr>
<tr>
<td>NY</td>
<td>-23</td>
<td>-18</td>
</tr>
<tr>
<td>PA</td>
<td>-20</td>
<td>-16</td>
</tr>
<tr>
<td>NJ</td>
<td>-18</td>
<td>-17</td>
</tr>
<tr>
<td>MD</td>
<td>-12</td>
<td>-14</td>
</tr>
<tr>
<td>DE</td>
<td>-17</td>
<td>-16</td>
</tr>
<tr>
<td>WV</td>
<td>-21</td>
<td>-14</td>
</tr>
<tr>
<td>VA</td>
<td>-14</td>
<td>-13</td>
</tr>
<tr>
<td>MEAN</td>
<td>-19%</td>
<td>-16%</td>
</tr>
</tbody>
</table>

from Resop et al. (submitted, 2016)
Yield/Silage Summary
- Climate change impact larger on potato than maize, especially under rainfed conditions
  - Reflects phenology responses to ↑T (decreased life cycle and CHO partitioning)
  - Rainfed versus Irrigated production difference associated with higher VPD and increased water stress

Geospatial Trends
- Similar to historical-climate responses
- Relative impacts on yield loss greater on North versus South, especially for potato

Food Security Metric
- 11% of all cropland (increase from ≈ 5%) required to achieve 100% for potato under mixed water management
- 110% of all cropland (increase from 89%) required to achieve 100% for maize if rainfed
SUMMARY

Crop models coupled with geospatial data and weather generators to map regional production potential for specific commodities

- **Land-base**
  - Similar production (< 3% difference per unit area basis) on ‘current’ versus ‘potential’ land-base

- **Historical climate**
  - Latitudinal dependencies for both crops, with increasing yields from S to N
  - Significant yield gaps for rainfed production
  - Regional self-reliance assessments within available crop-land constraint

- **Future climate**
  - Production declines for both crops with geospatial dependency
  - Significant yield gaps for rainfed production, especially for potato
  - Increased irrigation as possible adaptation measure
  - Regional self-reliance assessments no longer within available crop-land constraint
‘Utility’ of the Self-reliance metric
- Coarse metric ignores many, many factors (infrastructure, transportation/processing hubs, socio-economics, etc)
  - Tells us what ‘could’ be done, not what ‘should’ be done!
- Does provide insight into region’s capacity to support its own demand and could be used to re-assess or re-configure agricultural production in the region given understanding of geospatial sensitivities among commodities

Current & future research
- Additional commodities (wheat)
- Spatial resolution of climate data and evaluating gridded approach
- Methods to use metric to re-configure land-use for greater self-sufficiency
- Production on other land-use classes
- Crop modeling ensemble approach!
The CSGCL Geospatial Analysis Cluster