Evaluating the Sensitivity of Regional Production to Planting Date and Climate Change using a Yield Index

J. P. Resop, D. H. Fleisher, D. Timlin, and V. R. Reddy

USDA-ARS, Crop Systems and Global Change Lab, Beltsville, Maryland

Applying Systems Theory To Complex Agricultural Problems

Abstract

Explanatory crop models have been developed to estimate yield, growth, and development of individual plants. These models have been implemented extensively at the field-scale; however, there is interest in applying explanatory crop models to regional-scale studies to estimate properties of food systems such as potential production capacity (PPC). These models are well-suited to the study of climate change effects on regional food security and potential mitigation strategies. Corn and potato yields were simulated at a county level over the U.S. eastern seaboard region (Maine to Virginia) using a geospatial interface that implements the crop models SPUDSIM and MAIZSIM. A spatially-referenced yield index (YI) was developed to combine the results from both models, create an estimate of baseline productivity over the region, and provide a simple numerical analogue for production potential. The sensitivity of this index was evaluated with respect to changes in management (planting and harvesting dates) as well as changes in climate (temperature, precipitation, and atmospheric carbon dioxide). Future climate was simulated by adjusting monthly statistics used by the weather generator CLIGEN based on downscaled global climate model data. The results of this study could be used by regional planners for anticipating the potential risks of climate change (CC) and evaluating different mitigation strategies such as modifying crop management.

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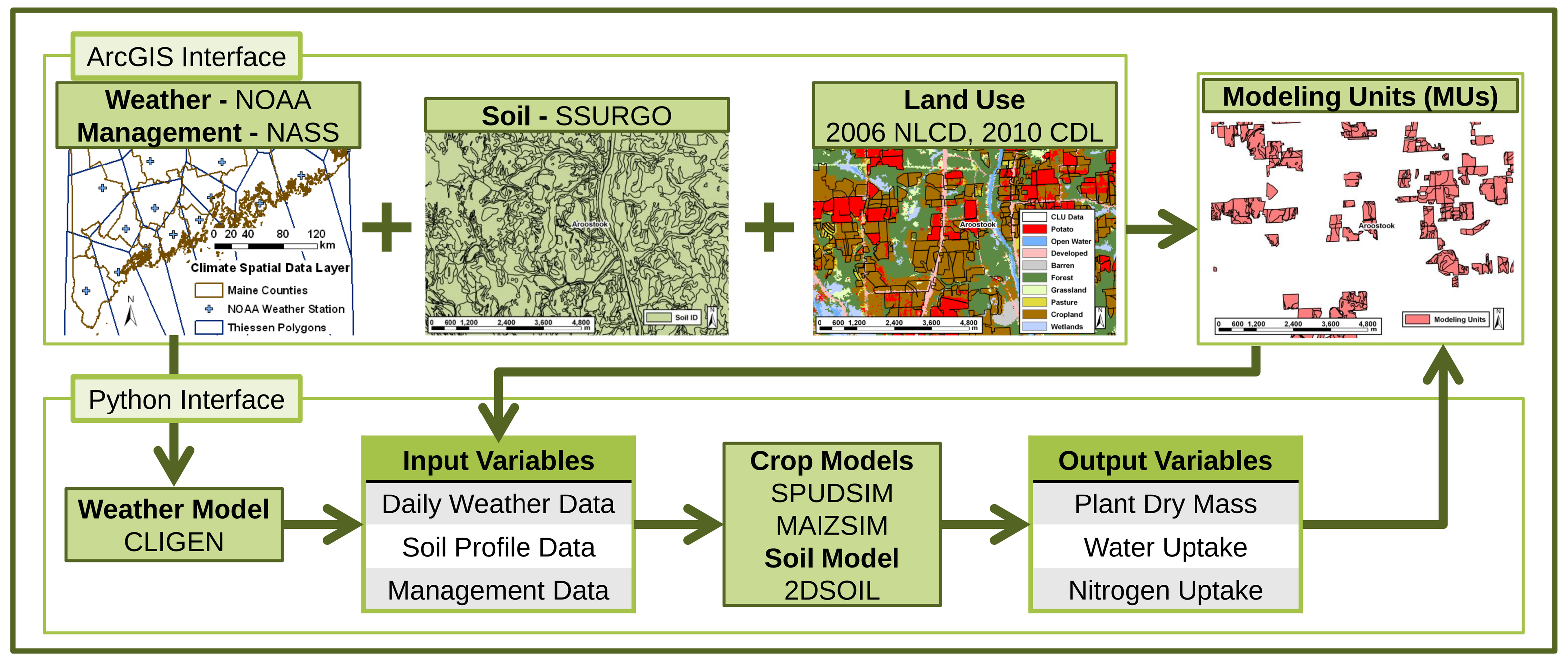
Objectives

- **Evaluate** the potential production capacity (PPC) for the ESR
- **Quantify** the PPC using an aggregated yield index (YI)
- **Compare** the YI over planting and climate change (CC) scenarios

Geospatial Crop Model Interface

1) Input data layers (weather, soil, management, land use) are georeferenced and organized in ArcGIS for the region of interest.
2) Spatially homogeneous modeling units (MUs) are created.



3) For each unique input combination, 30 independent growing seasons are simulated with SPUDSIM and MAIZSIM.
4) Output is spatially linked and aggregated to the county level. The top 3 MUs per county are used to reduce the number of simulations

Yield Index

Definitions and Equations

Yield Index (YI) is the average production per unit area over multiple crops.

Total Production is the amount of caloric energy that a given area can produce.

Crop Yield (Mg/ha) = Dry Matter (g/pl) * Density (pl/m²) / (1 - Moisture Content)

YI_i **(Mkcal/ha)** = Σ_j[Yield (Mg/ha) * Caloric Content (kcal/g) * Harvest Area (ha) * (1 - Moisture Content) * Harvest Index] / Σ_j[Harvest Area (ha)]

The YI is calculated for each county (i) over each crop (j) in the region of interest

Total Production (Mkcal) = Yield Index (Mkcal/ha) * Harvested Area (ha)

Assumed Crop Properties	Potato	Corn, Grain
Plant Density (pl/m²)	4.7	6.9
Caloric Content (kcal/dry g)	3.73	4.07
Moisture Content	0.80	0.115

What questions can we explore?
- How much food can the ESR produce?
- What crop grows best where?
- How can we mitigate effects of CC?

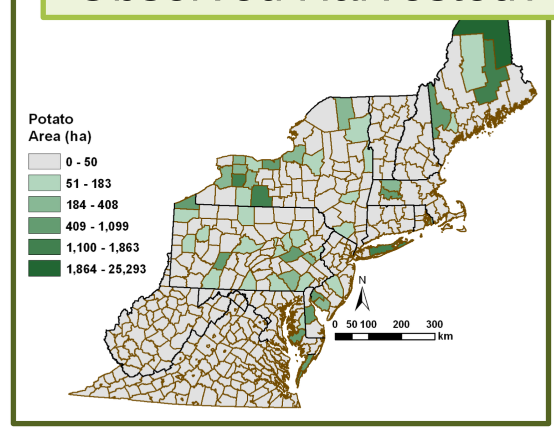
Why a Yield Index? • Aggregate multiple crops over space • Easily compare scenarios

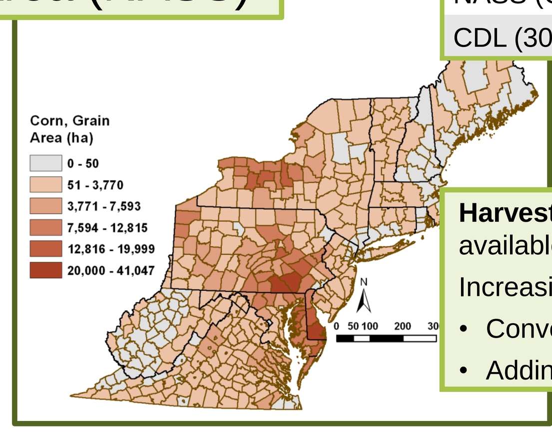
Potential Production Capacity

Total Harvested Area over ESR (ha)	Potato	Corn
NASS (County-level)	47,500	1,019,000
CDL (30-m) [a]	37.000	1,620,000

[a] CDL does not differentiate Corn Grain and Silage

Observed Harvested Area (NASS)

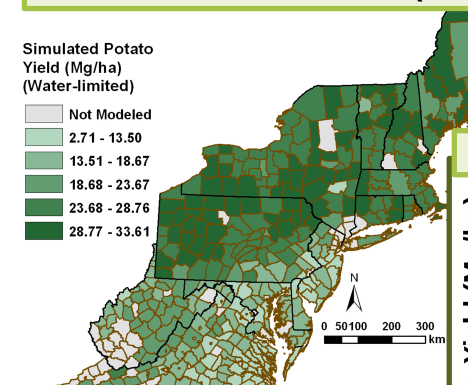




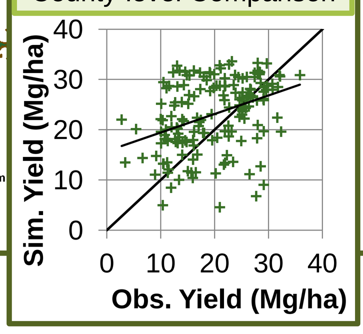
Harvested Area is the current baseline area available for production.

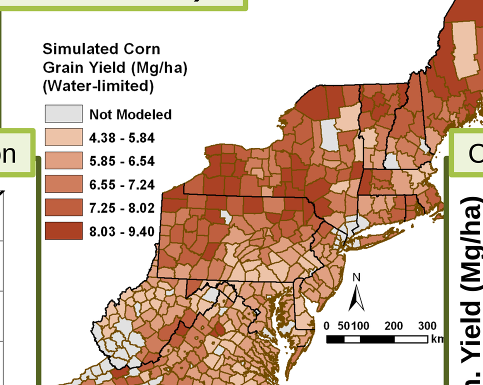
Increasing harvested area would require:
- Converting area from existing cropland **or**
- Adding marginal land not currently used

Simulated Yield (SPUDSIM and MAIZSIM)

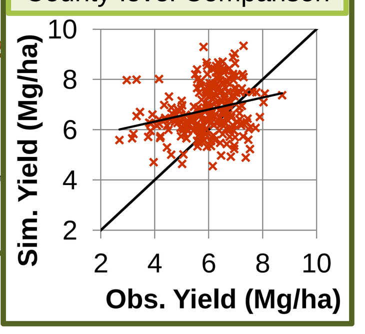


County-level Comparison

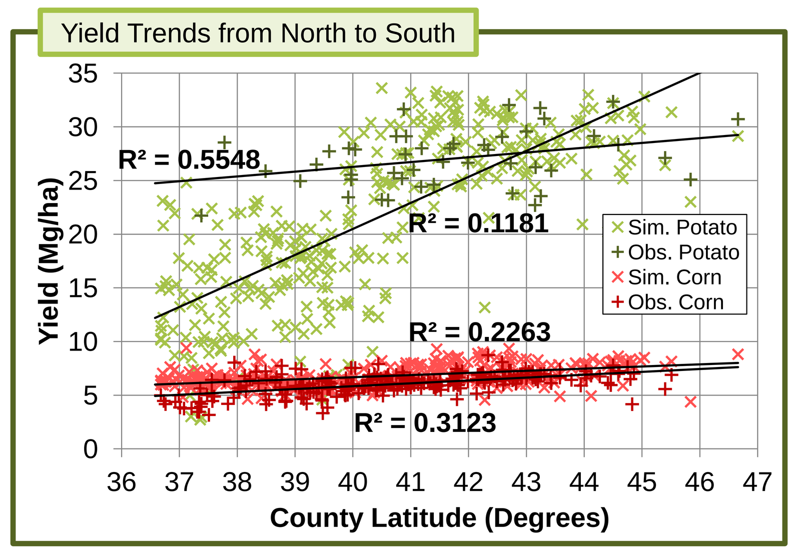




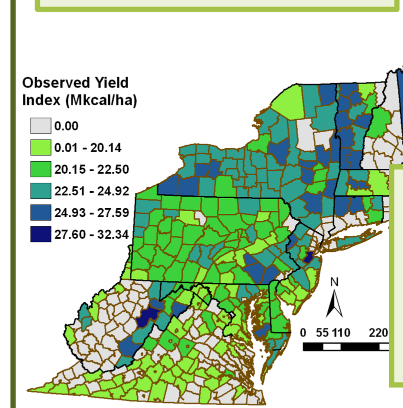
County-level Comparison



Yield Trends from North to South

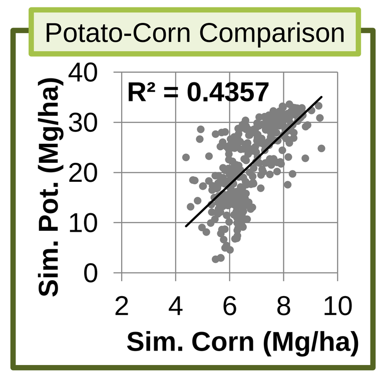


YI - Observed



- Current YI calculation has a side effect of weighting more to corn yield, since there is more corn area.
- Future iterations will try a more balanced approach.

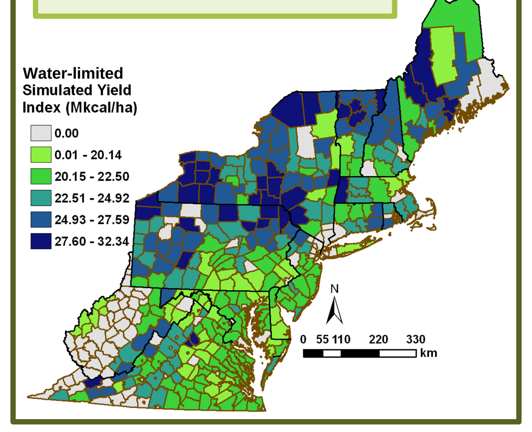
Potato-Corn Comparison



- Both crops had a north-south trend of average yield over the ESR.
- Water-limited potato model underestimated yield in the south, showing the need for irrigation. This was less of a factor for corn.
- Comparing equivalent MUs, potato and corn had a positive correlation.

Yield Index (Mkcal/ha)		
State	Obs.	Sim.
ME	22.78	22.83
VT	25.08	25.88
RI	19.93	24.86
NH	20.44	24.39
MA	24.13	23.60
CT	24.86	23.90
NY	24.16	26.20
PA	22.68	23.06
NJ	23.31	22.46
MD	21.16	20.75
DE	21.78	19.92
WV	22.45	19.27
VA	19.21	21.77
ESR	22.56	23.36

YI - Simulated



Planting Date Variability

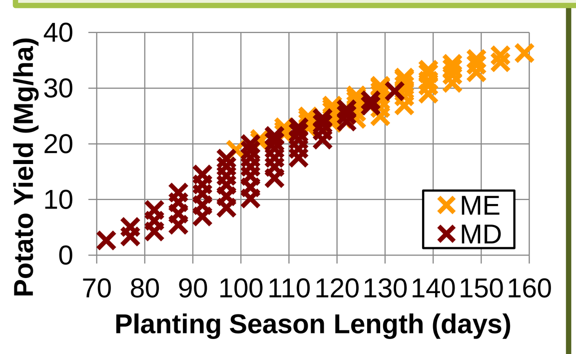
Sensitivity of Yield

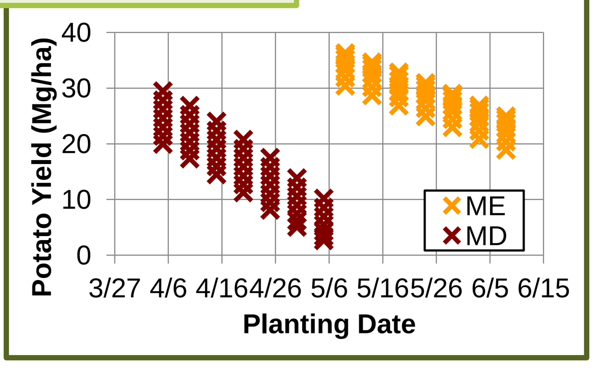
Simulated crop yield is highly sensitive to Planting (P) and Harvest (H) dates.
NASS provides ranges of dates at the state level, but there is uncertainty.
To study the sensitivity, planting and harvest dates were modified by ±5 days.

Preliminary Example
- Positive correlation between total season length, earlier planting dates, and YI.
- Potato yield dominates the overall YI.

Yield Index (Mkcal/ha) for Aroostook, Maine, which is dominated by potato production		Water-limited Conditions			Non-limited Conditions		
	Total Days	Potato YI	Corn YI	Total YI	Potato YI	Corn YI	Total YI
+5 P and -5 H	-10	19.48	28.12	19.50	26.75	34.40	26.76
Average Dates	0	21.72	30.32	21.74	28.86	36.94	28.88
-5 P and +5 H	+10	23.80	31.95	23.82	30.77	38.82	30.79

Effects of the Uncertainty in Planting Date on Yield



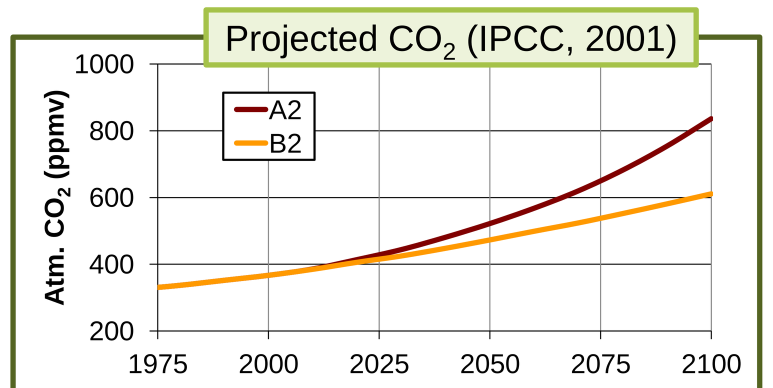


Another Example
- Two counties in two states used: Maine (ME), Maryland (MD).
- Expanded to ±15 days.
- Lots of uncertainty, a spread of ±30% for ME and ±80% for MD.
- Will need to explore as a way to mitigate CC effects, see below.

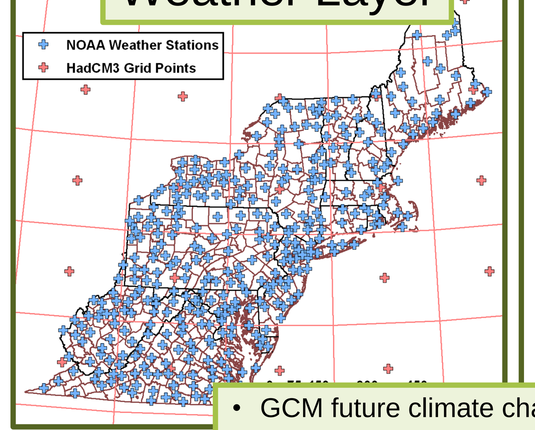
Climate Change

Baseline vs. **Future** Climate
- **Baseline** - 1970 to 2000 (NOAA)
- **Future** - 2050 to 2080 (HadCM3)
  - **A2** - Economic Development
  - **B2** - Ecological Sustainability

Projected CO_2 (IPCC, 2001)

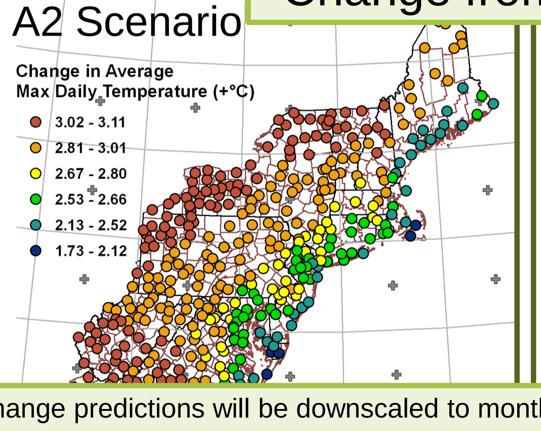


Weather Layer

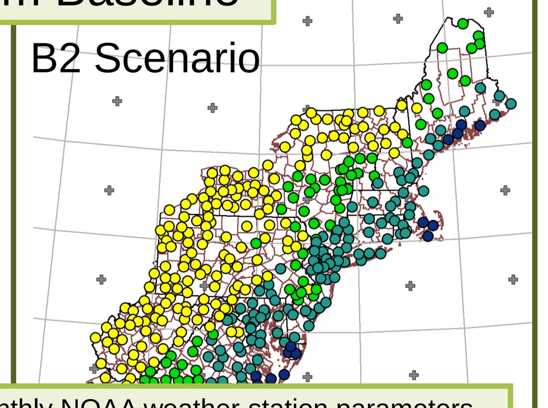


Change from Baseline

A2 Scenario

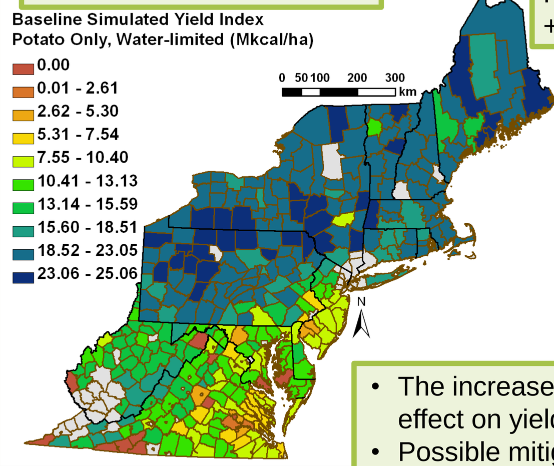


B2 Scenario



- GCM future climate change predictions will be downscaled to monthly NOAA weather station parameters.
- In general, the trend of increasing temperatures due to CC is greater away from the Atlantic coast.

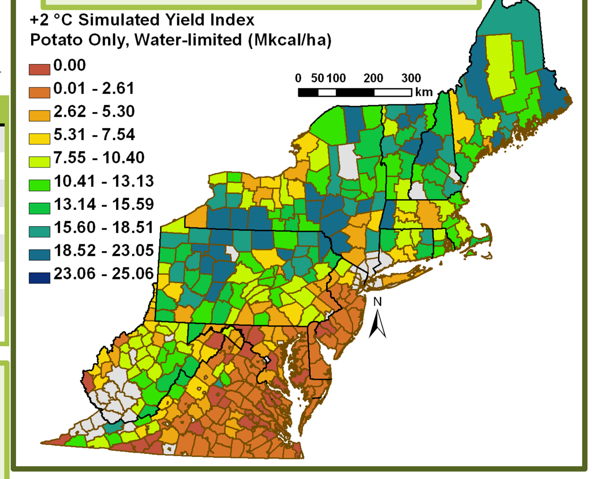
YI - Baseline



Preliminary Example
Potato Only, Water-limited
+2 °C Max/Min Daily Temp

Change in YI			
State	Change	State	Change
ME	-35%	PA	-39%
VT	-27%	NJ	-79%
RI	-43%	MD	-77%
NH	-28%	DE	-88%
MA	-51%	WV	-44%
CT	-46%	VA	-76%
NY	-43%		

YI - CC Scenario



- The increase in temp has a more significant effect on yield in the southeast by the coast.
- Possible mitigation by adding irrigation or modifying the planting and harvesting dates?

Overall Yield Index (Potato and Corn) for Maine		Water-limited Conditions		Non-limited Conditions	
	Observed	Baseline	CC	Baseline	CC
Yield Index	22.78	22.83	18.19	30.69	29.62

- In Maine, a 20% drop in YI from the Baseline to the CC Scenario.
- However, when irrigation is applied, there is only a 3% drop in the overall YI.
- Each county will likely require different mitigation strategies.

Total Potential Production Capacity is dependent on the Yield Index and Harvested Area. PPC increases or decreases if either **(1)** YI changes, which is ***f***(weather, soil, management) or **(2)** Harvested Area changes, which is dependent on land use and regional planning.

Future work will refine the YI, simulate the effect due to CC and explore mitigation strategies.