An Aggregated Crop Yield Index to Explore Regional Potential Production Capacity

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 adaptation 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 over water-limited (WL) and non-limited (NL) conditions. 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 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 adaptation strategies such as modifying crop management.

This research was supported by the USDA-ARS Headquarters Postdoctoral Research Associate Program and the USDA-NIFA AFRI Grant #2011-68004-30057: Enhancing Food Security of Underserved Populations in the Northeast through Sustainable Regional Food Systems.

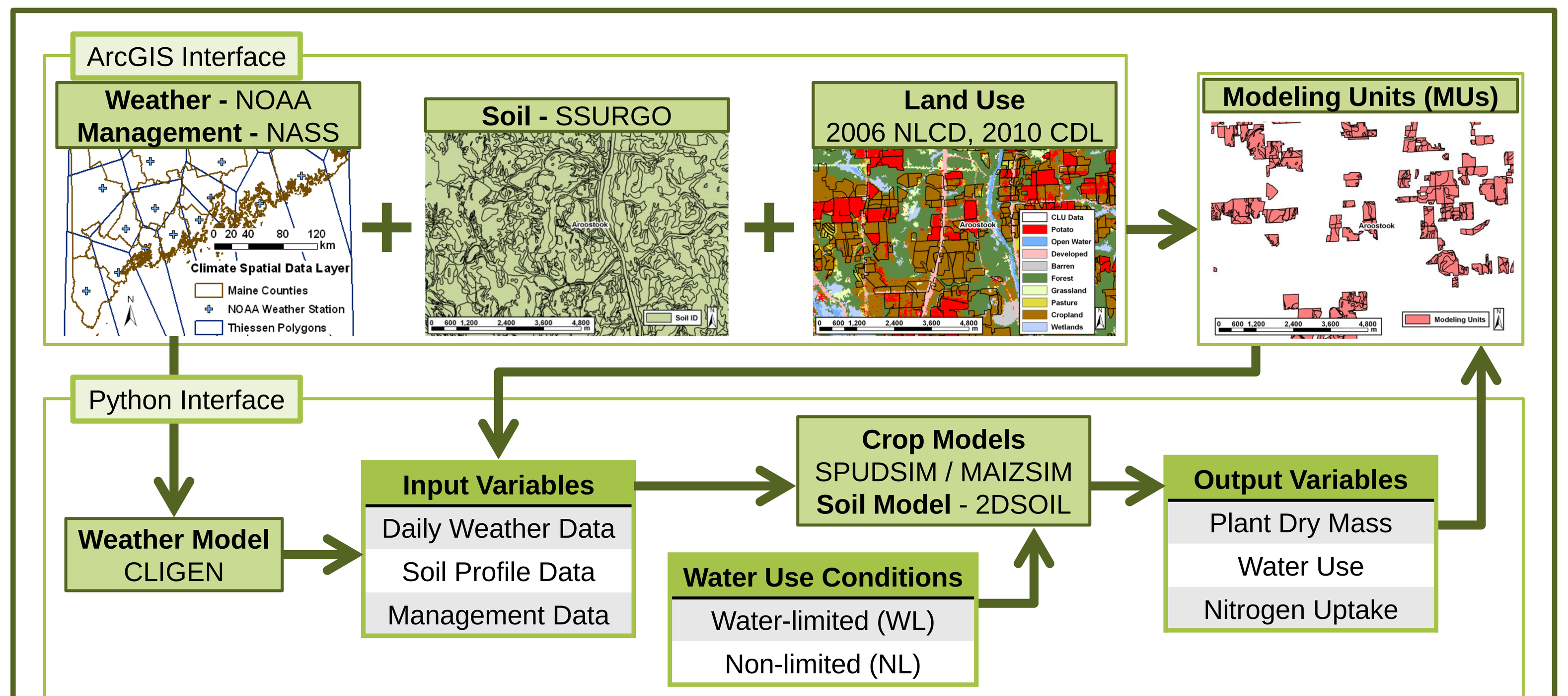
Objectives

- **Evaluate** the potential production capacity (PPC) for the ESR
- **Quantify** the PPC using an aggregated yield index (YI)
- **Compare** the YI over different 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/m^2) / (1 - Moisture Content)

$$YI_i \text{ (Mkcal/ha)} = \Sigma_j[\text{Yield (Mg/ha)} * \text{Caloric Content (kcal/g)} * \text{Harvest Area (ha)} * (1 - \text{Moisture Content}) * \text{Harvest Index}] / \Sigma_j[\text{Harvest Area (ha)}]$$

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/m^2)	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 adapt to the effects of CC?

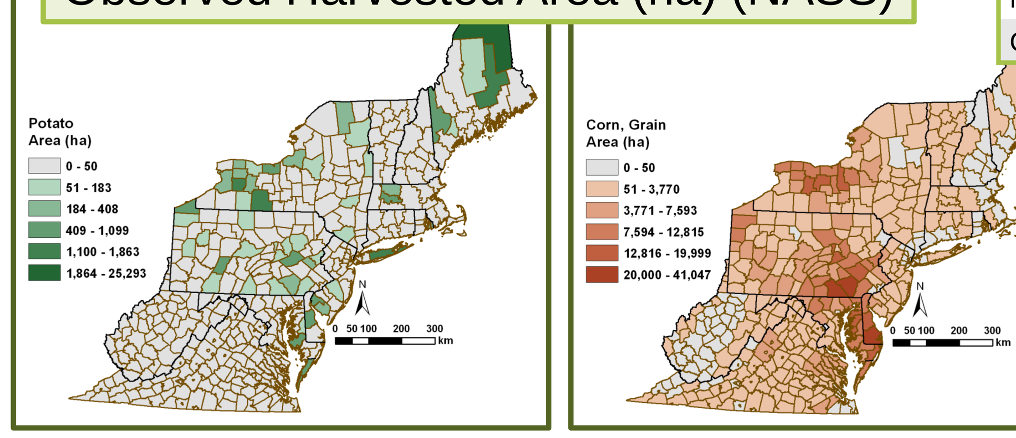
Why a Yield Index? • Aggregate multiple crops over space • Easily compare scenarios

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 (ha) (NASS)

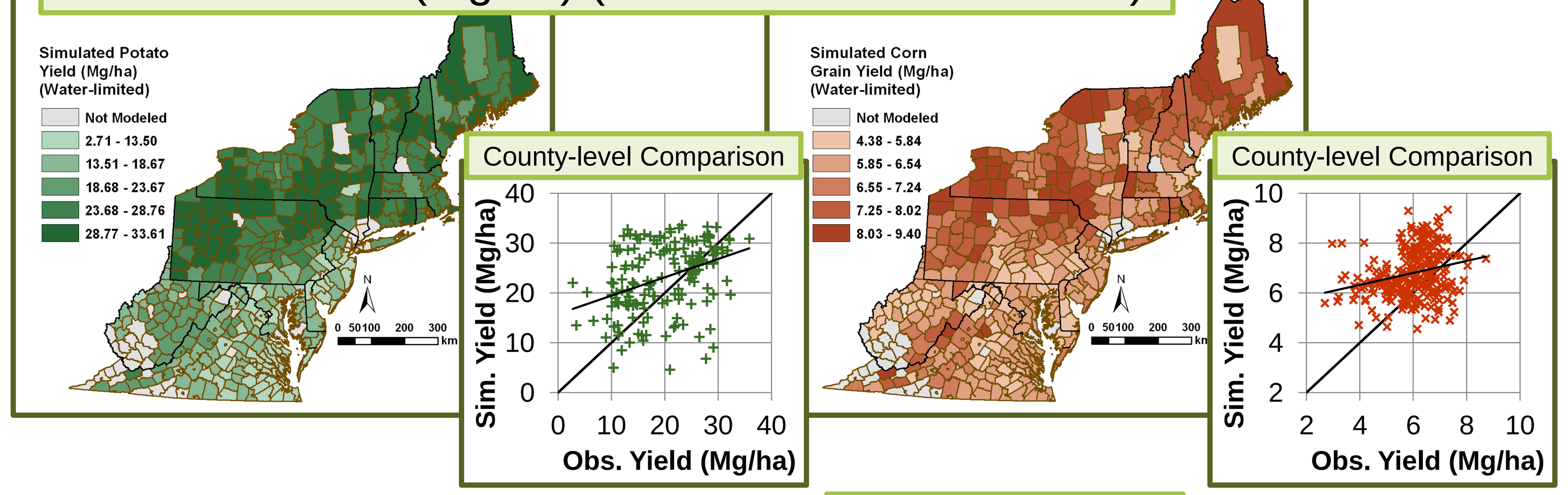


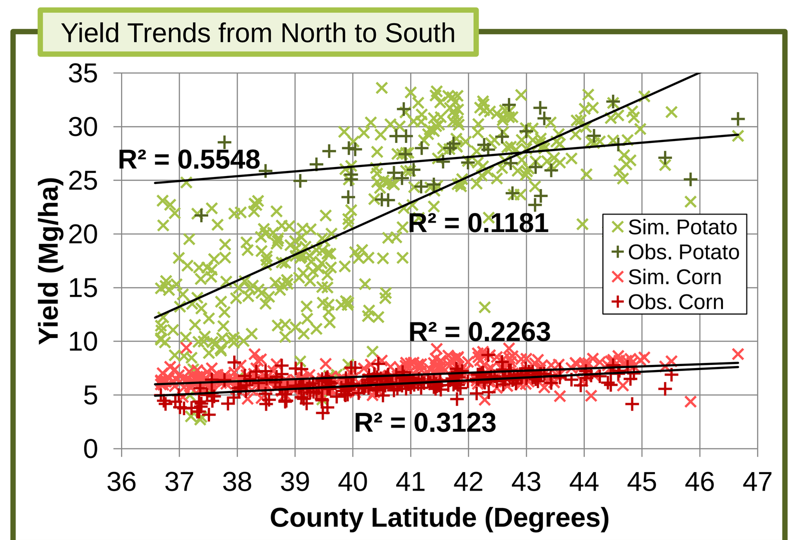
Harvested Area is the current or baseline area available for production.

Overall cropland in the ESR is decreasing.

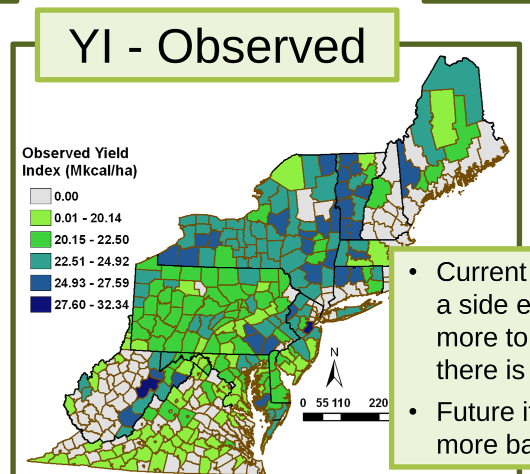
Increasing harvested area would require:
- Converting area from existing cropland
- Adding unused marginal land
- Other changes in regional land use

Simulated Yield (Mg/ha) (SPUDSIM and MAIZSIM)

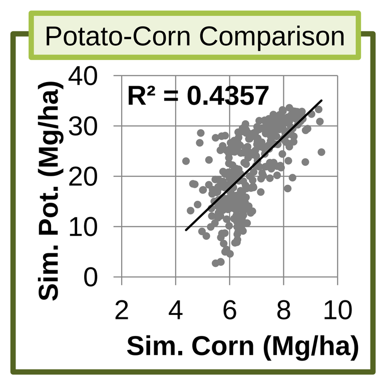




YI - Observed



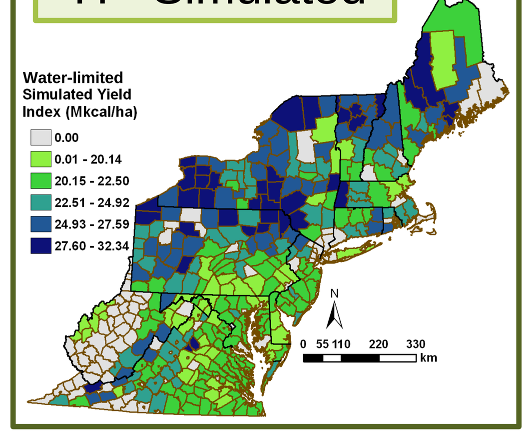
- Current YI calculation has a side effect of weighting more to corn yield, since there is more corn area.
- Future iterations will try a more balanced approach.



- 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 individual 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

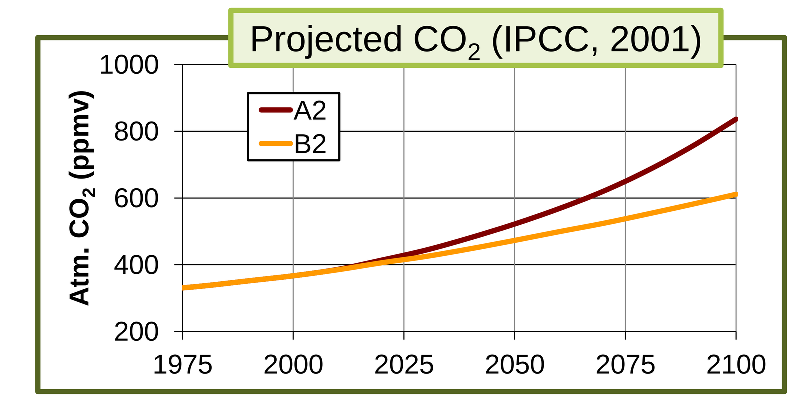
YI - Simulated



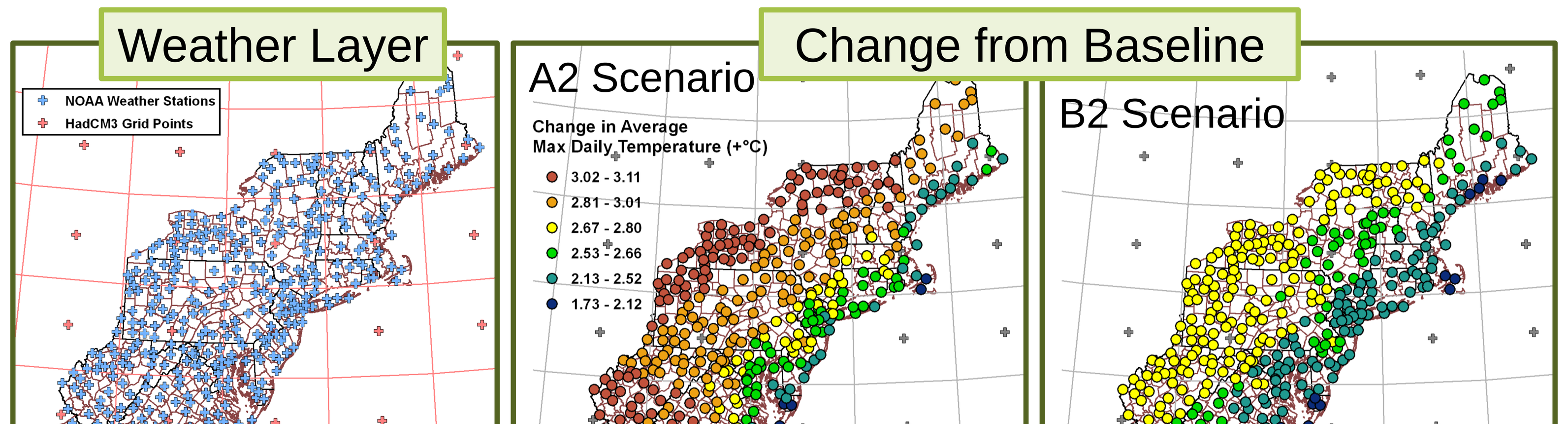
Potential Climate Change Scenarios

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)

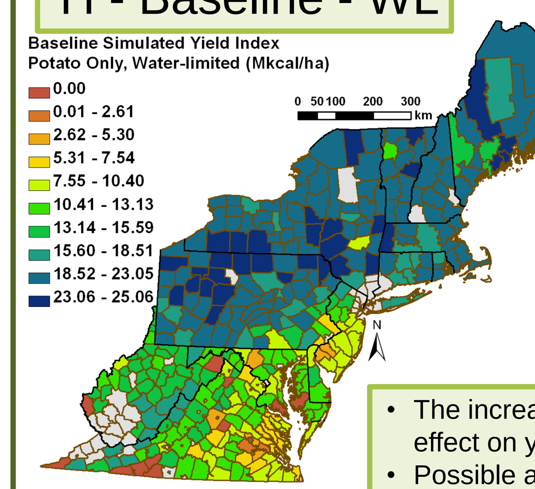


Weather Layer / Change from Baseline



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

YI - Baseline - WL

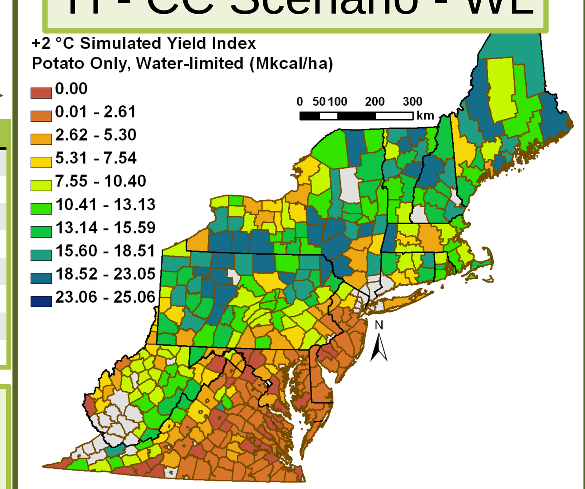


Simple CC Example
Potato Only, Water-limited (WL), +2 °C Max/Min Daily Temp

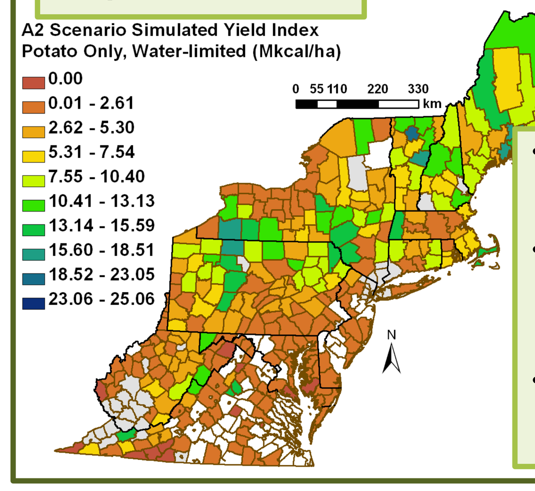
Change in YI			
State	Change	State	Change
ME	-35%	PA	-39%
VT	-27%	NJ	-79%
RI	-43%	MD	-77%
NH	-28%	DE	-88%
MA	-51%	WV	-44%
CT	-46%	VA	-76%
NY	-43%		

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

YI - CC Scenario - WL



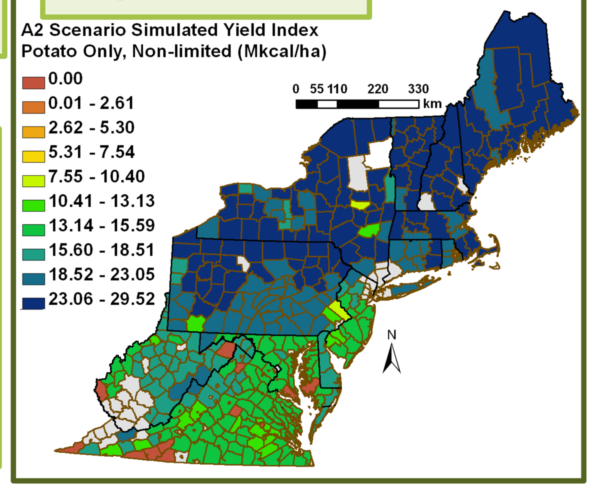
YI - A2 - WL



Using Downscaled GCM Data
Potato, WL and NL, A2 Conditions, Modifying Temp, Precip, and CO_2

- The negative effect on yield under the A2 scenario was much greater than assuming a simple +2 °C.
- While increased CO_2 and precip have the potential to increase yield, this was countered by a much greater increase in temp.
- However, assuming non-limited conditions, the loss in yield was much smaller.

YI - A2 - NL



State-level Overall Yield Index (Mkcal/ha) (Potato and Corn) (Current Land Use)

		Water-limited (WL) Conditions			Non-limited (NL) Conditions		
	Obs.	Baseline	A2	B2	Baseline	A2	B2
Maine - Potato	22.72	21.45	11.81	12.52	28.93	27.30	27.71
Maine - Corn	21.10	26.26	20.57	19.32	35.07	28.75	28.76
Maine - Overall	22.78	22.83	14.32	14.47	30.69	27.71	28.01
Maryland - Potato	16.37	11.30	1.12	1.45	19.12	15.55	16.11
Maryland - Corn	20.72	20.77	17.32	17.40	27.64	23.36	24.12
Maryland - Overall	21.16	20.75	17.30	17.38	27.63	23.35	24.11

- In Maine, majority potato land, there was a 37% drop in YI from Baseline to A2 assuming water-limited (rain-fed) conditions.
- However, when irrigation was used (no water stress), there was only a 10% drop in the overall YI.
- Climate change had a greater influence on potato than corn. The WL yield drop was 45% for potato and 22% for corn.
- In Maryland, majority corn land, corn was less influenced by A2. However, potato production dropped to near zero.
- Each county will likely require different adaptation strategies, emphasizing the importance of a spatially-dependent study.

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 adaptation strategies.