Fruit & Vegetable Supply Chains
Climate Adaptation & Mitigation Opportunities
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Enhancing the productivity, resilience, and sustainability of domestic produce food systems

Protocol for US Potato Simulations

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BACKGROUND

Potatoes are a main vegetable crop in the United States with an annual production of 4 million tons (dry tuber) grown on 0.4 million ha. Climate change could impact potato production in the US. Potato production could decline or increase in the current potato production areas. There could also be opportunities to produce potatoes in new areas of the US under future climate scenarios.

GOAL

Assess the climate change impact on potato tuber yields and potential adaptations, including possible shifts in production area in the US.

SELECTION OF REPRESENTATIVE COUNTIES

Potatoes are one of eight fruit and vegetable crops being studied within a current NIFA-funded project (Award #: 2017-68002-26789), "Fruit & Vegetable Supply Chains: Climate Adaptation & Mitigation Opportunities." The other seven crops are carrots, green (snap) beans, oranges, spinach, strawberries, sweet corn, and tomatoes. For efficiency, counties for open-field crop modeling were selected in a manner that considered the presence of all eight crops. The total production acreage for all eight crops was tabulated for all Crop Reporting Districts (CRD's), using data from the most recent USDA AgCensus (2012). The CRD's were then sorted in a descending manner, choosing the highest acreage CRD's necessary to capture 80% of all acreage for these eight crops. This resulted in a list of 31 CRD's, and the counties having the highest target crop acreage within each of these CRD's were then selected for all subsequent open-field crop modeling in the project (see Appendix Figure A1 & Table A1).

CROP MODELS

Up to six crop models (Table 1) will be used for the US potato simulations: SIMPLE (developed at University of Florida), CropSyst (developed at Washington State University) (Stöckle et al. 1994; Stöckle et al. 2003; Stöckle et al. 2014), LINTUL-POTATO-DSS (developed at Wageningen University; Haverkort et al., 2015), EPIC (via USDA collaboration) and DSSAT-Substore (Raymundo et al., 2017). Note: SIMPLE will also be used within the CropSyst simulation framework and is considered as a crop model here.

Table 1: Crop models that will be used for US potato simulations.

No.	Crop Model	Reference
1	SIMPLE	Unpublished
2	CropSyst	Stöckle et al. (1994)
3	SIMPLE-CropSyst	Unpublished
4	LINTUL-POTATO-DSS	Haverkort et al. (2015)
5	EPIC	Williams et al. (1989)
6	DSSAT-Substore	Raymundo et al. (2017)

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CROP MODEL PARAMETERIZATION

a. Crop models will be parameterized with available field experimental data.

b. Potatoes in the US are harvested well before the natural maturity of the crop, by killing the vines. For the baseline, the accumulated temperature requirement of a model will be set for each county (assuming different maturity types for each county), assuming that canopy cover for potato will still be about 80% at the harvest date. For the SIMPLE model, the accumulated temperature requirement for leaf area development to 50% of canopy cover will be constantly set at 680 °C d. The accumulated temperature requirement till maturity to reach 50% of canopy cover due to leaf senescence will constantly be set at 400 °C d. The thermal time requirement from sowing to maturity (Tsum) will be set to about 80% of canopy cover at harvest dates. Crop models will be calibrated (harvest index should be kept between 0.7 and 0.9) to reported gridded yield data from the year 2000 from Monfreda et al. (2008), which were corrected with yield data from variety trials from recent years (Table A2). Reported potato dry yield data are shown in Appendix Figure A2).

c. Planting and harvesting dates from Sacks et al. (2010) are shown in Figure 1 and Table A2 with corrections for California, Florida, Georgia, and Texas (see figure caption for details).

d. Full irrigation will be assumed to have been applied to avoid/minimize water stress. It will be assumed that there are no nutrient limitations.

SOIL DATA

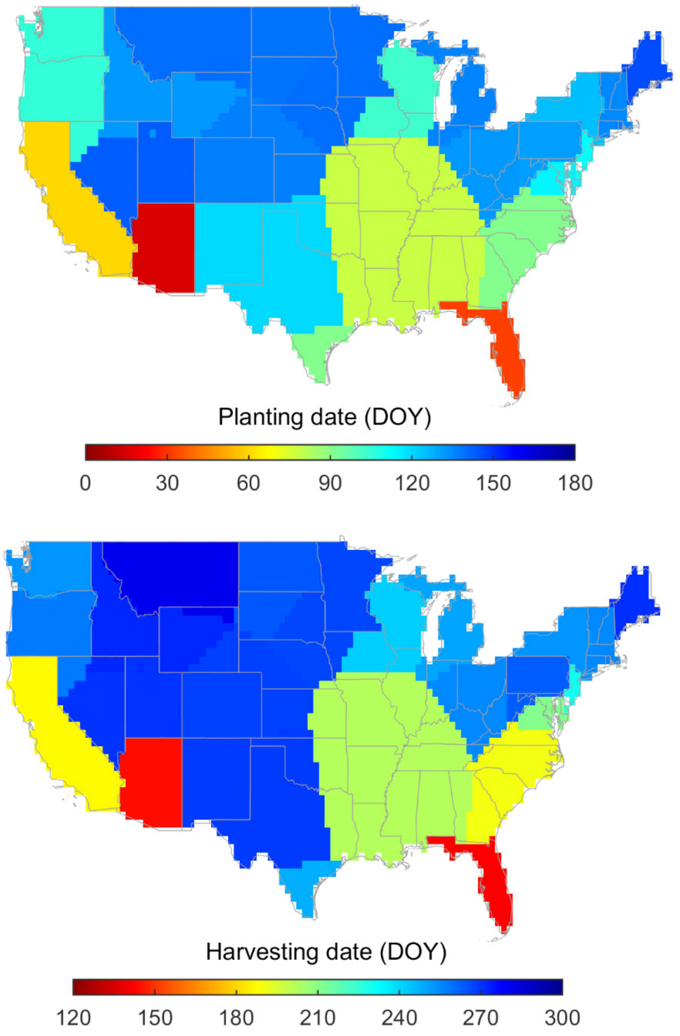
Soil data will not be required for this form of crop modeling, which assumes the complete absence of any water stress (fully-irrigated conditions).

CLIMATE DATA

Two sources of historical weather data, including AgMERRA/ISIMP future scenarios and high-resolution climate scenarios from the University of Idaho and two downscaling approaches will be used for the baseline. For the future scenarios, five downscaled and bias-corrected Global Circulation Model (GCM) scenarios were obtained from ISI-MIP (the Inter-Sectoral Impact Model Intercomparison Project) database (revised version from November 2015) from the Potsdam Climate Institute (PIK) (Table 2).

In each approach, monthly deltas from the GCM simulations for maximum and minimum temperature will be applied to the baseline data to create future temperature scenarios (RCP 8.5 IPCC emission scenarios). Note, rainfall is not required as this modeling will not consider the possibility of water stress. And, solar radiation will remain unchanged in the future scenarios. The baseline period is 1981-2010, future scenarios are for the 2030s (2021-2050) and 2050s (2041-2070).

Figure 1: Reported potato calendar for 2000 with 0.5 degree grid cells. Reported dates are from Sacks et al. (2010). Planting dates were corrected based on local knowledge for main potatoes counties in these states: California: January (Imperial county) and March (Fresno, Yolo, and Monterey county) instead of May for planting; Florida: January (Hendry and Polk county) and February (St. Johns county) instead of November for planting; Georgia: early March (Decatur county) instead of late March for planting; Texas: January (Hidalgo county) instead of April for planting.



CO$_2$ FERTILIZATION EFFECT

It is generally accepted that higher future atmospheric CO$_2$ concentrations will stimulate growth, however, the magnitude of the effect is subject to uncertainty and would likely be constrained under nutrient limitations (Kimball 2016). As most fruit and vegetables in the US receive adequate fertilizer and irrigation, such constraints of the CO$_2$ fertilizer effect are unlikely for the future scenarios considered within this project. Accordingly, for consistency with AgMIP protocols (Rosenzweig et al., 2013) and the assumed future temperature scenarios (RCP8.5), the atmospheric CO$_2$ concentration will be set at 360 ppm for the historical period (1981-2010), 445 ppm for the 2030's (2021-2050), and 571 ppm for the 2050's (2041-2070).

Table 2: General circulation models (GCM) used for future scenarios.

No.	GCM
1	HadGEM2-ES
2	IPSL-CM5A-LR
3	GFDL-ESM2M
4	MIROC-ESM-CHEM
5	NorESM1-M

AgMERRA with ISIMP future scenarios for SIMPLE/LINTUL-POTATO-DSS.

Baseline (1980-2010) daily temperatures, solar radiation, and precipitation will be taken from AgMERRA Climate Forcing Dataset (https://data.giss.nasa.gov/impacts/agmipcf/agmerra/) at a 0.5 x 0.5 degree resolution.

HIGH-RESOLUTION CLIMATE SCENARIOS FROM THE UNIVERSITY OF IDAHO

Daily weather for a 4 km x 4 km grid are available for historical (1981-2010) and future scenarios, including maximum and minimum temperature, precipitation, solar radiation, maximum and minimum relative humidity, and wind speed. The daily weather data were extracted from the Web Accessible Folder (http://cloud.insideidaho.org/webservices.html#waf) maintained by the University of Idaho, based on the methodology described in Abatzoglou and Brown (2012) and Abatzoglou (2013).

The historical gridded daily weather data are based on a methodology that blends desirable attributes of gridded climate data and desirable temporal attributes of regional-scale reanalysis and daily gauge-based precipitation to derive a high-resolution gridded surface meteorological dataset covering the continental United States (Abatzoglou, 2013). For future weather, climate simulations from global climate models (GCMs) in the Coupled Model Intercomparison Project, Phase 5 (CMIP5) were statistically downscaled over the contiguous United States using the Multivariate Adaptive Constructed Analogs (MACA) method with a joint bias correction of daily temperature and precipitation (Abatzoglou and Brown 2012). Downscaled data were trained using the 1/24th degree resolution gridded surface meteorological dataset of Abatzoglou (2013).

SIMULATION OF CLIMATE CHANGE IMPACT AND ADAPTATION

Climate change and adaptation scenarios are shown in Table 3. For adaptation, earlier planting and extra degree days will be used, and the harvest date will remain the same as historical (so the season length actually gets longer).

MULTI-MODEL ENSEMBLE

Each model will be used to simulate the baseline (1 simulation), as well as the impact and adaptation for two future periods (Table 3) with five GCMs (Table 2). The total number of simulations per model and grid cell is: 21 = 4 x 5 + 1 baseline).

Table 3: Protocol for US potato simulations.

No.	Scenarios	Time Period	CO_2 Conc.	Planting and Adaptation
1	Baseline	1981-2010	360	From Sacks et al. (2010) with correction for CA, FL, GA, and TX (see Figure 1 and Table A2 for details).
2	2030sNoAdaptation	2021-2050	445	Same as historical
3	2050sNoAdaptation	2041-2070	571	Same as historical
4	2030sWithAdaptation	2021-2050	445	7 days earlier planting + 150 degree-days to maturity
5	2050sWithAdaptation	2041-2070	571	15 days earlier + 300 degree-days to maturity

Table 4: Climate scenario source used for each crop model.

No.	Crop Model	Climate Source
1	SIMPLE	AgMERRA/ISIMP scenarios
2	SIMPLE-Crop-Syst	High-resolution scenarios
3	CropSyst	High-resolution scenarios
4	LINTUL-POTATO-DSS	AgMERRA/ISIMP scenario
5	EPIC	AgMERRA/ISIMP scenario
6	DSSAT-Substore	AgMERRA/ISIMP scenario

The ensemble-based yield impact will be calculated with the following steps:

1) Calculate the simulated mean tuber dry yield for climate change scenarios across 30 years (1981-2010) per single CM-GCM at each county.
2) Calculate the simulated mean tuber dry yield for climate change scenarios across 30 years (2021-2050 and 2041-2070 with or without adaptation) per single CM-GCM at each county.
3) Calculate the relative yield impact (%) per single CM and per GCM for each county, region, and the whole US. Note that CMs and GCMs simulation results must be kept separate at this stage for calculating uncertainties across CMs and GCMs.
4) For each crop model, the results from different GCMs will first be averaged.
5) The mean of the four CMs is then considered as the ensemble mean.

OUTPUT

Outputs will include % change in tuber dry weight (at 0% moisture), total biomass, N uptake (only for Cropsyst, LINTUL-POTATO-DSS, Substore, and EPIC), evapotranspiration demand (only for Cropsyst, LINTUL-POTATO-DSS, Substore, and EPIC), with uncertainty range aggregated at the county, region, and national scale for impact and adaptation for each future period relative to the baseline period (Table 5).

Any proportion of harvestable product left in the field (e.g., due to size or technology) will be calculated elsewhere.

Table 5: Output format is in % change of tuber dry weight (at 0% moisture), total biomass, N uptake, and evapotranspiration demand for US potato simulations (each is reported as a multi-model ensemble mean and an uncertainty range, 25 to 75% tile).

No.	Scenarios	Time Period
1	2030sNoAdaptation	2021-2050
2	2050sNoAdaptation	2041-2070
3	2030sWithAdaptation	2021-2050
4	2050sWithAdaptation	2041-2070

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Conflict of Interest Statement: The authors declare their affiliations and employers in the authors list. The ILSI Research Foundation is a non-profit, public charitable organization with a mission to bring scientists together to improve environmental sustainability and human health.

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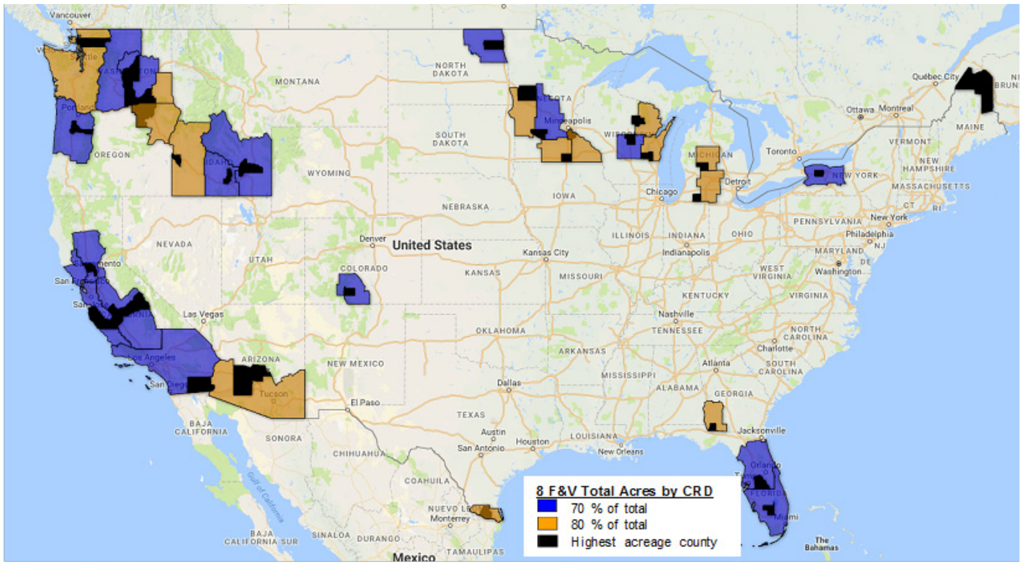
APPENDIX

Figure A1: Crop Reporting Districts (CRD's) making up 70% and 80% of total target crop acreage, as well as the highest target crop acreage county in each CRD.



Source: USDA 2012 Ag Census (quickstats.nass.usda.gov), NASS CDL, WAEES Fill-in

Figure A2: Reported potato yields for 2000 with 0.5 degree grid cells. Reported yield from Monfreda et al. (2008). All presented potato yields are at 0% moisture.

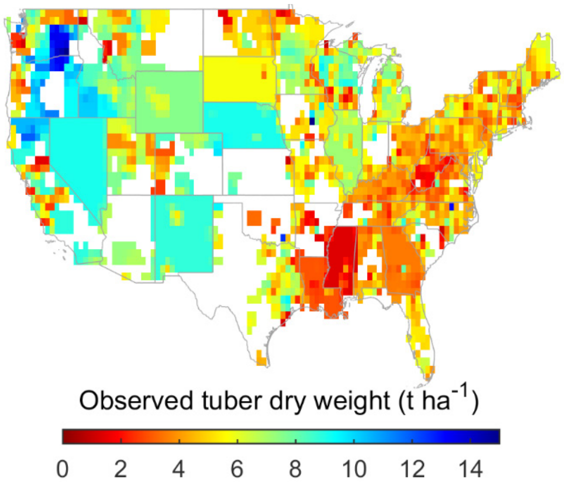


Table A1: Counties Selected for Open-Field Crop Modeling[1]

State	State Crop Reporting District (CRD)	Target Crop Area in the CRD (ha)	County	Target Crop Area in the County (ha)
Arizona	AZ80	7,223	Maricopa	3,173
California	CA51	186,624	Fresno	59,003
	CA80	35,381	Imperial	11,168
	CA40	24,658	Monterey	15,228
	CA50	32,326	Yolo	16,223
Colorado	CO80	22,900	Rio Grande	7,438
Florida	FL80	181,203	Hendry	41,242
	FL50	64,226	Polk	29,880
	FL50	64,226	St. Johns[2]	6,020
Georgia	GA70	10,002	Decatur	6,264
Idaho	ID90	100,707	Bingham	31,262
	ID70	7,275	Canyon	3,143
	ID80	35,569	Minidoka	12,770
Maine	ME10	23,205	Aroostook	23,205
Michigan	MI50	9,746	Montcalm	7,230
	MI80	6,240	St. Joseph	3,748
Minnesota	MN90	12,464	Dakota	3,505
	MN80	12,763	Freeborn	2,512
	MN40	6,460	Otter Tail	4,266
	MN50	22,859	Renville	9,813
New York	NY40	19,728	Genesee	4,295
North Dakota	ND30	25,906	Walsh	13,448
Oregon	OR10	16,180	Marion	6,932
	OR30	10,380	Umatilla	7,788
Texas	TX97	7,291	Hidalgo	6,601
Washington	WA20	27,984	Benton	25,024
	WA50	63,672	Grant	30,033
	WA10	9,899	Skagit	5,515
	WA90	7,152	Walla Walla	6,990
Wisconsin	WI60	6,307	Fond du Lac	2,052
	WI30	9,361	Langlade	6,596
	WI50	55,503	Portage	26,549

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[1] Note: Not all eight target crops (carrots, green beans, oranges, potatoes, spinach, strawberries, sweet corn, and tomatoes) can be grown in all 31 of these counties. Counties where open-field production is not possible (e.g. oranges in northern areas) will not be included in the modeling protocol for that crop.

[2] St. Johns County included to ensure representative modeling of potatoes in northern Florida.

Table A2: Potato planting, harvesting dates, and tuber dry weight for the counties selected for modeling. Observed yields from Manfredo et al. (2008) for year 2000 were corrected by 3.6 t/ha based on a comparison of several variety trial yields with Manfredo et al. (2008). As Fresno and Yolo (CA) had extremely low reported yields in Manfredo et al. (2008), we replaced the yields for these two counties with nearby variety trial yields.

State	County	Planting Date (DOY)	Harvesting Date (DOY)	Observed Tuber Dry Weight (t/ha)	Corrected Tuber Dry Weight (t/ha)
Arizona	Maricopa	15	135	7.26	10.86
California	Fresno	60	180	2.62	9.53
	Imperial	15	135	7.47	11.07
	Monterey	60	180	6.58	10.18
	Yolo	75	195	2.75	9.53
Colorado	Rio Grande	137	268	8.53	12.13
Florida	Hendry	1	111	6.42	10.02
	Polk	1	111	5.30	8.90
	St. Johns	30	140	5.29	8.89
Georgia	Decatur	60	160	3.51	7.11
Idaho	Bingham	132	272	8.02	11.62
	Canyon	132	272	9.71	13.31
	Minidoka	132	272	9.26	12.86
Maine	Aroostook	116	271	5.65	9.25
Michigan	Montcalm	136	250	7.58	11.18
	St. Joseph	136	250	6.81	10.41
Minnesota	Dakota	140	247	3.25	6.85
	Freeborn	140	267	6.49	10.09
	Otter Tail	140	267	8.51	12.11
	Renville	140	267	7.95	11.55
New York	Genesee	125	235	5.93	9.53
North Dakota	Walsh	139	264	4.49	8.09
Oregon	Marion	121	251	6.49	10.09
	Umatilla	105	258	13.33	16.93
Texas	Hidalgo	1	111	4.34	7.94
Washington	Benton	105	253	13.95	17.55
	Grant	105	253	13.35	16.95
	Skagit	121	246	4.59	8.19
	Walla Walla	105	253	14.38	17.98
Wisconsin	Fond du Lac	103	222	2.06	5.66
	Langlade	103	242	7.72	11.32