Geospatial Monitoring of Cropping System Dynamics and Production Footprints in Maine

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INTRODUCTION Tracking the spatial interdependencies of cropping systems is an often overlooked component of agricultural sustainability. Geospatial frameworks help resolve patterns and trends in production environments at multiple scales that may enable improvements in adaptive management strategies which enhance yield, increase whole-farm profitability, and foster sustainable land and water use. The objectives of this investigation were to: (1) assess production footprints for Maine cropping systems using 2008-2011 Cropland Data Layer (CDL), Common Land Unit (CLU), digital elevation models (DEM) and National Agriculture Image Program (NAIP) datasets; (2) examine geospatial relationships of potato, small grains, corn, and broccoli; (3) interrelate production areas with agri-environmental indicators (Soil Survey Geographic – SSURGO 2.2); and (4) evaluate dominant crop sequences and potential economic impacts of select alternate crops across 3 yrs (2008-2010) using a 324-ha potato farm model. Gauging these relationships helps food system researchers assess economies of scale linked to agro-ecoregions, productive capacity pools, and land quality.

MATERIALS and METHODS Georeferenced data for cropland/land use patterns (based on CDL/NLCD classifiers), farmland delineations (CLU), soils (SSURGO – farmland and erodibility classifiers), topography (NED 10 m) and NAIP datasets were integrated in ArcGIS (v.10). Producers and users accuracies for remotely-sensed crops (56 m resolution CDLs, Fig. 1) varied from year to year depending on image acquisition dates, planting dates, row crop adjacencies, field boundary complexity, weed species incursions, use of cover crops and/or strip cropping. Crop areas extracted from CDLs were compared with county-level Census of Agriculture records (Fig. 2). Small grains (barley (B), oat (O), rye (R), spring and winter wheat) were aggregated to improve aerial extent assessments. CLUs were then used to constrain CDL classification errors.
Economic Analyses. Crop sequences in potato production systems derived from the 2008-2010 CDL map products were used to assess the net farm income (NFI) for potatoes and the top 12 rotation crops. NFI was calculated in Excel spreadsheets for both individual crop enterprises as well as whole-farm scenarios. Representative enterprise and whole-farm budgets were constructed for potatoes and potato rotation crops. Sensitivity analyses were run to provide break-even yields for each potato rotation crop. In addition, "short-run" (S-R) and "long-run" (L-R) analyses were conducted in an attempt to account for potential yield impacts associated with rotation length. S-R assumed constant potato yields (31.66 Mg ha^{-1}); L-R assumed an increase 28.6% in 3-yr versus the traditional (or baseline) 2-yr rotations, whereas potato-potato-crop X (PPX) and continuous potatoes are expected to have potato yields that are 14.3% and 28.6% lower than potato-crop X two-year rotations (Myers et al. 2008; Mohr et al. 2011).

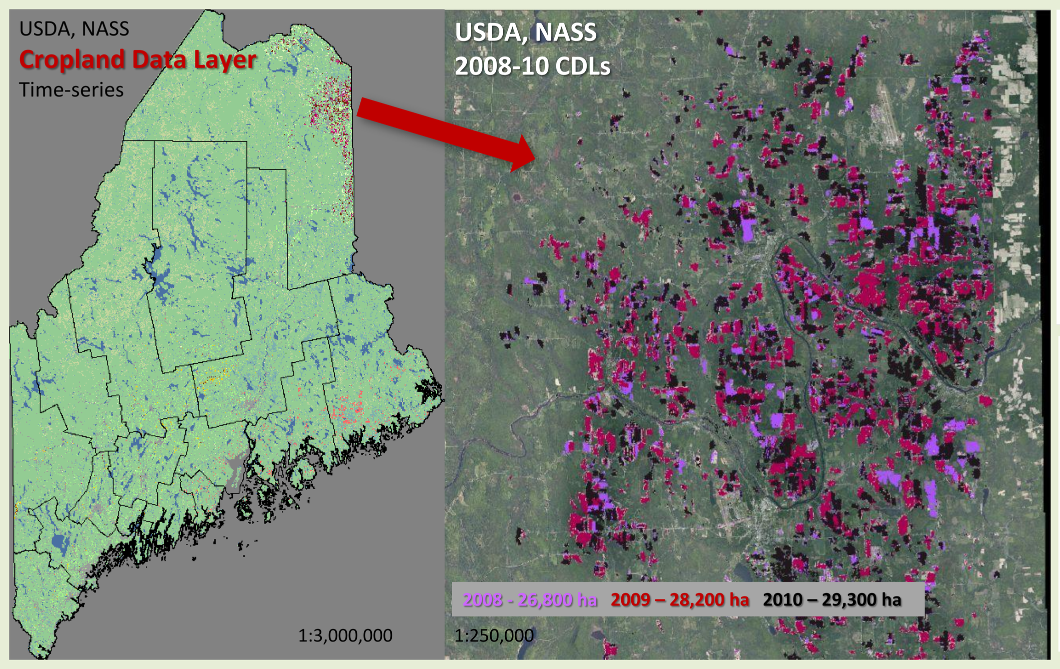


Figure 1. Cropland data layer (CDL) time-series with inset (on right) showing 3-yr mosaic of potato fields (around Caribou and Presque Isle, Aroostook County, ME).

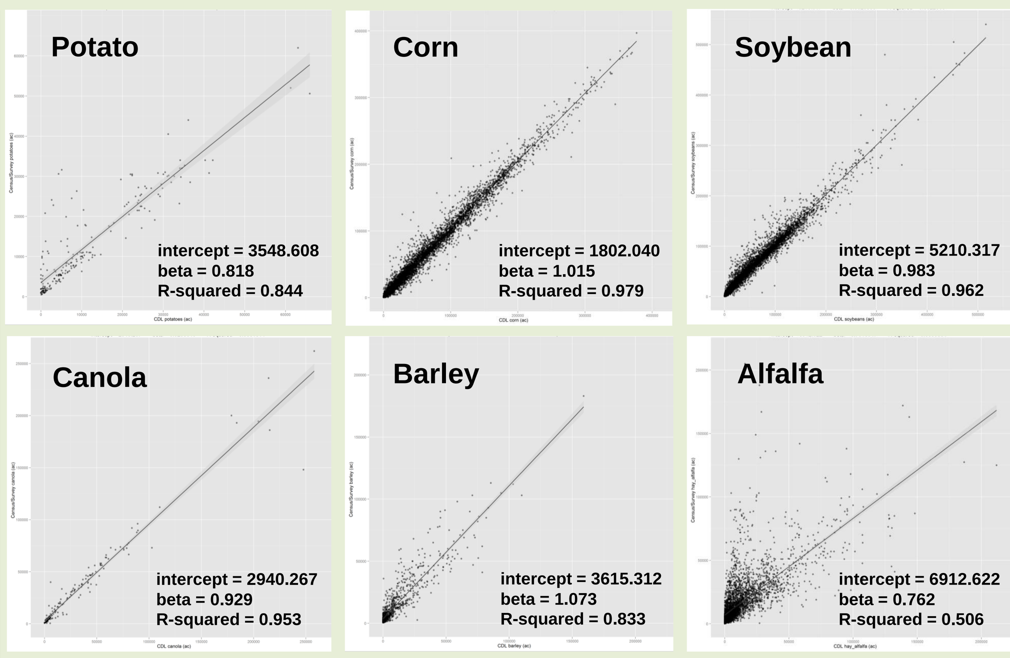
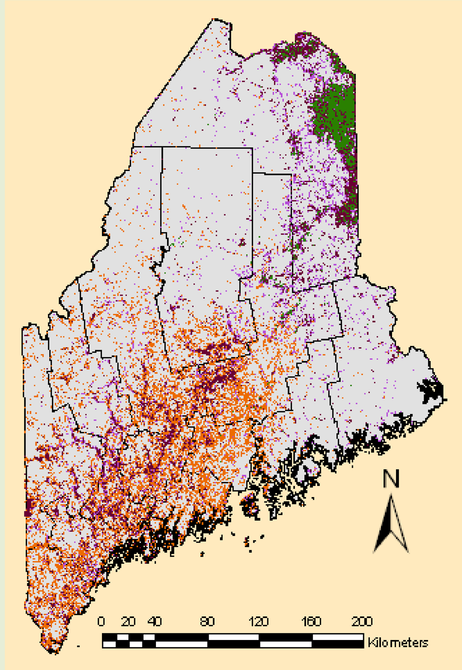


Figure 2. Crop-specific comparisons of county-level Census of Agriculture/Survey areas (on y-axis) with aerial extents extracted from CDLs (on x-axis) for all years throughout the US.

RESULTS Geospatial integration of CDL and CLU layers with soils revealed a 4-yr potato footprint estimated at 56,200 ha with 67% and 27% residing on 'prime farmland' (PF) and 'farmland of statewide importance' (FSI), respectively. Over 85% of potato production soils require the highest standards in conservation practices as they are classified 'potentially highly erodible land' (PHEL) or 'highly erodible land' (HEL) (DeFauw et al. 2012). Geospatial interdependency of potato-small grains (barley, rye, oat, spring and winter wheat) had an estimated 4-yr cropland overlap of 77% (Fig. 3-6). Broccoli (Br) was grown on 13% of the 4-yr potato cropping system land base (Fig. 3,5,6), whereas 6% was shared with corn (Fig. 3,5). Forecast models were developed to account for rotational complexity; the 6-yr land base estimate for sustaining Maine's potato systems is approx. 67,000 ha, small grains may occupy 65,000 ha, corn approx. 22,000 ha, and 10,000 ha for broccoli (Fig. 7). NFIs ha^{-1} for enterprises & rotation crops are summarized in Table 1 & 2.



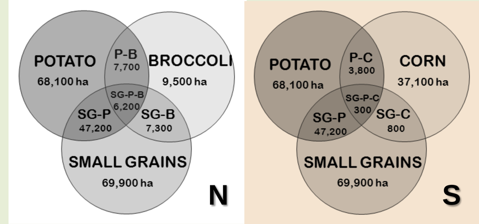


Figure 4. Spatial interdependencies derived from 2008-2011 CDLs (w/ "raw" values rounded to nearest hundred ha).

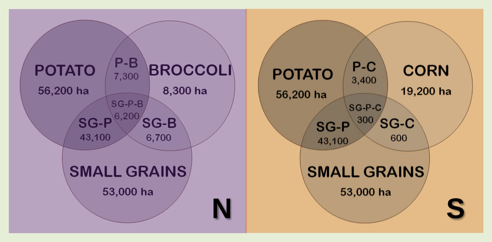


Figure 5. Spatial interdependencies derived from 4-yr CDLs using 'cropland' CLU delineations (hectare values have been rounded to nearest hundred ha).

Figure 3. Four-year production footprints for potato (dark brown pixels), "small grains" aggregation (purple – combines barley, oat, rye, spring and winter wheat), corn (amber), and broccoli (green).

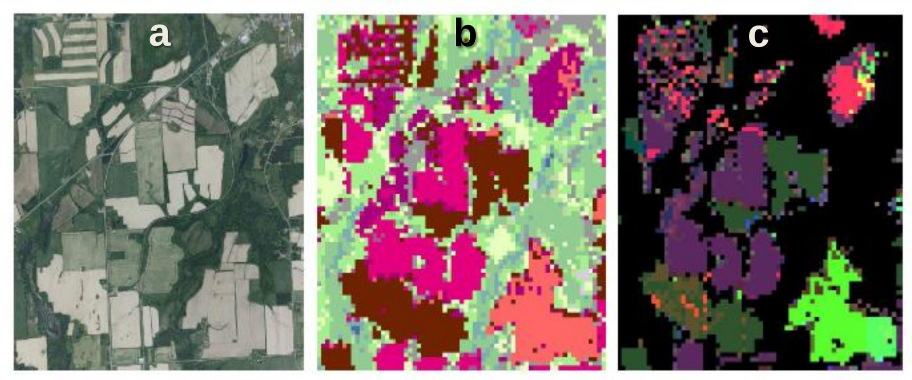


Figure 6. Comparison of raster scenes including: **a** USDA, FSA, NAIP 18 June 2009 (1 m resolution); **b** CDL 2009 (56 m) with B=deep pink, Br=orange, P=brown, R=purple; **c** RGB composite showing crop sequence mosaic from 2008-10 CDLs with P-B-P (purple), P-Br-B (bright green), B-P-B (dark green), Br-R-P (bright red). Scale:1:24,000.

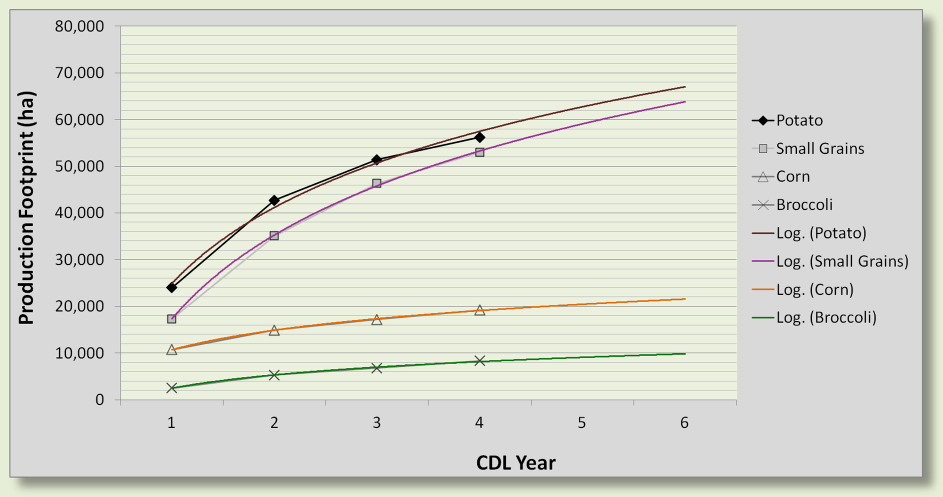


Figure 7. Production footprint '6-yr forecasts' derived from CDL datasets (2008-2011) and CLU delineations.

Table 1. Net farm income (NFI) ha^{-1} for row and forage crop enterprises (listed by production scale) for a 324-ha Maine farm.

	Break-Even Yield with Potatoes[e]						NFI			
Crop	Yield (Mg ha^{-1})	324-ha (Mg ha^{-1})	229-ha (Mg ha^{-1})	162-ha (Mg ha^{-1})	94-ha (Mg ha^{-1})	Price ($ Mg^{-1})	324-ha ($ ha^{-1})	229-ha ($ ha^{-1})	162-ha ($ ha^{-1})	94-ha ($ ha^{-1})
Broccoli	8.97	8.42	8.26	8.09	7.75	$551	$1,226	$1,010	$794	$362
Potato	31.66	-	-	-	-	$187	$927	$618	$310	-$307
Soybeans	2.81	3.54	3.16	2.77	2.00	$474	$583	$456	$329	$74
Alfalfa, perennial[a]	14.11	18.66	17.57	16.48	14.29	$101	$501	$294	$88	-$324
Corn silage	36.48	47.19	45.34	43.50	39.81	$51	$426	$204	-$18	-$463
Canola	1.68	2.96	2.65	2.34	1.72	$617	$151	$30	-$91	-$333
Barley grain + straw[b]	6.31	12.02	10.91	9.81	7.60	$171	$71	-$72	-$215	-$501
Wheat grain + straw[b]	7.16	13.12	11.94	10.76	8.40	$171	$51	-$84	-$220	-$490
Clover, perennial[a]	7.49	20.25	18.46	16.68	13.12	$83	-$45	-$218	-$391	-$736
Barley grain	3.39	7.87	7.08	6.29	4.71	$225	-$67	-$200	-$334	-$601
Pasture, perennial[a]	4.51	22.85	18.34	13.82	4.78	$61	-$101	-$157	-$212	-$322
Wheat grain[c]	3.03	7.45	6.72	5.99	4.54	$263	-$185	-$310	-$436	-$687
Corn grain	6.28	13.60	12.45	11.30	9.00	$157	-$222	-$350	-$478	-$734
Haylage, perennial[a]	13.54	34.11	33.05	31.99	29.87	$61	-$226	-$476	-$725	-$1,223
Oat grain + straw[b]	6.63	18.92	17.19	15.46	12.01	$111	-$252	-$395	-$538	-$824
Clover, est.year[a,d]	5.45	21.11	19.33	17.55	13.98	$83	-$267	-$440	-$612	-$958
Rye grain + straw[b]	4.83	15.00	13.63	12.25	9.50	$137	-$298	-$441	-$584	-$869
Pasture, est.year[a,d]	3.11	25.48	20.97	16.45	7.41	$61	-$327	-$383	-$438	-$548
Alfalfa, est. year[a,d]	9.73	23.63	22.54	21.44	19.25	$101	-$372	-$579	-$785	-$1,198
Dry hay, perennial[a]	5.76	20.79	19.55	18.30	15.80	$91	-$407	-$605	-$803	-$1,198
Rye grain	1.73	8.46	7.61	6.76	5.07	$211	-$466	-$599	-$732	-$999
Oat grain	2.56	13.14	11.82	10.50	7.87	$141	-$487	-$621	-$754	-$1,021
Dry hay, est.year[a,d]	3.97	15.97	15.11	14.25	12.52	$91	-$617	-$814	-$1,012	-$1,408
Haylage, est.year[a,d]	9.34	38.09	37.03	35.97	33.85	$61	-$686	-$935	-$1,184	-$1,682

[a] Assumes perennial stand (years) for alfalfa, haylage, dry hay, and pasture (5), and clover (3).
[b] Dry hay and straw harvested as round bales. For small grain+ straw, yield per hectare and price per metric ton for both straw and grain. [c] Spring wheat. [d] Establishment year only.
[e] Yield per hectare required to have NFI per hectare identical to potatoes at each of the four production scales evaluated.

Table 2. NFI ha^{-1} for potato rotations on a 324-ha Maine farm.

		Potato (hectares)	Crop X (hectares)	Crop Y (hectares)		Short Run[f]		Long Run[g]	
System	Percent potato in rotation				Crop rotation	for all crops PPX ($ ha^{-1})	NFI for all crops PX or PXY ($ ha^{-1})	for all crops PPX ($ ha^{-1})	NFI for all crops PX or PXY ($ ha^{-1})
Potato	100	324	-	-	Potato	$927	-	-$713	-
Potato -	66.7	216	108	-	Potato - Broccoli	$865	$860	$316	$860
Potato -					Potato - Soybean	$671	$550	$124	$550
Crop X					Potato - Alfalfa	$539	$430	-$8	$430
(PPX)[a]					Potato - Canola	$538	$343	-$9	$343
or					Potato - Corn silage	$517	$400	-$30	$400
Potato -	50	162	162	-	Potato - Wheat grain + straw[d]	$485	$278	-$62	$278
Crop X					Potato - Barley grain + straw[d]	$482	$281	-$65	$281
(PX)[b]					Potato - Barley	$449	$222	-$98	$222
					Potato - Wheat[e]	$419	$170	-$128	$170
					Potato - Pasture	$407	$150	-$140	$150
					Potato - Corn grain	$403	$148	-$144	$148
					Potato - Oat grain + straw[d]	$375	$120	-$172	$120
					Potato - Clover	$363	$156	-$183	$156
					Potato - Rye grain + straw[d]	$359	$97	-$187	$97
					Potato - Dry hay[d]	$326	$60	-$221	$60
					Potato - Haylage	$322	$104	-$225	$104
					Potato - Rye	$316	$23	-$231	$23
					Potato - Oat	$309	$12	-$238	$12
Potato -	33.3	108	108	108	Potato - Soybean - Broccoli	-	$587	-	$1,139
Crop X -					Potato - Barley - Broccoli	-	$364	-	$916
Crop Y					Potato - Soybean - Canola	-	$279	-	$827
(PXY)[c]					Potato - Alfalfa - Corn silage	-	$262	-	$809
					Potato - Oat - Broccoli	-	$224	-	$776
					Potato - Canola - Wheat grain + straw[d]	-	$93	-	$640
					Potato - Canola - Wheat grain	-	$27	-	$574
					Potato - Barley - Clover	-	-$109	-	$438
					Potato - Oat - Clover	-	-$249	-	$298

[a] Two years of potatoes followed by a third year of rotation crop. [b] One year of potatoes followed by second year of rotation crop.
[c] One year of potatoes followed by two years of rotation crops. [d] Dry hay and straw harvested as round bales. [e] Spring wheat.
[f] Short-run assumes potato yields are the same across rotations. Yields of other crops in rotation with potatoes are held constant.
[g] Long-run assumes potato yields are impacted by rotation effects on potato yield. Three-year rotations assume 28.6% higher yield than two-year rotations, while PPX and continuous potatoes have 14.3% and 28.6% lower yields than two-year rotations respectively (Myers et al. 2008, Mohr et al. 2011). Yields of other crops in rotation with potatoes are held constant.

CONCLUDING REMARKS Agronomists and farmers are tasked with attempting to double food production over the next 30 years which may entail spatial reallocation and optimization of crop water and energy footprints to better comply with 'localized' soil and water resource constraints. Distinctive shifts in Maine agroecosystems occur from north to south with more intensively managed irrigated farms to the north undergirded by the southern "dairy belt". Over 25 years ago, Hepler and colleagues (1985) noted a shift toward increased dependence on PF soils in cropping systems (especially potato). Our latest findings indicate that 67% of the 4-yr potato production footprint (CDL-CLU derived) resides on prime farmland; ~50,000 ha require the highest standards in soil conservation (PHEL or HEL). Potato is in the top tier of crops with the highest erosion risk as harvest-related erosion rates are of the same order of magnitude (almost 10 Mg ha^{-1} yr^{-1}) as water and tillage erosion on sloping land (Auerswald et al. 2006). Across 4 years, ~600 ha was detected in continuous potato. Potato systems in 2-year rotations involved ~14,000 ha (out of 22,000-23,000 ha planted yr^{-1}) suggesting farmers have diversified their operations and appear to be shifting to rotations of 3+ years. The geospatial methodologies developed also facilitate monitoring shifts in crop adjacencies and thus provide a basic framework to evaluate future finer-scale dynamics of yield impacts as well as pest and/or pathogen pressures (and associated resistance issues) that may develop as a result of these configurations. Assessments linking land use, agri-environmental indicators and current crop sequences in key agroecosystems (such as potato or corn) serve to help producers, communities and policy makers begin to gauge land base requirements, spatio-temporal stability of productive capacity pools, natural resource use, land quality, farmscape economies and potential food systems security risks at multiple scales.

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