Spatial Interpolation of Crop Budgets

Documentation of POLYSYS regional budget estimation

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Introduction

The Policy Analysis System model (POLYSYS), is an agricultural simulation model developed and maintained at the University of Tennessee-Knoxville. Historically, the model has used unique operation budgets for all 305 Agricultural Statistics Districts within the lower 48 states, with 8 traditional crops and hay across 3 tillage regimes. The operation budgets within the Agricultural Budgeting System were compiled by consulting local extension service agencies on the standard operations used in their region. The original compiling of the operation budgets was completed in 1994-1996, and included over 3,000 individual operating budgets. Compilation and maintenance was the sole responsibility of a research associate. Since the original compilation, budgets were updated when time and funding permitted. In 2007 a major update was completed with the inclusion of nationwide no-tillage coverage.

Several critical problems with the large current database of budgets have become apparent. The major problem occurs because of differences in budgeting assumptions (of the original extension agency sources), which leads to large border differences, where operational budgets, and therefore costs of production, change suddenly across political boundaries. Differences in budgeting assumptions occur because some extension agents list the common operations and input quantities, whereas others may list the recommended operations and inputs for maximum yield potential. Oftentimes, where the sudden changes occur, there is little to no difference in geophysical, cultural, or technical traits between the costs of crop production on either side of the border.

During a recent audit of the large budget databases of budgets between 2011-2013, budgets with missing critical operations were discovered, such as nitrogen application or harvesting. Further, many budgets are critically obsolete, using chemicals and application methods a decade old. The survey-based approach is operationally impractical and financially infeasible to maintain.

The proposed alternative is a methodology which uses fewer 'sourced' budgets at the regional level, yet yields regionally-specific budgets without rapid changes in underlying original source assumptions(and corresponding costs) or major omissions of data. The new methodology uses 'spatial interpolation', is a geographic information science operation that uses a few known data points to fill in and spatially smooth (average) data points in between.

The interpolated approach allows for any number of variable point sources. In this first generation of enhanced crop budgets, we use 13 sourced regional budgets for each crop and tillage combination to estimate budgets in all 305 regions. The 13 sourced budgets roughly correspond to the Farm Resource Regions defined by the USDA as unique cropping regions. The spatial interpolation method of 'inverse distance weighting' was chosen as the best method to estimate all unknown regional budgets. The methodology presented here uses the 13 representative regions to yield specific estimates for all Agricultural Statistic District regions (N=305; and hereafter POLYSYS Regions) of the following variables per acre of production: total cost of production, input quantities (N, P_2O_5, K_2O, lime, diesel), embodied energy (BTU), and embodied carbon (CO_2*eq*).

Methodology

Overview

Regional budgets are estimated using the Agricultural Budgeting System (ABS) (Slinsky and Tiller 1999). As a first step, ABS uses only 13 sourced regional budgets for each crop and tillage combination to represent management practices in each of 13 regions roughly corresponding to the Farm Resource Regions defined by the USDA as unique cropping regions. The sourced regional management practices are compiled by consulting local extension service agencies on the standard operations used in their region, and budgets are calculated using methods recommended by the American Agricultural Economics Association (American Agricultural Economics Association 2000). The latest update of management practices occurred in 2015, with input costs updated in 2018. Next, the spatial interpolation method of inverse distance weighting is used with the original 13 sourced budgets to estimate unique budgets for all 305 sub-regions (Hellwinckel 2015). Finally, regional crop costs of production are adjusted (based on their planted acreage weights) to match annual USDA baseline projections for national average costs of production.

Spatial interpolation

Spatial interpolation is the process of using points with known values to estimate values at other points in spatial data environments where a few points are known, but values in between the known points are not known. Spatial interpolation is a process of filling in values between the sample points. A basic assumption of spatial interpolation is that the value to be estimated at a point is more influenced by nearby known points than those that are farther away.

There are several methods of spatial interpolation, which fall into two main groups, global and local interpolation. Global interpolation uses every known point available to estimate the unknown values. Local interpolation uses a sample of known points to estimate unknown values. Methods include Thiessen polygons, density estimation, regression, trend surface, splines, kriging, and inverse distance weighting.

We use inverse distance weighting (IDW), which is an exact deterministic method (Chang 2001). IDW starts with a group of known point values, or 'control points'. IDW predicts a value at the point locations that is the same as its known value. The value of a point using IDW is influenced more by nearby known points than by those farther away. IDW is defined as the following:

Equation 1:

$$z_0 = \frac{\sum_{i=1}^{s}\left(z_i \frac{1}{d_i^k}\right)}{\sum_{i=1}^{s}\left(z_i \frac{1}{d_i^k}\right)}$$

Where,

z_0 is the estimated value at point 0, z_i is the z value at known point i, d_i is the distance between point i and point 0, s is the number of known points used in estimation, and k is the specified power.

Power, k, controls the degree of local influence. If k equals 1, there is a constant rate of change in value between points (linear). If k has a value of 2 or higher, then the rate of change is higher near a known point and levels off away from it. Zimmerman et al. (1999) show that a smaller number of known points actually produces better estimations than a larger number of known points.

Application to Crop budgets

Determining representative regions

To narrow down sourced operation budgets, the USDA Farm Resource Regions (FRR) were reviewed (figure 1). The USDA regions "depict geographic specialization in production of U.S. farm commodities". One source of the FRR used cluster analysis to identify regions with similar farm characteristics (Sommer and Hines), another source of the FRR (NRCS) used soil, slope and land types to delineate regions. Together, the USDA regions identify regions with similar cropping traits. We used USDA FRR as a starting point for determining our key regions where source budgets must be located.

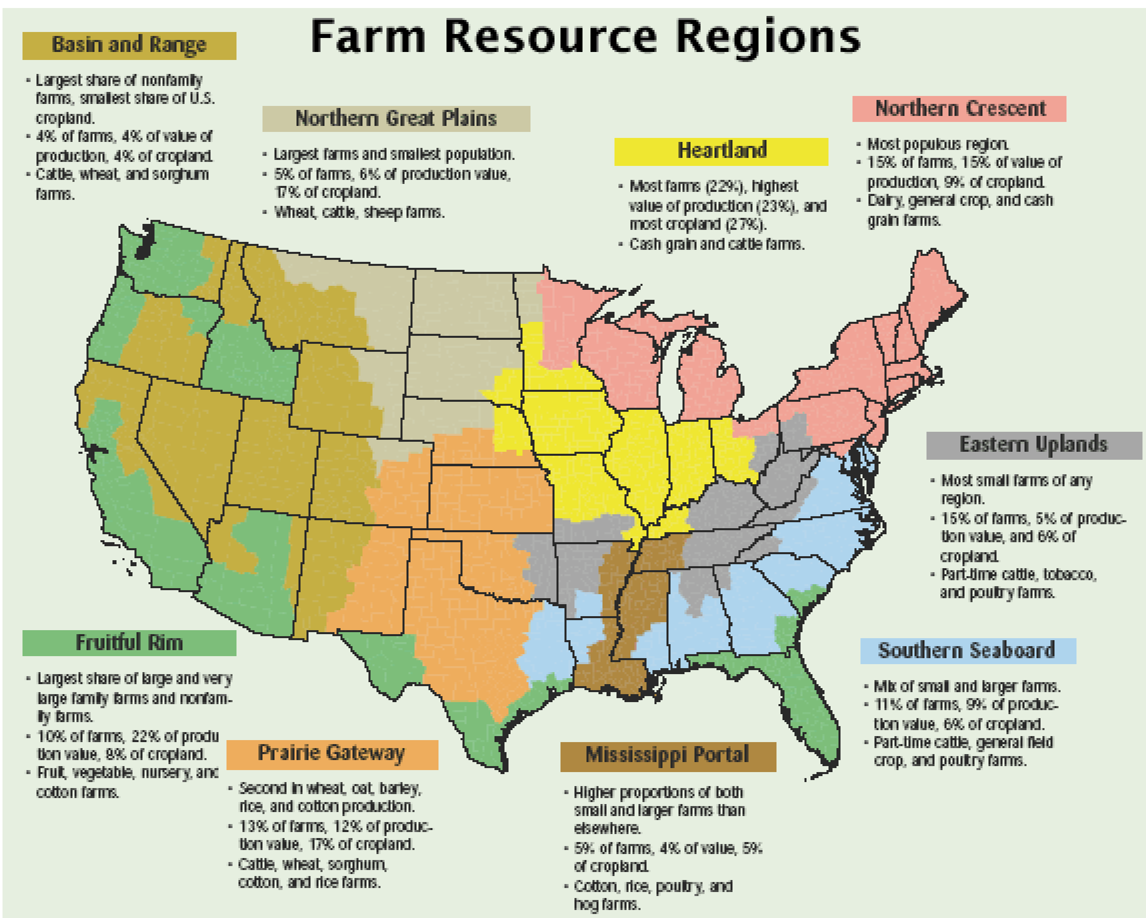

Figure 1. USDA Farm Resource Regions. USDA geographic delineation of unique cropping regions of the U.S. (USDA-ERS, 2010).

We modified the USDA farm resource regions to form the POLYSYS Farm Resource Regions (PFRR) (figure 2). The prime differences are that we divided the 'Fruitful Rim' FRR into 3 separate regions, and divided the 'Southern Seaboard' into east and west regions (figure 2, and table 1). The fruitful rim formed one region in the FRRs because of the similarities of growing fruits and vegetables. Fruits and vegetables are not included in POLYSYS, and there may be distance differences in major commodity cropping patterns, thus the region was divided.

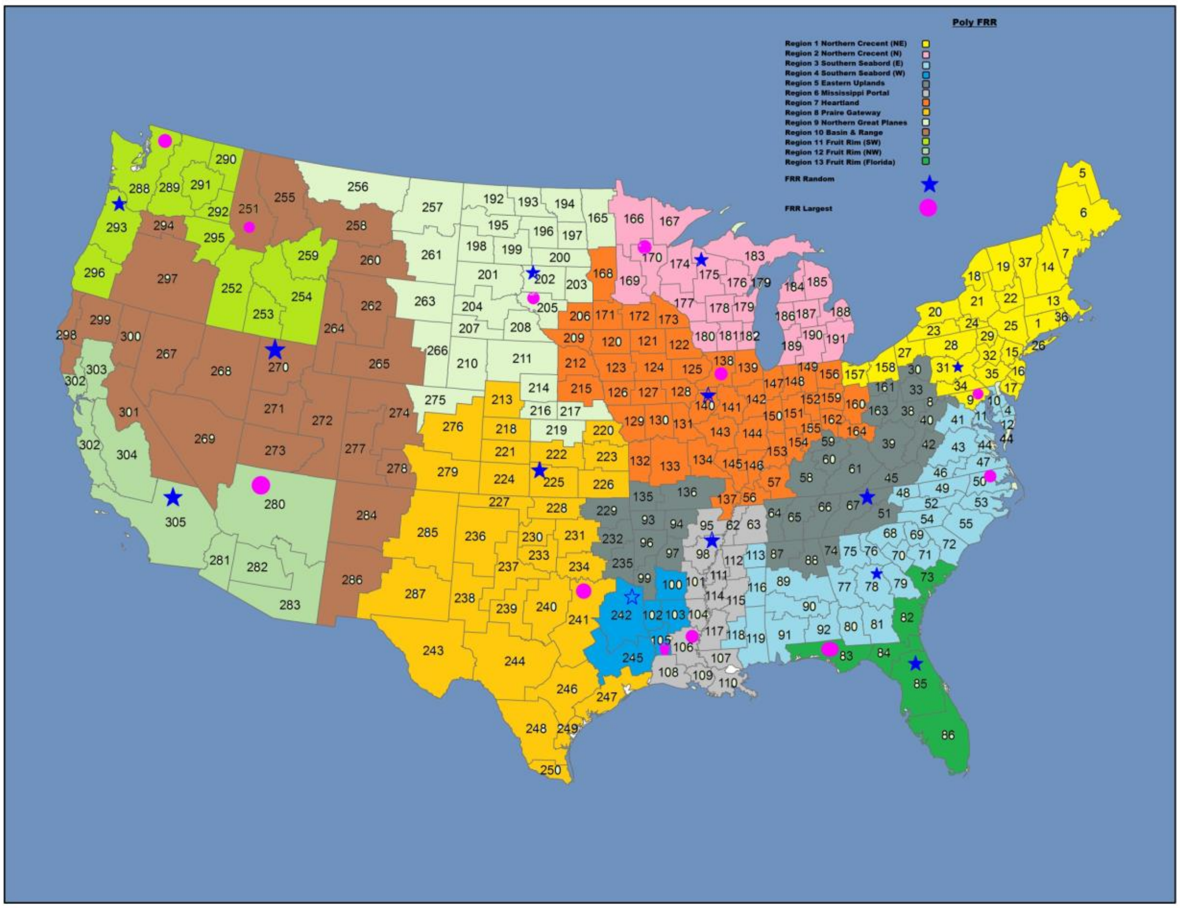

Figure 2. Map of all 305 POLYSYS regions, the 13 POLYSYS Farm Resource Regions (PFRR) (colored areas), with the POLYSYS regions with the most acreage in corn within each PFRR (blue stars). The blue-starred regions are used as representative regions and the pink circles are the largest POLYSYS region within the PFRR. Operation budgets are compiled for each starred regions. The interpolation method uses the blue-starred regions to interpolate values for all other regions.

The representative POLYSYS regions (13 of 305) for each crop were chosen by the region with the most planted acreage in each crop in each unique PFRR. The blue stared regions in figure 2 are used as representative regions (for corn). The representative regions may be different for some crops. Sourced operation budgets are compiled for only the starred regions and crop budgets are interpolated between the starred regions

Table 1. POLYSYS Farm Resource Regions (PFRR), the corresponding Farm Resource Region, and the representative POLYSYS region within each PFRR (for corn).

Polysys Farm Resource Regions (PFRR)		Description	Representative POLYSYS region
1	Northern Crecent(northeast)	Northeast	31
2	Northern Cresent (lake states)	Lake states	175
3	Southern Seaboard (east)	Alabama thru Virginia	78
4	Southern Seaboard (west	East Texas, Some of AR and LA	242
5	Eastern Uplands	Applachia	67
6	Mississippi Portal	Lower Mississippi lands	98
7	Heartland	Corn Belt'	140
8	Pairie Gateway	Texas through Kansas	225
9	Northern Great Plains	Nebraska thru North Dakota	202
10	Basin and Range	Desert west	270
11	Fruitful Rim (southwest)	Southwest	305
12	Fruitful Rim (northwest)	northwest	288
13	Fruitful Rim (Florida)	Florida	85

Computation of budgets

Operation budgets for the representative regions list the order of operations, machinery used, chemicals and fertilizers applied, their rates of application, and seeding rates (table 2). Equations in the spreadsheet convert quantities of inputs into monetary costs, embodied energy and carbon (ABS 1996, Nelson 2007).

POLYSYS budgets list the specific operations of each management budget. Types of operations, machinery used, and input quantities associated with each management practice within POLYSYS were compiled by consulting with regional extension service publications and personnel (APAC 1996). In the POLYSYS budgets, quantities of applied fertilizer and applied chemicals were obtained from extension service sources and standardized following established restrictions for herbicides and insecticide use (Meister, 2002a; Meister, 2002b). Traction and implement equipment were obtained from regional extension sources, and regional equipment efficiencies were standardized with data on regional machine efficiencies provided by the USDA Economic Research Service (Economic Research Service).

Machinery time and fuel usage were calculated by following American Society of Agricultural and Biological Engineering (ASABE) Standards (ASABE 2010). The ASABE equations are used for estimating length of time per acre of each operation as a function of equipment width, ERS equipment efficiency, and equipment speeds provided by the ASABE machinery database. ASABE methodology is then used to transform horse-power of each traction operation and machinery time into an estimate of fuel usage per operation.

Machinery time and fuel usage were calculated by following American Society of Agricultural Engineering Standards published in the American Agricultural Economics Association Costs and Returns Handbook (American Agricultural Economics Association, 2000). The American Society of Agricultural Biological Engineers (ASABE) equations are used for estimating length of time per acre of each operation as a function of equipment width, ERS equipment efficiency, and equipment speeds provided by the ASAE machinery database. ASAE methodology is then used to transform horse-power of each traction operation and machinery time into an estimate of fuel usage per operation.

Both direct and indirect emissions are estimated and tied to each unique management practice in POLYSYS budgets. Carbon dioxide emissions from fossil fuels used in the production, transport, and application of agricultural inputs have been calculated by West and Marland (2002) for cultivated lands. Emissions of nitrous oxide (N_2O) resulting from the application of nitrogen (N) fertilizer were estimated according to IPCC guidelines (IPCC 2006) and as outlined by Marland et al. (2003). 'Direct carbon' includes emissions from the use of fuel on farms, dissolution of agricultural lime, changes in soil carbon, and carbon equivalent emissions of N2O. Carbon content of diesel was estimated at 6.75 lbs C/gal diesel. Emissions from lime is 0.06 ton of carbon per ton of limestone applied. Carbon equivalent emissions of nitrous oxide from the use of nitrogen fertilizers are estimated using 2.22 tons of carbon equivalent released per ton of nitrogen applied.

Indirect carbon, or embodied carbon, includes emissions from the processing, manufacturing and transportation of seeds, fertilizers, and chemicals applied to the field (West and Marland 2002). Quantities of seed, fertilizer and chemical inputs in each operating budget were linked to associated energy and carbon content. Indirect carbon emissions from 81 combinations of organic and inorganic fertilizers, and 403 chemical pesticides were linked to the operation budgets. This method of linking carbon emissions follows that used by Nelson et al. (2009). Direct and indirect carbon emissions are summed to estimate total carbon equivalent emissions as a result of each unique regional management practice.

Table 2. Representative operation budget of corn under a no-tillage production system in POLYSYS region 140 in western Illinois. Similar operation budgets are compiled for remaining 13 representative regions for each crop and tillage combination.

Budget Month	Budget Day	MachName	TractorName	Mach Time	Labor Time	FertName	FertLbs	ChemName	Chem Rate	Chem Units	Chem AI	Seed	Seed Rate	Seed Unit
3	25	Chem Applicator GE30ft (trailer r	Tractor 2wd 205 hp (diesel)	0.039	0.043		0	Roundup 4S (Glyphosate	1.5	PT	0.75		0	
4	10	Dry Fert Spreader (trailer mtd)	Tractor 2wd 205 hp (diesel)	0.087	0.096	Anhydrous Ammonia	155		0				0	
4	10	Dry Fert Spreader (trailer mtd)	--	0	0	P2O5	56		0				0	
4	10	Dry Fert Spreader (trailer mtd)	--	0	0	K20	36		0				0	
4	15	7 Row No-till Planter	Tractor 2wd 290 hp (diesel)	0.2	0.22		0		0			Corn Seed	26	thousand kernals
4	15	Granule Appplicator (24ft)	--	0	0		0	Counter15G (Terbufos)	7	LB	1.05		0	
4	25	Chem Applicator GE30ft (trailer r	Tractor 2wd 205 hp (diesel)	0.039	0.043		0	Roundup Ultra 4S (Glyph	1.5	PT	0.75		0	
11	10	Combine w/ Row Header-2wd (self-prop)		0.164	0.18		0		0				0	
11	10	Single-axle Truck 2 ton (gas) (self-prop)		0.33	0.363		0		0				0	
11	15	Dry Fert Spreader (trailer mtd)	Tractor 2wd 205 hp (diesel)	0.087	0.096	Limestone	1000		0				0	

Geographic Interpolation from Representative Region Data

Monetary costs, embodied energy and carbon, and major input quantities are totaled for every representative region (example in table 3) and read into ArcGIS. The interpolation procedure uses the data from the 13 representative regions to estimate values for all regions in between. Figure 3 shows an example of the distribution of representative region data.

Table 3. Category values from representative regional operation budgets. The representative values are used as initial values to interpolate all other regions by each category listed (corn).

PFFR	POLY	TotalCost ($\$$ ac^{-1})	TotalEnergy (Mil btu ac^{-1})	TotalCarbon (MT C eq ac^{-1})	N	P_2O_5 (lbs)	K_20	Lime	Diesel (gal ac^{-1})
1	31	383.41	6.16	0.28	136	50	35	1000	7.6
2	175	342.64	5.02	0.21	122	41	46	0	7.2
3	78	303.27	5.20	0.23	120	80	45	500	6.9
4	242	314.87	3.96	0.14	70	27	0	0	7.7
5	67	302.16	3.72	0.13	30	50	35	1000	5.2
6	98	314.87	3.96	0.14	70	27	0	0	7.7
7	140	395.44	6.33	0.27	127	56	36	1000	7.7
8	225	311.89	4.37	0.17	76	30	20	500	6.5
9	202	271.83	3.27	0.11	50	19.251	0	0	8.0
10	270	384.85	5.70	0.22	112	5	0	0	13.7
11	305	299.91	3.75	0.13	58	10	0	0	9.2
12	288	390.74	5.69	0.24	140	65	0	0	6.7
13	85	340.13	5.74	0.25	127	17	17	660	8.4

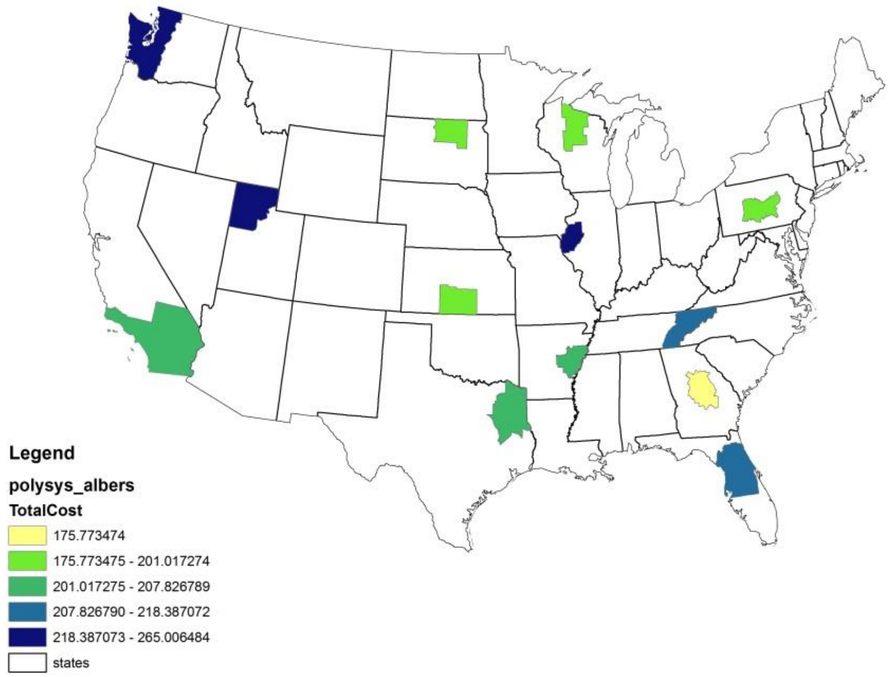

Figure 3. Representative regions used to interpolate all other regions in POLYSYS (example: sorghum).

We use the geoprocessing tool of Inverse Distance Weighting within ArcGIS to perform the geographic interpolation from the representative regional data. The power (k) in equation 1 of categories Total Cost, total energy, total carbon and diesel are set to 1.0, which means there is a constant rate of change in values between known points (table 4). The power of k set to 2 or higher allows nearby known values to impact the value of unknown points more than distant values in a non-linear fashion. A higher value leads to more impact of nearby values and less impact of distant values in estimation of unknown points. Potassium and phosphate usage are relatively region-specific, so it was determined to reduce the impact of distant values by assigning a k power of 4. Lime is the most region-specific input, therefore we assigned a high value of 30 to k. Lime drops off rapidly between known points of lime usage (figure A-8 in appendix A).

Table 4. Power of k (equation 1) used in inverse distance weighting interpolation procedure. K value of 1 indicates a linear change in values over distance. K values more than 2 indicate a non-linear change with closer point values impacting estimates more than distant point values.

Data Category	k power
Total Cost	1.0
Total Energy	1.0
Total Carbon	1.0
N	1.0
P_2O_5	4
K_20	4
Lime	30
Diesel	1.5

When the interpolation method is run, estimated values are generated in a raster map. Figure 4 shows the total costs contour-lines that result. The raster values are averaged to the Agricultural Statistic District level where data categories (such as total cost) are estimated at the ASD POLYSYS region scale. Figure 5 displays the results of total costs of no-till corn production after the raster data is averaged to ASD level. The result is a smooth transition from one representative region to the next. Resulting maps of all 8 interpolated data categories are shown in Appendix A.

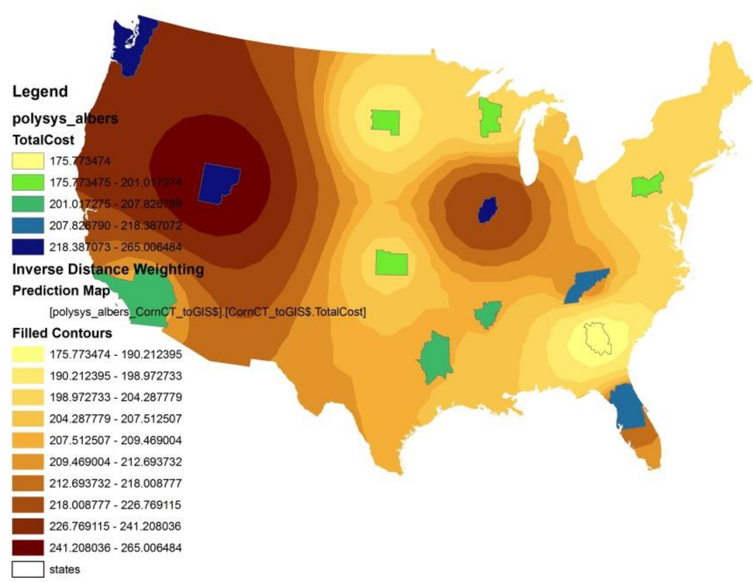

Figure 4. Initial representative regions and the interpolated contour line values (total costs in $/acre, sorghum).

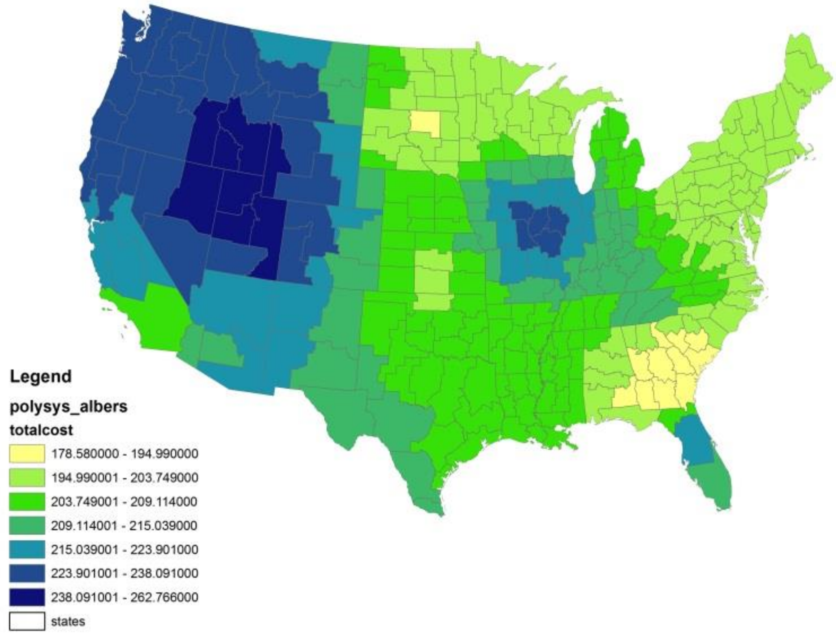

Figure 5. Interpolation results are averaged at the POLYSYS region (Total costs, sorghum).

The interpolation method is run for all 8 data categories, and the results are read into POLYSYS for use in agricultural policy simulations. Table 5 gives an example of the results for the ASDs of Iowa and Missouri. Values change smoothly over the regions. Total Cost of production is the variable POLYSYS uses, along with price and production, to determine the ranking of regional net returns, and, therefore, is very important in the land allocation decision making. Total energy and carbon are included for potential policies targeting their levels, such as a carbon policy. The input quantities are included for potential soil and water quality studies.

Table 5. Spatially interpolated results by POLYSYS region (corn).

POLY	TotalCost ($ ac^{-1})	TotalEnergy (Mil btu ac^{-1})	TotalCarbon (MT C eq ac^{-1})	N	P_2O_5 (lbs)	K_20	Lime	Diesel (gal ac^{-1})
120	327.7	4.6	0.2	89.3	32.2	17.9	133.5	7.6
121	338.8	4.9	0.2	98.1	43.9	33.7	577.6	7.6
122	347.4	5.1	0.2	104.1	48.9	38.2	673.1	7.5
123	334.6	4.8	0.2	92.6	41.3	25.7	812.5	7.6
124	346.7	5.1	0.2	100.7	51.2	34.2	999.9	7.5
125	360.9	5.5	0.2	109.3	55.1	36.0	1000.0	7.5
126	338.3	4.9	0.2	93.9	45.6	29.1	995.2	7.5
127	351.0	5.2	0.2	101.7	53.4	34.5	1000.0	7.5
128	370.6	5.7	0.2	113.4	55.8	35.9	1000.0	7.6
129	341.2	5.0	0.2	94.8	47.2	30.0	977.9	7.5
130	354.9	5.3	0.2	103.3	54.4	34.8	1000.0	7.5
131	367.9	5.7	0.2	111.3	55.7	35.8	1000.0	7.5
132	335.0	4.8	0.2	90.4	40.5	23.8	753.6	7.3
133	341.0	5.0	0.2	94.5	46.8	27.1	890.0	7.3
134	346.4	5.1	0.2	97.6	50.2	29.9	983.0	7.3
135	327.4	4.6	0.2	85.1	31.9	12.2	184.0	7.3
136	330.4	4.6	0.2	86.4	33.0	9.2	49.5	7.3
137	328.1	4.6	0.2	84.4	31.2	6.8	11.9	7.3

* There are 305 POLY regions, only 18 are shown here for an example.

Disaggregating Total Cost Estimates for IMPLAN

In some analyses it is useful to have total costs of production disaggregated to individual input cost categories. For example, in regional economic impact analyses using the IMPLAN model, known expenditures on unique inputs carry unique impacts. The interpolation procedure is not completed for all disaggregated cost categories. Instead, an index is used to disaggregate the estimated total costs to individual input categories. An index for each of the original representative regions is computed and entered into POLYSYS (table 6). All POLYSYS regions within an individual PFFR use the PFFR index to distribute the interpolated total costs across input categories. This methodology assumes that although total costs may vary across regions within the larger PFFR region, equal proportions make up the individual input costs.

Table 6. Index values to distribute estimated ‘total costs’ into disaggregated cost categories (corn).

PFFR	POLY	Labor	Seed	Fuel	Lube	Repairs	N	P_2O_5	K_20	Mixed fert	Lime	Herbicides	Insectides	Other Chem	Irrigation	Other	Housing	Insurance	Interest	Depreciation	Sum of indices
1	31	0.04	0.23	0.08	0.00	0.06	0.22	0.05	0.03	0.00	0.06	0.03	0.03	0.00	0.00	0.00	0.01	0.01	0.07	0.07	1
2	175	0.05	0.25	0.08	0.00	0.06	0.22	0.05	0.05	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.01	0.01	0.07	0.08	1
3	78	0.06	0.21	0.09	0.00	0.07	0.16	0.10	0.05	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.09	1
4	242	0.06	0.29	0.09	0.00	0.08	0.11	0.03	0.00	0.00	0.00	0.11	0.02	0.00	0.00	0.00	0.01	0.02	0.07	0.09	1
5	67	0.05	0.23	0.07	0.00	0.06	0.06	0.07	0.04	0.00	0.08	0.10	0.06	0.00	0.00	0.00	0.01	0.01	0.07	0.08	1
6	98	0.06	0.29	0.09	0.00	0.08	0.11	0.03	0.00	0.00	0.00	0.11	0.02	0.00	0.00	0.00	0.01	0.02	0.07	0.09	1
7	140	0.05	0.22	0.07	0.00	0.06	0.15	0.06	0.03	0.00	0.06	0.08	0.05	0.00	0.00	0.00	0.01	0.01	0.07	0.07	1
8	225	0.06	0.24	0.08	0.00	0.08	0.11	0.04	0.02	0.00	0.04	0.06	0.07	0.00	0.00	0.00	0.01	0.02	0.07	0.09	1
9	202	0.07	0.22	0.11	0.00	0.09	0.07	0.00	0.00	0.06	0.00	0.13	0.02	0.00	0.00	0.00	0.02	0.02	0.07	0.11	1
10	270	0.08	0.20	0.14	0.00	0.08	0.22	0.01	0.00	0.00	0.00	0.08	0.02	0.00	0.00	0.00	0.01	0.02	0.07	0.09	1
11	305	0.06	0.25	0.12	0.00	0.09	0.15	0.01	0.00	0.00	0.00	0.10	0.02	0.00	0.00	0.00	0.01	0.02	0.07	0.10	1
12	288	0.05	0.19	0.07	0.00	0.06	0.27	0.07	0.00	0.00	0.00	0.06	0.06	0.00	0.00	0.00	0.01	0.01	0.07	0.07	1
13	85	0.06	0.21	0.10	0.00	0.07	0.15	0.02	0.02	0.00	0.05	0.14	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.09	1

Discussion

The backbone of POLYSYS consists of the crop budgets. Costs of production impact crop net returns ranking, and therefore impact land allocation dynamics. Budgets should be as accurate as possible, yet there remains uncertainty in estimating budgets. In a given region, there is heterogeneity in farmer characteristics and farm operations and costs. These differences in equipment, chemicals, fertilizer quantities, seeding quantities, rotations, ownership, and rental agreements all lead to differences in total and average costs of production from farmer to farmer. The POLYSYS linear programming model runs at the county level, requiring aggregation and averaging. Further, budget estimations from state extension agents that may more accurately represent sub regional production costs require assumptions on many variables to come to an 'average' representative budget. Even so, some extension budgets are not representative of average costs of production for the region, but rather 'recommended' operations and inputs for optimal yield. Using budgets compiled using different assumptions in neighboring regions leads to "boundary effects" and border discrepancies in costs of production.

The purpose of the methodology presented in this document is to (1) increase the accuracy estimating an average 'representative' total cost of production for each region, and (2) decrease the incidence of sudden geographic changes in total costs of production between neighboring regions. The benefit of this procedure is that spatial interpolation allows for smooth transitions of variable estimates from one known region to another. A disadvantage that arises is that the accuracy of the new interpolated estimates now dependent upon fewer sourced data points. Are these accurate? With fewer initial data points, we can have more certainty over the accuracy of these specific points than if there were over 3000 budgets. Time and resources had not allowed for rigorous validation of thousands of operation budgets. With fewer budgets, we can now work our way through each budget individually. Yet in interpolating budgets in between the sourced budgets, there is still reason for uncertainty. Possibly there is a geophysical, climate, and cultural rationale for a sudden change in operations that the interpolation procedure is missing. To test our methodology the next step is to validate the estimates in interpolated regions. Validation would require comparing interpolated costs of production from regionally sourced operation budgets. If there is a rationale and data to indicate that the interpolated results are not accurately estimating costs of production for a given region, then extension sourced operation budgets can be entered into the budgeting system for that region and the interpolation process can then be run again with the additional sourced budget.

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Appendix A

Interpolated results from all data categories (total costs, total embodied energy, total embodied carbon, nitrogen, potassium, phosphorous, lime, diesel) for no-tillage corn production.

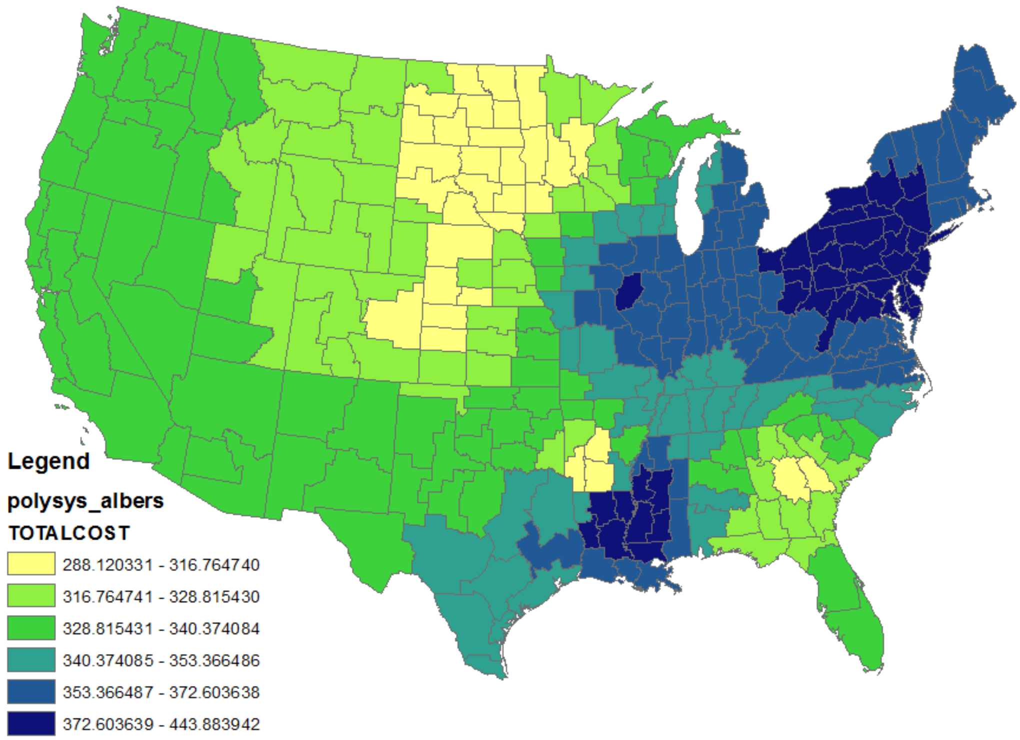

Figure A-1. Estimated total cost of production at the POLYSYS ASD level. Corn No-tillage.

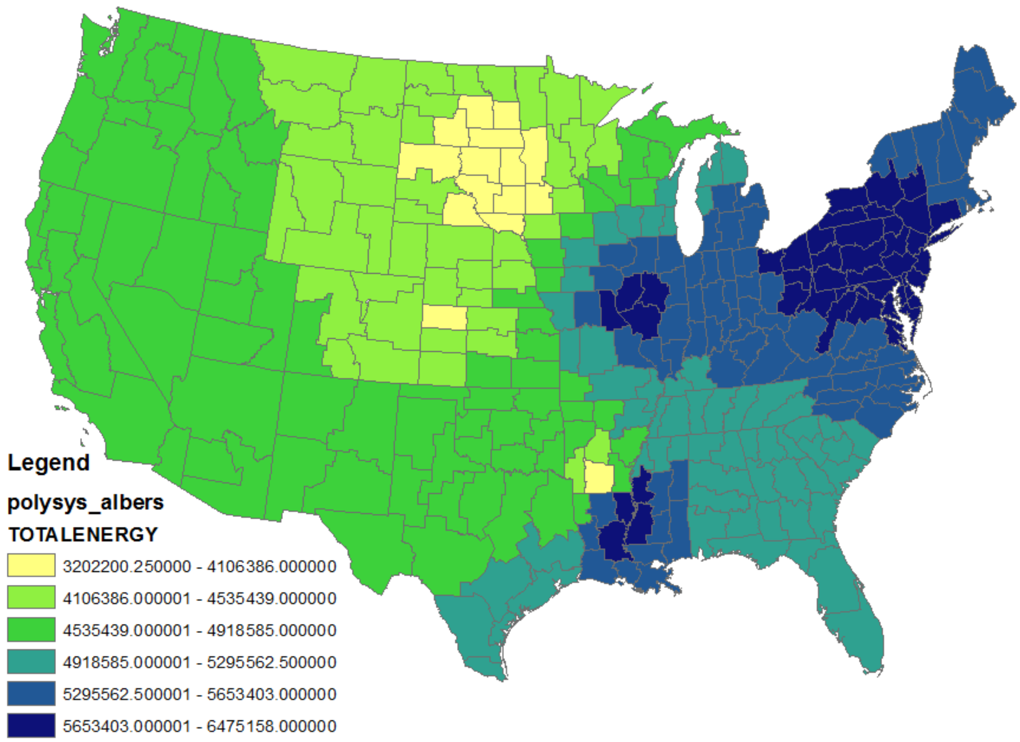

Figure A-2. Estimated total embodied energy at the POLYSYS ASD level. Corn No-tillage.

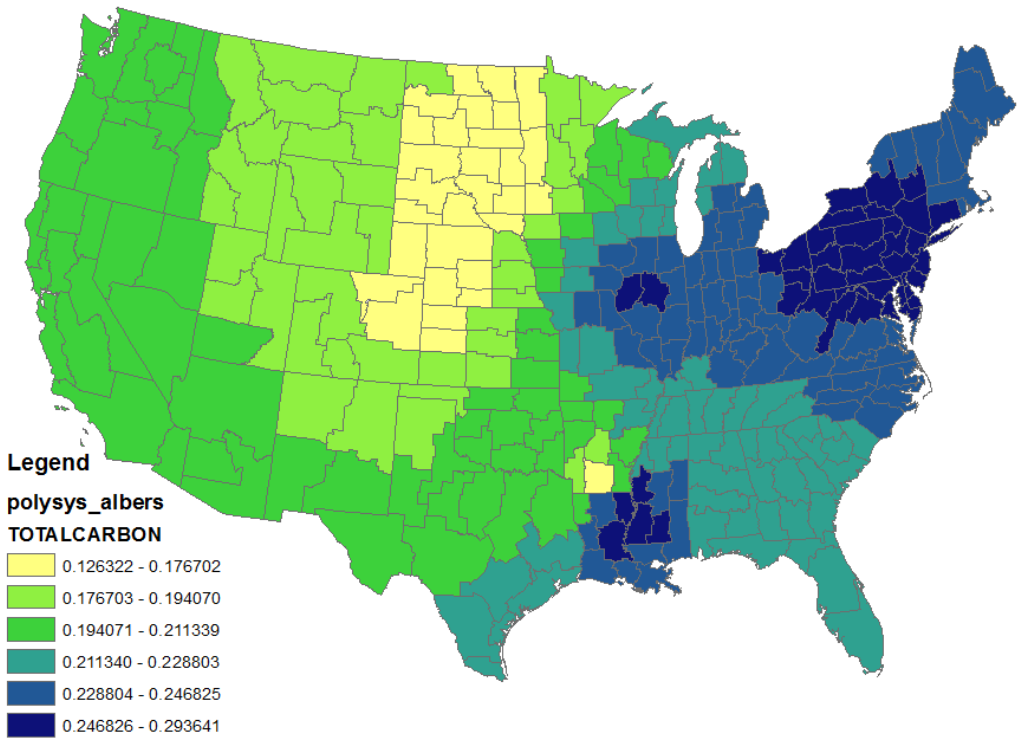

Figure A-3. Estimated total embodied carbon at the POLYSYS ASD level. Corn No-tillage.

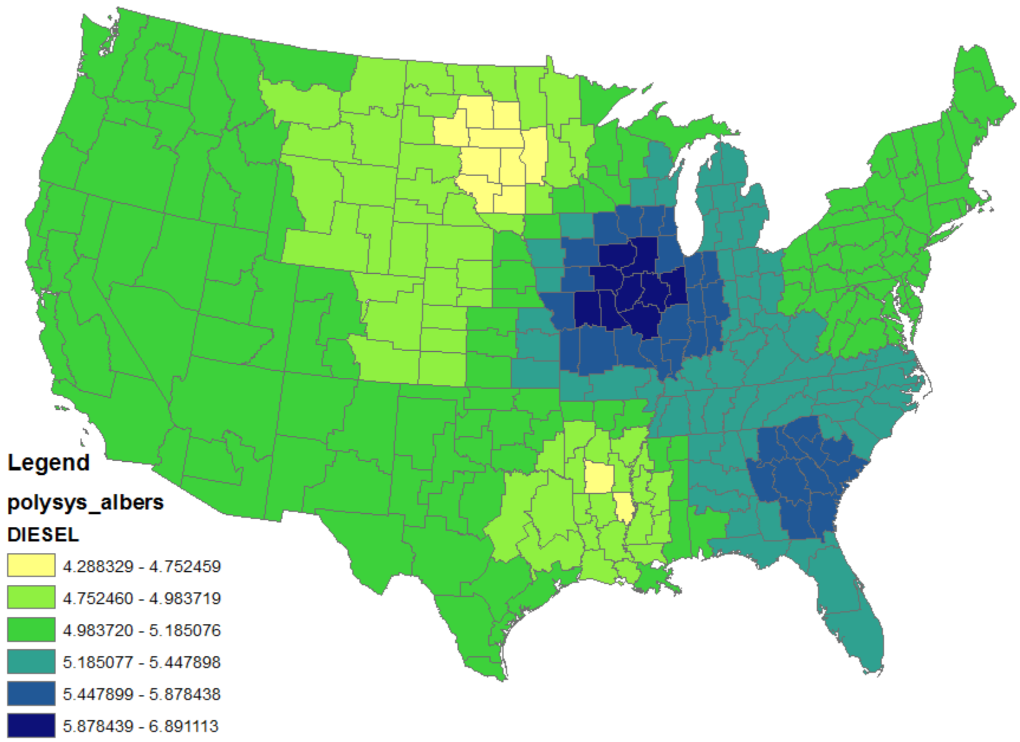

Figure A-4. Estimated total diesel fuel usage at the POLYSYS ASD level. Corn No-tillage.

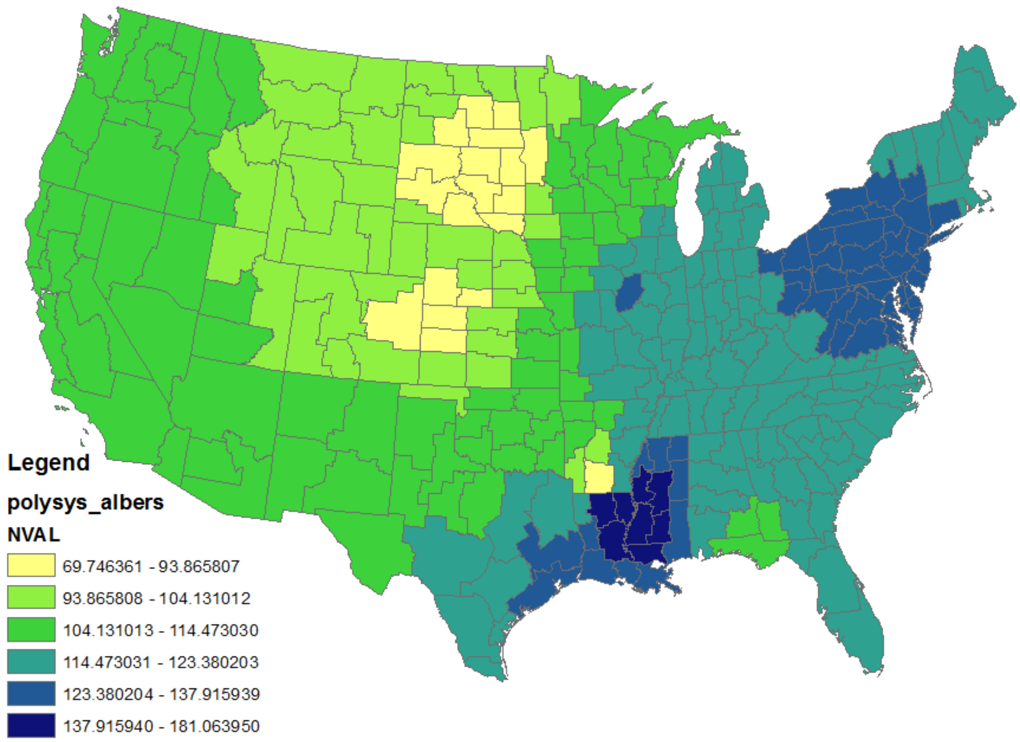

Figure A-5. Estimated total applied nitrogen at the POLYSYS ASD level. Corn No-tillage.

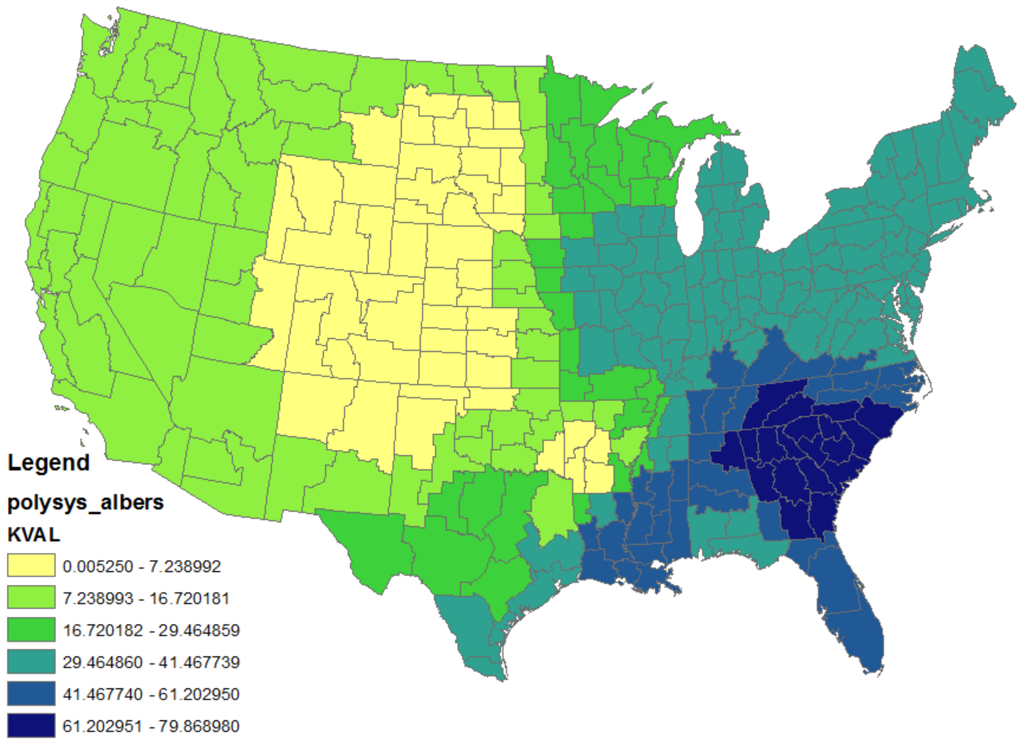

Figure A-6. Estimated total applied potassium (k) at the POLYSYS ASD level. Corn No-tillage.

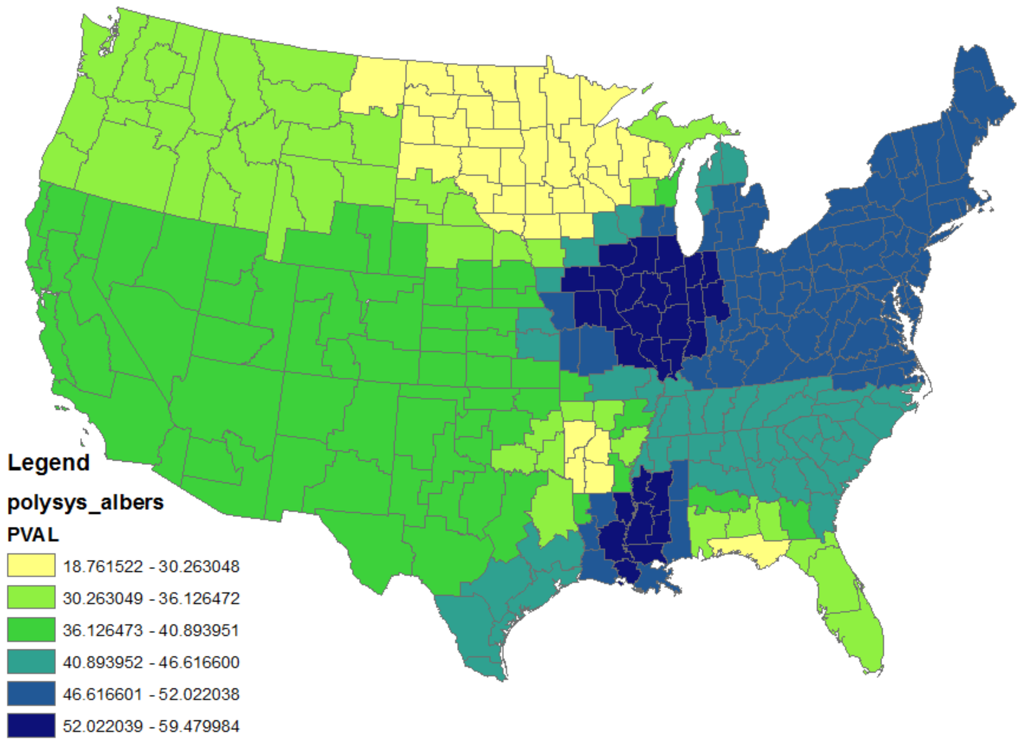

Figure A-7. Estimated total applied phosphorous (P) at the POLYSYS ASD level. Corn No-tillage.

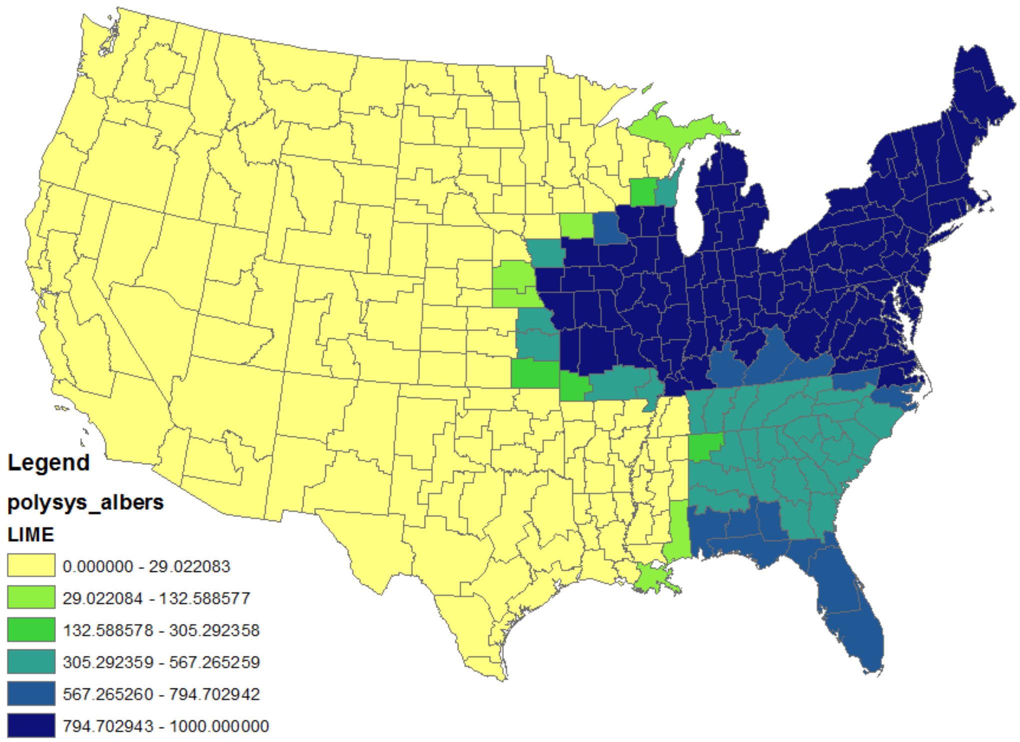

Figure A-8. Estimated total applied lime at the POLYSYS ASD level. Corn No-tillage.