Spatial Variability Mapping of pH in Oregon Organic Farms using Geographic Information Systems (GIS) Geospatial Interpolation Models

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Introduction

". . . it is our work with living soil
that provides sustainable
alternatives to the triple crises
of climate, energy, and food. No
matter how many songs on your
iPod, cars in your garage, or
books on your shelf, it is plants'
ability to capture solar energy
that is at the root of it all.
Without fertile soil, what is life?"

—VANDANA SHIVA, 2008

This internship project (Dr. Dawn Wright—Department of Geoscience) was a synthesis of several aspects of the research process. The documentation of methods consisted of: primary data collection of soil samples, geographical coordinates, georeferencing, basemap creation, laboratory machine operation, laboratory methods, laboratory quality control planning, statistical analysis, and geo-statistical analysis using geospatial interpolation tools.

There were many behind the scene players in data collection and analysis. In our research, many of us simply send our samples or data collection requests off to the laboratory or appropriate persons and later retrieve the results. The goal of this internship research process was to gain understanding of these many steps that are vital to the creation and retrieval of a scientific project. Careful thought was given in an effort to implement every step of this process so that others might gain understanding, and find this study useful in some way.

Farmers have for centuries recognized variation in the soil and taken it into account in their management. They have divided their land into fields, within any one of which they could treat the soil as if it were uniform. In recent times they have come to realize that the fields that they or their predecessors created are not uniform, that in many instances the variation within them is substantial, and that with modern technology they can increase yields and make better use of fertilizers and other agrochemicals by taking that variation into account in their management. This realization has lead to the current interest in precision agriculture and the need to map the variation.

Quantitative information must derive from measurement, and we cannot measure the soil everywhere; we can at best measure the soil with planned samples. So accurate information for any region is available only at isolated points or for small bodies of soil. Whatever we state for intermediate positions or larger blocks of land involves some kind of interpolation or estimation from the measurements. That in turn carries with it uncertainty, and so we want some measure of that uncertainty too.

Engineers at first tried to predict values of soil properties from sample data by combining classical statistics with soil classification. They sampled classes delineated on soil maps at random. Then, for each soil property of interest, they computed from their data the means for the classes and used those means as predictors for the classes. They also computed the associated prediction variances, which gave them measures of uncertainty. The method proved a success for several engineering properties of the soil, such as Atterberg limits and particle size fractions. It did not work for the plant nutrients in the soil, which were strongly affected by farm management, nor could it be expected to work for pollutants, which bear no relation to the geology or physiography. Further, the results depended on the skill and predilections of the individual soil surveyors who made the maps in the first place. The utility of geostatistics as it relates to farming can be very impressive. "Initially, the main objective of geostatistics in soil science was to enhance the quality of spatial prediction of soil properties (Kuzyakova et al., 2001)."

The characterization of geostatistics can be explained for soil in this study as a suite of variables that are continuous in space, and it describes their random variation in terms of spatial dependence. Specifically, geostatistics treats those variables as though they were the outcomes of random processes, and then it uses geostatistical methods to estimate both plausible generating functions of the processes and predicted values of the realizations at unsampled places.

The topic of pH was chosen as a variable of interest to take through this stepwise process to the end result. Other nutrient variables are included in this study for the purpose of useful information to the actual growers on the farms. Nutrient cycling through soils is highly variable and nutrient budgets are dynamic models of continuous inputs and outputs.

A definition of a specific soil pH has been difficult due to the heterogeneous nature of soils and buffering effects of different soil components. An operational definition of the pH of a soil sample is the average pH that is measured in a suspension of the soil sample in water or an electrolyte solution at a defined solid-to-solution ratio. Soil pH determines the mobility and leachability of cations and over all influences sorption reactions.

Spatial variability of soil pH plays a central role in the development and management of organic farming. "Soil pH may vary dramatically over very small distances (millimeters or smaller). For example, plant roots may raise or lower pH in their immediate vicinity, making the pH there quite different from that in the bulk soil just a few millimeters away, (Brady & Weil, 2010)."

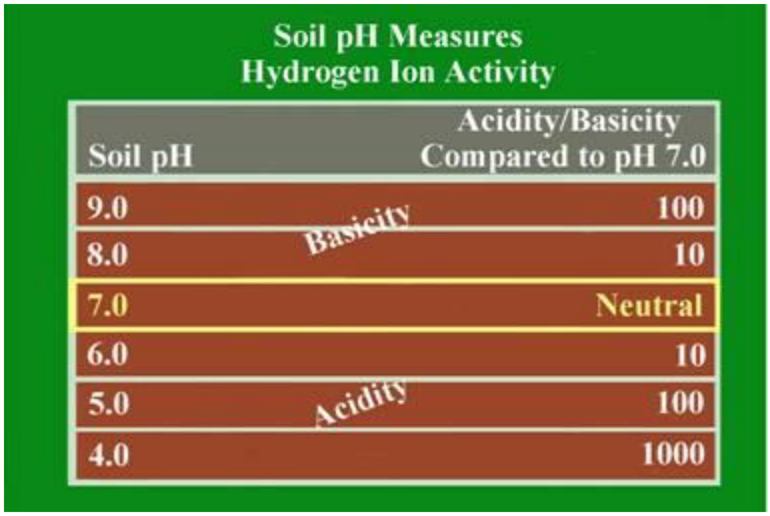
Water and nutrient cycling play vital roles however; pH is the mediator of all molecular behavior and exchange within the soil stratum. Natural Resources Conservation Service describes pH under several different molecular arrangement behaviors as "seasonal changes in soil moisture, temperature, microbial activity and plant growth can cause soil pH to vary (NRCS, 2011). For example, during seasonal changes in temperature and reduced moisture concentration of salts in the soils fluctuate as the soil dries and soluble salts accumulate. These increased concentrations allow soluble cations to replace exchangeable hydronium (H_3O^+) or aluminum ions. The cation exchange creates a more acid solution within the soil. The solubility of CO_2 and the impact of CO_2 on soil acidity can be highly variable in all seasons. As temperatures decreases, CO_2 becomes more soluble, creating carbonic acid (H_2CO_3) within the soil solution. The formation of carbonic acid by hydration of CO_2 predominates at a pH of less than 8 pH units.

$$CO_2 + H_2O \rightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

In the warmer seasons an increase in acidity can be noted that while CO_2 may be less soluble there is an increase in microbial activity during warmer temperatures. As water percolates through the soil, microbial respiration and metabolism of roots increases the concentrations of CO_2 dissolved in soil water. This drives the above equation to the right creating more acidity in the soil "Carbonic acid is a weak acid and its contributions to soil acidity are significant when the pH is greater than 5.0, (Bradley & Weil, 2010)." Carbonic acid solubilizes limestone parent material of calcium rich rock and produces calcium bicarbonate ($Ca(HCO_3)_2$), which is relatively soluble.

$$H_2CO_3 + CaCO_3 \leftrightarrow Ca(HCO_3)_2$$

One very important note that often has been misunderstood regarding pH, and alkalinity was the definition of alkalinity and how it relates to pH. Alkalinity is defined as a measure in milliequivalents of acid required to neutralize the carbonate, bicarbonate and hydroxyl ions in a liter of water. Alkalinity is an "intrinsic" property of the solution, a measure of the solution's ability to neutralize the carbonate, bicarbonate and hydroxyl ions, whereas, basicity refers to a measure of pH. pH is defined as a measure of hydroxyl ions. In soil solution, the pH can therefore be increased (lowering basicity) while the alkalinity remains the same as illustrated in Figure 1 below. Therefore, to say that a solution is "more alkaline" is incorrect when in fac,t the solution has become more basic when adjustment of pH has resulted in an increase in the pH.


Soil pH Measures
Hydrogen Ion Activity

Soil pH	Acidity/Basicity Compared to pH 7.0
9.0	100
8.0	10
7.0	Neutral
6.0	10
5.0	100
4.0	1000

Figure 1. Soil pH measures as related to acidity/basicity.

pH is the regulator of nutrient supply, establishing the environment and conditions of nutrient uptake by plants. Management of soil organic matter (SOM) to optimize biological, physical and chemical properties of the soil is a primary goal of organic farming systems. Soil processes and organic farm management have been significant influences on the suppression of weeds, pests and diseases, in addition to nutrient cycling. For example, types of amendments, and crop rotation have shown meaningful evidence that related to changes in pH. Organic farming systems have a longer strategy that is more “preventative” rather than reactive.

Adjustment for allochthonous (outside the system) as well as the autochthonous (within the system) seasonal inputs can be challenging for organic growers. This study attempted to synthesize essential components; in an effort to create a meaningful model for organic farming with land- use quality control and sampling methods.

Geostatistical tools in soil science can be used for studying and predicting soil contamination in industrial areas, for building agrochemical maps at the field level, or even to map physical and chemical soil properties to a global extent. The users of the output maps are going from soil scientists to environmental modelers. The specificity of geostatistical outputs is the assessment of the spatial accuracy associated to the spatial prediction of the targeted variable. The results, which are quantitative, are then associated to a level of confidence which is spatially variable. The spatial accuracy can then be integrated into environmental models, allowing for a quantitative assessment of soil scenarios. Armed with an informed quality control plan and understanding of how variable pH, nutrient cycling, water content, biotic and abiotic influences impact soil management brings a more sustainable product.

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- Laboratory testing methods
- GIS Interpolation models
- Statistical methods

Materials and Methods

Collection of 20 soil samples from each Oregon organic farm were tested in the Oregon State University Central Analytical laboratory. The spatial variability of pH was investigated using Geographical Information Systems interpolation tools.

Both study areas were textured as silty loam in the field.

Oregon Organic Growers Farm is located in Corvallis Oregon. National Resources Conservation Service classifies this soil as Chehalis silty clay loam.

- Elevation: 150 to 600 feet
- Mean annual precipitation: 40 to 50 inches
- Mean annual air temperature: 52 to 54 degrees F
- Frost-free period: 165 to 210 days

Setting

- Landform: Flood plains
- Landform position (three-dimensional): Tread
- Down-slope shape: Linear
- Across-slope shape: Linear

- Parent material: Recent moderately fine textured alluvium derived from mixed sources

Properties and qualities

- Slope: 0 to 3 percent
- Depth to restrictive feature: More than 80 inches
- Drainage class: Well drained
- Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
- Depth to water table: More than 80 inches
- Frequency of flooding: Occasional
- Frequency of ponding: None
- Available water capacity: High (about 11.5 inches)

The Little Redbarn Farm is located in Walton Oregon. National Resources Conservation Service classifies this soil as Eilertsen silt loam.

- Elevation: 20 to 800 feet
- Mean annual precipitation: 60 to 90 inches
- Mean annual air temperature: 52 to 54 degrees F
- Frost-free period: 140 to 200 days

Setting

- Landform: Stream terraces, alluvial fans
- Landform position (three-dimensional): Tread
- Down-slope shape: Concave
- Across-slope shape: Linear
- Parent material: Alluvium derived from mixed sources

Properties and qualities

- Slope: 0 to 3 percent
- Depth to restrictive feature: More than 80 inches
- Drainage class: Well drained
- Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
- Depth to water table: More than 80 inches
- Frequency of flooding: None
- Frequency of ponding: None
- Available water capacity: High (about 12.0 inches)

Oregon Central Analytical laboratory methods:

In the laboratory, two grams of each soil sample for each farm were massed wet in order to find the soil water content of each soil location. The samples were then put into the laboratory oven at 105° F overnight to dry. Dry weights were taken from each soil sample and water content was calculated by equation wet-dry/wet to obtain the water content of each soil sample. The remaining soil (- the 2 grams already subtracted) was put into the dryer at 90° F to dry overnight. Samples were then taken out of the dryer and ground in a soil grinding machine, which also sifted to eliminate all large particles.

An extracting (Mehlich) solution was then prepared for use in extracting metals from soil solution in preparation for sampling in the "inductively coupled plasma mass spectrometer," abbreviated "ICP"—(PerkinElmer Inc.-Optima 2100 DV).

Soil samples were massed (20g) into 3 oz. cups and 40ml of DI H_2O was added. After 15 minutes, each sample was stirred and stirred again after another 15 minutes in preparation to measure pH with a pH meter. The pH meter consists of a glass electrode probe, a voltometer, a dial and digital readout screen. A glass electrode is a combination of two electrodes in one electrochemical cell. The electrode is attached to a voltometer. The first electrode is sensitive to the H_3O^+ concentration in the solution, and the second electrode serves as a reference. When immersed in solution, the voltage between the electrodes is proportional to the pH of the solution. The meter was calibrated with a solution of known pH, and the measured cell potential was converted into a reading of the pH of the solution. All 40 soil samples from both farms were tested for pH. For quality control of pH testing, a known pH of a solution (SRW) was also randomly inserted into the testing process to check for sustained accuracy of the readings.

Soil samples were massed at 2g and 20ml of Mehlich extracting solution was added to samples. Each of the 40 samples were then filtered and put into test tubes. These tubes were labeled and prepared for testing in the ICP for cation concentrations. The cation concentrations that were measured included the following: P, K, Ca, Na, Mg, Mn, Cu, B, Zn, & Fe.

The ICP is a programmed autosampler and the computer was told where the samples were in reference to test tube location. Then the desired cation tests were selected from the computer program. For quality control, samples of known cation concentrations were initially run at the onset of testing in the ICP. After the probe extracted a solution sample, the sample was sent to a nebulizer where the sample was turned into a vapor. After the sample left the nebulizer the sample was caught by a carrier gas (argon is used at OSU) and pushed through the plasma chamber. The ICP contains lenses and cones so that smaller and more detailed ions are extracted. The next stage is a quadrapole that uses different electric pulses to separate out ions by mass. At the end, the ICP has a detector shield with the mass spectrometer which counts how many ions of each mass are hitting the detector per second.

The ICP computer generated graphs and tables of each cation concentration for each sample and these were printed when the run was finished.

Geographical Information Systems data collection and implementation methods:

Two farms were under study for pH and cation soil analysis using spatial geostatistics interpolation tools in Geographical Information Systems Arcmap 9.3.1.

Oregon State University Organic Growers Farm is located just a few miles from the Oregon State University campus and is approximately 2 acres in area. The site is used by students and faculty as a hands-on teaching tool. Soil-amended areas have been amended each year with deciduous leaf litter and occasional amendments of chicken manure. The property lies 44.565534°N -123. 240242°W.

Perimeter geographic coordinates were taken with a Garmin GPS 76S unit. These perimeter points were then downloaded and imported into Arcmap as a shapefile through the DNR Garmin program developed by the state of Minnesota.

Soil sample locations were designated within the perimeter of the farm at five locations. A block of approximately 12 feet in length was designated at each corner of the farm and one at the center. Sample sites included three amended sites and two unamended sites for soil sample collection. Each soil sample was taken at an approximate “root depth” of 10 cm. Within each sampled block, four soil samples were taken. Each sample was bagged and labeled by its geographic location with respect to a northing direction within the farm, e.g., the southeast sample within the northwest block, viz, NW-SE.

After shapefiles were imported into Arcmap, a geodatabase was created for each farm. Perimeter points were georeferenced in Arcmap using a Google Earth image and then exported to the geodatabase. A feature class called "sitearea" was created in the geodatabase and with the target layer set to sitearea, a polygon was created for each farm from Georeferenced perimeter points.

From these georeferenced perimeter points, a polygon of each farm was created in an editing session in Arcmap (different maps). It is important to note that Google Earth and other orthophoto tools available use a geographic coordinate system. In order for an area of a polygon to be calculated "on the fly" in Arcmap, the data within the data frame must be reprojected to a projected coordinate system (Price, 2011). Distances or lengths cannot be found with latitude and longitude information and therefore area cannot be calculated. For this project, the reprojection was set to the projected coordinate system: NAD 1983 UTM 10N.

Values for pH and other nutrients were input into soil sample site attribute tables through an editing session. After the completion of a very basic basemap (Fig 2) of each farm, data exploration began in an effort to determine appropriate interpolation tools. "Ordinary kriging is substituted for simple kriging in order to obtain an unbiased estimator that is robust to local variations of the Gaussian data mean (Emery, 2006)."

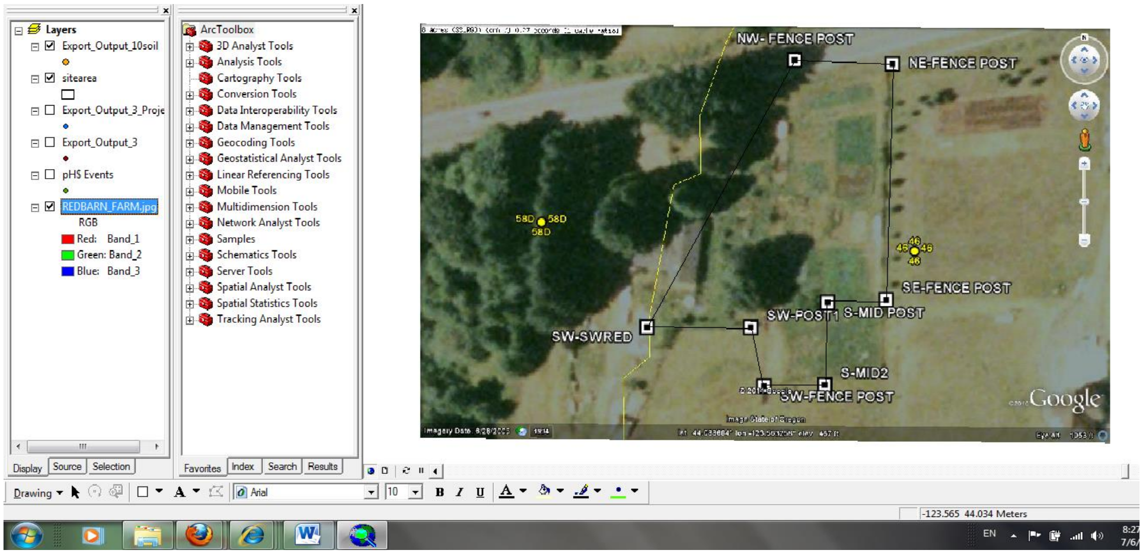


Figure 2

Geostatiscal analysis tool was added to Arcmap. The data frame was set to the extent of the area by the following:

The data for The Little Redbarn farm for pH was explored, see histogram in Figure 3 below for pH.

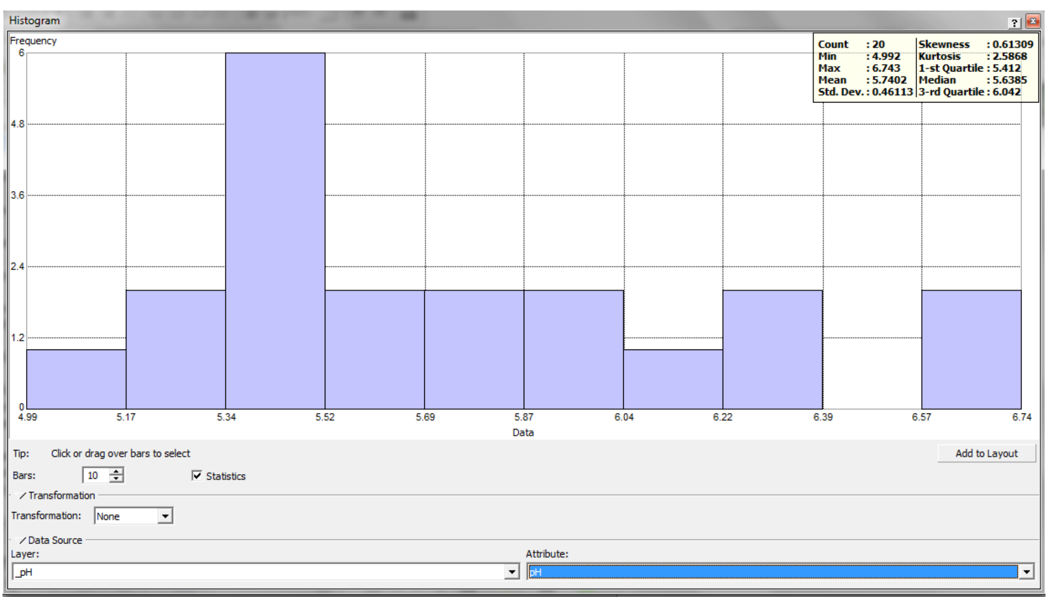


Figure 3. Little Redbarn Farm values for pH.

Before the appropriate tool was chosen, some assumptions must be made to use certain interpolation tools. Several methods exist for interpolation of spatial data and fall into two broad catagories: deterministic and probalistic. The deterministic methods have a mathmatical process that is based on assumptions about the functional form of the interpolator e.g., inverse distance weighted (IDW) interpolation tool. The probalistic methods have their foundation in statisical theroy and assume a statistical model for the data. When probalistic methods are used for interpolation, they are referred to as methods for spatial prediction. Within these predictors are standard errors that quantify the uncertainty assiciated with the predicted values. As estimated parameters report standard errors and confidence intervals, spatial analysis should report measures of uncertainty. If this is not possible, then interolators should choose statistical models. For example, "… IDW does not provide prediction uncertainty limits and should not be used for data that can cause harm such as prediction of human exposure to contaminants in ecological analysis (Krivoruchko, 2004)."

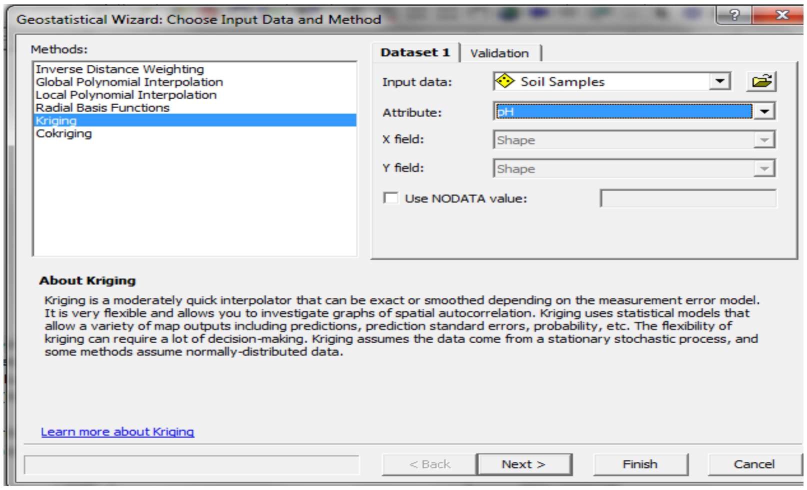
A few definitions are necessary to explain the interpolation methods below.

Variogram: The variogram characterizes the spatial continuity or roughness of a data set**.** Ordinary one-dimensional statistics for two data sets may be nearly identical, but the spatial continuity may be quite different. Adjustment of variogram parameters is the essence of the model.

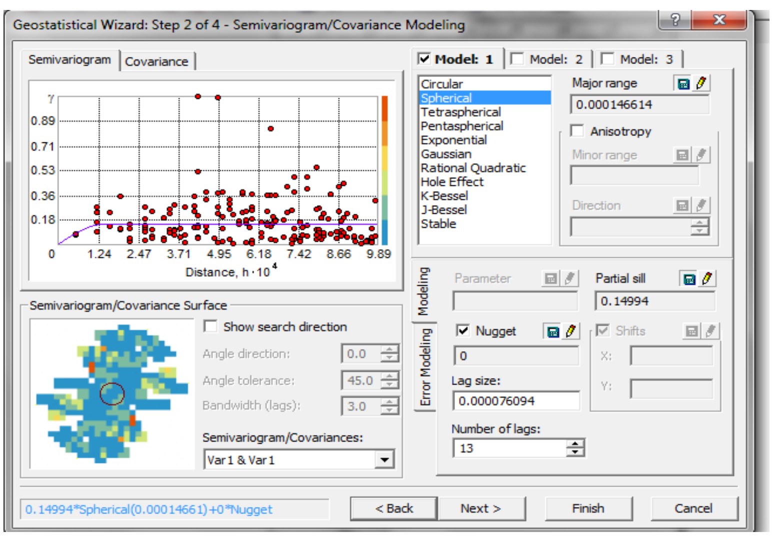
"A surface interpolation is the estimation of z values of a surface at an unsampled point based on the known z values of surrounding points, (ESRI, 2011)." This was done when estimating data values at locations where measurements have not been sampled through the kriging interpolation tool.

Kriging interpolation analysis steps:

- Under the geostatistical analyst bar, select geostatistical wizard.

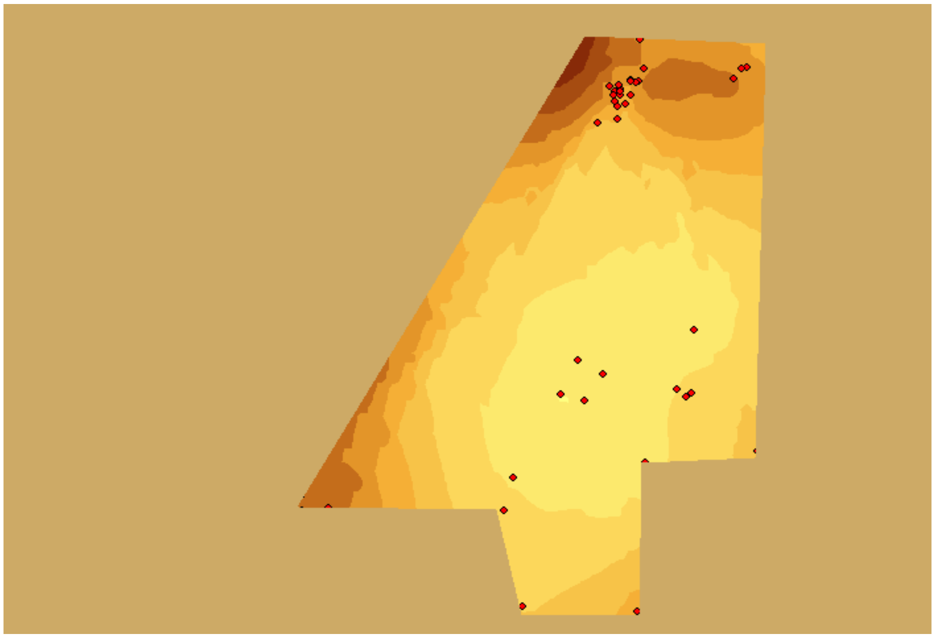


- Select input data →soil samples
- Select attribute →pH
- Select →Kriging
- Select →Next →Next

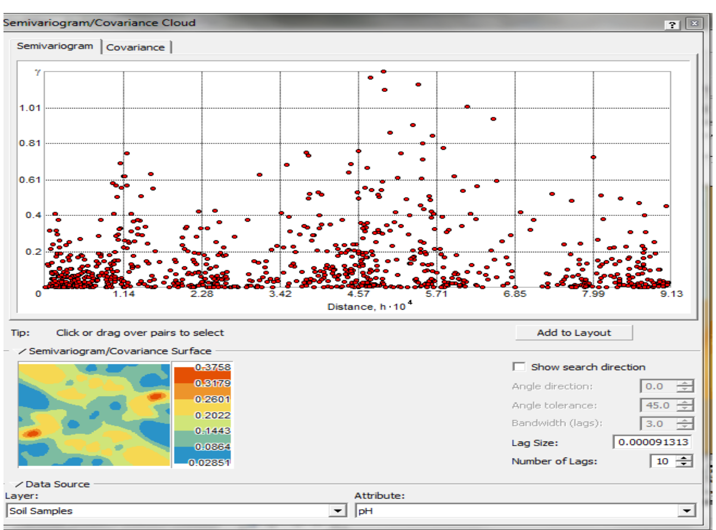


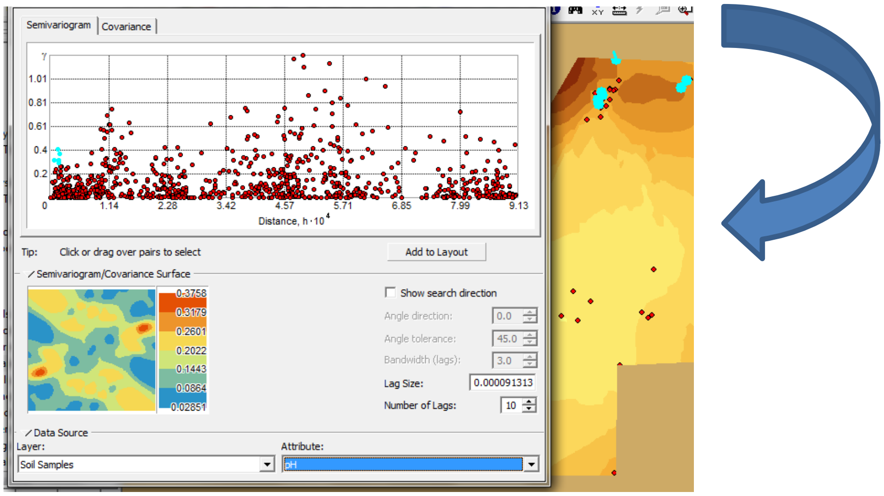
Reducing the lag size allows for capturing the spatial autocorrelation at short distances, where it is most important for interpolation. The reduced lag size allows the fitted semivariogram to rise sharply, then leveling off. This flattening of the semivariogram indicates there is little autocorrelation after this point in the semivariogram.

- Select Next→O.K.

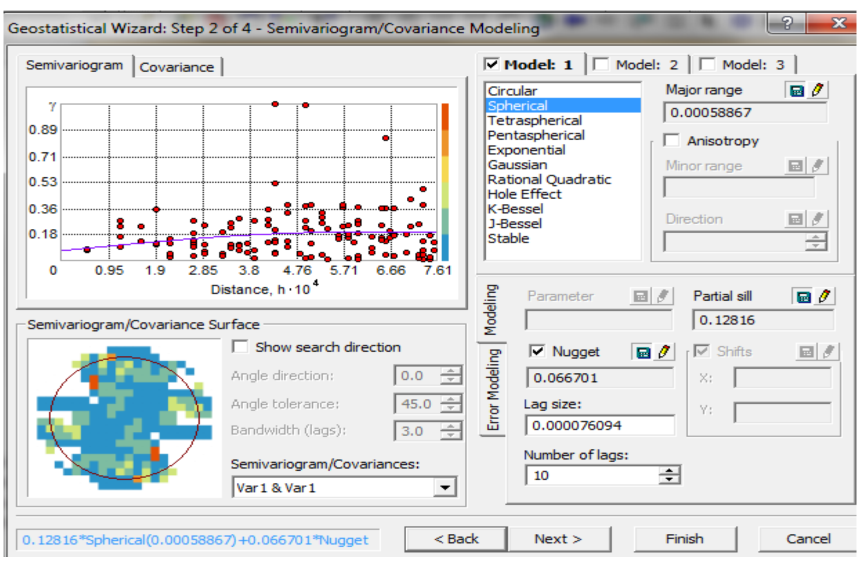


Spatial autocorrelation: Below is a semivariogram of the Little Redbarn Farm soil sample pH values. The correlation depends on the distance or direction that separates the location of related than things far apart." This represents a positive spatial autocorrolation.

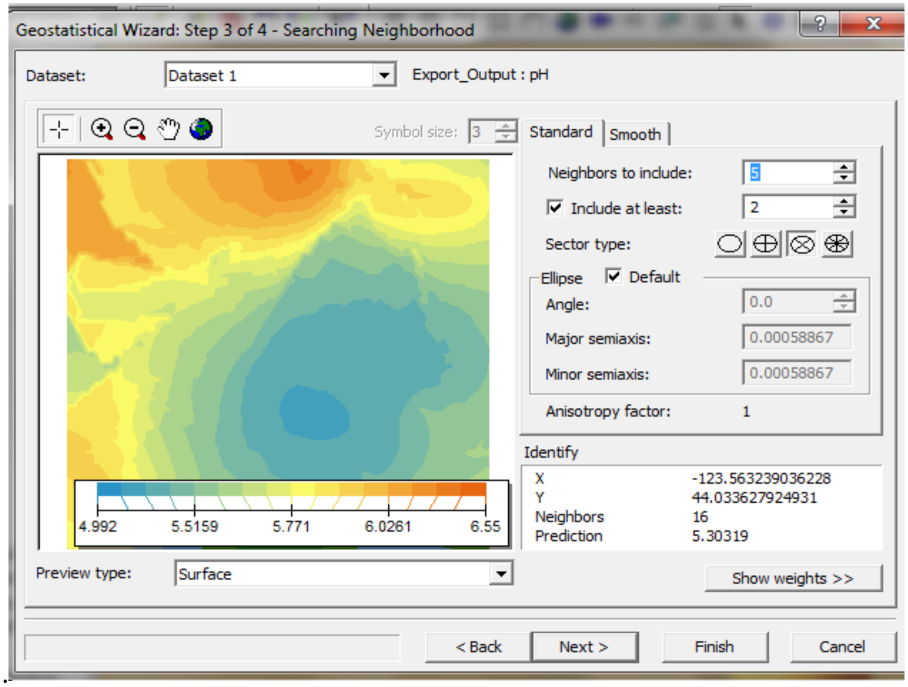




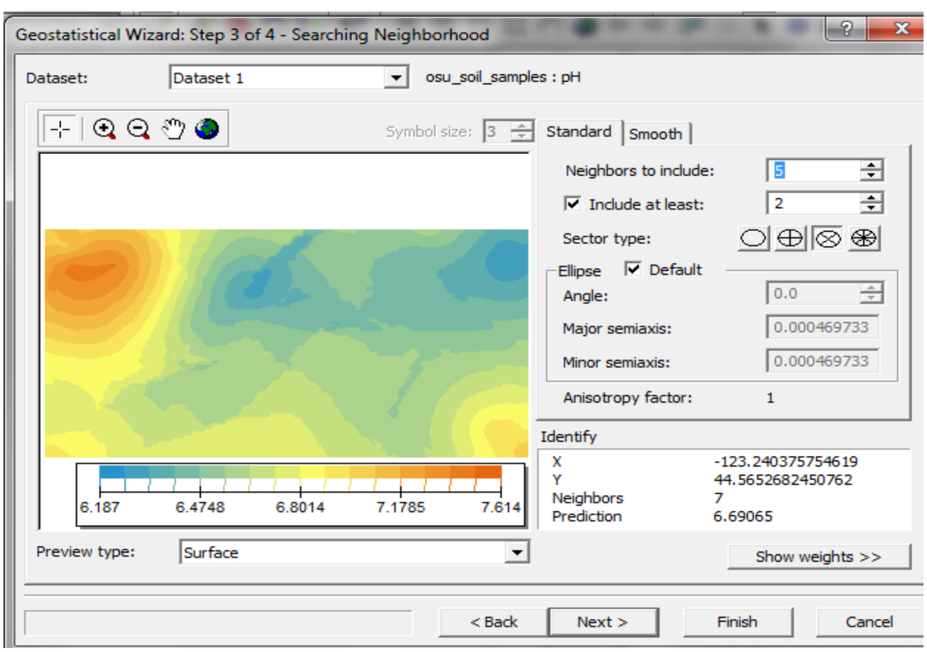
The x axis above shows the distance between sample points while the y axis shows how different the values are for each pair of points.Some locations that are closer together have higher semivariogram values.The pairs of points with high semivariogram values and short distances are in the upper Northwest direction of The Little Redbarn property which is the area that tested high for pH.

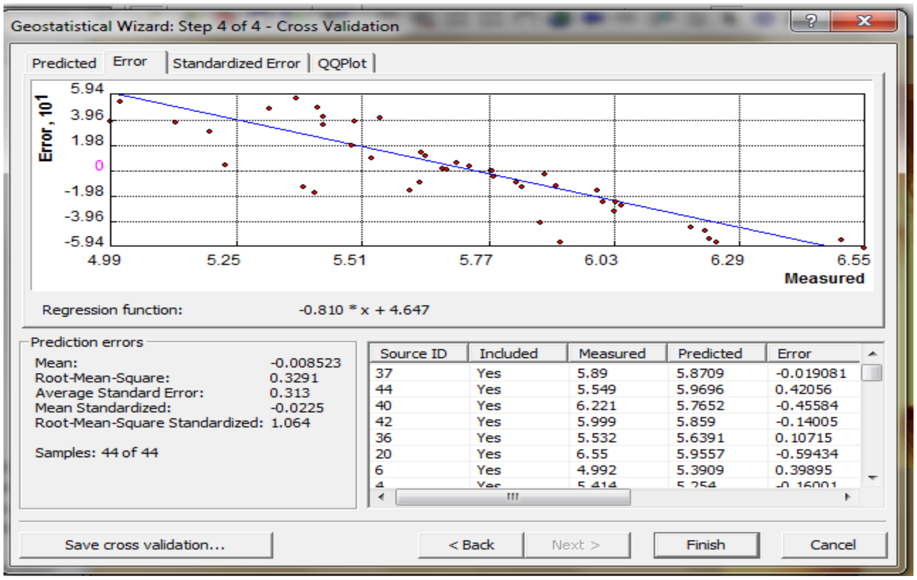


Under the ordinary kriging tool spatial relationships between measured points are examined. ThePurple curve below is the semivariogram model and the graph shows if the points that are closer together have similar values, they are more alike. The semivariogram model is used to predict unsampled area values. A model that fits the emipirical semivariogram well, will produce better predictions than one that fits poorly

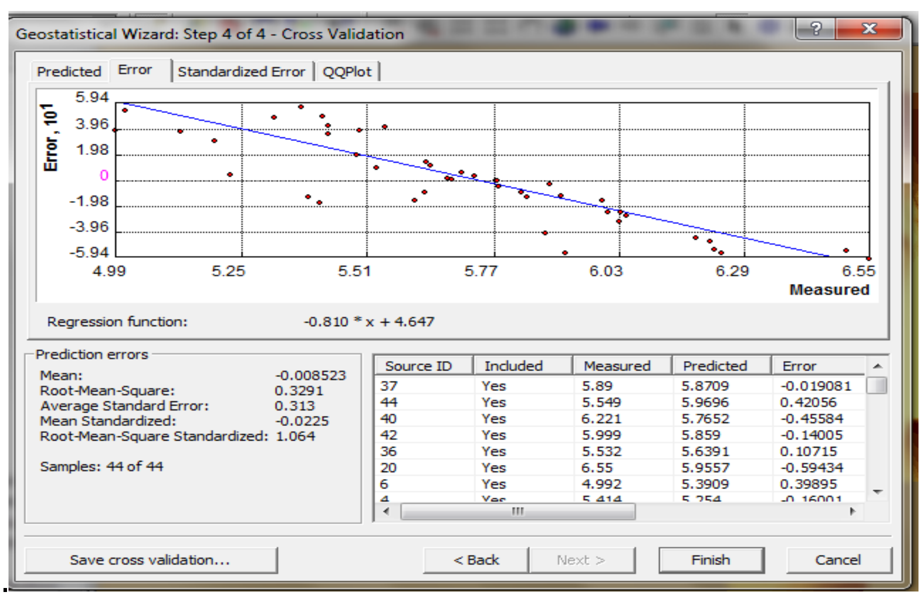


The above is a preview of the map of predicted values created from the model design for The Little Redbarn pH data. Below is the preview map of predicted values for OSU Organic Growers Farm pH data.

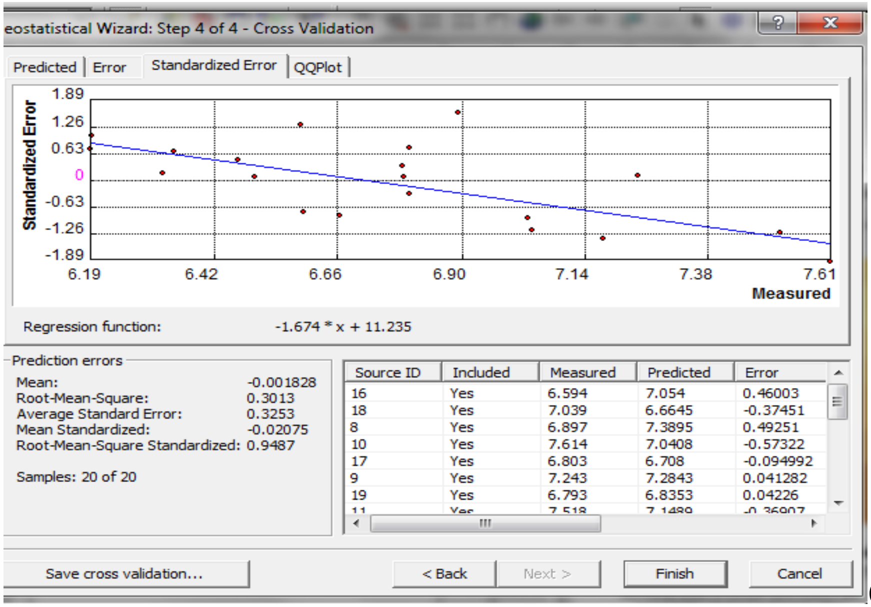




The cross validation panel has tools to see how well the model predicts values. The prediction errors are displayed in the lower left panel. Cross validation removes each data value and predicts a value for that location based on the rest of the remaining data; then compares the measured and predicted values. The scatter of points show the measured values plotted against the values predicted by the model. The blue line is the best fit line through the scatter plot and it expressed by the regression function displayed. The black dashed line represents the ideal case of a 1:1 between predicted and measured values

.

Redbarn



OSU

ESRI defines instructions for making predictions with the kriging interpolation method, two tasks are necessary:

- Uncover the dependency rules.
- Make the predictions.

To realize these two tasks, kriging goes through a two-step process:

1. It creates the variograms and covariance functions to estimate the statistical dependence (called spatial autocorrelation) values that depend on the model of autocorrelation (fitting a model).
2. It predicts the unknown values (making a prediction).

It has been said that kriging uses the data twice because of these requirements. Kriging uses the data to first estimate the spatial autocorrelation and then once again to make predictions.

Statistical Methods:

Initially, descriptive statistics were run on both farms for pH data, and a statistical test for “Homogeneity of Variance” was run in Excel to determine the most appropriate statistical test to run on the data. The results indicated that the variance was not homogeneous from one farm to the other. Hence, statistical tests for differences between means in pH were run with "single factor ANOVA's" and "***t***-tests for two samples assuming unequal variances" were used (this affords a more accurate and more conservative test for the differences between means, because of heterogeneity of variances among the data in the two farms). Excel 2010 methods were used for computational results.

Results

Oregon Central Analytical laboratory results:

The cation results for The Little Redbarn listed below by geographic coordinates. All units are in mg/L or ppm.

LAT	LONG	P	K	Ca	Mg	Mn	Cu	B	Zn	Fe	Na
44.033463	-123.563618	1.953	662.9	646.5	320.5	1.649	1.698	3.472	1.392	6.847	19.01
44.03347	-123.563483	1.037	141.1	337.9	123.8	2.674	1.774	2.779	1.633	7.966	11.84
44.033513	-123.563627	1.066	224.2	459.3	127.8	3.167	1.796	2.856	1.291	7.552	13.09
44.03352	-123.56344	1.241	266.2	296.3	88.4	2.645	1.587	2.455	1.16	6.298	10.60
44.033569	-123.563058	76.92	777	1999	368	13.26	5.042	2.62	15.84	8.219	17.8
44.033579	-123.562887	104.2	487.3	1575	275.8	9.256	5.109	2.447	16.64	12.31	17.45
44.033677	-123.563059	85.43	752.5	1723	313.5	11.55	4.529	2.48	13.38	8.85	15.77
44.033702	-123.562888	90.09	762.9	1659	282.6	11.68	4.943	3.015	13.31	9.513	15.54
44.033795	-123.563058	23.83	329.1	1256	224.3	13.77	2.876	2.375	9.581	13.82	15.7
44.033806	-123.562948	143.3	253.3	1625	226.8	16.2	3.937	2.364	20.7	15.48	18.03
44.033846	-123.563132	33.66	195.3	126	182.9	14.47	2.69	2.248	9.264	14.06	12.83
44.033891	-123.56297	47.67	222.5	1118	151	16.07	6.315	2.247	13.89	14.51	12.2
44.033993	-123.56298	24.09	432.7	1758	273.5	8.126	3.118	2.453	6.846	10.9	13.05
44.033977	-123.562866	5.915	160.5	711.6	149.3	4.63	2.649	2.251	2.244	10.56	12.13
44.034082	-123.562932	2.042	107.7	659.4	177.9	1.767	2.628	2.224	1.231	11.65	12.19
44.034071	-123.562844	2.855	142	503.2	125.3	3.846	2.405	2.2	1.381	9.581	12.88
44.033954	-	40.95	1051	2080	257.4	13.93	3.233	2.438	5.275	8.888	40.87

	123.563072										
44.033937	- 123.562997	57.75	864.9	2253	256.1	9.019	3.321	2.454	6.164	7.851	13.39
44.034031	- 123.563126	17.45	1054	1528	224.5	12.22	2.913	2.469	4.144	10.41	11.56
44.034056	-123.56305	39.22	1020	2248	251.8	16.31	2.574	2.553	6.683	9.213	13.26

The soil sample cation results for the Oregon State University Organic Growers garden.

LAT	LONG	P	K	Ca	Mg	Mn	Cu	B	Zn	Fe	Na
44.565614	-123.240665	93.41	458.5	1385	396.6	16.28	2.797	2.348	2.663	18.98	21.25
44.565624	-123.240498	78.3	143.2	1241	330.5	12.46	2.809	2.186	1.914	18.79	19.37
44.565501	-123.240693	58.37	197.5	1090	310	6.967	3.448	2.148	1.7	16.33	19.22
44.565481	-123.240693	59.24	166.7	1053	275.9	4.901	3.589	2174	1.805	15.2	15.85
44.565868	-123.239892	51.46	114.6	1224	365.9	6.247	4.012	2.336	2.418	14	24.96
44.565842	-123.239666	62.45	203.4	1338	404.7	8.031	3.518	2.262	2.805	14.91	31.26
44.565767	-123.239943	94.44	92.22	1735	497.2	7.682	4.212	2.154	2405	14.45	30.02
44.565748	-123.239621	60.98	120	1334	376.1	5.31	3.497	2.114	2.576	14.51	26.77
44.565803	-123.241125	0.219	- 85.64	51.35	1.58	0.23	0.695	1.639	0.417	-0.1	1.53
44.565796	-123.241014	134	438.9	1624	436.8	6.342	3.685	2.558	8.147	11.08	28.83
44.565728	-123.241117	77.77	704.2	1790	518.7	10.81	3.31	3.083	6.61	12.57	14.51
44.565736	-123.240968	126.3	493.8	2099	589	12.28	2.873	3.199	5.764	12.72	18.56
44.565104	-123.239686	83.36	783.2	1831	609.7	11.85	3.597	3.256	7.71	13.04	14.78
44.565094	-123.239569	78.77	740.5	1843	542.5	11.37	3.662	3.037	6.772	12.98	15.95
44.56503	-123.239722	133.7	176.3	2334	722.4	7.644	4.004	3.226	8.973	9.884	17.81
44.565036	-123.239562	170.5	676.8	1998	590.3	7.006	3.78	3.116	8.292	11.57	22.36
44.565122	-123.241204	253.9	1359	1841	473.9	19.8	3.334	3.414	7.115	13.25	33.32
44.565124	-123.241015	233.5	1463	1560	423.7	12.29	3.544	2.894	7.108	13.57	39.26
44.56501	-123.241175	301.5	1523	2045	510	11.24	3.179	3.295	9.21	11.43	34.5
44.564994	-123.241	360	1539	2405	584.4	11.61	3.712	3.699	10.09	11.41	36.5

The soil sample pH laboratory results from the Oregon State university Organic Growers garden are presented below.

SAMPLE	NAME	LAT	LONG	pH
1	CEN 1	44.565614	-123.240665	6.503
2	CEN 2	44.565624	-123.240498	6.191
3	CEN 3	44.565501	-123.240693	6.472
4	CENT 4	44.565481	-123.240693	6.599
5	NE 1	44.565868	-123.239892	6.669
6	NE 2	44.565842	-123.239666	6.328
7	NE 3	44.565767	-123.239943	6.349
8	NE 4	44.565748	-123.239621	6.187
9	NW 1	44.565803	-123.241125	6.897
10	NW 2	44.565796	-123.241014	7.243
11	NW 3	44.565728	-123.241117	7.614
12	NW 4	44.565736	-123.240968	7.518
13	SE 1	44.565104	-123.239686	7.03
14	SE 2	44.565094	-123.239569	6.803
15	SE 3	44.56503	-123.239722	6.789
16	SE 4	44.565036	-123.239562	7.176
17	SW 1	44.565122	-123.241204	6.594
18	SW 2	44.565124	-123.241015	6.803
19	SW 3	44.56501	-123.241175	7.039
20	SW 4	44.564994	-123.241	6.793

The soil sample laboratory pH results for The Little Redbarn farm.

SAMPLE	NAME	LAT	LONG	pH
1	SW-SWR	44.033463	-123.563618	6.048
2	SW-SER	44.03347	-123.563483	6.036
3	SW-NWR	44.033513	-123.563627	5.392
4	SW-NER	44.03352	-123.56344	5.414
5	SE-SWR	44.033569	-123.563058	5.231
6	SE-SER	44.033579	-123.562887	4.992
7	SE-NWR	44.033677	-123.563059	5.231
8	SE-NER	44.033702	-	5.497

			123.562888	
9	CENT-SWR	44.033795	-123.563058	5.492
10	CENT-SER	44.033806	-123.562948	5.643
11	CENT-NWR	44.033846	-123.563132	5.735
12	CENT-NER	44.033891	-123.56297	5.708
13	NE-SWR	44.033993	-123.56298	6.033
14	NE-SER	44.033977	-123.562866	5.634
15	NE-NWR	44.034082	-123.562932	5.377
16	NE-NER	44.034071	-123.562844	5.432
17	NW-SWR	44.033954	-123.563072	6.245
18	NW-SER	44.033937	-123.562997	6.743
19	NW-NWR	44.034031	-123.563126	6.23
20	NW-NER	44.034056	-123.56305	6.575

The sodium adsorption ratio was calculated for each farm using the following formula.

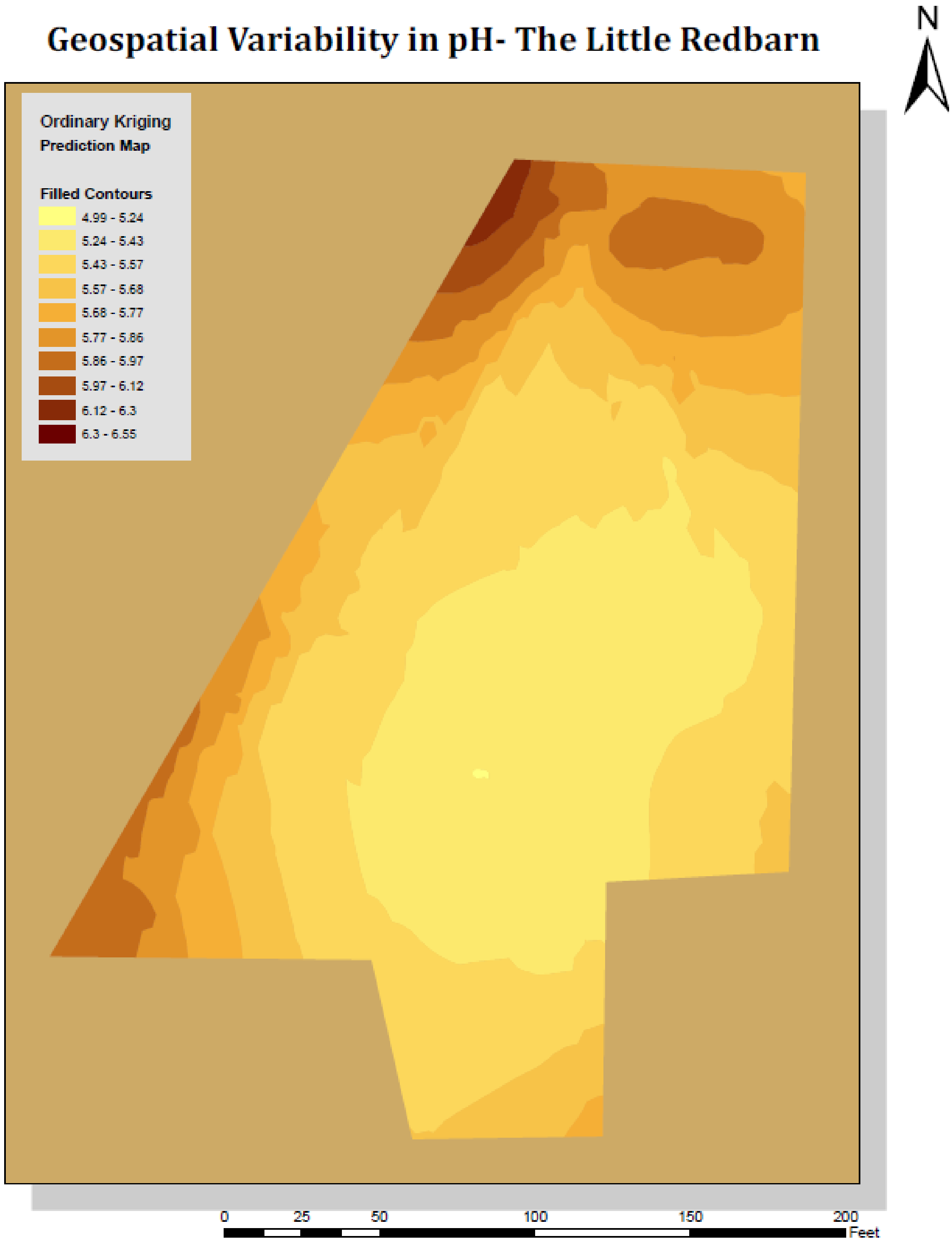
Sodium levels in soil are often reported as the sodium adsorption ratio (SAR). This is a ratio of the amount of cationic (positive) charge contributed to a soil by sodium, to that contributed by calcium and magnesium. The SAR is determined from a water extract of a saturated soil paste. A SAR value below 13 is desirable, (OSU Extension, 2008).

$$SAR = \frac{Na}{\sqrt{\frac{(Ca^{++}) + (Mg^{--})}{2}}}$$

Both farms SAR was <5% when averaged. The target number is<13, each farm was<.05.

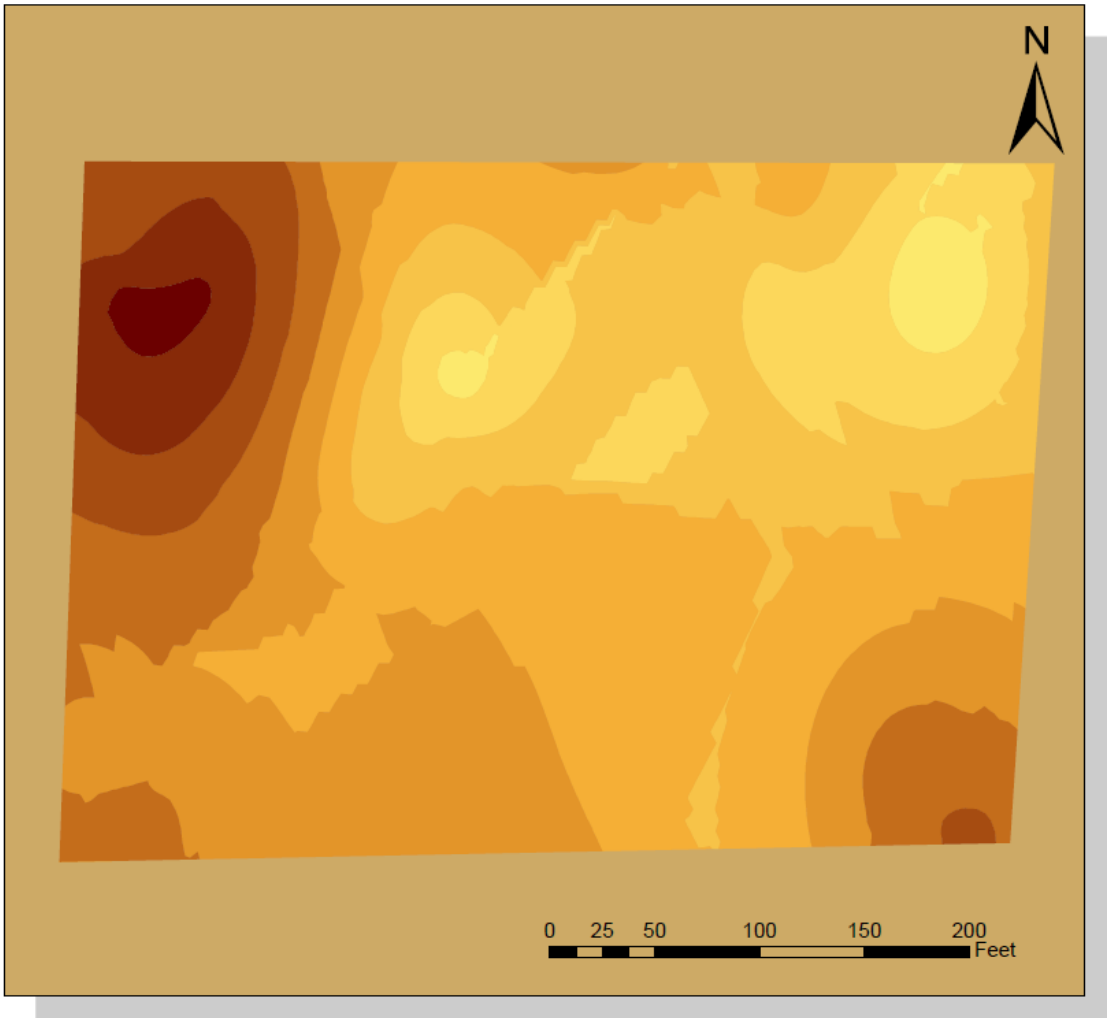
Geographical Information Systems interpolation results:

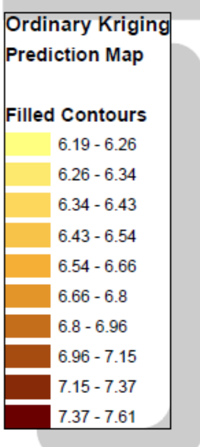
Geospatial Variability in pH- The Little Redbarn



Location: The Little Redbarn Farm
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

Oregon State University Organic Growers Garden pH Distribution

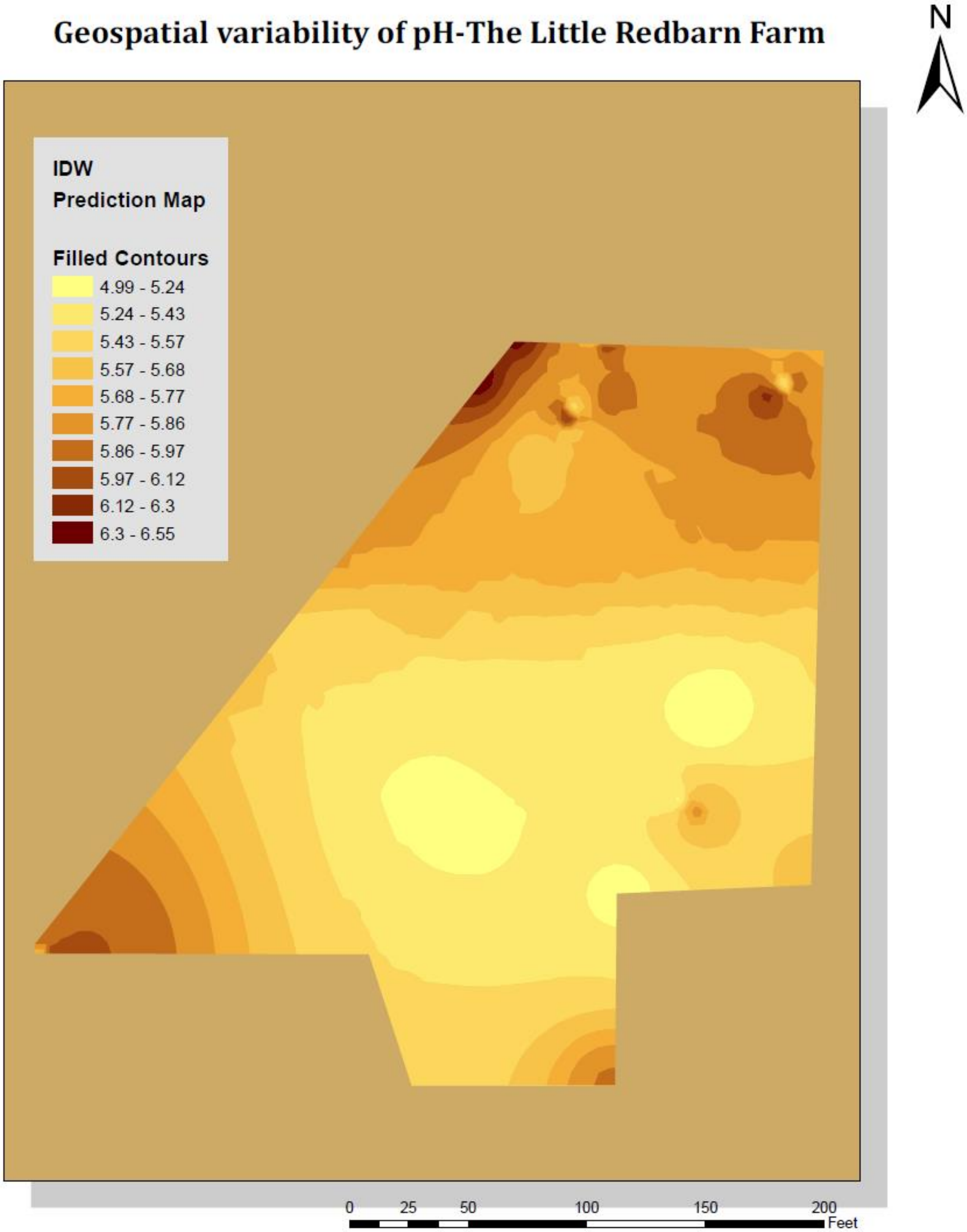




Increased areas of soil pH distribution are indicated by darker graduated colors. Jagged areas in geostatisical interpolation methods indicate undersampled area error and are not fluctuations in actual data.

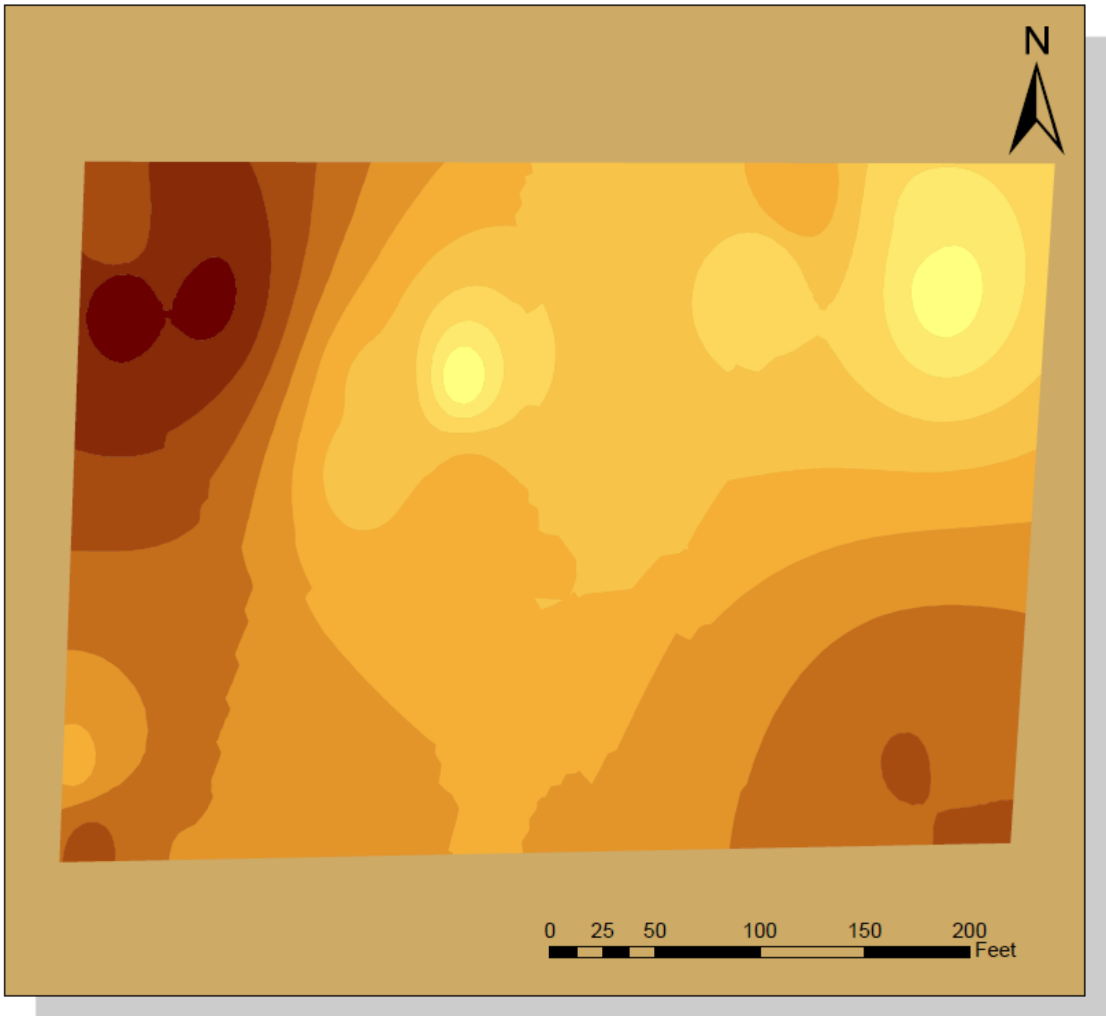
Location: Organic Growers Farm OSU
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

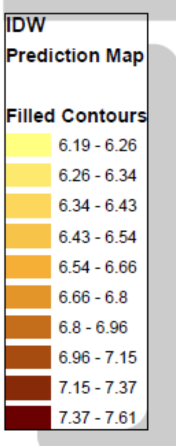
Geospatial variability of pH-The Little Redbarn Farm



Location: The Little Redbarn Farm
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

Oregon State University Organic Growers Garden pH Distribution

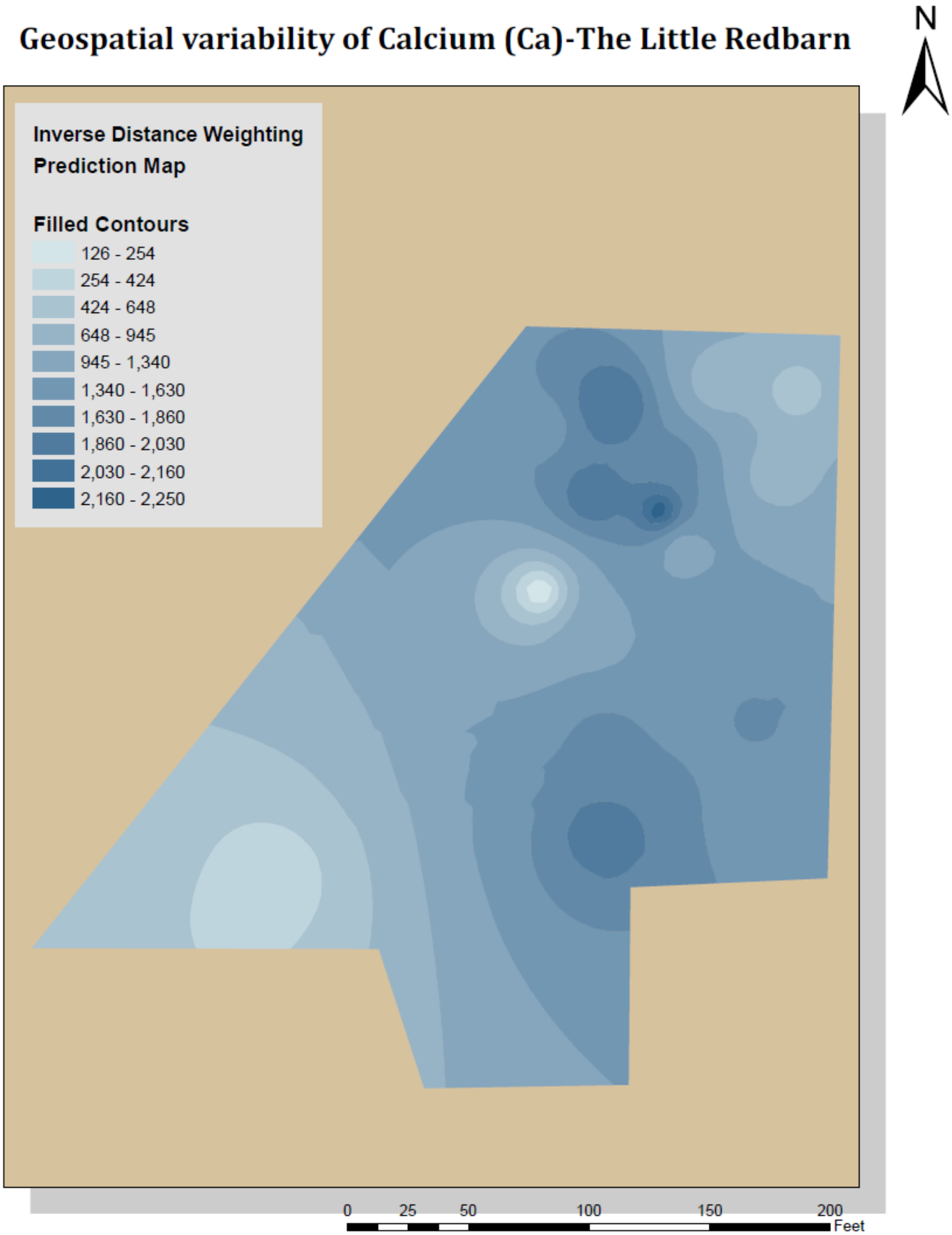




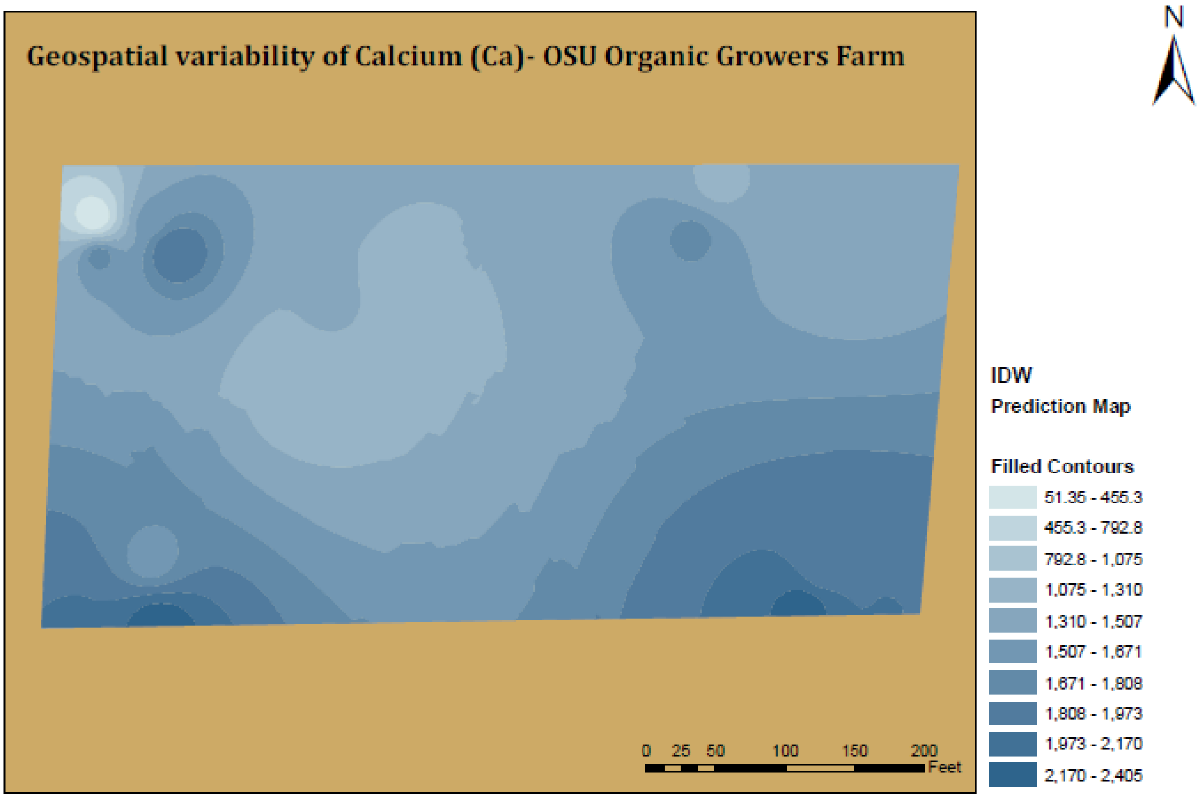
Increased areas of soil pH distribution are indicated by darker graduated colors. Jagged areas in geostatisical interpolation methods indicate undersampled area error and are not fluctuations in actual data.

Location: Organic Growers Farm OSU
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

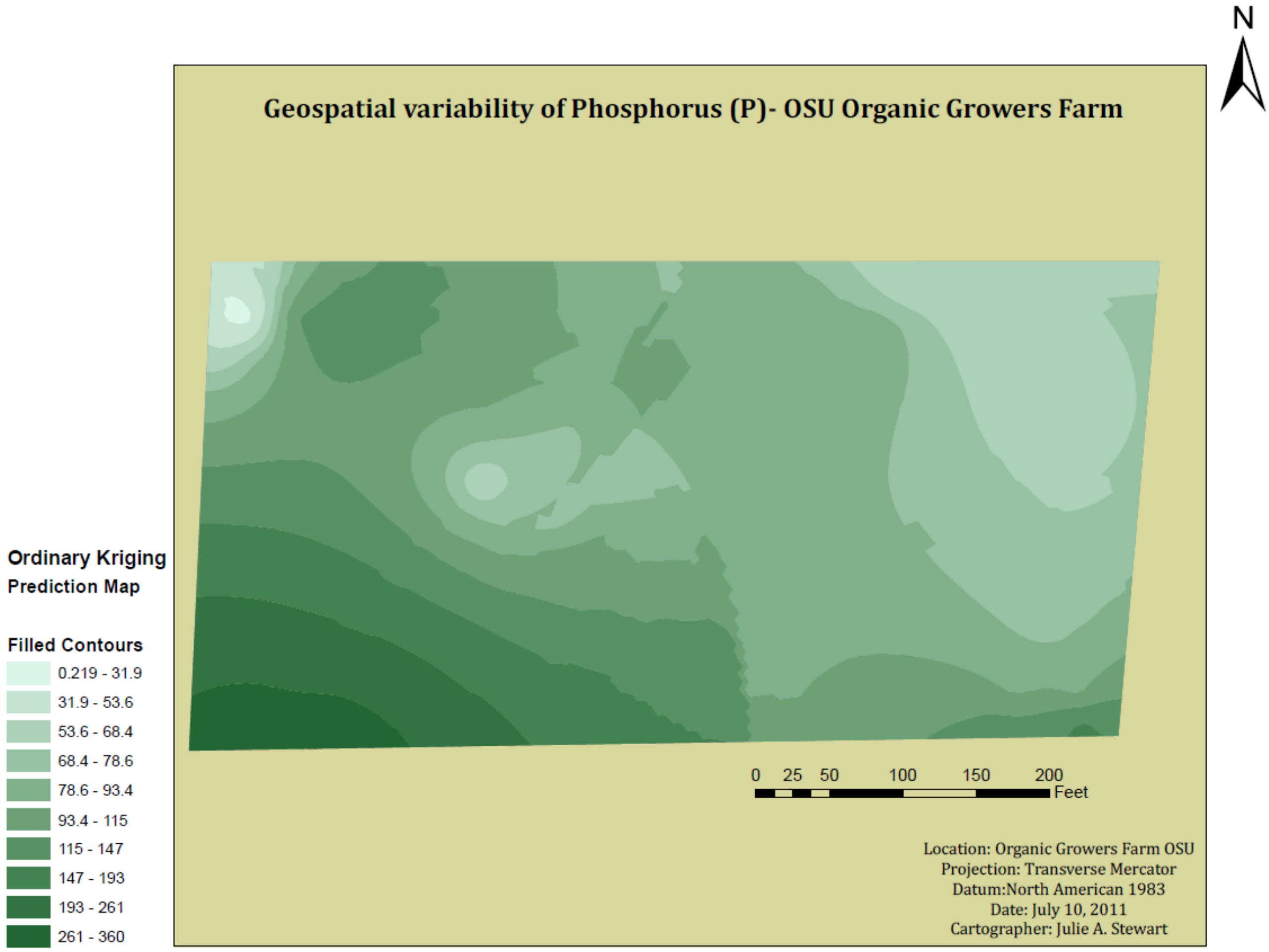
Geospatial variability of Calcium (Ca)-The Little Redbarn



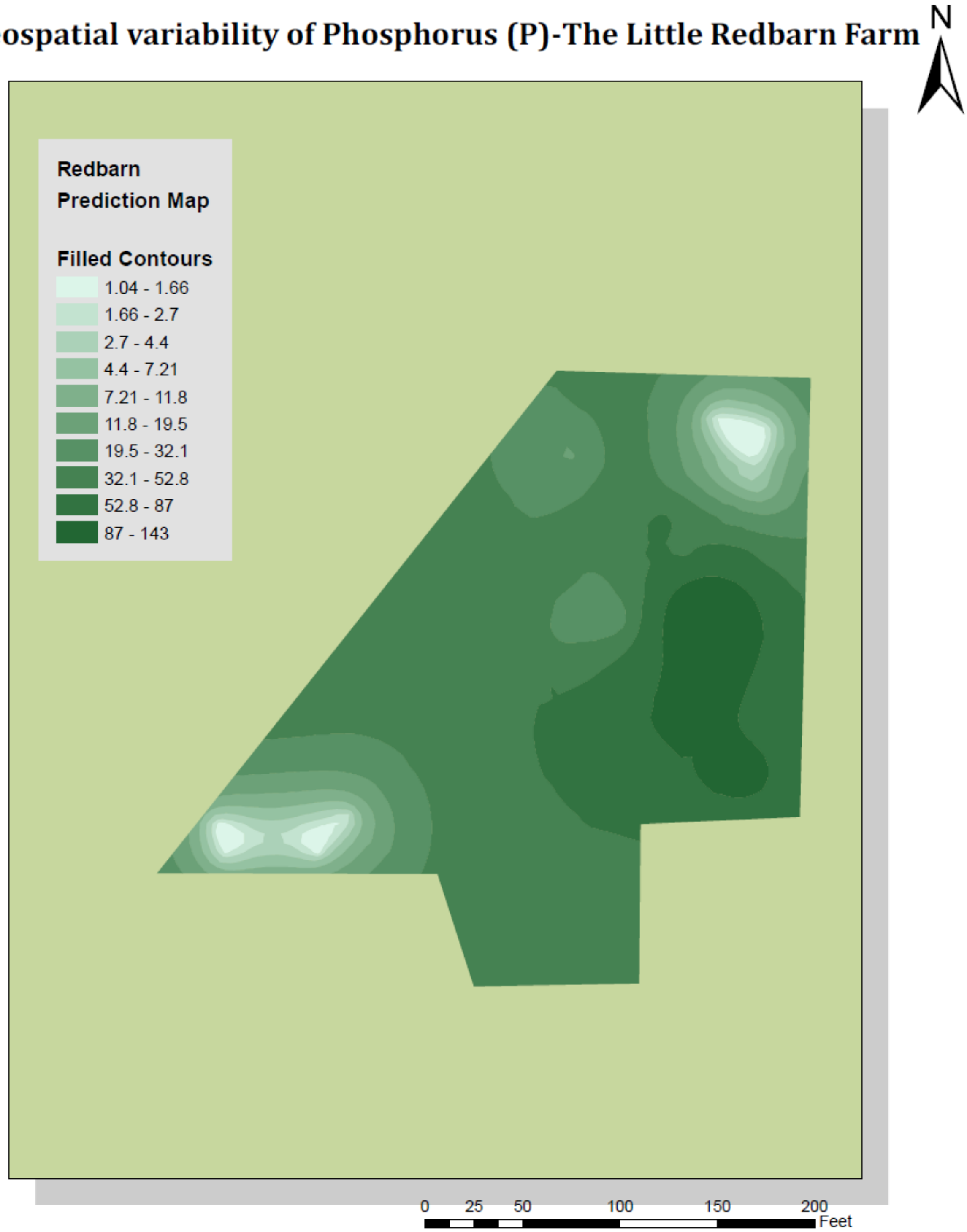
Location: The Little Redbarn Farm
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart



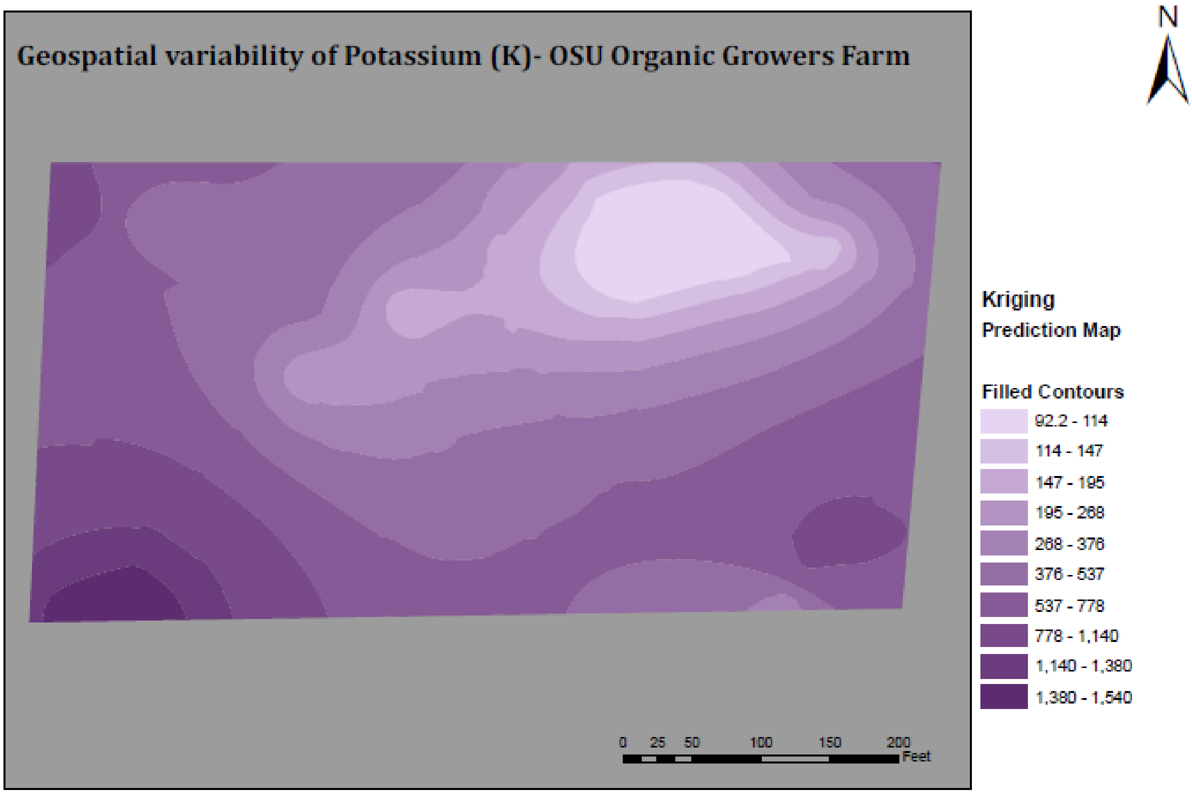
Location: Organic Growers Farm OSU
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart


N
Geospatial variability of Phosphorus (P)- OSU Organic Growers Farm
Ordinary Kriging
Prediction Map
Filled Contours
0.219 - 31.9
31.9 - 53.6
53.6 - 68.4
68.4 - 78.6
78.6 - 93.4
93.4 - 115
115 - 147
147 - 193
193 - 261
261 - 360
0 25 50 100 150 200
Feet
Location: Organic Growers Farm OSU
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

Geospatial variability of Phosphorus (P)-The Little Redbarn Farm

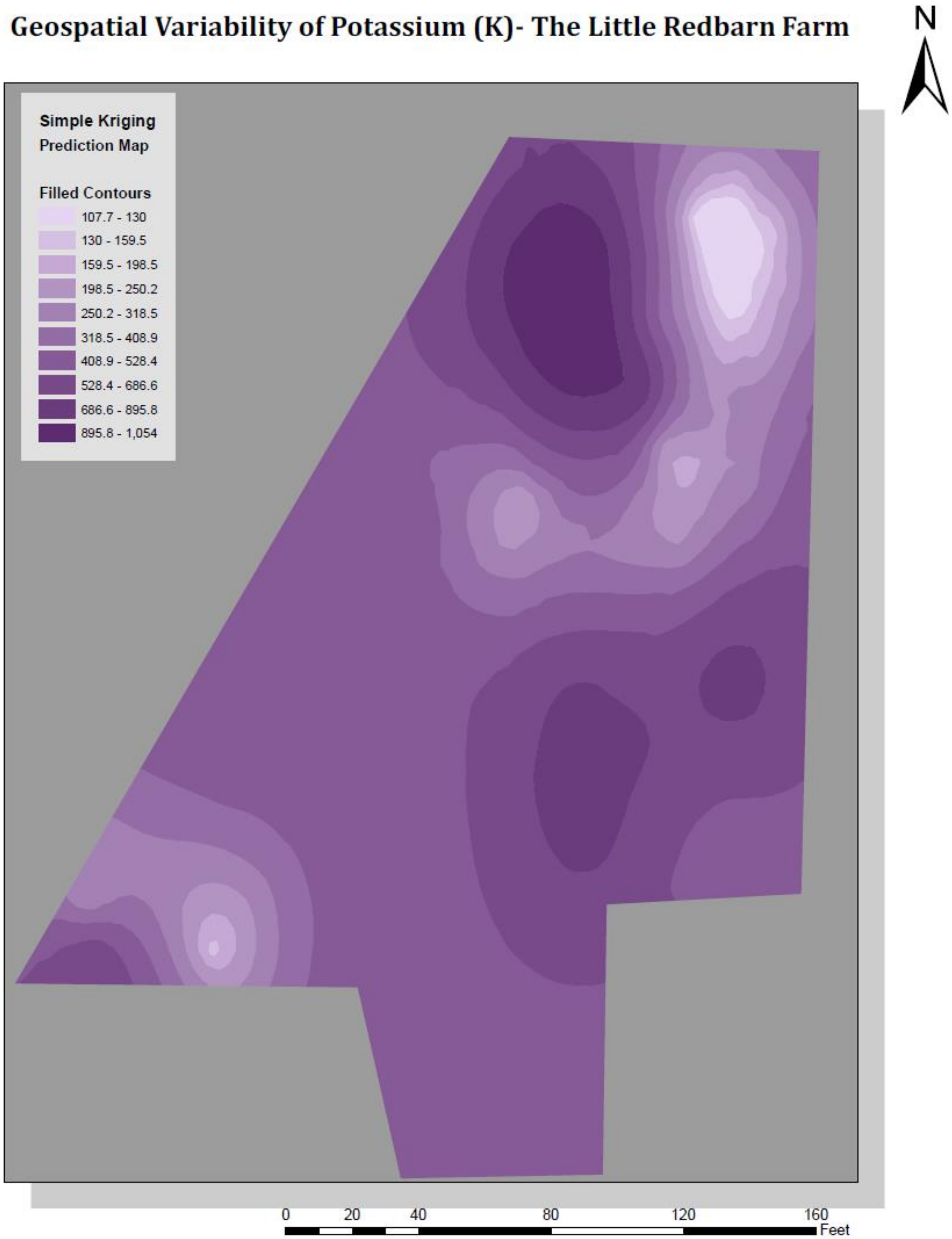


Location: The Little Redbarn Farm
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart



Location: Organic Growers Farm OSU
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

Geospatial Variability of Potassium (K)- The Little Redbarn Farm



Location: The Little Redbarn Farm
Projection: Transverse Mercator
Datum:North American 1983
Date: July 10, 2011
Cartographer: Julie A. Stewart

Statistical results:

The descriptive statistics for both farms below indicate that a one way ANOVA test would be the appropriate test to run on the pH data for both farms to determine statistical significance of pH between the two farms.

`pH-The Little Redbarn Farm		*pH-OSU- Organic Growers Farm*	
Mean	5.74025	Mean	6.77985
Standard Error	0.103112327	Standard Error	0.090260858
Median	5.6385	Median	6.791
Mode	#N/A	Mode	6.803
Standard Deviation	0.461132345	Standard Deviation	0.403658829
Sample Variance	0.212643039	Sample Variance	0.16294045
Kurtosis	-0.166190011	Kurtosis	-0.28102009
Skewness	0.663966475	Skewness	0.4711777
Range	1.751	Range	1.427
Minimum	4.992	Minimum	6.187
Maximum	6.743	Maximum	7.614
Sum	114.805	Sum	135.597
Count	20	Count	20

Table 1. Descriptive statistics for the pH values of two sampled farms.

ANOVA	Single Factor-Count	Sum	Average	Variance	P-Value	F Critical
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	20	135.597	6.77985	0.16294045		
Column 2	20	114.805	5.74025	0.21264304		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.8076816	1	10.8076816	57.5514201	4.01565E-09	4.09817173
Within Groups	7.1360863	38	0.187791745			
Total	17.9437679	39				

Table 2. Source table for ANOVA for pH data.

t-Test: Two-Sample Assuming Unequal Variances

	OSU	*Redbarn*
Mean	6.77985	5.74025
Variance	0.16294045	0.212643039
Observations	20	20
Hypothesized Mean Difference	0	
Df	37	
t Stat	7.58626523	
P(T<=t) one-tail	2.38042E-09	(p<.0001)
t Critical one-tail	1.68709362	
P(T<=t) two-tail	4.76085E-09	(p<.0001)
t Critical two-tail	2.026192463	

Table 3. Summary of t-test results comparing Little Redbarn Farm vs. Oregon State University Growers Garden for pH.

Discussion/Conclusions

Soil fertility is fundamental in determining the productivity of all farming systems.” Soil fertility is most commonly defined in terms of the ability of a soil to supply nutrients to crops, Swift & Palm (2000)” however, suggest that it is more helpful to view soil fertility as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production. This broader definition is appropriate to organic farming, as organic farming recognizes the complex relationships that exist between different system components and that the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system.

The foregoing data analyses reflected that easily detectable and statistically reliable differences (p<.0001) were found between two organic farms that were both characterized as silty loam soils. These large differences could be demonstrated using the laboratory analyses described, and the gross differences could further be effectively mapped with geospatial analytic techniques such as the kriging method, affording prediction and interpolation tools, with accompanying estimates of error variance. The study clearly demonstrated that two similarly described agricultural enterprises using minimal non-commercial amendments to the soils, could produce such radically different soil characteristics in terms of recognized important variables such as pH (a focus of this report), as well as concentrations of a number or important agricultural cations. These gross differences in acidity and other variables would in turn be expected to produce very different results or productivities in terms of crop yields or the quality of such yields.

Some organic farms use common techniques to correct acidity (low pH) such as liming and manure (e.g., Little Redbarn Farm), while others use deciduous leaf litter combined with manure. This study showed that even these minimal differences in amendments produce gross differences in the same type of soil separated by only 50 miles. On the basis of these variables studied, one would predict very different productivity for selected crops planted since the pH ranges were so discrepant between them. Further, inspection of one of the organic farms (Oregon State University Organic Growers Garden) in terms of pH and cations indicated that the minimally amended soil contained concentrations of plant nutrients in wasteful excess. While this study was not intended for the purpose of making recommendations to either farm, the data would suggest that rather than working to further modify/enrich the organic soil, the growers would be better advised to be more selective in decreasing the presence of some cations in the soil, despite the fact that these plant nutrients observed are often viewed as rich. In fact, some of these nutrients could be effectively decreased from excess values by selecting specific plants that will uptake these excesses, and perhaps improve the soil for other crops in future plantings.

Crop rotation is another practice that could be beneficial in organic farming as different plants take up different amounts of these valuable cations. Crop rotation is a system where different plants are grown in a recurring, defined sequence. Crop rotations, including a mixture of leguminous 'fertility building' crops are the main mechanism for nutrient supply within organic systems. "Rotations can also be designed to minimize the spread of weeds, pests and diseases (Stockdale et al, 2001)." The development and implementation of well-designed crop rotations is central to the success of organic production systems. Organic rotations are divided into phases that increase the level of soil nitrogen and phases that deplete it. "The nitrogen building and depleting phases must be in balance, or show a slight surplus, if long-term fertility is to be maintained (Stockdale et al, 2001)." This type of rotation provides the basis for forward planning of nitrogen supply, necessary in the absence of soluble nitrogen. The nitrogen building and depleting phases could theoretically be applied to organic agriculture for cation maintenance.

The research process was a highly successful training experience for the author for many reasons. Among the benefits were that the study required mastery of soil sampling and processing techniques, the effective use of standardized soil science analysis tools (e.g., massing soil, chemical extraction methods for cations, and accurate use of spectrometry equipment that afforded the precise measurement of minerals. Finally, this research demonstrated the utility of newer versions of ArcGIS in geostatistical analysis, and mapping of the results in a useful visual/graphic display. This mapping tool applied to much larger agricultural units could be extremely valuable to commercial enterprises which require straightforward and readable suggestions regarding what should be done to large areas of soil and where these amendments should be considered. While modest in the scope of samples taken and size of areas covered, this exploratory study was highly successful as an internship training to learn the essentials of more generalizable, larger scale research projects in the future.

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