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Explaining Spatial Variation in Yields of Irrigated Corn

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ABSTRACT

Precision agriculture technology was used to find and explain variations in plant and soil data within a sandy, irrigated field of corn in south-central Kansas. The field was mapped into a grid with a data-collecting point located at the center of each cell. These points provided the basis for collection of plant, soil, and yield data. Upon completion of data collection, surface interpolation was used to create surface maps for each test. Many strong correlations were found to exist between the soil properties and soil nutrients. Stalk nitrate tests indicated that some areas of the field received more or less nitrogen than was needed. Input efficiency could possibly be maximized in the future with further testing and variable rate application of plant nutrients.

Keywords: *yield variation, irrigated corn, precision agriculture, GPS, GIS*

INTRODUCTION

Precision Agriculture, especially site-specific management has shown great potential as a means of increasing efficiency in crop management. Many variables exist in cropping environments, especially in areas where there are large variations in soil texture and nutrient content in fields under irrigation. Variable rate application of water, nitrogen, phosphorus, potassium, plant variety, and plant populations can help gain efficiency and reduce yield variation within these fields. By measuring variabilities in water, soil texture, organic matter, phosphorus, potassium, soil electrical conductivity, and nitrate content within the field, variations in yield can be explained. Knowing this would benefit the producer by giving insight as to which nutrients are needed and what changes in application rates and changes in areas of application could reduce input expenses while maximizing yield and profit (Cummins). This knowledge could benefit not only agriculture, but also improve environmental management due to the variable spatial and temporal application possibilities.

Recent technological breakthroughs in Variable Rate Technology (VRT) have shown precision agriculture to be a cost-effective practice to maximize profits while minimizing inputs and expenses. Global Positioning Systems (GPS), Geographical Information Systems (GIS), and VRT have been shown to greatly benefit farmers by improving accuracy, efficiency, profitability, decision-making and management (Cummins).

Grid soil sampling has provided an accurate basis for variable rate application maps, but research shows the cost and labor associated with sampling from plots small enough to provide accurate mapping may be prohibitive (Fleming 2000). Possible grid sizes for sampling include one-acre, 2.2-acre, and four-acre plots, with the larger plots being more cost efficient for the farmer, while the smaller plots provide the most accurate information (Wesley 2001).

While soil testing for precision inputs has been done for many variations throughout the upper mid-east and corn belt, little experimentation has been done to determine the possible improvements and effectiveness of variable-rate application on fields under irrigation in the semi-arid Midwest or to explain yield and soil variation in these types of fields (Heermann 2000).

The purpose of this study was to find and explain variations within sandy, irrigated fields, and show what improvements in efficiency through inputs and yield increase could be implemented through the use of these precision agriculture practices.

MATERIALS AND METHODS

The field under study was an irrigated half-circle of 66 acres in Pratt County, Kansas, located on the southwest quarter of Section 25, Township 26, Range 14 (Figure 1). The following soil series were represented within the field: Hayes, Saltcreek, and Solvay (Table 1). The field had adequate water rights for irrigation to ensure that drought stress was minimized. Also, the field was in an adequate crop scouting plan in order to ensure that yield loss due to insects, weeds, and diseases were minimized.

The field was planted on May 15, 2005 with Pioneer's 31A13 corn hybrid at 30,000 seeds per acre with 1.3 ounces/acre of Capture insecticide and 3 ounces/acre of Lexar preemerge herbicide, both of which were applied with the planter. Total fertilizer application consisted of 260 pounds/acre of nitrogen, 37 pounds/acre of phosphorus, 30 pounds/acre of potassium, and 8 pounds/acre of sulfur. Total irrigation consisted of 9 inches of water.

The field was mapped into a 2.2-acre grid with a total of 28 cells using SST Stratus (SST Development Group, 824 North Country Club Road, Stillwater, OK 74075). The field was sampled on April 12 with an Oakfield soil sample probe. The center of each grid cell was located using a GPS receiver (BTGPS II Trine Receiver) and a handheld computer (Dell Axim X50). SST Stratus software was used to produce the grid.

Five soil samples were taken around a 10-foot radius of each sampling point and composited. Each sample was 10 inches deep.

Compaction was measured at the time of soil sampling and again on June 12, with a Dickey-John 200207 penetrometer. Compaction readings were taken twice at each sample point at both 6 inches and 12 inches on each date.

Soil was ground using a soil grinder to pass through a 1.2 mm sieve. Texture was determined using the Buoyoucos Hydrometer Method. The soil was analyzed for nitrate, phosphorous, potassium, organic matter, and pH by Servi-Tech Laboratories, 1816 E. Wyatt Earp, Dodge City, KS 67801.

Five stalks were sampled at each location by cutting 7-inch pieces from cornstalks between 8 and 15 inches above the ground on September 12. The stalks were then dried for 20 hours at 60 degrees C, and ground to 2 mm and then reground to 1 mm with a Wiley mill. These samples were analyzed by Servi-Tech Labs for nitrate.

The corn was harvested on September 22, using a John Deere 9860 STS combine equipped with a 12-row corn head and Green Star yield monitor, which was used to map the yield variation throughout the field.

Upon completion of data collection, soil and plant test result surface maps were created using Surfer 8 interpolation software (Golden Software, Inc. Golden, CO 80401). The Kriging technique was chosen for interpolation. These maps show the changes and variation in the soil's properties across the field in 60 foot grids.

Nearest neighbor interpolation was chosen to create the yield map. Statistical analysis was used to isolate and delete misleadingly high and low yield points. These erroneous data points include areas in the field where the machine may not have been harvesting a full swath or areas where the machine was turning. These points were isolated by first deleting all points outside of 1.75 standard deviations of the field's average yield. Because impossibly high and low points still remained, this technique was used once more, screening the data again at the 1.75 standard deviation mark. Once these high and low yield data points were isolated, surface maps were created.

To match the yield data to the 28 soil/plant data points, an average yield at each point was calculated by using SST Toolbox version 3.6 software to query all data points falling within 60 feet (2 combine swaths' width) of each point. This yield data was averaged and assigned to each corresponding sample data point.

To define the meaning of this data, statistical analysis was also done using the SSToolbox program to calculate minimum, maximum, standard deviation, and coefficient of variation for each variable (Table 2). A correlation matrix was created, again using the SSToolbox software. This matrix (Table 3) includes correlations of all variables measured.

Table 2. Descriptive statistics of plant and soil variables.

	Min	Max	Mean	SD	CV
pH	6.4	7.4	7.07	0.21	0.03
Sol Salts	.06	0.22	0.12	0.04	0.33
NO_3 (ppm)	2	12	5.22	2.45	0.47
P (ppm)	14	115	42.35	23.8	0.56
K (ppm)	71	309	153	54.6	0.36
Stalk $N0_3$ (ppm)	100	6400	1618	1500	0.93
Sand (%)	80	98	92.4	3.83	0.04
Silt (%)	0	11	4.9	2.5	0.51
Clay (%)	1	9	2.75	1.8	0.65
OM (%)	0.6	1.8	1.12	0.3	0.27
Compaction (psi)					
6" April	0	300	156	59	0.38
6" June	0	400	282	11	0.04
12" April	75	400	278	96	0.35
12" June	275	400	380	39	0.10

RESULTS

Surface maps were made for yield, pH, soil texture, soil nitrate, soil phosphorus, soil potassium, soil organic matter, compaction, and stalk nitrate. The yield map (Figure 2) shows that yield was fairly consistent across the field, and the field as a whole averaged 224 bushels/acre. As seen on the pH map (Figure 3), the pH did vary somewhat but was not variable enough in any area to be considered especially high or low. The soil texture maps (Figures 4 through 6) show the percentage of sand, silt, and clay throughout the field. As these three figures show, a more clayey area exists in the southern part of the field on the east side of the pivot. Soil nitrate, soil phosphorus, and soil potassium (Figures 7 through 9) all varied somewhat throughout the field and are somewhat similar to the soil texture maps. Figures 10 and 11 show the variation in organic matter and soluble salts, respectively. Both of these variables correlate somewhat with other soil variables, as the correlation table (Table 2) shows. The compaction maps (Figures 12 through 15) show that the entire field became more compacted through the growing season when compared to the April compaction maps. The stalk nitrate map (Figure 16) shows a large variation throughout the field, with very high readings through the center of the field and low readings in other parts, especially in the southwest corner.

Many strong correlations were found between some soil tests (Table 3). Many of these correlations are due to physical properties like electrical charges of nutrients and the more clayey soils' ability to hold these nutrients better than sand. However, very few strong correlations were found with yield. The strongest correlation, which is with pH, is only .36. This correlation is not helpful either, as the pH across the entire field is at least 6.4. Without a much higher or lower pH, no change in the soil's pH will likely change the crop's yield.

DISCUSSION

Because the objective of this project was to explain yield variation, the results would have been more informative had there been move variation in the yield. Much of this lack of variation is due to the similar soil qualities, such as percent sand (texture), and the equality in soil nutrients like N, P, K, and the even pH across the field. Also, fertilizer application across the field was high enough to even out most variation in soil nutrients available for the corn crop. Good drainage, good water distribution, and good management also helped this field be very consistent.

The most obvious variation in the yield was the low yields along the border of the field. This is easily explained because a few of these outside rows were outside of the water pattern and did not receive as much moisture as the interior of the field. Because this occurred, the plants also grew more slowly and did not reach the height that the rest of the field did. This then led to a poorer and later canopy, which allowed some late-season weeds to grow and compete with the corn for water and nutrients. A lower, slightly less well-drained area is also evident in the yield map. This area probably lost some yield because of the lower elevation and poorly-drained, higher-clay soil, leading to a saturated and anaerobic environment for much of the growing season.

The test with the most meaningful variation was stalk nitrate. As the corn plant finishes grain-fill accumulation and nears maturity, it continues to take up nitrogen when high levels of nitrogen exist in the soil. This excess nitrogen accumulates in the lower portion of the stalk (Blackmer 1996). Figure 14 shows that the producer applied more nitrogen than was most likely necessary at the "high" points and potentially lost some yield at the "low" points. The plants at these lower-level points most likely ran out of nitrogen and did not reach their yield potential. The low readings in the southwest area of the field can be explained by the producer's failure to apply UAN solution through the irrigation system (fertigation) to this area while the rest of the field was properly fertigated.

It may seem surprising that there was little correlation between stalk nitrate and yield, as that was the biggest variable found. However, when considering that the high areas accounted for the majority of the field, this is understandable. Once the plant has used all the nitrogen it needs, an increase in nitrogen supply will not net any higher or lower yield unless the over-applied rates are extreme.

If variable-rate application of nitrogen is to be implemented in the next corn season, it would probably be best to again grid sample or cell sample the areas of the field that were in the high and low levels of stalk nitrate. If these post-season soil nitrate levels correlate with the 2005 stalk nitrate levels, a variable-rate application of nitrogen in the next corn season may be a cost-saving precision agriculture technique.

ACKNOWLEDGEMENTS

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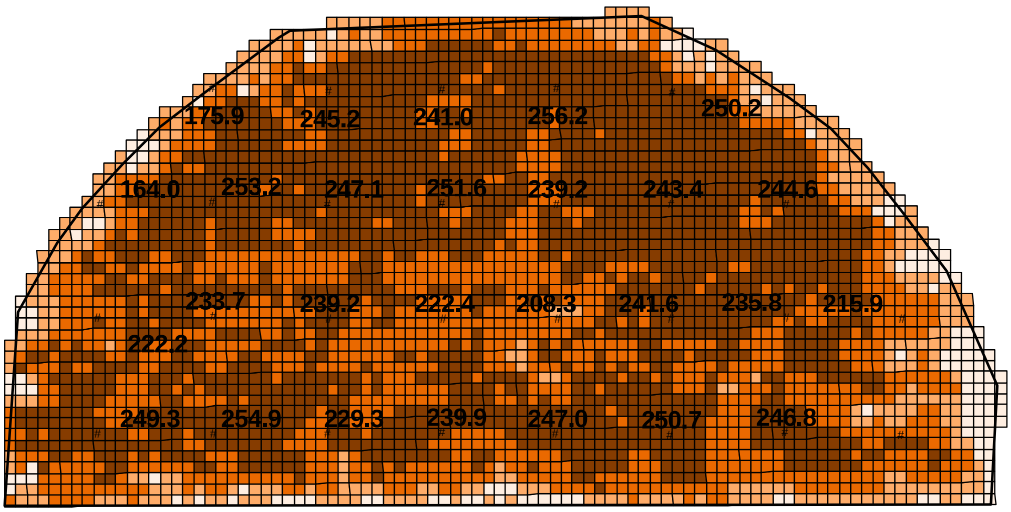

Figure 2. Variation in Corn Yield. Low areas are light and high areas are dark. The field averaged 224 bushels/acre.

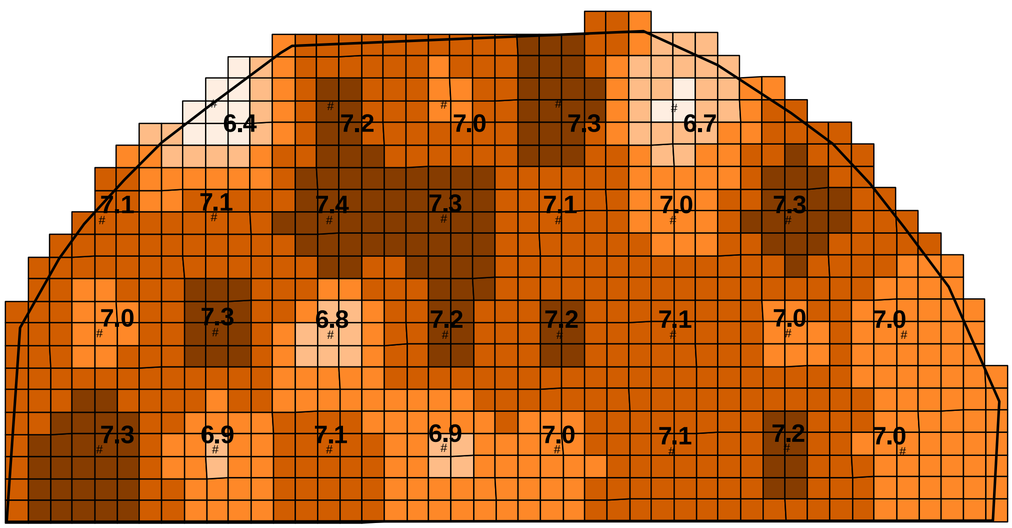

Figure 3. Variation in pH.

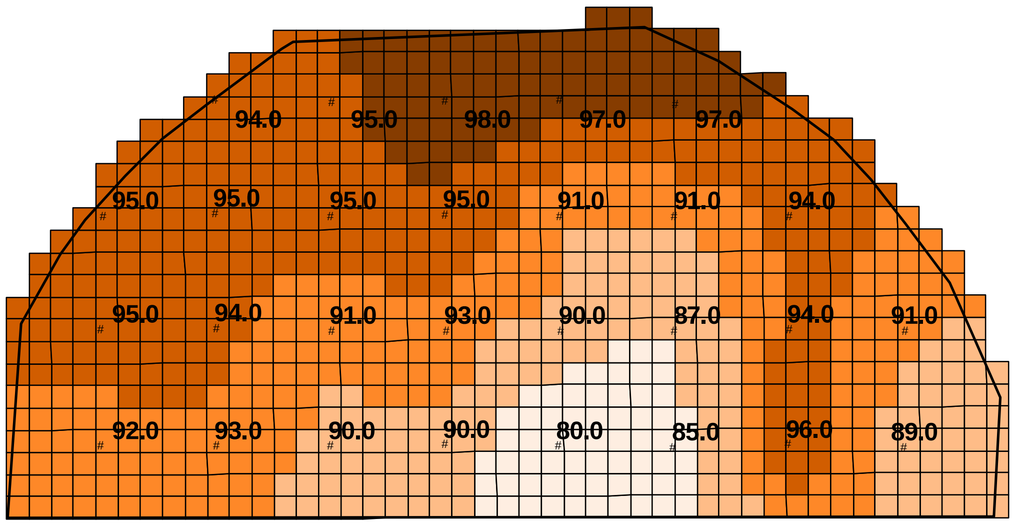

Figure 4. Variation in Texture: Percent Sand

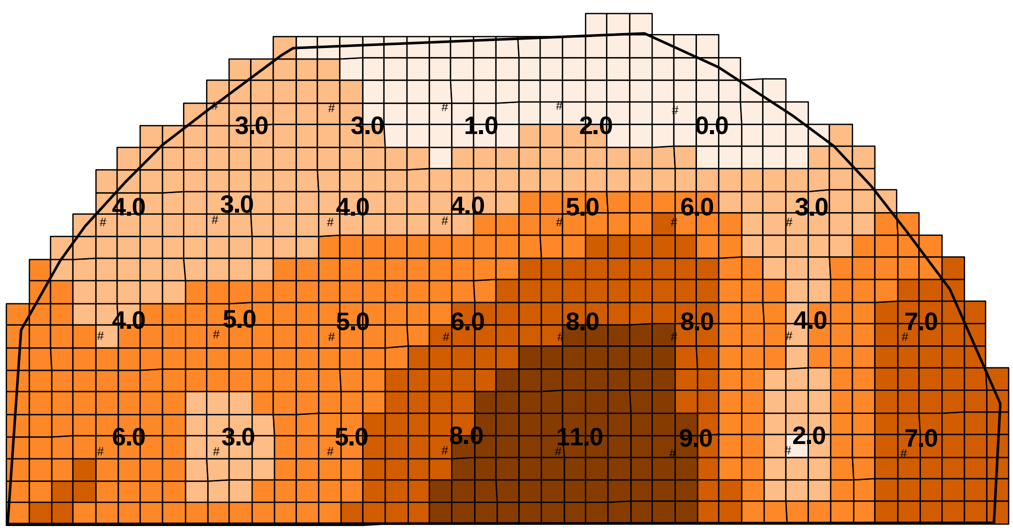

Figure 5. Variation in Texture: Percent Silt

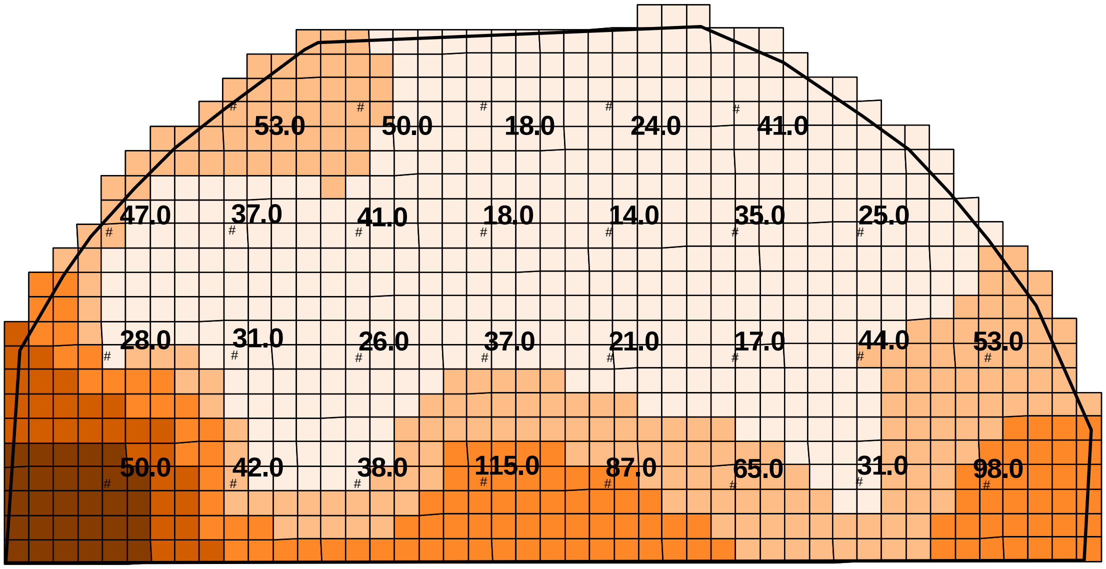

Figure 6. Variation in Texture: Percent Clay

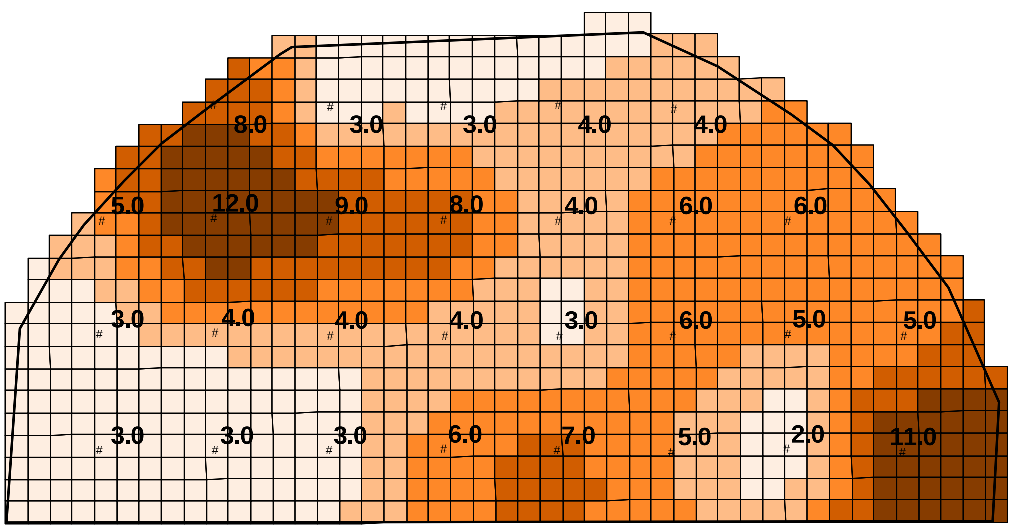

Figure 7. Variation in Preseason Soil Nitrate (Parts Per Million)

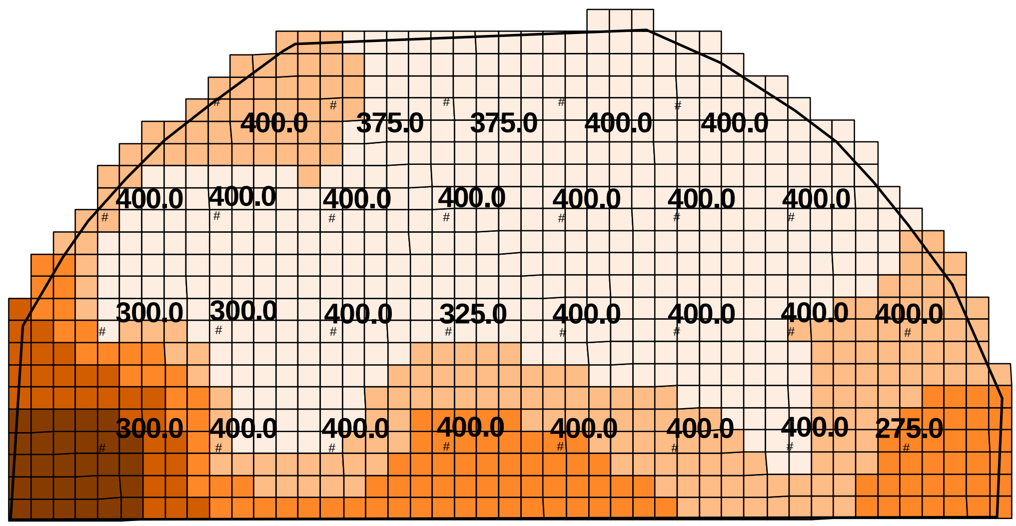

Figure 8. Variation in Preseason Soil Phosphorus (Parts Per Million)

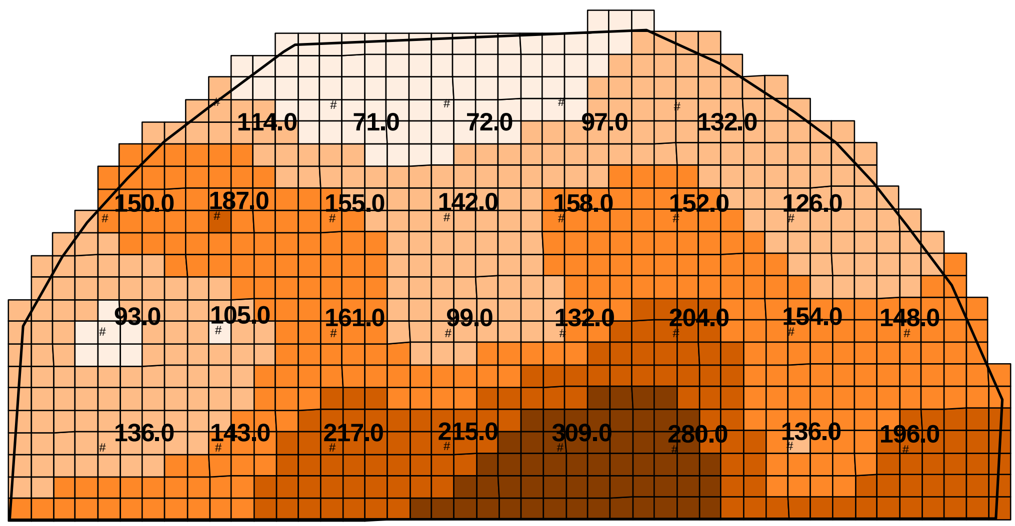

Figure 9. Variation in Preseason Soil Potassium (Parts Per Million)

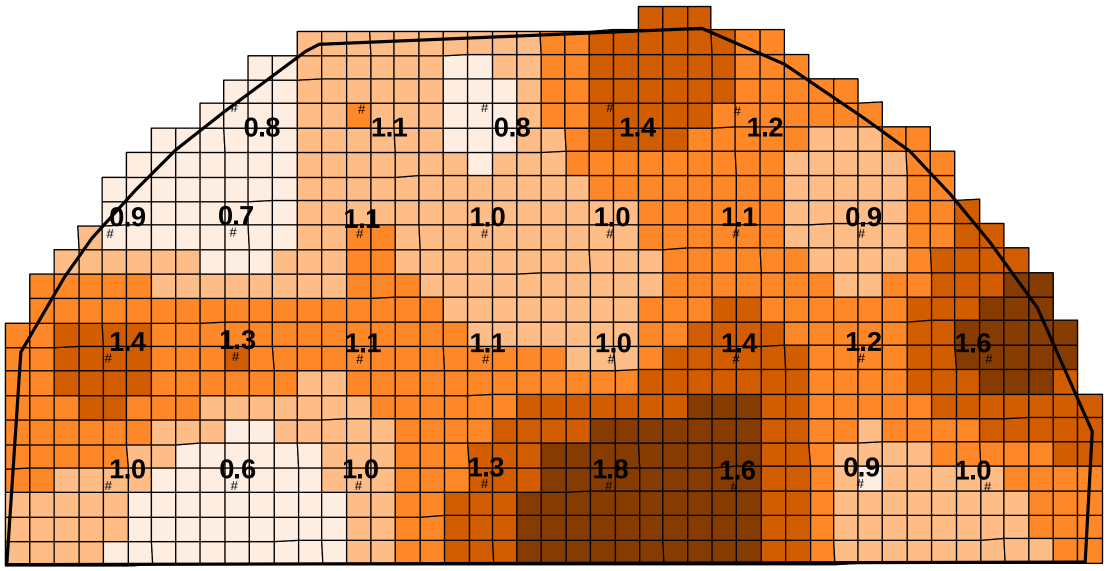

Figure 10. Variation in Percentage of Organic Matter

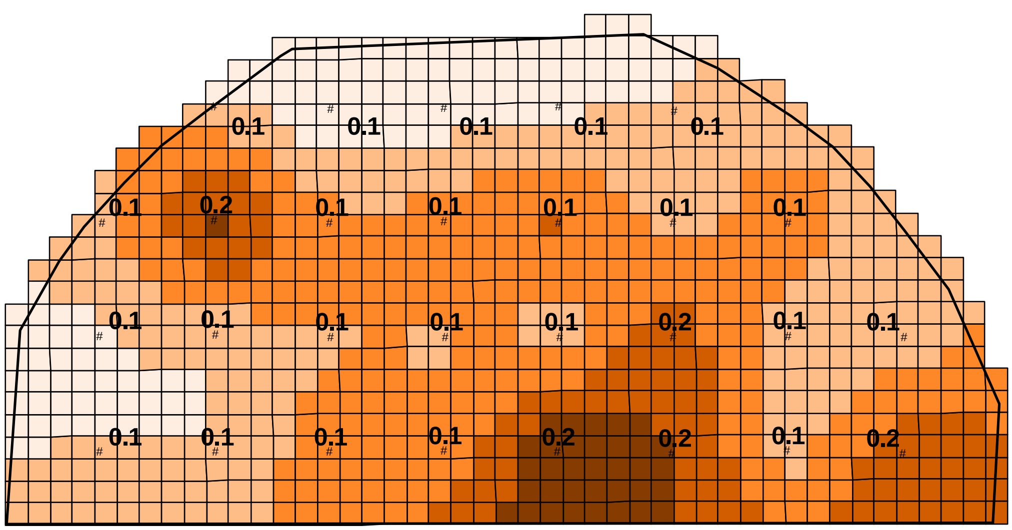

Figure 11. Variation in Soluble Salts

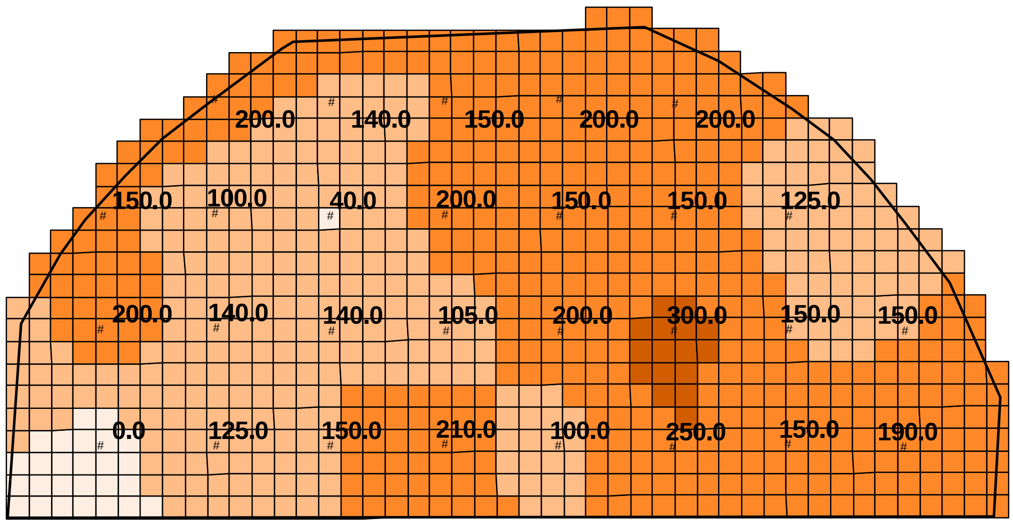

Figure 12. Variation in Soil Compaction in April (6 Inch Depth)

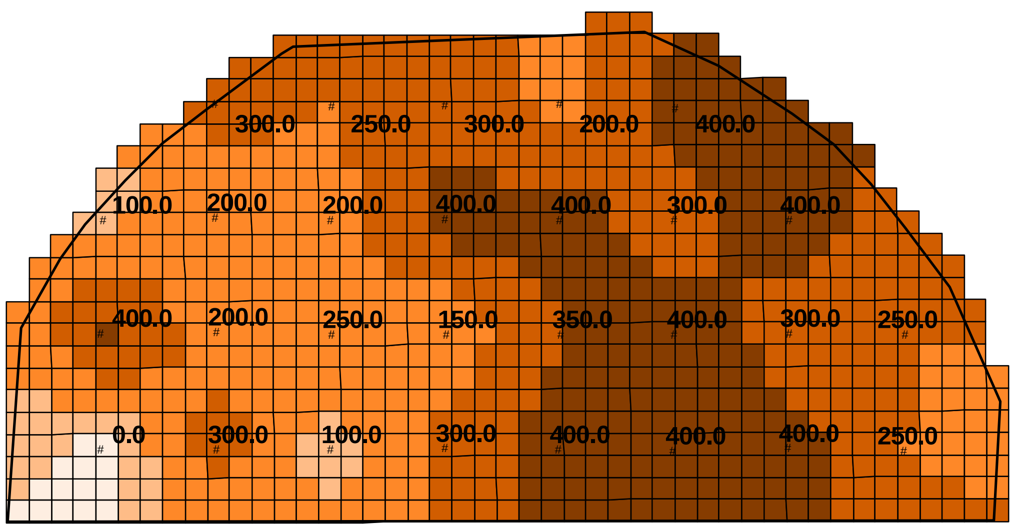

Figure 13. Variation in June Compaction (6 Inch Depth)

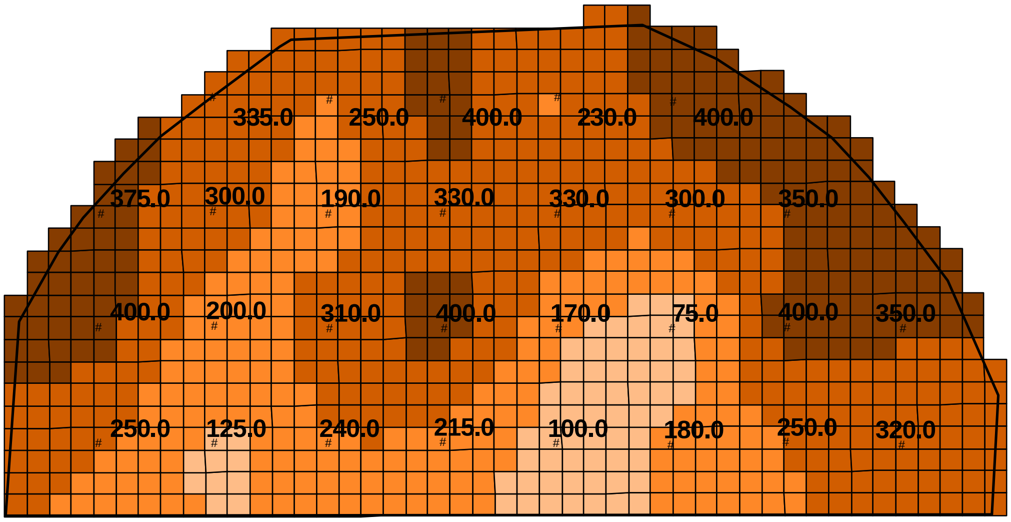

Figure 14. Variation in April Compaction (12 Inch Depth)

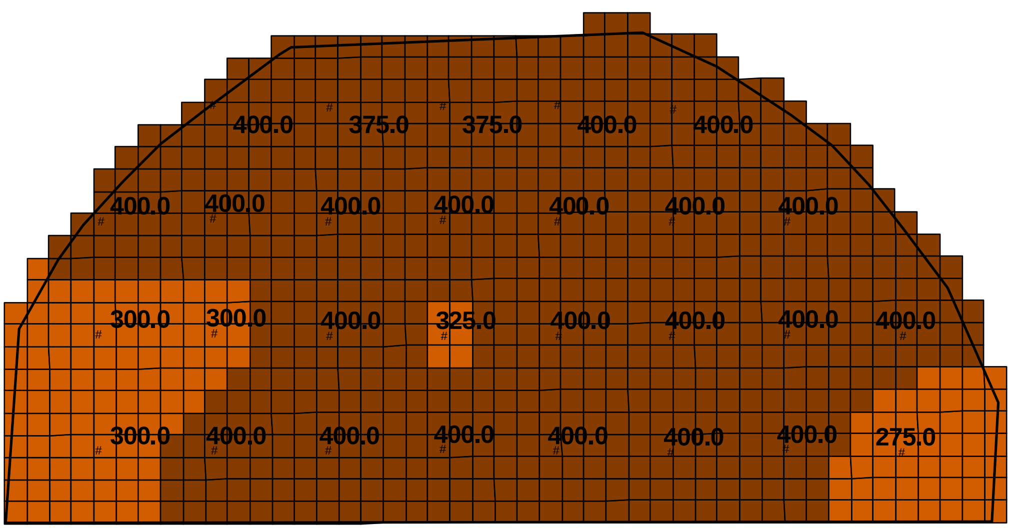

Figure 15. Variation in June Compaction (12 Inch Depth)

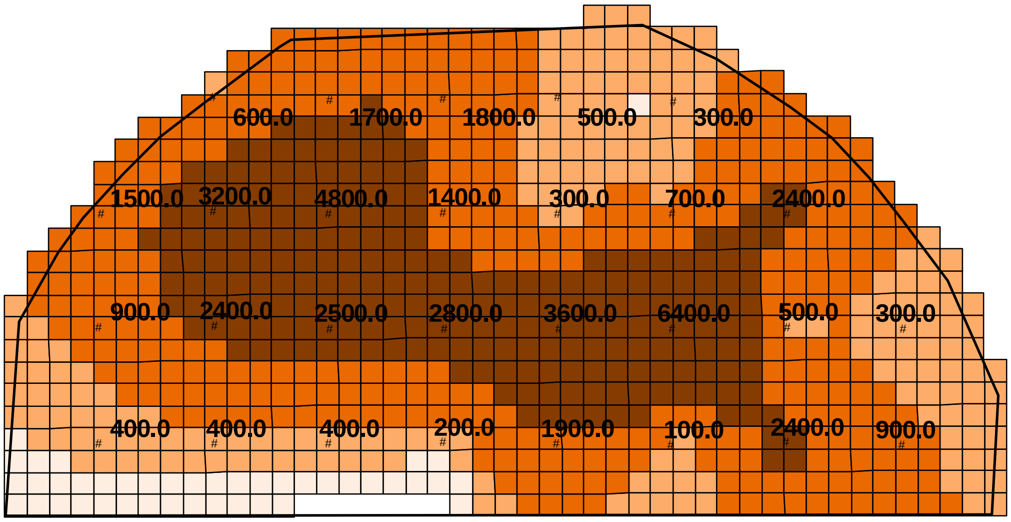

Figure 16. Variation in Season-end Stalk Nitrate (Parts Per Million)

Table 3. Correlations of soil tests, plant tests, and yield. Bold entries show correlations of +/- .3 or stronger.

VARIABLES	**pH**	**Soluble Salts**	**Soil Nitrate**	**Soil Phosphorus**	**Soil Potassium**	**Stalk nitrate**	**% sand**	**% silt**	**% clay**	**Organic matter**	**April 6" compaction**	**April 12" comp.**	**June 6" comp.**	**June 12" comp.**	**Yield**
pH	-	0.05	(0.08)	(0.29)	(0.10)	**0.36**	0.09	0.08	(0.29)	0.07	**(0.32)**	(0.23)	(0.23)	(0.18)	**0.36**
Soluble Salts	0.05	-	**0.61**	**0.34**	**0.85**	0.20	**(0.70)**	**0.57**	**0.69**	0.26	0.07	**(0.34)**	0.22	0.12	0.16
Soil Nitrate	(0.08)	**0.61**	-	**0.35**	**0.37**	0.22	(0.16)	0.17	0.11	(0.07)	(0.02)	(0.01)	0.01	0.02	(0.06)
Soil Phosphorus	(0.29)	**0.34**	**0.35**	-	**0.54**	**(0.35)**	**(0.48)**	**0.48**	**0.34**	**0.30**	(0.01)	(0.18)	(0.10)	(0.17)	(0.12)
Soil Potassium	(0.10)	**0.85**	**0.37**	**0.54**	-	(0.01)	**(0.84)**	**0.71**	**0.80**	**0.43**	0.14	**(0.50)**	0.18	0.26	0.14
Stalk nitrate	**0.36**	0.20	0.22	**(0.35)**	(0.01)	-	(0.05)	0.12	(0.05)	(0.04)	0.00	**(0.36)**	0.07	0.07	0.05
% sand	0.09	**(0.70)**	(0.16)	**(0.48)**	**(0.84)**	(0.05)	-	**(0.92)**	**(0.84)**	**(0.55)**	(0.16)	**0.57**	(0.19)	(0.05)	(0.03)
% silt	0.08	**0.57**	0.17	**0.48**	**0.71**	0.12	**(0.92)**	-	**0.56**	**0.59**	0.13	**(0.51)**	0.06	(0.09)	(0.08)
% clay	(0.29)	**0.69**	0.11	**0.34**	**0.80**	(0.05)	**(0.84)**	**0.56**	-	**0.36**	0.16	**(0.50)**	**0.33**	0.23	0.17
Organic matter	0.07	0.26	(0.07)	**0.30**	**0.43**	(0.04)	**(0.55)**	**0.59**	**0.36**	-	0.28	(0.26)	0.23	(0.03)	0.14
April 6" compaction	**(0.32)**	0.07	(0.02)	(0.01)	0.14	0.00	(0.16)	0.13	0.16	0.28	-	(0.09)	**0.57**	0.20	(0.15)
April 12" compaction	(0.23)	**(0.34)**	(0.01)	(0.18)	**(0.50)**	**(0.36)**	**0.57**	**(0.51)**	**(0.50)**	(0.26)	(0.09)	-	(0.08)	(0.18)	**(0.32)**
June 6" compaction	(0.23)	0.22	0.01	(0.10)	0.18	0.07	(0.19)	0.06	**0.33**	0.23	**0.57**	(0.08)	-	0.33	0.23
June 12" compaction	(0.18)	0.12	0.02	(0.17)	0.26	0.07	(0.05)	(0.09)	0.23	(0.03)	0.20	(0.18)	0.33	-	0.11
Yield	0.36	0.16	(0.12)	(0.12)	0.14	0.05	(0.03)	(0.08)	0.17	0.14	(0.15)	**(0.32)**	0.23	0.11	0.00

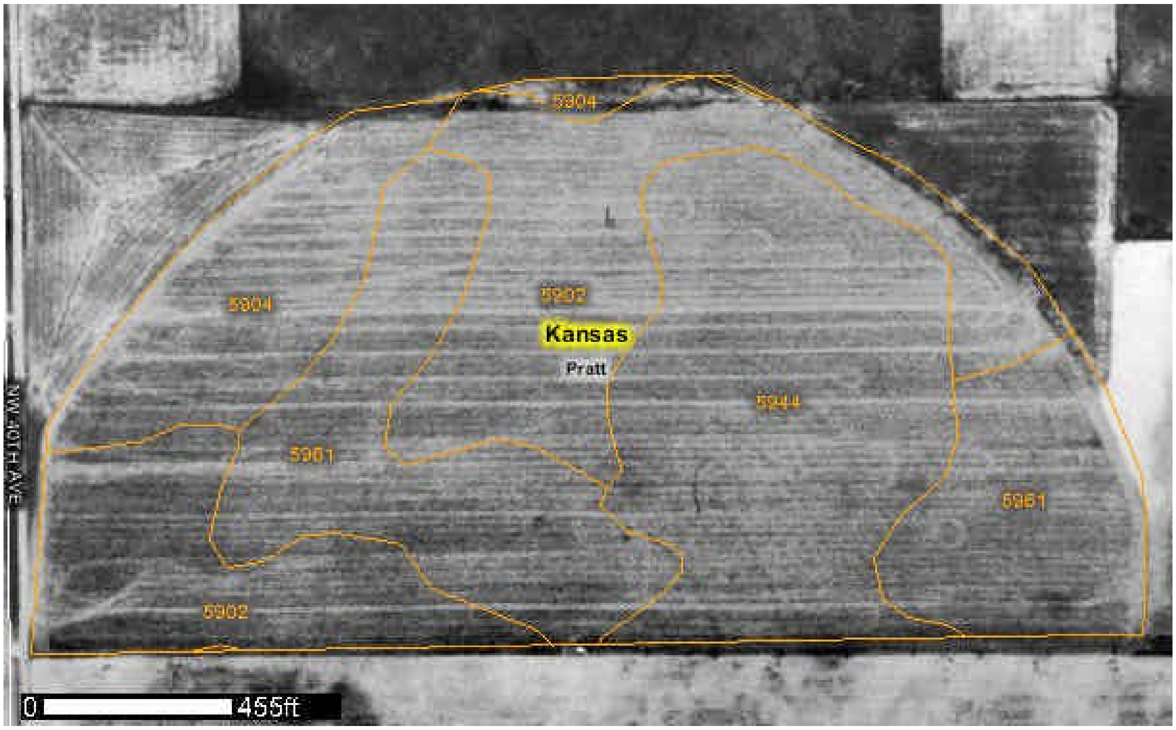

Figure 1. Soil map of research field. Numbers on map refer to Table 1 below.

Table 1. Soil Series and descriptions of research field. Right-hand columns of table refer to the "area of interest."

Pratt County, Kansas

Map Unit Symbol	Map Unit Name	Acres	Percent of field
5902	Hayes fine sandy loam, 1 to 5 percent slopes	21.1	32.0
5904	Hayes loamy fine sand, 5 to 10 percent slopes	8.5	12.8
5944	Saltcreek and Naron fine sandy loams, 1 to 3 percent slopes	17.7	26.7
5961	Solvay loamy fine sand, 0 to 2 percent slopes	18.9	28.5