Spatially consistent corn yield variability on the Loess Hills of Northwest Iowa: A critical look

by

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ABSTRACT

In Iowa, precision agriculture technology continues to be embraced by the agricultural community and large volumes of data are continually being collected. One type of data collected is spatially dense georeferenced yield points that are converted into maps to show the magnitude and variability of corn yield. The first part of this thesis reports on the use of "Anselin Local Moran's I Cluster tool" to quantify spatial corn yield variability in the Loess Hills of Northwest Iowa and then validate the results using a residual method. A 32 hectare site with geo-referenced corn yield data collected from 2006-2013 was identified. Cluster analysis was performed to identify the following three yield cluster types: high, low, and average yielding. Results showed that 2.3% of the site had consistently high and low yielding clusters. To validate the efficiency of the "Anselin Local Moran's I cluster tool" in identifying high and low yielding clusters, a residual method was used on the same dataset. This method identified areas of persistent yield variability previously identified by the cluster tool. Identifying these consistent clusters or areas of persistent yield variability may provide a tool to help create zones in a field for variable rate management.

The second part of this study sought to determine any relationships between soil chemical and/ or physical characteristics associated with persistent long-term high and low yielding clusters previously identified using cluster analysis. It was observed that high yielding clusters were deeper to a maximum depth of mollic colors and contained higher levels of soil test P and K to the depth of 0-25 cm when compared to the low yielding

clusters. TC, TN, pH, and particle size distribution were not significantly different across the study site irrespective of cluster type.

These results suggest these fields show little consistent yield variability in the long term. This may be due to the type of parent material as well as consistent management by the farm operator. Based on these findings variable rate management would not be economically justifiable in a loess parent material but results may change with different soil parent materials and management strategies.

CHAPTER 1. GENERAL INTRODUCTION

Introduction

Producing more with less has become a new paradigm in the agricultural community as precision agriculture is becoming increasingly embraced. The definition for precision agriculture continues to evolve with technology but Robert et al. (1995), Pierce and Nowak (1999), and Miao et al. (2006) define precision agriculture as an integrated information and technology-based management system, designed to manage spatial and temporal variability associated with all dimensions of agricultural production for optimum profitability, sustainability, and protection of the environment. The rationale behind precision agriculture, as explained by Blackmore and Griepentrog (2002), is to identify and manage crop yield variability and the drivers behind it in order to improve existing systems, enhance profitability and minimize any negative impact of agriculture on the environment.

Combine-mounted yield monitors have become one of the most widely used precision farming tools as discussed by Ping and Dobermann (2005). As grain flows through the combine, it is measured by a mass flow sensor. This measures the impact force of grain flowing through the clean grain elevator (Shearer et al., 1997). The information collected by these monitors are spatially dense geo-referenced yield points, which can be examined to identify the magnitude and location of crop yield variability. Before yield maps are created, however, the quality of the data can be greatly improved by analyzing and filtering instantaneous yield data to eliminate or reduce errors (Arslan and Colvin, 2002).

Specifically, fluctuations in mass flow rate measurements occur, which suggests that a single measurement (yield data point) does not accurately indicate grain flow (Arslan and Colvin, 2001). Therefore post-harvest remedial corrections such as data averaging can reduce flow rate error. This remedial correction is accomplished by creating boxes or cells based on combine speed and header width. Yield information collected within each cell are averaged to provide one yield value per cell. Cells based on a time duration of 4 to 6 seconds can reduce flow rate error to under 4% (Arslan and Colvin, 2002). Once yield corrections are accounted for, reconstructed data can be translated into visual maps, which help farmers make decisions for the following growing season. Further analysis of these maps could be exploited to understand the drivers behind yield variability.

Yield variability, as defined by Blackmore and Larscheid (1997), can be spatial or temporal variation. Spatial variation is easily seen in yield or soil maps across space or distance. In this case, yield increases or decreases across a field. Yield variability maps, such as those produced by yield monitors, can provide feedback for determining the combined effects of weather, soil properties, and management practices on crop yield (Streeter, 2013). Using yield maps to make management decisions continues to increase but there is a need for robust, more automatic data-screening algorithms (Ping and Dobermann, 2005). For example, effort should be made to fully utilize secondary screening processes because creating high quality yield maps often requires a great deal of knowledge of the data in addition to manual editing. The agriculture community could benefit from understanding the processes behind yield maps and use them to identify areas of consistent yield variability even using previously unprocessed yield data. In doing this, crop yield variability patterns become visible and associations between the variability and soil and other environmental characteristics can be determined (Blackmoore and Moore, 1999).

Yield variability identified from yield maps for individual years does not reveal underlying factors responsible for the yield variability but simply provides entry-level understanding. In addition, determining the location of crop yield variability based on individual year's data can be difficult since grain yields may vary both in space and in time (Eghball and Varvel, 1997; Jaynes et al., 2003). Also, relationships between yield and yield-influencing factors are not always the same among years (Halvorson and Doll, 1991; Jaynes et al., 1995; Jaynes et al., 2003). Due to all these contributing factors, including management-induced errors, it becomes necessary to analyze multiple years of geo-referenced yield data (Streeter, 2013).

Maps produced from yield monitor data show in-field variability but do not statistically assess the difference between high and low yielding areas. However, geographical information system (GIS) mapping and multivariate analyses can be used to identify spatial patterns (Zhang and Lin, 2006). For example Zhang and McGrath (2004) used Local Moran's I to look at spatial and temporal changes in soil organic carbon over a 30 year period and successfully identified spatial outliers. Goovaerts and Jacquez (2004) used Local Moran's I to identify hotspots or clusters of cases of West Nile Virus. Zhang et al. (2008) also successfully used Local Moran's I to locate hotspots of lead pollution in the urban soils of Galway, Ireland. When using Local Moran's I, an index examines individual locations, enabling hotspots to be identified based on a comparison with the neighboring samples (Zhang et al. 2008). A high positive local Moran's I value indicates that neighboring points have similar high or low values and as a result, a cluster may be identified.

The use of Local Moran's I has not been extensively explored to detect crop yield variability but Streeter (2013) used this tool to identify persistent areas of low and high yielding clusters as well as statistical outliers on the Des Moines lobe of Iowa. This study showed that spatially consistent clusters of corn yield variability can be successfully identified by the use of "Anselin Local Moran's I Cluster analysis tool" (ESRI, 2014).

The spatial variability in crop yields and quality is often related to the spatial variability in soil quality indicators as noted by Papiernik et al. (2005). Soil quality is highly influenced by climate, management, soil physical and chemical properties. Specifically, some of the properties influencing yield variability include available water, pH, organic carbon, nutrient availability, soil texture, and topography (Bruce et al., 1988; Kosmas et al., 2001; Sparovek and Schnug, 2001; Johnson et al., 2002; Cox et al., 2003; Kravchenko et al., 2003; and Papiernik et al., 2005). Kravchenko et al. (2003) found that topographical features in combination with selected soil physical properties such as texture, helped explain yield variability due to water redistribution. High Corn yields are associated with soils having higher amounts of organic matter and medium to fine textures. Lower yields are typically found on steep slope positions while higher yields are associated with lower slope positions (Kravchenko et al., 2003). Corn yields also tend to be lowest in eroded areas where calcareous subsoil is exposed and highest in concave positions which have relatively deep top soil, especially in dry years (Kravchenko and Bullock, 2000; Stewart et al., 2002; Cox et al., 2003). Papiernik et al. 2005 also found that low yielding areas often occurred on landscape positions impacted by high soil loss often related to tillage erosion on convex slope locations. Given the amount of variability in soil chemical and physical properties and their importance in determining crop yield, some property or combination of properties may serve as a basis for site specific soil management (Cox et al., 2003). The first part of this thesis reports on the use of "Anselin Local Moran's I Cluster tool" to quantify spatial corn yield variability in the Loess Hills of Northwest Iowa.

The second part of this study sought to determine any relationships between soil chemical and/ or physical characteristics associated with persistent long-term high and low yielding clusters identified using "Anselin Local Moran's I cluster analysis" tool (ESRI 2014) existed.

Explanation of Thesis Format

This thesis consists of two papers prepared in standard format for articles to be published in scientific journals. Each paper is preceded by a general introduction which describes the rationale for conducting this study and the specific research questions being addressed. Each of the two papers includes an abstract, introduction, materials and methods, results and discussion, conclusion, recommendations for further study and references.

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CHAPTER 2. ASSESSMENT OF SPATIALLY CONSISTENT VARIABILITY OF CORN YIELDS ON THE LOESS HILLS OF NORTHWEST IOWA

A paper to be submitted to *Precision Agriculture*

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Abstract

The adoption of precision agriculture for row crop production in Iowa has resulted in the generation of large volumes of data. Using Geographic Information Systems technology, these data are utilized to make crop yield variability maps, fertility maps and plant seeding maps. The objective of this study is to use "Anselin Local Moran's I Cluster tool" to quantify persistent spatial corn yield variability in the Loess Hills of Northwest Iowa. The Study site is located in Sioux County, Iowa and it consists of two fields totaling 32 hectares. The fields are made up of predominantly of Galva Silty Clay Loam and Judson Silty Clay Loam soil series. Eight years of geo-referenced corn (Zea mays) yield data were collected from 2006 – 2013 and the mean yield for the entire site was 11,180 kg $^{ha-1}$. Field 1 had a mean of 10,825 kg ha^{-1} which was significantly different (p-value <0.0001) from 11,593 kg ha^{-1} for field two. "Anselin Local Moran's I Cluster Analysis Tool" in combination with the "Intersecting layers masks (cartography)" tool were used to identify persistently high and low corn yielding clusters. Results were verified using a residual method. These two methods showed that 2.3% of the entire

study site had persistent yield variability (high or low yielding) over the study period. The magnitude of the yield variability identified may not justify the allocation of resources for variable rate management on these loess derived soils.

Introduction

In Iowa, precision agriculture technology continues to be embraced by the agricultural community and large volumes of data are continually being collected. One integral component to the collection of data has been combine-mounted yield monitors. As grain moves through the combine, the weight is measured by a mass flow sensor. This specifically measures the impact force of grain flowing through the clean grain elevator (Shearer et al., 1997). The impact force of the grain produces a voltage reading as grain hits a pressure plate (Risius, 2014). The reading is then converted into a usable value for the yield monitor by an electronic control unit. These values are recorded every 1 to 2 seconds as data points. The data obtained from yield monitors are therefore spatially dense geo-referenced yield points and they are collectively put together to create a yield map. Maps can be examined to identify the magnitude and location of crop yield variability (Ping and Dobermann, 2005).

As yield data is accumulated, there becomes an increased need for robust data processing and interpretation techniques (Ping and Dobermann, 2005) but before data can be used to make visual interpretation, remedial corrections and yield map reconstruction are necessary to eliminate any erroneous data and reduce grain flow measurement error. If erroneous data is not eliminated, resulting maps may be skewed and in turn, impair the operators management decisions for the following growing season.

Specifically, fluctuations in mass flow rate measurements occur, which suggests that a single measurement (individual yield data point) may not indicate grain flow accurately (Arslan and Colvin, 2001). To counter the effects of false individual data points, Arslan and Colvin (2002) found that smoothing and averaging yield points into cells reduced the total grain flow error to under 4 percent. In order to accomplish yield map reconstruction, advanced Geographical Information System (GIS) programs equipped with statistical analysis packages can be used. Through the use of GIS software, the magnitude and variability of crop yields can be observed visually. This also provides insight into the combined effects of weather, soil properties, and management practices on crop yields (Streeter, 2013).

The magnitude and variability of yield can be spatial and/or temporal as described by Blackmoore and Larsheid (1997). Spatial variability is defined as yield variation seen across space in the same time frame. This could be yield variability as seen on yield maps. Temporal variability is defined as variability across time. Identification of spatial yield variability can be accomplished through the use of local Moran's Index statistics (Getis and Ord, 1992; Anselin, 1995; Getis and Ord, 1996). Local Moran's Index evaluates individual locations or yield points, enabling hotspots (high yielding areas) and cold-spots (low yielding areas) to be identified based on a comparison with neighboring points (Zhang et al.,2008). For example, Zhang and McGrath (2004) used Local Moran's I to look at spatial and temporal variations in soil organic carbon over a 30 year period and successfully identified spatial outliers. Goovaerts and Jacquez (2004) used Local Moran's I to successfuly identify hotspots or clusters of cases of West Nile Virus. Zhang et al. (2008) also used Local Moran's I as the approach to locate hotspots of lead pollution in the urban soils of Galway, Ireland.

When applying Local Moran's I, it becomes essential to locate a suitable study site. If care is not taken in choosing such a site, yield variability misrepresentation may lead to the delineation of improper site-specific management zones. Because various properties such as topography, spatial variations in soil properties, climatic conditions, changes in short-term and long-term management, and accuracy of georeferenced yield data can all create inconsistent yield variability (Schepers et al. 2004). The use of Local Moran's I has not been extensively explored to detect crop yield variability but Streeter (2013) used this tool to identify low and high yielding clusters as well as statistical outliers on the Des Moines Lobe of Iowa.

The objectives of this study were to;

(i) determine if the "Cluster and Outlier Analysis" tool (ESRI, 2014), which uses Local Moran's Index statistics, could be used to identify areas of consistent spatial corn yield variability over multiple years on the Loess Hills of Western Iowa; and

(ii) to test the validity of local Moran's Index with an alternative method in identifying yield clusters.

Materials and Methods

Study site

The potential site consisting of 204 ha which are under the same long-term management, were located on the Northwest Iowa Loess soil parent material region in Sioux County, Iowa (Figure 1a and 1b). The geographic x and y coordinates (decimal degrees) encompassing this potential site are (-96.401469, -96.224092) and (42.997164, 43.069808), respectively. All soils in this area formed from Peoria loess and localized colluvium. According to Ruhe (1969), approximately 29,000 to 14,000 years ago, prevailing westerly winds picked up silts from channel bars and floodplains in the Missouri River Valley and deposited them in an easterly direction, with the thickest deposits accumulating near the source and thinning to the east. As a result, Peoria Loess covers the broad upland flats and ridges and extends down the side slopes (Oschwald et al., 1965). The predominant soil series in this soil parent material region include the Galva and Primghar series. The Galva series (Fine-silty, mixed, superactive, Typic Hapludoll) and Primghar series (Fine-silty, mixed, superactive, mesic Aquic Hapludolls) (Soil Survey Staff, 2015) account for 85.4% of the potential study site. Other soil series in the initial study site included Ely (Fine-silty, mixed, mesic, Cumulic Hapludolls), Ida (Fine-silty, mixed (calcareous), mesic, Typic Udorthents), Judson (Fine-silty, mixed, mesic, Cumulic Hapludolls), and Radford (Fine-silty, mixed, mesic Fluvaquentic Hapludolls). The slopes of these soil series ranged from 0 to 12% and the soils developed mostly under tall grass prairie.

Preliminary analysis of the initial 204 hectares showed that the fields in the selected area were overwhelming with regards to volume of data to be analyzed. Therefore a 32 ha area containing two fields was selected (figure 1c.) Fields 1 and 2 were selected based on yield data and available management records. Geographic x and y coordinates of the two fields were (-96.401469, -96.391647) and (43.015106, 43.018783) for fields 1 and 2, respectively. The two study fields contained 86.5% Galva series, 10.2% Judson series, 3% Ida series, and 0.3% Ely series as shown in Figure 1c.

For the study period of 2006-2013, mean annual air temperature was 8.3^{o} C and mean annual precipitation was 774 mm compared to a 64 year average of 682 mm (ISU, 2015). The mean annual number of growing degree days and rainfall distribution were less consistent (ISU, 2015). Figures 2a and 2b show the average rainfall distribution over the potential growing season (April through October). Figures 3a and 3b show the total growing degree units for fields 1 and 2 from 2006 to 2013. Our assumption was that understanding these climatic factors would aid in explaining the consistent yearly variations in corn yield as suggested by (Rose, 1936).

Site Management

The current operators have managed the final study site for the last 20 years. Discussions with them revealed that overall management practices such as field preparation, planting dates, and fertility management have been consistent over the last 20 years. Table 1 shows planting dates for each year of the study. The fields were in a corn soybean rotation. Field 1 was planted to corn in odd numbered years and field 2 was planted to corn in even numbered years except in 2012 where fields 1 and 2 were both planted to soybeans. No corn yield information was collected because of yield monitor issues in 2011 and crop rotation deviation in 2012. Land preparation for corn cultivation included inline ripping in the fall and a spring mulch finishing for final seed bed preparation. Planting was accomplished using a 12 m planter with 0.762 m spacing between rows. Fertility management included hog manure, when available, supplemented with urea for nitrogen with a goal of 495 units per hectare. Chicken litter was used to satisfy potassium and phosphorus removal rates, and sulfur was also applied as needed to meet removal rates. Weed control was performed as needed using both pre-emergence and post emergence herbicides. No weed control was done in season with cultivation.

Corn was harvested with a combine harvester equipped with a Case IH 372 (CNH Global, 2014) global positioning system (GPS) receiver. Wide Area Augmentation System (WAAS) correction service was used with this receiver. Data collected using this correction service has 15 to 20 centimeter horizontal accuracy from one pass to another and 90 centimeter accuracy from one year to the next. The harvester was also equipped with a Case IH Pro 600 yield monitor precalibrated to Case IH and Case IH Advanced Farming Systems (CNH Golobal, 2014) factory specifications. The combine was used with an 8 row (6.1 meter) corn head and the mass flow sensor measured yield every 1 second as represented by point data. Grain moisture was recorded by the yield monitor and all yield points were then calibrated to the dry grain storage moisture standard of 15%. Required calibrations were performed yearly and on per needed basis due to changing field conditions. Scale tickets from the cooperative were used for the required calibrations. Harvested corn was hauled to either on-farm storage or the local cooperative. Post-harvest calibrations were made if needed using Ag Leaders Spatial Management Software (Ag Leader, 2015). Data were then exported as .shp files and imported into ESRI ArcGIS 10.2.2 (ESRI, 2014) for data analysis. Due to the rotation, three years of corn yield information was obtained for each field for this study.

Derivation of data set

Yield data obtained with combine-mounted georeferenced yield monitors are affected by multiple systematic and random sources of measured yield variation (Stafford et al., 1996; Doerge, 1999; Arslan and Colvin, 2002; Simbahan et al., 2004). Blackmore and Moore (1999) also noted that all geo-referenced crop yield data contain exceptions and inclusions that deviate from the true mean yield. Causes of these deviations could arise from management or measurement error. For example, turning the combine around at the end of a pass, sudden stops in the middle of the pass, or changes in combine harvester ground speed, could create extreme yield values falsifying the data. But according to Simbahan et al. (2004) cleaned and accurate yield maps are needed to make better future agronomic decisions. Therefore, it was first necessary to trim and remediate the data in order to eliminate any untrue yield points. Specifically, fluctuations in mass flow rate measurements occur which suggests that a single measurement (a single yield data point) does not always accurately indicate mass grain flow (Arslan and Colvin, 2001). Data averaging or smoothing used as remedial correction can reduce this measurement error. It is accomplished by creating a grid of boxes or cells based on combine speed and header width. Yield information collected within each cell inside the grid are averaged to provide 1 yield value per cell. Cells based on combine speed over a duration of 4 to 6 seconds can reduce flow rate error to under 4% (Arslan and Colvin, 2002).

For this study the average operating speed for the combine was 2.055 m s^{-1} and the harvesting head was 6.1 m wide. Using the "Create Fishnet (data management)" tool (ESRI, 2014), a grid with cell sizes 6.1 by 8.2 m was overlaid across both fields. The point data contained in each cell were averaged to obtain one yield value per cell by adjusting the parameters in the tool. This tool would be ideal if cells would follow the path of the harvester along the contour but limitations in programming available toolsets in ArcGIS did not allow this. Instead the cells in the grid were aligned north to south and east to west.

Although mass flow errors were eliminated using the data averaging step, management error still existed. For example, when an operator stops in the middle of a pass or turns the combine around at the end of a pass, the combine continues to thresh unless it is shut off. This continued threshing results in recorded extreme or false data (Blackmore and Marshall, 1996; Arslan and Colvin, 2002). These false yield values typically occur in the headlands/ turn rows, point rows, and field entrances and a lag time occurs from new grain entering the harvester until it reaches the mass flow sensor which creates erroneous values. However, these values can most often be easily removed without largely influencing the overall dataset. Simbahan et al. (2004) recommended eliminating yield values greater than 3 standard deviations from the mean in irrigated fields. However, yield maps from dryland farming with wide ranges of true yield variation should consider eliminating data outliers wider than 3 standard deviations. Therefore, using an original python script (Figure 4), extreme low and high yields, which are zero yields and those with a value greater than 5 standard deviations from the original mean yield (24,489 kg ha^{-1}) were eliminated from the original data set. Summary statistics of corrected data are presented in Table 2.

Derivation of yield variability clusters

Maps of mean corn yields from adjusted data for the years of the study are presented in Figure 5. It is observed that interpretation was nearly impossible to identify areas of consistent yield patterns from this data. However, it is possible to use GIS and multivariate analyses to identify spatial patterns (Zhang and Lin, 2006). In this analysis, it was decided to use the “Cluster and Outlier Analysis (Anselin Local Moran’s I)” tool (ESRI, 2014). Cluster analysis, as defined by Ortega and Santibanez (2007), is the search for similar groups in a data set, in such a way that objects grouped in the same cluster resemble each other. Clusters can be generated based on a yearly data to show spatial variability within a field or on a multi-year basis to represent spatially consistent variability.

Using the “Cluster and Outlier Analysis (Anselin Local Moran’s I)” tool (ESRI, 2014), clusters were generated on an independent yearly basis. The clusters created have the following attributes which characterize the yield variability: I index, z-score, p-value, and cluster/ outlier (CO) type. A sample output from the cluster analysis tool is shown in Table 3. The I-index value can be either positive or negative. A positive I-index value indicates that a point has neighboring points with similar high or low values, where as a negative I-index value suggests that neighboring points were dissimilar and therefore classified as outliers. The z-score is a measure of statistical significance and functions similarly to the I-index. A high positive z-score value indicates that the surrounding areas have similar values, that are high (high yielding) or low (low yielding), and a low negative z-score represents a significant spatial outlier. The p-value, similar to the z-score, is also a measure of statistical significance and shows when to reject the null hypothesis ($p < 0.05$). The null hypothesis says that all yield values are not significantly different from the field mean. Finally, the cluster/ outlier (CO) type expresses only statistically significant values. In terms of symbology, high cluster (HH) yields are significantly higher than the mean yields of the field where low clusters (LL) have significantly lower yields than the field mean yield. Spatial outliers are low-high (LH) areas with a single low yield value surrounded by multiple high yield values or high-low (HL) where a single high yield value is surrounded by multiple low yield values. The tool then conceptualizes the spatial relationships between neighboring features by inverse distance weighting (IDW). IDW allows the nearby neighbors of the target feature or value to have a larger influence on the computation of the target feature versus features that are further away. This guarantees that each cell has at least one neighbor. The distance from one feature to the next is measured by Euclidean Distance which is defined by ESRI (2014) as the straight-line distance between two points. Within the "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014), different distant bands or thresholds may be specified manually in order to adjust the effect neighbors at greater distances have on identifying clusters of yield variability. However, not specifying a specific threshold distance causes the tool to calculate a default distance which ensures every feature has at least one neighbor. For this project, we did not specify a threshold distance and the default setting was utilized.

The "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI. 2014) was used on data for each independent year in the two fields and the analyses are shown in Figure 6. These clusters represent isolated yield variability for specific years over the entire study period. In order to locate spatially consistent yield variability during the study period, "intersecting layers masks (cartography)" tool was utilized. This identifies spatially consistent yield variability and it represents intersection of consistent spatial clusters over time (Figure 7). The clusters identified are high yielding, low yielding, and areas that were not significantly different from the field mean.

Testing the validity of cluster analysis

In order to test the validity of "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014) the output was tested against another method used to identify corn yield variability. In the data averaging step, we created grids across both fields based on the combine harvester header width of 6.1 m and distance traveled over a duration of 4 seconds for a length of 8.2 m. Each cell in the grid was then assigned a specific identification number along with the respective yield value. The identification number was the same for each cell for all years of the study. The next step was to determine whether a cell was considered high, low or average yielding by calculating the residuals. A statistical residual, as defined by Ramsey and Schafer (2002), is an observation value minus the estimated population mean. In Excel (Microsoft Corporation, 2015) the residuals for each cell in the grid were determined by subtracting the field mean from the yield value for each cell respectively (Table 2). A cell was considered high yielding if the residual was greater than 1 standard deviation of the field mean yield for the respective year, low yielding if the residual was smaller than one negative standard deviation of the field mean yield, and average yielding if the residual was within ± one standard deviation from the field mean yield. For example, the mean yield for field 2 in 2010 was 12,724 kg ha^{-1} and the standard deviation was 2,676 kg ha^{-1}. Cell 2 had a yield of 15,371 kg ha^{-1} and the residual would be 2,647 kg, which is smaller than the standard deviation of 2,676 kg and would then be considered as an average yielding cell. Table 4 shows the equations and sample output for residual and yield identification from the validation method in 2010. Figure 8a shows the spatially consistent yield variability in the study site obtained using the residual method compared to Figure 8b which shows clusters identified using "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI 2014).

Results

Spatial variability and spatially consistent clusters

The "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool successfully located spatial variability for each independent year. Results from this independent analysis (Table 5), show that on average, 13.2% of field 1 was identified as clusters of variability and 0.6% could be defined as outliers. On average, 11.6% of field 2 was also identified as clusters of variability and 0.7% of the field was classified as outliers.

The "Intersecting Layers Masks (cartography)" tool (ESRI, 2014) was used to identify spatially consistent areas of corn yield. This tool was used to find the intersection of persistent yield clusters. This analysis showed that combining fields 1 and 2, a total of 2.3% (0.72 hectares) of the study area were spatially consistent areas of corn yield, which was composed of both high and low yielding clusters. The high clusters in particular were most often found in either intermittent drainageways or other areas of accumulation on the landscape (Figure 9).

Comparison of cluster analysis versus residual method

The intersection of consistently high and low yielding residuals over the spatially consistent clusters found by "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014) can be seen on Figure 10. After overlaying areas of consistent variability identified using the residual method over those obtained from the "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014), it was observed that 28% of the high yielding and 32% of the low yielding cells in field 1 occurred as inclusions in the clusters previously identified. In field 2, 38% of the high yielding and 35% of the consistent low yielding cells were located within formerly established clusters.

Discussion

Total corn yield trends in the fields

The study site contained two fields but they were not combined for joint analysis. Corn yield data from 2011 were discarded due to improper data collection and in 2012, the entire site was planted to soybean.

As shown in figure 5 there were differences in corn yields for the different years within specific fields. It was therefore necessary to analyze multiple years of data in order to identify areas of consistent variability. We believe the variability in corn yields within fields could be a response to differences in rainfall, both in total amounts during the growing season and distribution, fluctuations in climatic conditions, and a response to other edaphic features. It has been observed that increased corn yields in the U.S. Corn Belt are obtained in years in which rainfall is higher than the long term average for the month of July and average precipitation for the remainder of the year (Thompson, 1969). According to Somerhalder (1962) and Sionit and Kramer (1977), the effect of moisture stress on total grain yields in corn (Zea mays) depends on the degree of the stress and on the growth stage at which the stress occurs. With regards to our study area, the lowest corn yield of 9,409 kg ha^{-1} in field 1, was obtained in 2007. We speculate that this low yield was influenced more by the distribution rather than total amount of rainfall. The total rainfall of 714 mm was 147 mm above the 64 year average. However, this field did not receive any measurable rainfall in the month of July (Figure 3a). In field 2, the lowest corn yield was obtained in 2006 when the July rainfall was 14 mm compared to the 64-year average of 87 mm (Figure 3b). This agrees with the assertion of Denmead and Shaw (1960) that moisture stress during the silking stage of corn more significantly impacts grain yields compared to at any other growth stage.

Besides total amounts and distribution of rainfall, another factor that could have influenced corn yield is Growing Degree Days. In crop phenology and development, the concept of heat units measured in growing degree days has vastly improved the description and prediction of phenological events (Gilmore and Rogers, 1958; Cross and Zuber, 1972; Klepper et al., 1984; Russelle et al., 1984; McMaster and Smika, 1988; McMaster, 1993; McMaster and Wilhelm, 1997). Growing degree days are a measure of heat units recorded daily and cumulated over the growing season. Growing degree days are calculated by the following equation:

Growing degree days = $\left[\frac{(Temperature_{Max} + Temperature_{Min})}{2}\right] - Temperature_{Base}$

The ***Temperature***$_{Max}$ is a measurement of the daily maximum temperature and does not exceed 86 degrees Fahrenheit. For example, if the high temperature for one random day during the growing season is 96 degrees Fahrenheit then the recorded ***Temperature***$_{Max}$ for that day will be 86 degrees but if the ***Temperature***$_{Max}$ is 81 degrees then 81 will be recorded. ***Temperature***$_{Min}$ is a measurement of the daily minimum temperature and it cannot go below 50 degrees Fahrenheit. ***Temperature***$_{Base}$ is dependent on crop and is most often specified at 50 degrees Fahrenheit for corn. Russelle et al. (1984) stated that temperature indices alone, such as growing degree days, can often explain over 95% of the variability for phenological development in corn. Figure 4a shows that cumulative growing degree days in 2009 were 2,563 which is 632 units lower than the 64 year average (ISU, 2015). This would be the same as completely eliminating the month of August for plant growth in an average year. This could have resulted in the low yield for field 1 in 2009.

We speculate that having more years of usable yield information would have affected our results in one of two ways. First, processing additional years of yield information may have potentially decreased the size of our consistent high and low yielding clusters. We believe this would be a result of increased climatic variability with more years of yield information. Second, having more years of yield information would have allowed us to analyze only years with similar climatic conditions. In turn, we hypothesize that our clusters of consistent yield variability would have increased.

Spatially consistent yield variability patterns

It was observed that corn yields on 2.3% of the two fields were consistently high or low yielding during the study period. It was also observed that localized high yielding clusters in particular, were consistently found in areas of deposition or intermittent drainageway positions. Soil properties associated with specific landscape positions affect patterns in plant available water-holding capacities or soil drainage and aeration (Jaynes and Colvin, 1997; Mulla and Schepers, 1997). Grain yields tend to be greater at the lower positions on the landscape which receive both surface and subsurface water from adjacent higher elevations (Daniels, et al., 1985; Stone et al., 1985). Increased plant available water in the lower landscapes, especially helps in droughty years, could be reason for the high occurrence of high yielding clusters on these positions (Figure 9).

Verification of spatial variability with residual method

The "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014) successfully identified areas of statistically significant high yielding clusters, low yielding clusters, and spatial outliers at our study site during the study period. These clusters are statistically different from the field mean for the yearly data sets as determined by the I-index, z-score, and p-values. In comparison, the residual method also identified cells of high, low, and average corn yields (Figure 8a). This method uses specified cutoff values based on the standard deviation associated with the field yield means to identify these zones for each year of the study. The cells or spots in the field where the residuals were greater than one positive standard deviation from the field mean yield were considered as high yielding. On the other hand, cells with residuals which were lower than one negative standard deviation from the field mean yield were considered as low yielding. Unlike the cluster analysis tool, this method has no means of spatial aggregation but rather examines individual cells. However, similar contiguous cells will often align creating groups of residuals comparable to clusters. We observed that 28% high yielding and 32% of the low yielding cells identified by the residual method intersected previously identified Local Moran's I spatially consistent clusters in field 1. In field 2, 38% of the high yielding and 35% of the low yielding cells from the residual method intersected Local Moran's I clusters. However, complete correspondence of spatially consistent yield values found with the residual method over clusters found with Local Moran's I was not obtained. We speculate that the difference in statistical methods is the reason for not obtaining complete correspondence.

Conclusion

Through the use of the "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014), high and low yielding clusters as well as outliers were successfully located and validated by the residual method. These clusters are areas whose mean yields are significantly different than the field average. Spatially consistent high and low yielding clusters accounted for 2.3% of the entire study from 2006-2013.

These results suggest that the fields do not show much of any consistent yield variability in the long term. This may be due to the type of parent material as well as consistent management by the farm operator. Based on these findings, it could be suggested that variable rate management would not be economically justifiable on this loess derived landscape. However, exploring this methodology in a region of variable and mixed parent materials may produce different results.

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Table 1. Yearly planting dates and planting density (1000's) for fields 1 and 2.

Year	Planting Date	Planting density (1000) ha^{-1}
	Field 1	
2007	1-May	79.1
2009	24-Apr	79.1
2013	5-May	84
	Field 2	
2006	29-Apr	79.1
2008	1-May	80.3
2010	1-May	82.8

Table 2. Summary statistics of adjusted corn yields (kg ha^{-1}) for fields 1 and 2.

Year	Minimum (kg ha^{-1})	Maximum (kg ha^{-1})	Mean (kg ha^{-1})	Std. (kg ha^{-1})
		Field 1		
2007	919	19398	9409	1261
2009	2071	16285	10286	2109
2013	2330	24122	12767	2203
Combined Average	919	24122	10825	2379
		Field 2		
2006	777	18232	9539	1939
2008	1049	24154	12555	1884
2010	2042	21176	12724	2676
Combined Average	777	24154	11593	2643
Study Site	777	24154	11180	2533

Table 3. Sample output from cluster analysis tool.

ID	Yield (kg/ha)	I index	z score	p-value	COType	Year	Field
128	13797	0.7577	2.6274	0.0086	HH	2009	1
129	13765	0.6947	2.4090	0.0160	HH	2009	1
549	12795	0.5953	2.0644	0.0390	HH	2009	1
1133	14056	0.9474	3.2849	0.0010	HH	2009	1
1134	13205	0.6289	2.1809	0.0292	HH	2009	1
1191	13739	0.5890	2.0425	0.0411	HH	2009	1
1192	13390	0.6696	2.3220	0.0202	HH	2009	1
1379	13297	0.5677	1.9686	0.0490	HH	2009	1
1788	13790	0.7503	2.6017	0.0093	HH	2009	1
1837	12954	0.7950	2.7565	0.0058	HH	2009	1
1838	14061	1.2841	4.4521	<0.0001	HH	2009	1
1839	14291	1.2275	4.2561	<0.0001	HH	2009	1
1879	12714	0.7332	2.5422	0.0110	HH	2009	1
1880	13388	1.1767	4.0798	0.0000	HH	2009	1
1881	13931	0.7500	2.6007	0.0093	HH	2009	1
1961	13713	0.8035	2.7861	0.0053	HH	2009	1
2002	12158	0.6688	2.3193	0.0204	HH	2009	1
2003	13756	0.7176	2.4884	0.0128	HH	2009	1
2041	12682	0.6480	2.2469	0.0246	HH	2009	1
2042	12754	0.6891	2.3896	0.0169	HH	2009	1
2082	13130	0.7236	2.5090	0.0121	HH	2009	1
2083	12934	0.7502	2.6012	0.0093	HH	2009	1
2084	12702	0.6288	2.1805	0.0292	HH	2009	1
2119	12542	0.6439	2.1247	0.0336	HH	2009	1
2123	12239	0.6648	2.3054	0.0211	HH	2009	1
2125	12562	0.6325	2.1933	0.0283	HH	2009	1
2126	13179	0.8041	2.7883	0.0053	HH	2009	1
2160	13331	0.6684	2.1879	0.0287	HH	2009	1
2164	15113	1.0463	3.6279	0.0003	HH	2009	1
2165	13079	0.9872	3.4230	0.0006	HH	2009	1

Table 4. Sample calculation of residual identification using yield data from 2010.

Cell ID #	Cell Yield	Field Mean Yield	St. Dev	Residual*	Cell** type
0	12987	12724	2676	263	A
1	13096	12724	2676	372	A
2	15371	12724	2676	2647	A
3	17332	12724	2676	4608	H
4	18057	12724	2676	5333	H
5	15360	12724	2676	2636	A
6	13589	12724	2676	865	A
7	15391	12724	2676	2667	A
8	15025	12724	2676	2301	A
9	14422	12724	2676	1698	A
10	15371	12724	2676	2647	A
11	13869	12724	2676	1145	A
12	8374	12724	2676	-4350	L
13	15085	12724	2676	2361	A
14	17719	12724	2676	4995	H
15	15561	12724	2676	2837	H
16	12464	12724	2676	-260	A
17	10517	12724	2676	-2207	A
18	14742	12724	2676	2018	A
19	9793	12724	2676	-2931	L
20	7774	12724	2676	-4950	L
21	7596	12724	2676	-5128	L
22	12304	12724	2676	-420	A
23	12997	12724	2676	273	A

*Residual: Cell Yield – Field Mean = 263

**Cell type = Average because 263 < 2676 (example)

H= High yielding, residual > 1 positive st. dev.

A= Average yielding, reidual is > 1 negative st. dev and < 1 positive st. dev.

L= Low yielding, residual < 1 negative st. dev.

Table 5. Summary of estimated cluster type variability as a percent of total field area. (HH = high yield, HL = high outlier, LH = low outlier, LL= low yield)

Year	HH	HL	LH	LL	Total	Outlier
			Field 1			
2007	2.1	0.4	0.1	7.8	9.9	0.5
2009	8.9	0.3	0.1	9.7	18.6	0.4
2013	4.7	0.5	0.3	6.4	11.1	0.8
Average	5.2	0.4	0.2	8	13.2	0.6
			Field 2			
2006	4.1	0.7	0.5	7.9	12	1.2
2008	2.1	0.3	0.1	7.4	9.5	0.4
2010	3.6	0.5	0.2	9.6	13.2	0.7
Average	3.3	0.5	0.3	8.3	11.6	0.8

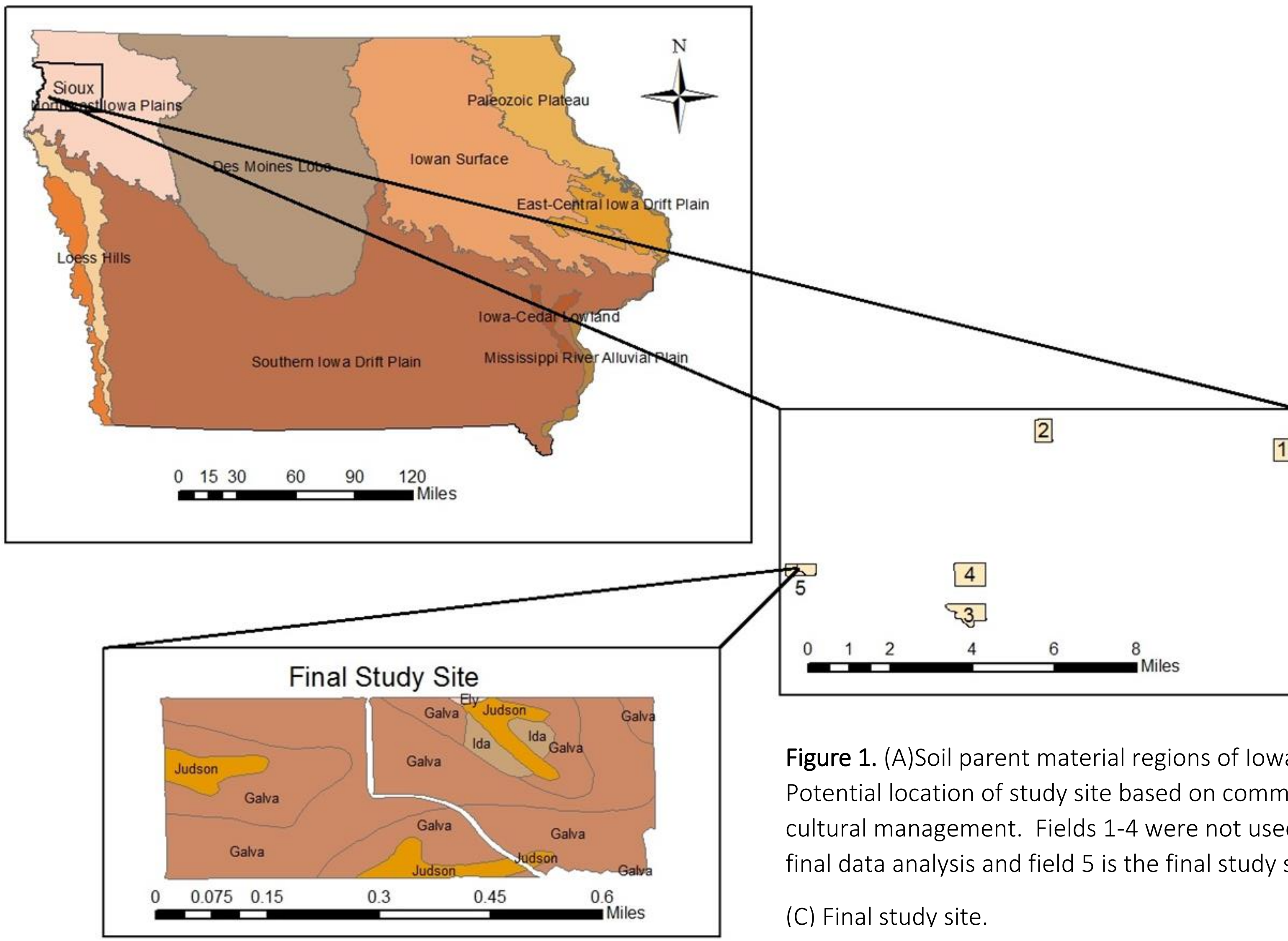
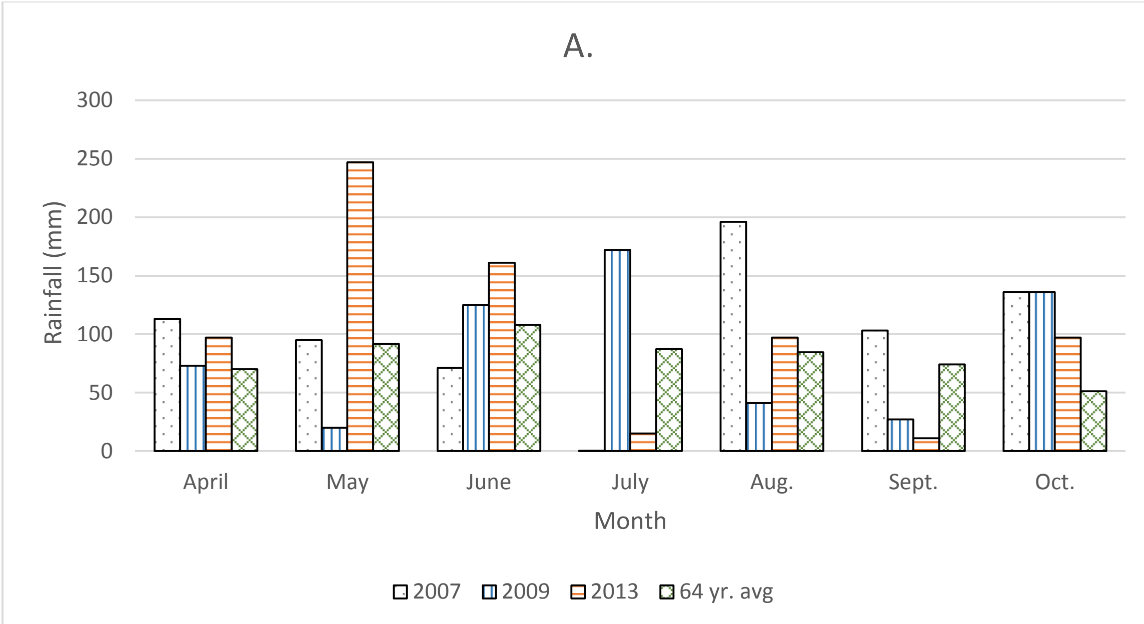


Figure 1. (A)Soil parent material regions of Iowa (B) Potential location of study site based on common cultural management. Fields 1-4 were not used for final data analysis and field 5 is the final study site.

(C) Final study site.



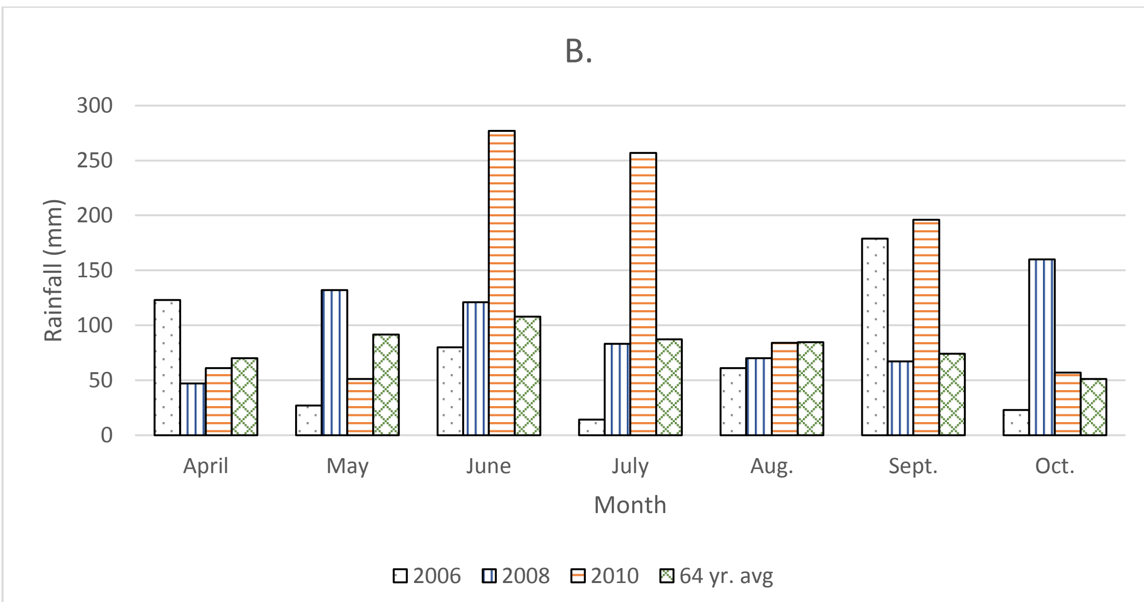


Figure 2. Rainfall distribution for the growing season (April-October) during study period for (a) Field 1 and (b) field 2.

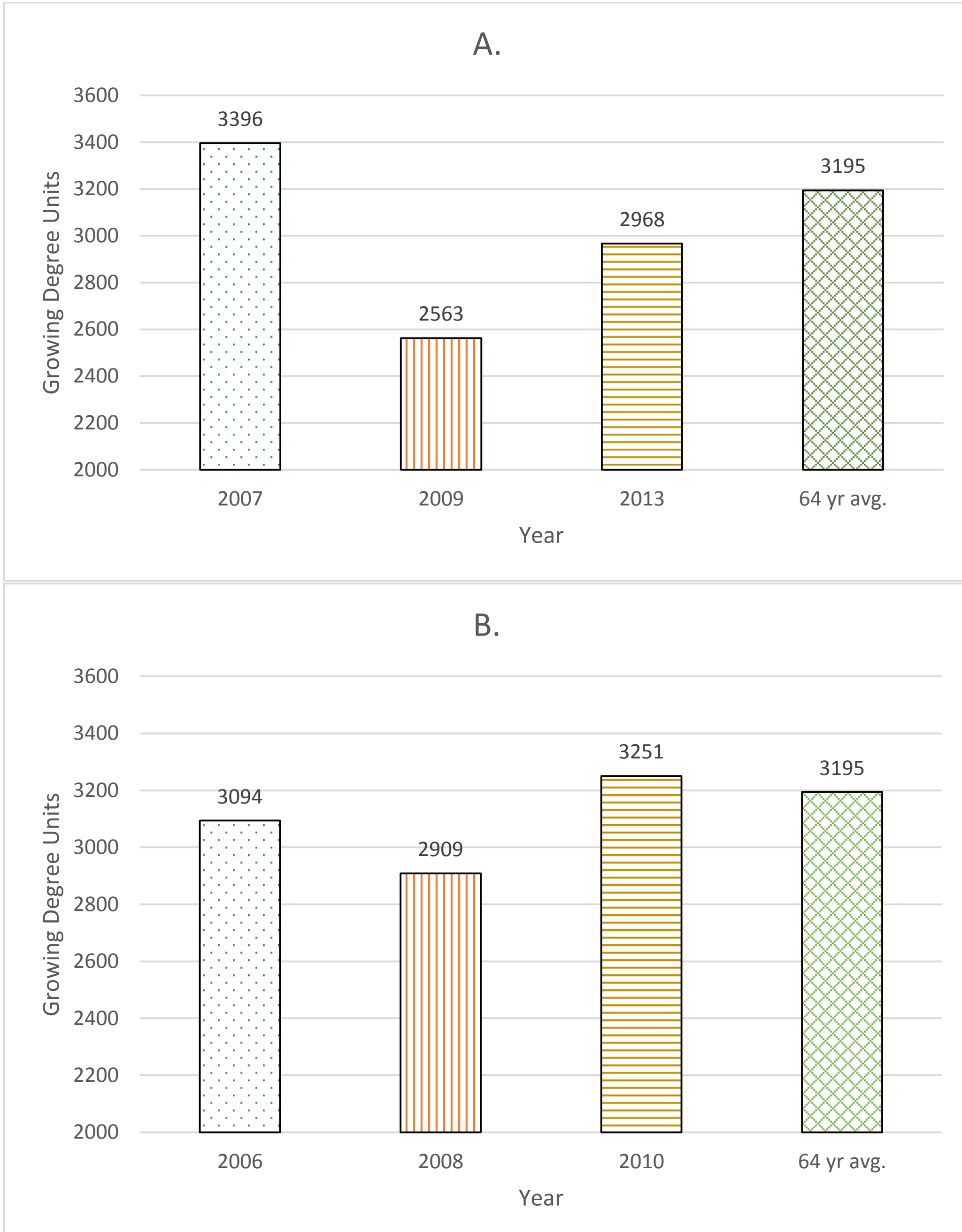


Figure 3. Growing degree units for (a) for field 1 and (b) field 2.

```
#--------------------------------------------------------------------------
# no extreme values script.py
#   (generated by ArcGIS/ModelBuilder)
# Usage: no extreme values script <Input_Folder><Max_Value><Output_Folder>
#Description:
# This tool will remove all features that are equal to 0 bushels or greater than the amount
entered into the Max Value.  A new shapfile will be created in the folder specified, Output
Folder.  This allows the original data to stay intact.
#--------------------------------------------------------------------------

# Import arcpy module
Import arcpy

# Load required toolboxes
Arcpy.ImportToolbox("Model Functions")

# Script arguments
Input_Folder = arcpy.GetParametersAsText(0)

Max_Value = arcpy.GetParametersAsText(1)

Output_Folder = arcpy.GetParametersAsText(2)

#Local variables:
Feature_Class = Input_Folder
v_Name_=Feature_Class
Name = Input_Folder

#Process: Iterate Feature Classes
Arcpy.IterateFeatureClasses_mb(Input_Folder, "", "", "NOT_RECURSIVE")

#Process: Select
Arcpy.Select_analysis(Feature_Class, v_Name_, "\Yield_Vol_Dr\" >=10 and
\"Yield_Vol_dr\" <%Max Value%)
```

Figure 4. Script for removing extreme yield values

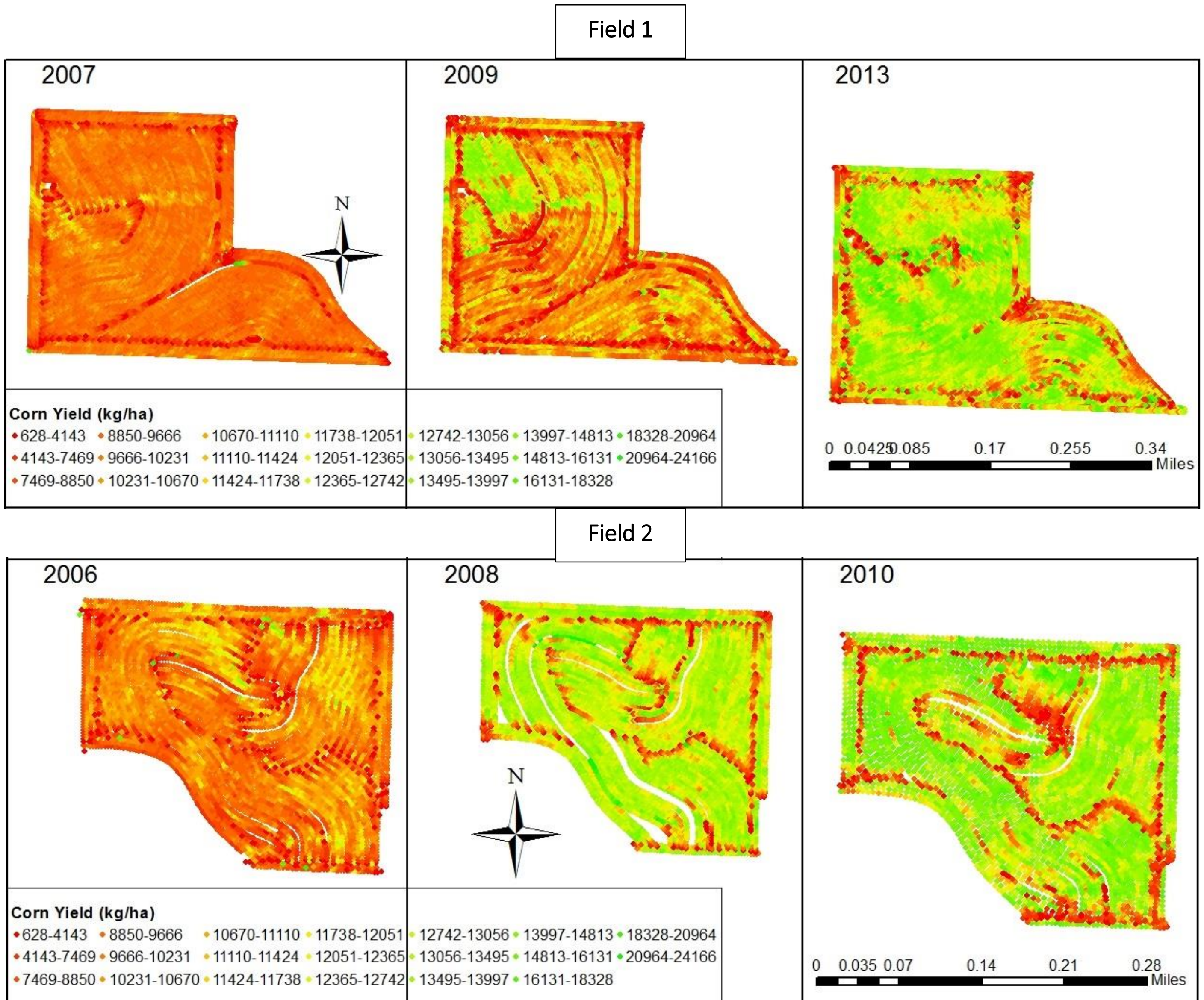


Figure 5. Yield maps of raw corn yield data for the study site.

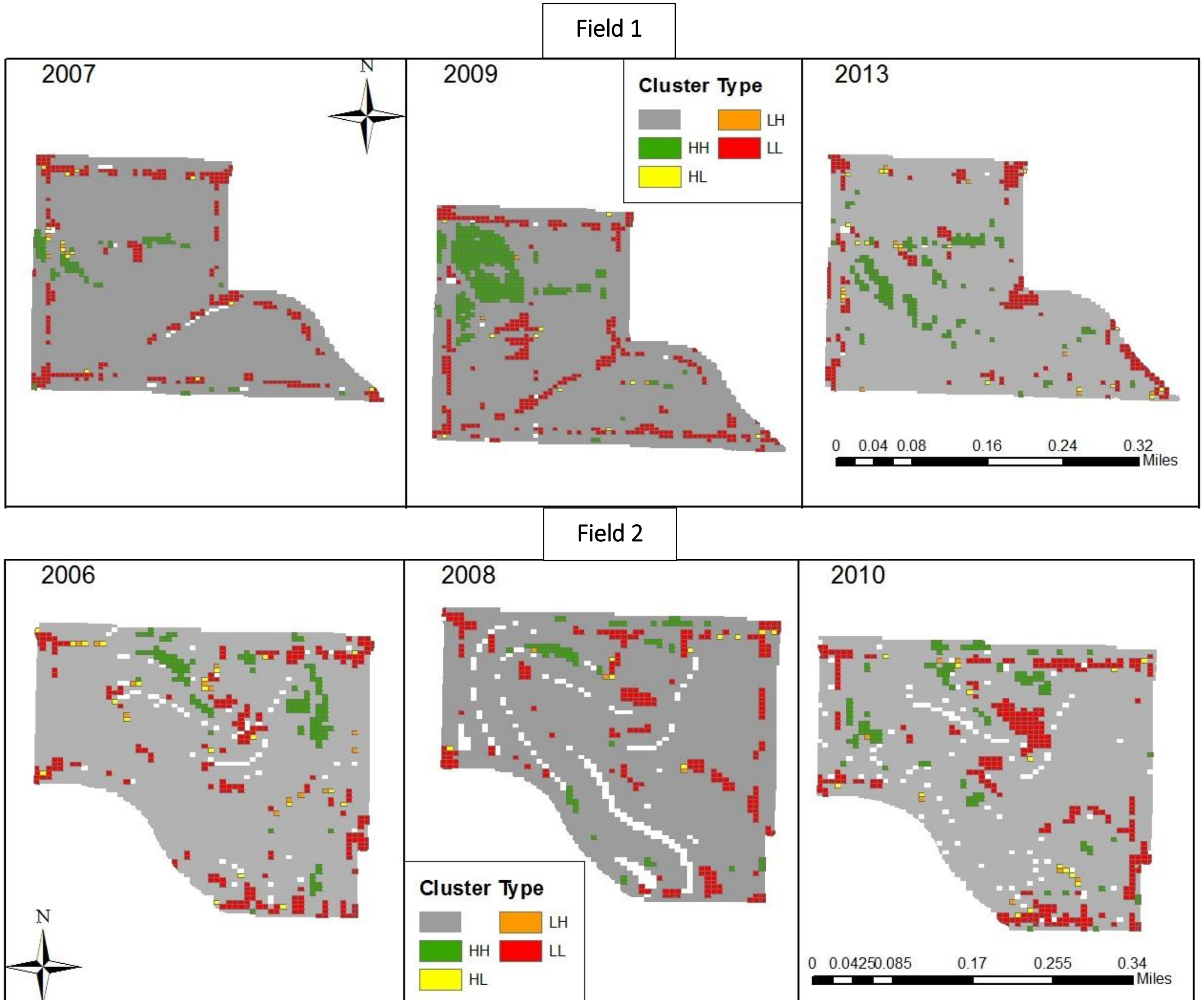


Figure 6. Corn yield variability clusters for the study site by year. (HH = high yield, HL = high outlier, LH = low outlier, LL = low yield)

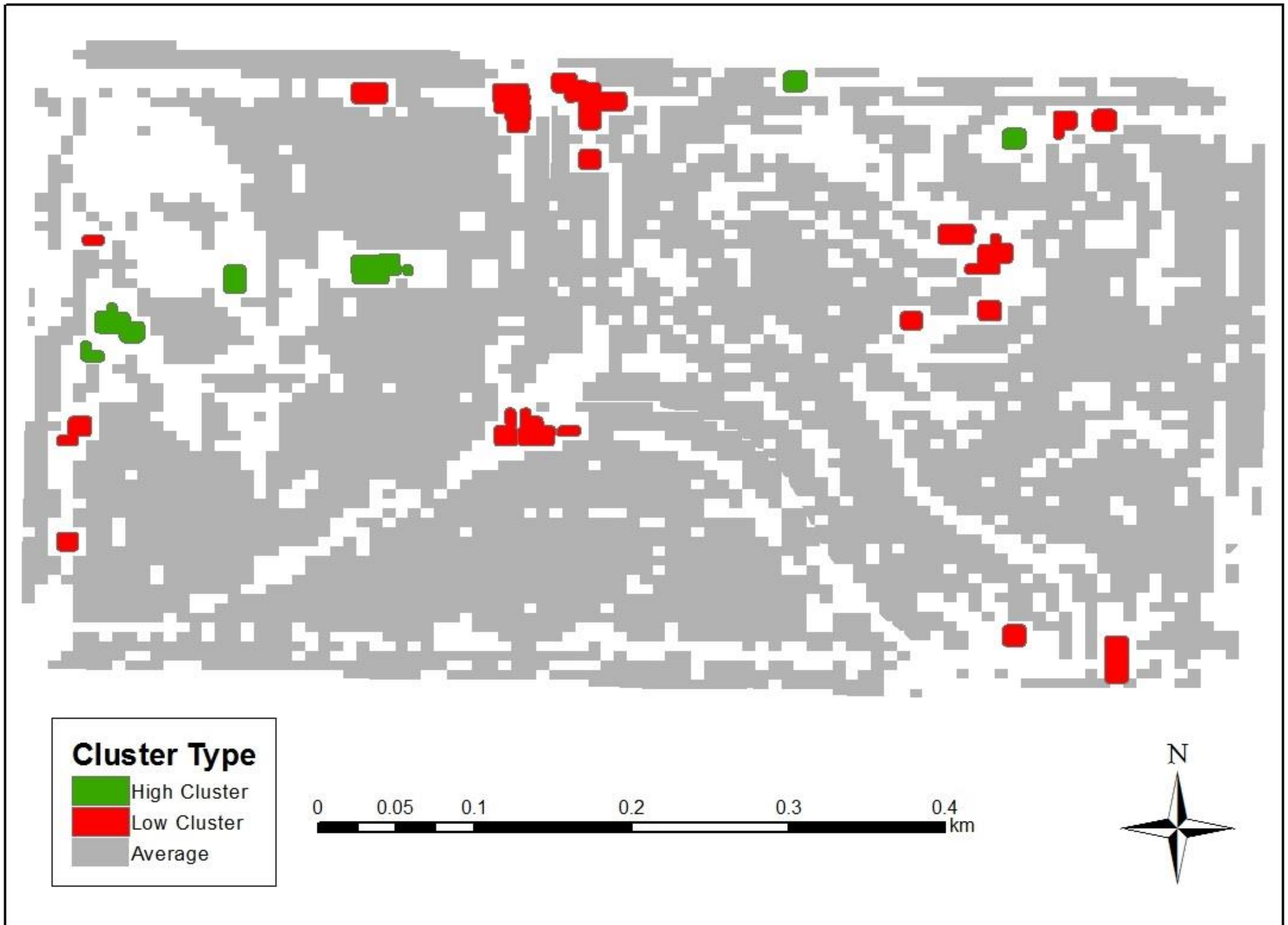


Figure 7. Spatially consistent clusters of corn yield variability for the entire study site.

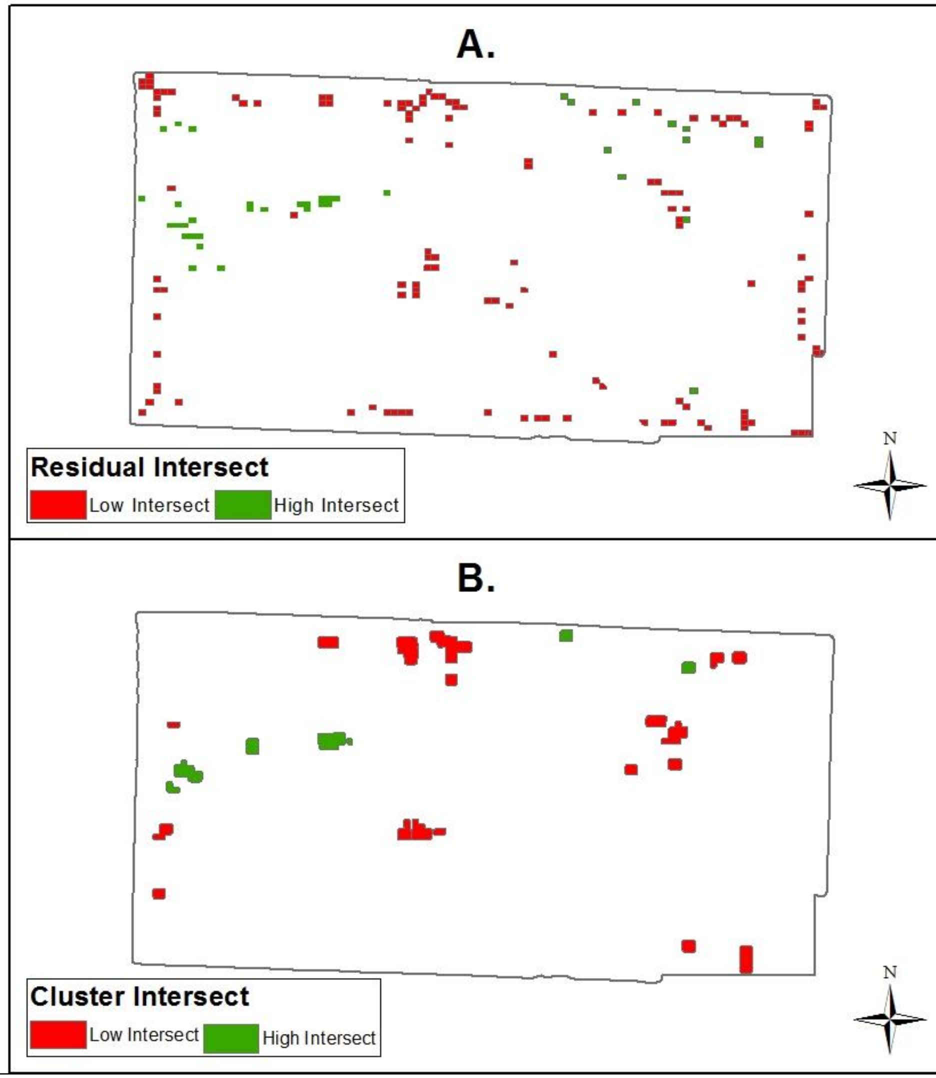


Figure 8. Identification of spatially consistent yield variability. A.) Spatially consistent cells found by the residual method B.) Spatially consistent clusters found by "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI 2014).

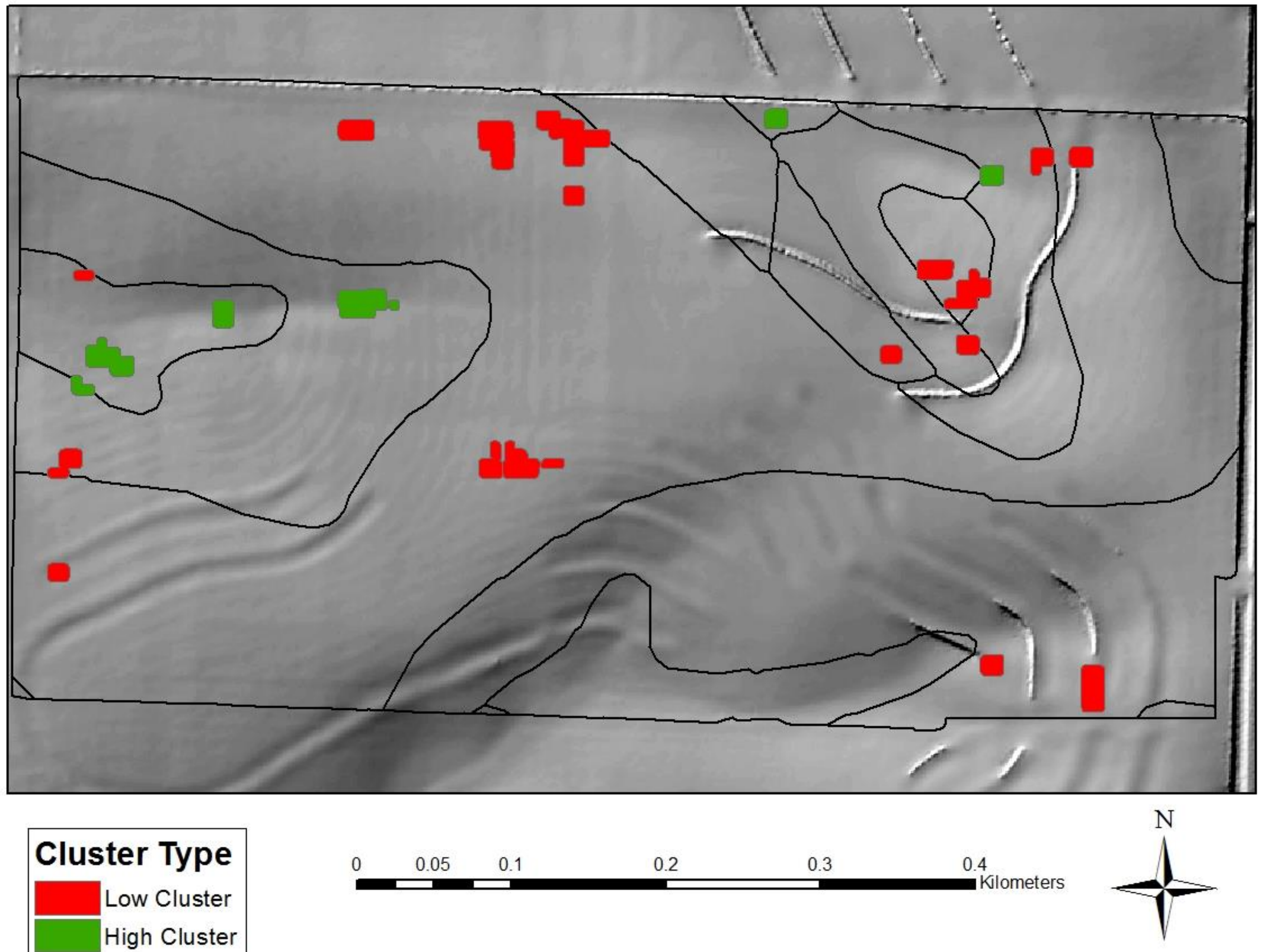


Figure 9. Spatially consistent high and low yielding clusters from 2006-2013 draped over 1 meter hill shade Digital Elevation Model (DEM) generated from LIDAR data.

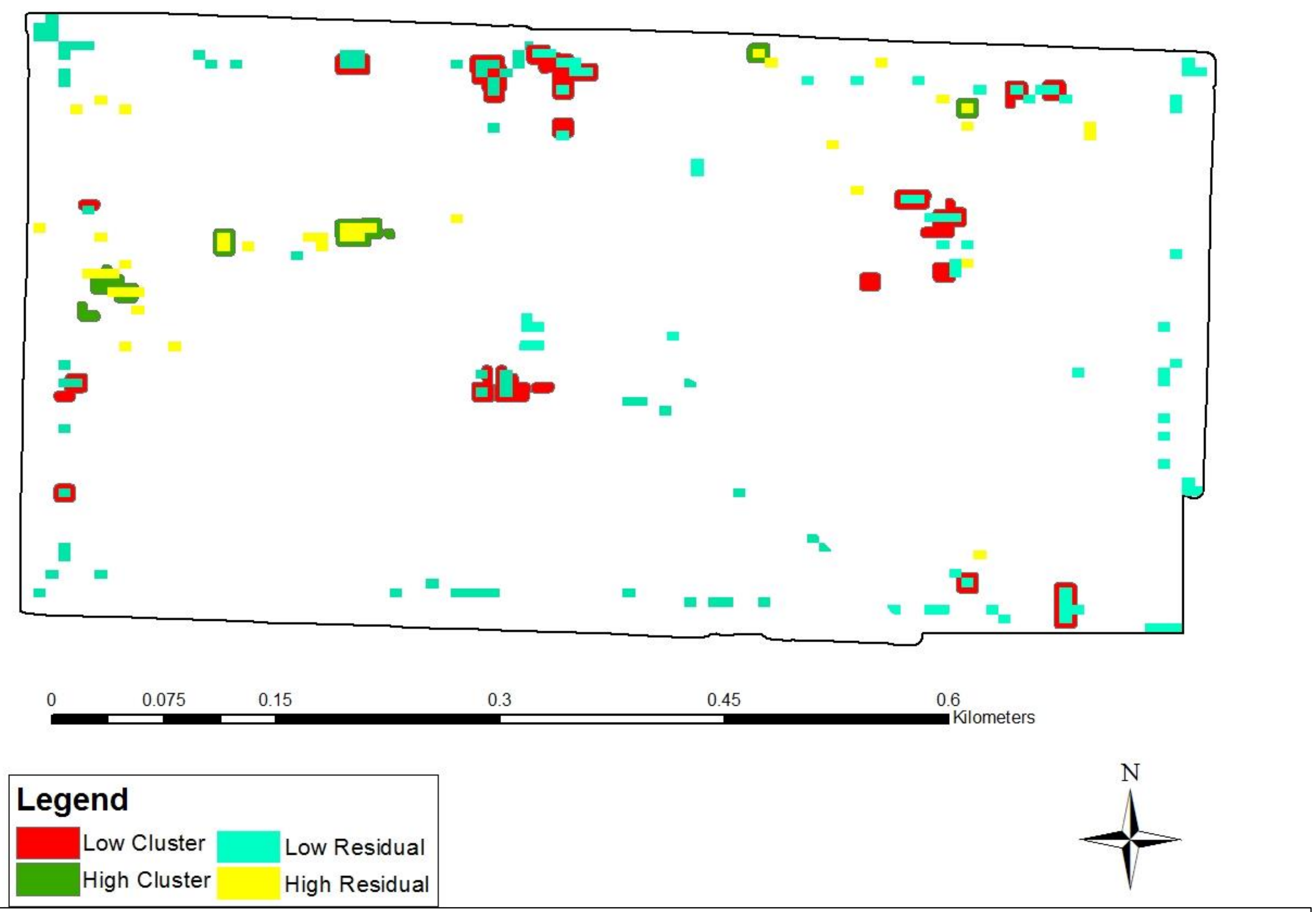


Figure 10. Consistent high and low cells identified by the residual method are intersected with high and low clusters found using "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI 2014).

CHAPTER 3. RELATIONSHIPS BETWEEN CORN YIELD VARIABILITY AND SELECTED SOIL CHARACTERISTICS ON THE LOESS HILLS OF NORTHWEST IOWA

A paper to be submitted to *Soil Science Society of America Journal*

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Abstract

Modern precision agriculture in Iowa provides the foundation for identifying relationships between soil characteristics and corn (Zea mays L.) yield variability. The purpose of this paper was to investigate the underlying soil factors responsible for yield variability in the soils of the loess hills of Northwest Iowa. Three corn yielding clusters (high, low, and average) were identified in a 32 ha field using "Anselin Local Moran's I Cluster tool." Soil cores were sampled from within the respective clusters and samples were analyzed for morphological, physical, and chemical characteristics including maximum depth to mollic colors, minimum depth to calcium carbonate, soil texture, total nitrogen (TN), total carbon (TC), Mehlich 3 phosphorus (M3P), Mehlich 3 potassium (M3K), and pH. The characteristics were compared at 0-25 cm, 25-100 cm, and >100 cm.

The high yielding clusters had deeper maximum depth to mollic colors and had significantly higher levels of M3P and M3K concentrations, especially in the 0-25 cm depth. However, no significant differences were obtained in these nutrients at the 25-100 cm depth and below. There were significant correlations between silt and M3K at all depths. It could be concluded that variability in corn growth on these loess-derived soils are not directly related to variation in soil properties given the uniform nature of the loess parent material.

Introduction

Mapping yield variability has become an integral component of modern precision agriculture. Yield maps provide a foundation for identifying the relationship between soil properties and corn (Zea mays L.) yield variability. Once the relationships are understood then a basis can be established for increasing gross productivity, economic returns, and sustainability.

In Iowa, corn production may be influenced by multiple factors including climate, crop physiology, topography, soil physical and chemical properties, and management. Increased corn yields in the U.S. Corn Belt are obtained in years in which rainfall is higher than the long term average for the month of July and average precipitation for the remainder of the year (Thompson, 1969). According to Somerhalder (1962) and Sionit and Kramer (1977), the effect of moisture stress on vegetative growth and grain yields in corn (Zea mays) depends on the degree of stress and the stage of growth of corn at which stress occurs. Stages at which crop stress is detrimental to productivity would be during silking and tasseling. Denmead and Shaw (1960) observed that stress in corn during silking was more harmful to grain yields than stress during any other growth stage. This stress may stem from lack of precipitation or by the combined influence of topography and soil physical and chemical characteristics.

The amount of plant-available water is important and water redistribution due to topography can also be of practical significance (Holt et al., 1964; Daniels et al., 1987; Wright et al., 1990; Afyuni et al., 1993 Fiez et al., 1994; Kravchenko and Bullock, 2000). Grain yields tend to be greater at lower positions on the landscape as lower landscape positions have been suggested to receive both surface and subsurface water from higher elevations (Daniels, et al., 1985; Stone et al., 1985). This may in turn, explain why yields tend to be low in eroded areas where calcareous subsoil is exposed and tend to be high in concave positions which have relatively deep topsoil (Kravchenko and Bullock, 2000; Stewart et al., 2002; Cox et al., 2003). In addition to this, Cox (2003) found that higher clay content was associated with higher yields which may also be the effect of increased soil moisture. Johnson (2002) observed that soil pH, phosphorus (P), and soil organic matter may all directly influence crop and fiber yields. The culmination of these factors may affect yield, both positively and negatively, therefore making interpretation of long-term consistent yield difficult.

Delineating management zones based on yield maps relies on direct observations (Jaynes et al., 2005) but according to Huggins and Alderfer (1995), Sadler et al. (1995), and Schepers et al. (2004), practical application of yield mapping to identify management zones has been plagued by spatial and temporal variation in measured yield. To add to this, factors effecting the delineation of soil and yield associations are climate, constraints of accurately georeferenced yield data, and inconsistent farm management (Schepers et al., 2004). Therefore careful selection of an appropriate study site is essential to accurately locate spatially consistent corn yield variability in order to draw associations between consistent yield and soil characteristics.

The null hypothesis for this study is that soil properties do not play a significant role in the variable yields of corn on a landscape. The objective is to study the influence of soil physical and chemical properties on consistent corn yield variability on a loess landscape identified using the ”Cluster and Outlier Analysis (Anselin Local Moran’s I)” tool (ESRI, 2014).

Materials and Methods

Study site

The potential site consisting of 204 ha which are under the same long-term management, were located on the Northwest Iowa Loess soil parent material region in Sioux County, Iowa (Figure 1a and 1b). The geographic x and y coordinates (decimal degrees) encompassing this potential site are (-96.401469, -96.224092) and (42.997164, 43.069808), respectively. All soils in this area formed from Peoria loess and localized colluvium. According to Ruhe (1969), approximately 29,000 to 14,000 years ago prevailing westerly winds picked up silts from channel bars and floodplains in the Missouri River Valley and deposited them in an easterly direction with the thickest deposits accumulating near the source and thinning to the east. As a result, Peoria Loess covers the broad upland flats and ridges and extends down the side slopes (Oschwald et al., 1965). The predominant soil series in this soil parent material region include the Galva and Primghar series. The Galva series (Fine-silty, mixed, superactive, Typic Hapludoll) and Primghar series (Fine-silty, mixed, superactive, mesic Aquic Hapludolls) (Soil Survey Staff, 2015) account for 85.4% of the potential study site. Other soil series in the initial study site include Ely (Fine-silty, mixed, mesic, Cumulic Hapludolls), Ida (Fine-silty, mixed (calcareous), mesic, Typic Udorthents), Judson (Fine-silty, mixed, mesic, Cumulic Hapludolls), and Radford (Fine-silty, mixed, mesic Fluvaquentic Hapludolls). The slopes of these soil series ranged from 0 to 12% and the soils developed mostly under tall grass prairie.

Preliminary analysis of the initial 204 hectares using all the cultivated fields in the selected area will be overwhelming with regards to total volume of data to be analyzed. Therefore a 32 ha area containing two fields was selected (Figure 1c.) Fields 1 and 2 were selected based on availability of yield data and management records. Geographic x and y coordinates of the two fields were (-96.401469, -96.391647) and (43.015106, 43.018783) for fields 1 and 2, respectively. The two fields contained 86.5% Galva series, 10.2% Judson series, 3% Ida series, and 0.3% Ely series as shown in Figure 1c.

For the study period 2006-2013, mean annual air temperature was 8.3^{o} C and mean annual precipitation was 774 mm compared to a 64 year average of 682 mm (ISU, 2015). The mean annual number of growing degree days and rainfall distribution were less consistent (ISU, 2015). Figures 2a and 2b show the average rainfall distribution over the potential growing season (April through October). Figures 3a and 3b show the total growing degree units for fields 1 and 2 from 2006 to 2013. Our assumption was that understanding these climatic factors would aid in explaining the consistent yearly variations in corn yield as suggested by (Rose, 1936).

Site management

The current farm managers have been working on the final study site for the last 20 years. Overall management practices such as field preparation, planting dates, and fertility management have been consistent. The study site is in corn-soybean (Glycine max) rotation. Field preparation for corn planting included inline ripping in the fall and a spring mulch finishing for final seed bed preparation. Planting was accomplished by using a 12m (16 row) planter. For fertility management, a flat rate goal of 494 units per hectare of nitrogen was used. Soybean nitrogen credit was taken into consideration in the rotation and the rest of the needed nitrogen was applied as urea or from hog manure when the later was available. Chicken litter was used to meet potassium and phosphorus removal rates as described in PM 1688 (Mallarino et al., 2013) and sulfur was also applied as needed. Weed control was performed as needed using both pre-emergence and post emergence herbicides. Weeds were not controlled by in-season cultivation. Table 2 shows planting dates for each year of the study. In 2012, the entire site was planted to soybean and no corn yield data was obtained. In 2011, yield monitor issues prevented data collection.

Soil sampling

Yield clustering includes characterizing the spatial and temporal nature of yield clusters (Jaynes et al., 2003). In order to identify and characterize yield clusters, preliminary analysis was carried out using the "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool in Arcmap (ESRI, 2014). This tool creates clusters of variability based on three components: I-index value, z-score, and p-value. The I-index value can be either positive or negative. A positive I-index value indicates that a point has neighboring points with similar high or low values, where a negative I-index value suggests that neighboring points were dissimilar and therefore classified as outliers. The z-score is a measure of statistical significance and functions similarly to the I-index. A high positive z-score indicates that surrounding areas have similar values, that are either high (high yielding) or low (low yielding), and a low negative z-score represents a significant spatial outlier. The p-value, similar to the z-score, is also a measure of statistical significance and tells when to reject the null hypothesis ($p < 0.05$). The null hypothesis says that all yield values are not significantly different from the field mean. This clustering exercise identified three distinct areas; (i) HH, areas where corn yield was significantly higher than the mean field yield, (ii) LL, areas where corn yield was significantly lower than the mean field yield (LL), and (iii) Average, areas where corn yields represented the mean yield for the field (Figure 4).

To ensure that samples were taken within the specific clusters and due to GPS accuracy of 1 m, a 2 m buffer was created around the perimeter of each distinct cluster. A randomized sampling pattern was generated for the clusters using the "Create Random

Points (Data Management)" tool within each of the three distinct cluster types: HH, LL, and Average. Initially 10 samples were taken from each of the three different cluster sites but after a final cluster analysis revision, 19 soil cores were able to be utilized: 10 samples from clusters representing mean field yield (Average), 5 samples from significantly low yielding clusters (LL), and 4 samples from significantly high yielding clusters (HH). Figure 5 shows the final sampling points.

The generated sampling points were georeferenced using a GPS unit with 100 cm accuracy. Soil sampling was accomplished with a truck-mounted hydraulic soil sampling and core machine (Gidding's Machine Company, 2015). Soil cores were 6 cm in diameter and taken to a maximum depth of 144 cm.

Soil characterization

Standard soil survey and characterization methods explained in the Field Book for Describing and Sampling Soils (Schoeneberger et al., 2012) were used to describe all soil cores. The following characteristics were recorded for all soil cores: horizon type and depth, distinction, depth of plow layer, structural grade and type, moist consistency, presence of redoximorphic features, presence of clay films. Soil color was determined for the moist soil hue, value, and chroma of each horizon using Munsell Soil Color Charts (Munsell, 2015). Presence of carbonates was determined using 0.1 molar hydrochloric acid, effervescence was recorded.

Soil texture was determined using the pipette method of the National Soil Survey Center (Soil Survey Staff, 1996). Soil pH (1:1) was measured in water with an Orion pH meter (Thermo Scientific, 2015). Total carbon (TC) and nitrogen (TN) were determined by a Leco Truspec elemental analyzer through dry combustion (Leco Corporation, 2015). Mehlich 3 extractable phosphorus (M3P) and potassium (M3K) levels were determined using the Mehlich 3 extraction method (Mehlich, 1984). These eight physical and chemical properties were chosen due to their overall influence on crop growth and development.

Statistical analysis

For each soil core, the continuous and numerical soil properties for each horizon were aggregated by depth from the soil surface. The characteristics include: sand, silt, clay, M3P, M3K, TC, TN, and pH. The mean values for all characteristics were grouped into the following three depth classes: 0-25 cm, representing a typical plow layer; 25-100 cm, the average rooting depth for corn, and > 100 cm depth as maximum sampling depth (Soil Survey Staff, 2015). The resulting data set included one value for each soil characteristic at each depth class for the respective soil core from the 19 sampling points.

For each soil characteristic, linear mixed effects models were run using PROC MIXED in SAS (SAS Institute Inc., 2015) in order to compare values for means of soil properties for high, low, and average yield cluster types for the respective depth classes. The linear mixed effects models contained yield cluster type, depth, and their interaction as fixed effects. We included a unique cluster id as a random effect to account for correlation between observations taken from the same core. A Least Squares Mean

Estimate (LSMESTIMATES) statement was also used within the PROC MIXED statement to test the significance (p-value < 0.05) of differences between means for each soil characteristic by the depth classes and cluster yield type. Finally, pairwise correlations were determined using Microsoft excel (Microsoft Corp., 2015)

Results and Discussion

Morphological features

When comparing the high, average, and low yielding cluster types, the mean depth to mollic colors were 81.5, 59.4, and 28.6 cm, respectively. Statistical analysis (least square means estimate) showed that the maximum depth of mollic colors of the high and low yielding clusters were significantly different (Figure 6). Mollic colors extended to deeper depths in the high yielding clusters than the average yielding versus the low yielding clusters. This could be related to the physiographic positions in which the different yield clusters occur on the landscape. The high yielding clusters primarily occur in areas of accumulation on the landscape. They are located predominantly in the upland drainageways, footslopes, and upland alluvial fans as shown in Figure 5. Soils in these landscape positions receive depositions of sediments, organic matter, and nutrients eroded from the upper part of the landscape (Spomer and Piest, 1982 and Brubaker et al., 1993). Low yielding clusters on the other hand, are associated with localized summits, shoulders and backslopes and often times were moderately to severely eroded.

Average minimum depths to calcium carbonate were observed at 122.8, 104.9, and 74.6 cm for the high, average and low yielding clusters, respectively, and they were not statistically different (Figure 7). However, in the low yielding clusters, carbonates were more often found closer to the surface. Calcium carbonate, when found in the rooting zone, interferes with crop nutrient uptake, specifically phosphorus. Phosphorus in the soil or phosphorus added as a fertilizer is rapidly attracted to calcium carbonate (Cole et al., 1953). The result of this attraction is the formation of very insoluble carbonatoapatite (McGeorge and Breazeale, 1931). Therefore calcium carbonate at the surface of the low yielding clusters areas may be a possible cause for yield depression. On the contrary, carbonates did not appear until much deeper in the soil profiles of the high yielding cluster areas. Daniels et al. (1985) and Stone et al. (1985) observed that lower landscape positions received both surface and subsurface water from higher elevations. This may have led to increased leaching on the lower landscape positions where the high yielding clusters were observed. Secondly, lower landscape positions receive sediment from eroding surfaces up slope which may have buried carbonates deeper.

Physical and chemical properties

A total of eight quantitative soil characteristics were measured through laboratory analyses for each of the 19 respective soil cores and then averaged by three depth classes as discussed. In Table 3, the amount of sand ranged from 2.1-64.9 g $100g^{-1}$, silt amounts ranged from 22.8-72.3 g $100g^{-1}$, and clay amounts ranged from 12.3-35.2 g $100g^{-1}$ across the study site. There were no significant differences in the soil textural variables when comparing yield cluster types and depth classes (Figure 8). This could be due to the nature of loess parent material at the site. Loess is a wind deposited sediment that is commonly horizontally stratified and unconsolidated composed mostly of silt sized particles (Ruhe, 1969). Because loess is deposited by wind and contains mostly finer sediments, it is usually very uniform within localized areas but its composition changes with distance from the source.

Total carbon ranged from 0.2-3.0 g $100g^{-1}$ (Table 3) across the study site. When comparing the three cluster types by respective depth classes, there were no significant differences, indicating that cluster type was not a discriminating factor for TC at the three depths (Figure 9). Total nitrogen went from 0-0.4 g $100g^{-1}$ across the study site (Table 3). There were not statistical differences in TN between clusters at 0-25 cm and 25-100 cm (Figure 10). However, at greater than 100 cm depths, TN was significantly greater in the high yielding clusters compared to the low yielding clusters. TC and TN were non-discriminating factors affecting corn yield between clusters. Again we speculate that this may be due to the uniformity of the loess parent material.

Mehlich 3 phosphorus ranged from 1.0-196.0 mg kg^{-1}. At the 0-25 cm depth, the high and average yielding clusters had significantly greater M3P concentrations than the low clusters. At depths greater than 100 cm the high yielding clusters had significantly high levels of M3P compared to the average and low yielding clusters (Figure 11).

The M3P in the three different cluster types were not significantly different at the 25-100 cm depth. Mehlich 3 potassium went from 65-630 mg kg^{-1} (Table 3) across the study site. The M3K concentrations in the high, average, and low yielding clusters were significantly different at the 0-25 cm depth (Figure 12). However, there were no significant differences in M3K in the yield clusters at the 25-100 cm and > 100 cm depth classes. Both P and K are essential for corn development and yield. P is involved in respiration, energy transfer, and important for both deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) (Sawyer et al., 2000). K provides stimulation for early growth, helps increase protein production, and aids in water use efficiency (Rehm and Schmitt, 2002). Kuchenbuch and Barber (1987) found that P and K levels in the top 15 cm of the soil were significantly correlated to ear leaf development and therefore influential on overall yield. They also found that when P and K were lacking, root density was much lower in the top 15 cm which in turn led to lower yields. We believe that the high M3P and M3K levels in the root zone of the soils could be important factors in corn yields in these clusters. According to PM 1688 (Mallarino et al., 2013) the high and average yielding clusters were rated as having very high levels of both M3P and M3K from 0-25 cm and therefore requiring no additional P_2O_5 or K_2O. However, the Low yielding clusters were rated as having optimum levels of M3P and M3K and would require additional applications of P_2O_5 and K_2O to meet crop removal rates.

Soil pH ranged from 4.8 - 8.2 across the study site (Table 5.) There were no significant differences in pH across depth classes and cluster types (Figure 13). However, the low yielding clusters located in upper landscape positions had higher pH values than the high yielding clusters found on lower landscape positions. This could be related to the relationship Brubaker et al. (1993) found, which showed that pH was lower in the footslope or lower positions on the landscape as compared to soils on the upper landscape positions. We observed this same kind of relationship on our study site and the pH distribution could be related to the presence of carbonates at shallow depths in the lower yielding cluster areas as opposed to the excessive leaching in the high yielding cluster areas.

Relationships between soil properties

At the 0-25 cm depth, the only significant correlations among the fertility and physical parameters were between M3K concentration and TN and M3P concentration (Table 4). Soil pH was only weakly correlated with TN at this depth. There were significant positive correlations of silt and clay with TN. Burke et al. (1989) found that soil organic matter increased with increasing clay content in the soil. Silt was also significantly correlated with M3K. Doll et al. (1965) reported that in most soils, K^+ is released from the clay and silt fraction. With the loess parent material made up of predominantly clay and silt, we expect high M3K concentrations

In the 25-100 cm and > 100 cm depth classes, there were a lot of significant correlations between and among the soil fertility and physical properties. The relationship between organic matter and fertility parameters is indicated by significant correlations among total carbon, total nitrogen, M3P, and M3K. Bauer and Black (1994) pointed out that soil organic matter acts as a soil chemical reservoir and is a local provider of soil available nitrogen, it contains P, provides S, and serves as a source of many other essential plant nutrients. There are also high correlations between M3K and the fine fractions of the soil.

Conclusion

Precision agriculture is dependent on identifying relationships in corn yield variability from a number of factors. The objective of this study was to identify relationships of soil morphology, chemical and/or physical characteristics on consistent spatial corn yield variability previously identified using "Cluster and Outlier Analysis (Anselin Local Moran's I)" tool (ESRI, 2014). In general, high yielding clusters had mollic colors to deeper depths, were higher in Mehlich 3 phosphorus and Mehlich 3 potassium from 0-25 cm, and higher in TN and Mehlich 3 phosphorus at depths greater than 100 cm. The high clusters were most commonly located in areas of soil accumulation on the landscape including intermittent drainageways, footslopes, and upland alluvial fans. Low clusters were not identified on a consistent landscape position but rather occurred on localized summits, shoulders and backslopes that were moderately to severely eroded. By understanding these relationships, precision agriculture may be improved and in turn increase economic feasibility and environmental sustainability of Iowa farms. However, application of this technology may not be economically feasible on uniform loess soils.

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Table 1. Yearly planting dates and planting density (1000's) for fields 1 and 2.

Year	Planting Date	Planting density (1000) ha^{-1}
	Field 1	
2007	1-May	79.1
2009	24-Apr	79.1
2013	5-May	84
	Field 2	
2006	29-Apr	79.1
2008	1-May	80.3
2010	1-May	82.8

Table 2. Summary statistics of adjusted corn yields (kg ha^{-1}) for fields 1 and 2.

Year	Minimum (kg ha^{-1})	Maximum (kg ha^{-1})	Mean (kg ha^{-1})	Std. (kg ha^{-1})
		Field 1		
2007	919	19398	9409	1261
2009	2071	16285	10286	2109
2013	2330	24122	12767	2203
Average	919	24122	10825	2379
		Field 2		
2006	777	18232	9539	1939
2008	1049	24154	12555	1884
2010	2042	21176	12724	2676
Average	777	24154	11593	2643
Study Site	777	24154	11180	2533

Table 3. Summary statistics of the soil characteristics for the study site.

Variable	Minimum	Maxiumum	Mean	Standard Dev
Sand g $100g^{-1}$	2.1	64.9	9.9	11.0
Silt g $100g^{-1}$	22.8	92.3	64.4	8.4
Clay g $100g^{-1}$	12.3	35.2	26.0	5.3
TC g kg^{-1}	2.0	30.0	12.0	8.0
TN g kg^{-1}	0.0	4.0	10.0	1.0
M3P mg kg^{-1}	1.0	196.0	16.2	23.7
M3K mg kg^{-1}	65.0	630.0	179.2	86.3
pH	1.8	8.2	6.7	1.0

Table 4. Correlations of soil characteristics for: (a) 0-25 cm (b) 25-100 cm (c) >100 cm.

0-25 cm

	tot. C	*tot. N*	*m3P*	*m3K*	*pH*	*sand*	*silt*	*clay*
tot. C	1.00							
tot. N	0.40	1.00						
m3P	0.12	0.24	1.00					
m3K	0.35	0.52*	0.70***	1.00				
pH	0.18	-0.50*	0.17	0.20	1.00			
sand	0.16	-0.76***	-0.30	-0.35	0.56**	1.00		
silt	0.32	0.49*	0.39	0.66**	0.01	-0.37	1.00	
clay	-0.36	0.50*	0.07	-0.03	-0.60**	-0.83***	-0.22	1.00

(a) 25-100 cm

	tot. C	*tot. N*	*m3P*	*m3K*	*pH*	*sand*	*silt*	*clay*
tot. C	1.00							
tot. N	0.38***	1.00						
m3P	-0.29*	0.02	1.00					
m3K	-0.15	0.48***	0.45***	1.00				
pH	0.32*	-0.57***	-0.34**	-0.71***	1.00			
sand	0.17	-0.46***	-0.15	-0.68***	0.68***	1.00		
silt	-0.04	0.38**	0.12	0.49***	-0.45***	-0.91***	1.00	
clay	-0.30	0.44***	0.10	0.71***	-0.76***	-0.83***	0.54***	1.00

(b) > 100 cm

	tot. C	*tot. N*	*m3P*	*m3K*	*pH*	*sand*	*silt*	*clay*
tot. C	1.00							
tot. N	-0.35*	1.00						
m3P	-0.73***	0.24	1.00					
m3K	-0.45**	0.27	0.48**	1.00				
pH	0.77***	-0.42**	-0.68***	-0.72***	1.00			
sand	0.12	-0.24	-0.24	-0.69***	0.44**	1.00		
silt	-0.03	0.14	0.12	0.51***	-0.31	-0.89***	1.00	
clay	-0.55***	0.30	0.59***	0.84***	-0.77***	-0.67***	0.47**	1.00

*p<0.05

**p<0.01

***p<0.001

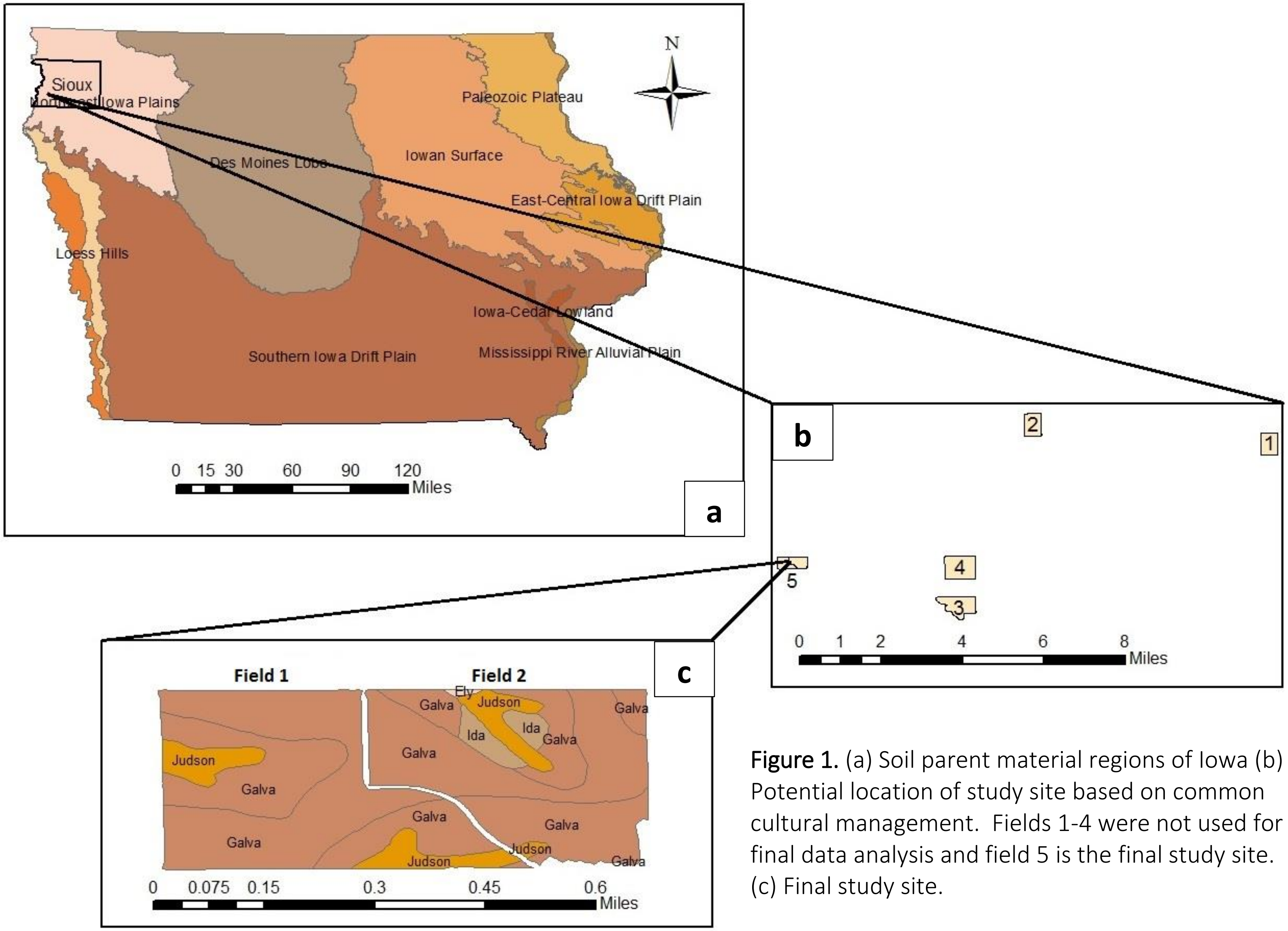

Figure 1. (a) Soil parent material regions of Iowa (b) Potential location of study site based on common cultural management. Fields 1-4 were not used for final data analysis and field 5 is the final study site. (c) Final study site.

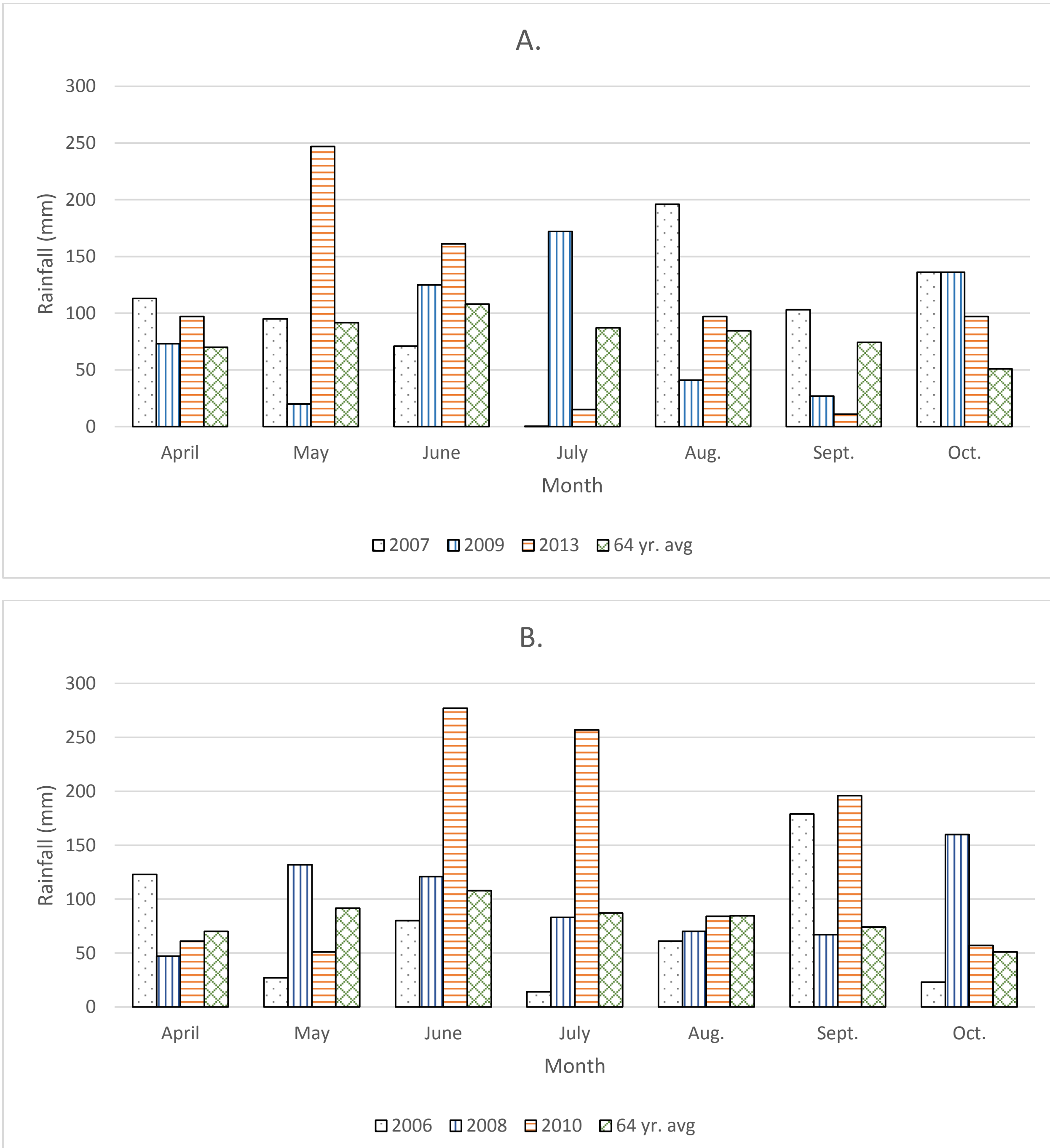

Figure 2. Rainfall distribution for the growing season (April-October) during study period for (a) Field 1 and (b) field 2.

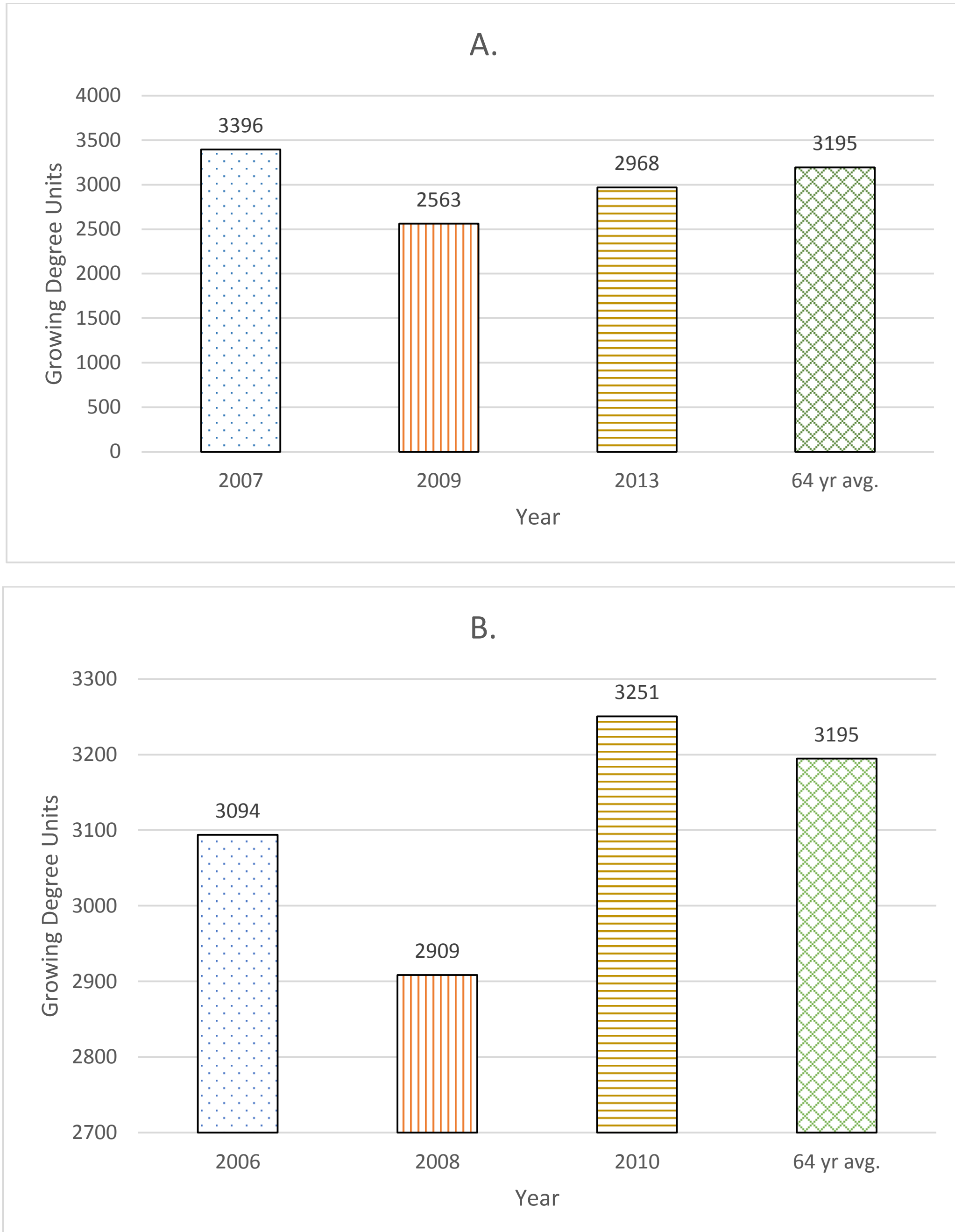

Figure 3. Growing degree units for (a) for field 1 and (b) field 2.

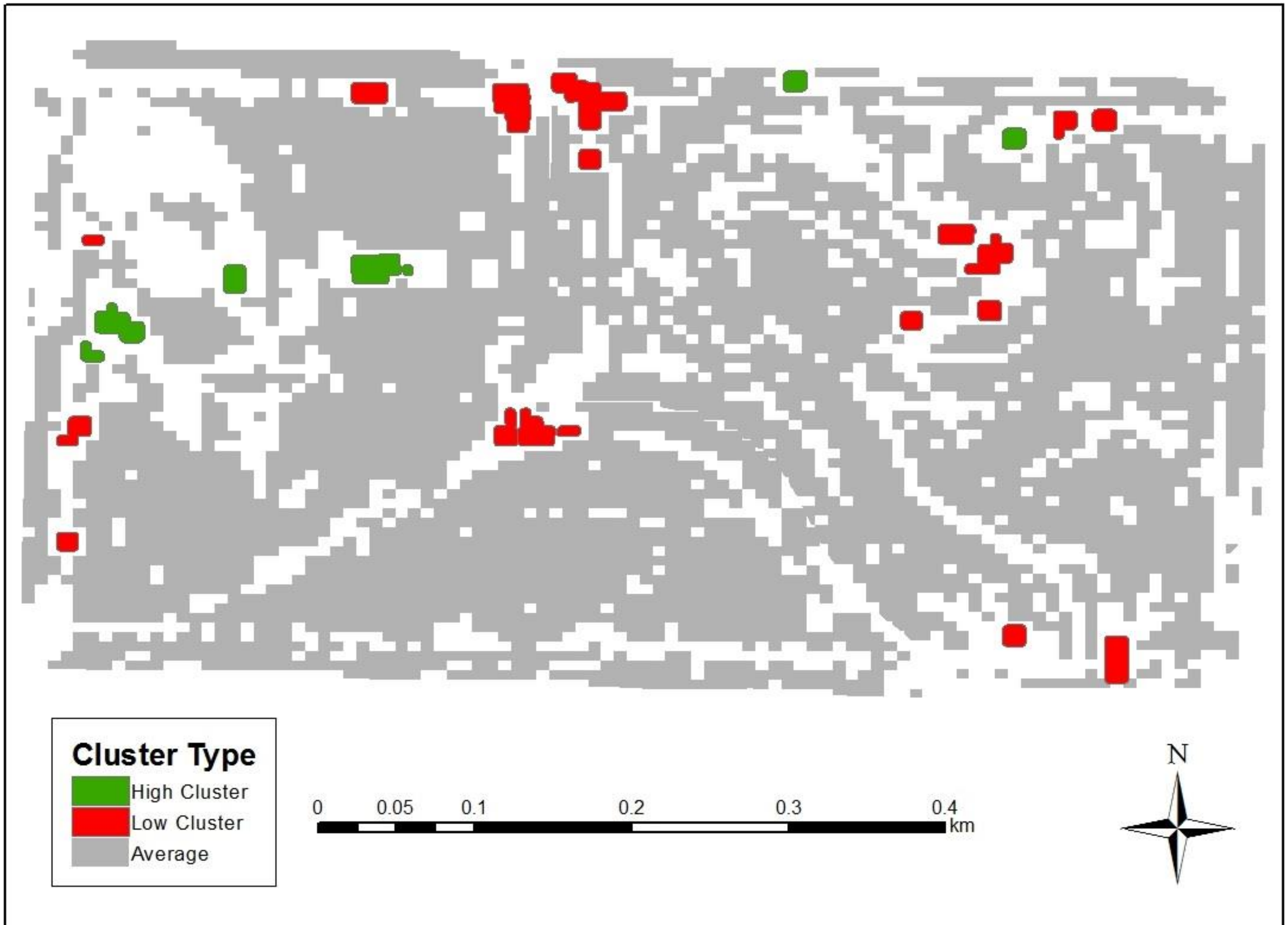

Figure 4. Spatially consistent clusters of corn yield variability for the final study site.

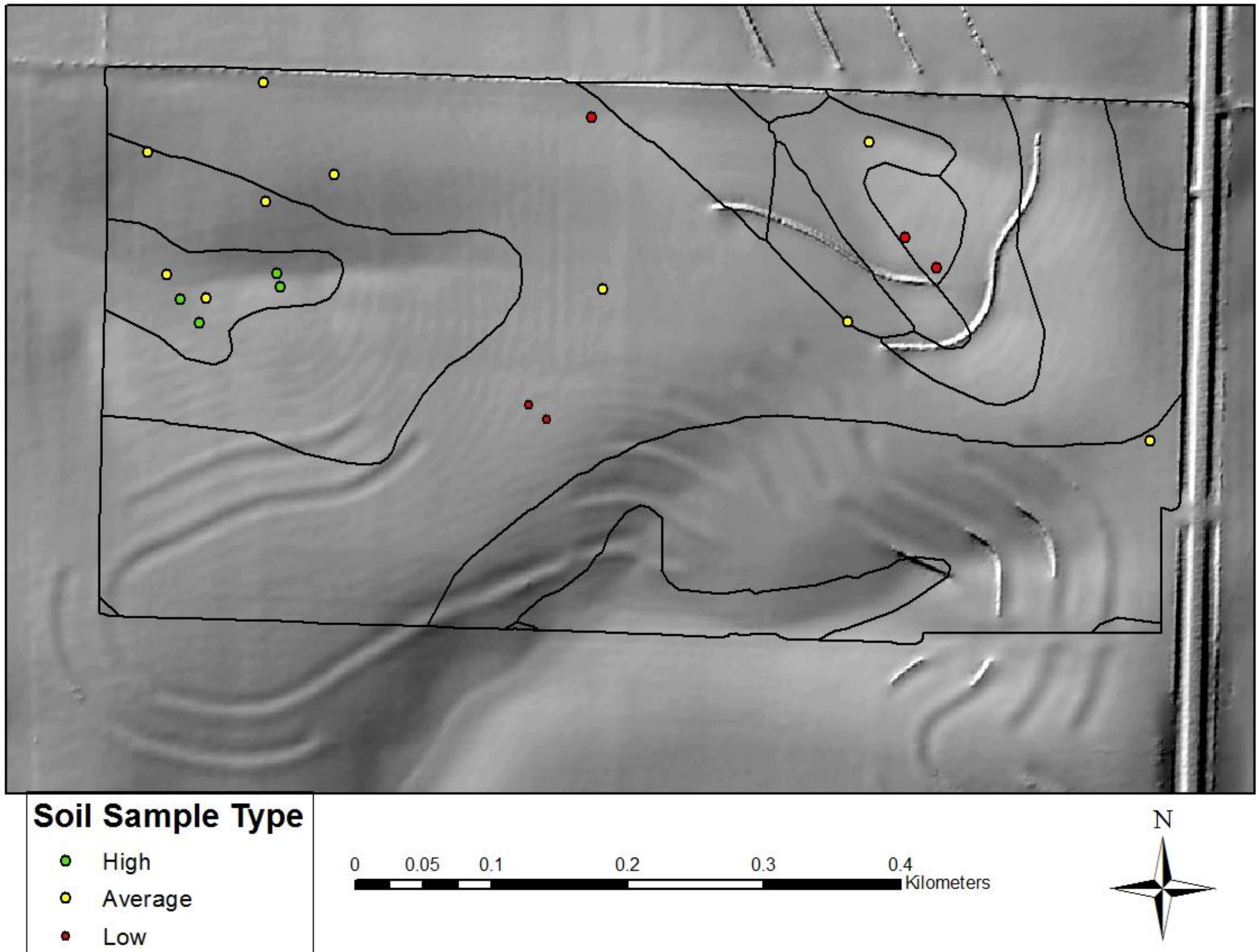

Figure 5. Soil sampling map overlaid onto 1 Meter LIDAR hill shade. Colors circles indicate the area where a soil sample was taken.

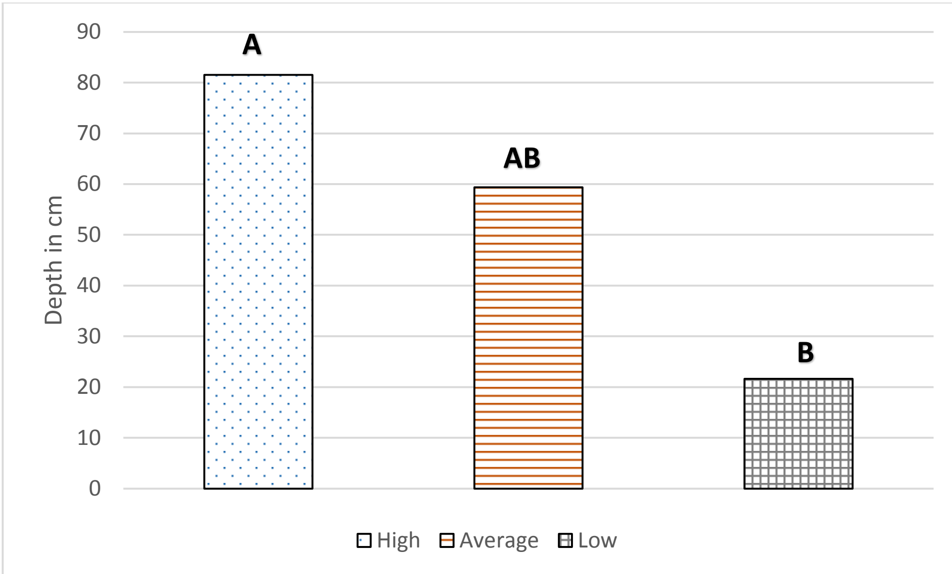

Figure 6. Maximum depth to mollic (moist color value and chroma of 3/3 or less) colors (cm). Bars with the same letter are not significantly different (p<0.05).

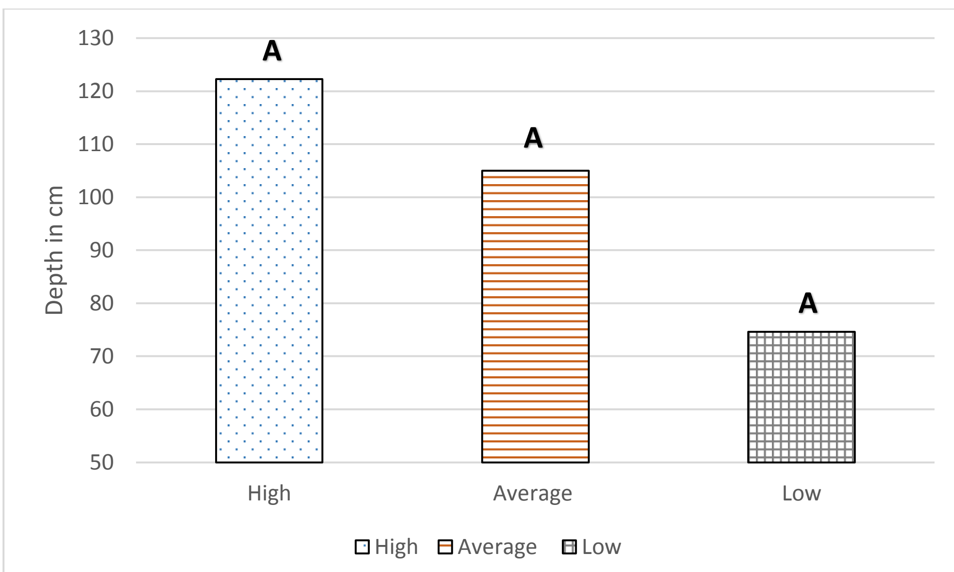

Figure 7. Minimum depth to calcium carbonate. Bars with the same letter are not significantly different (p<0.05).

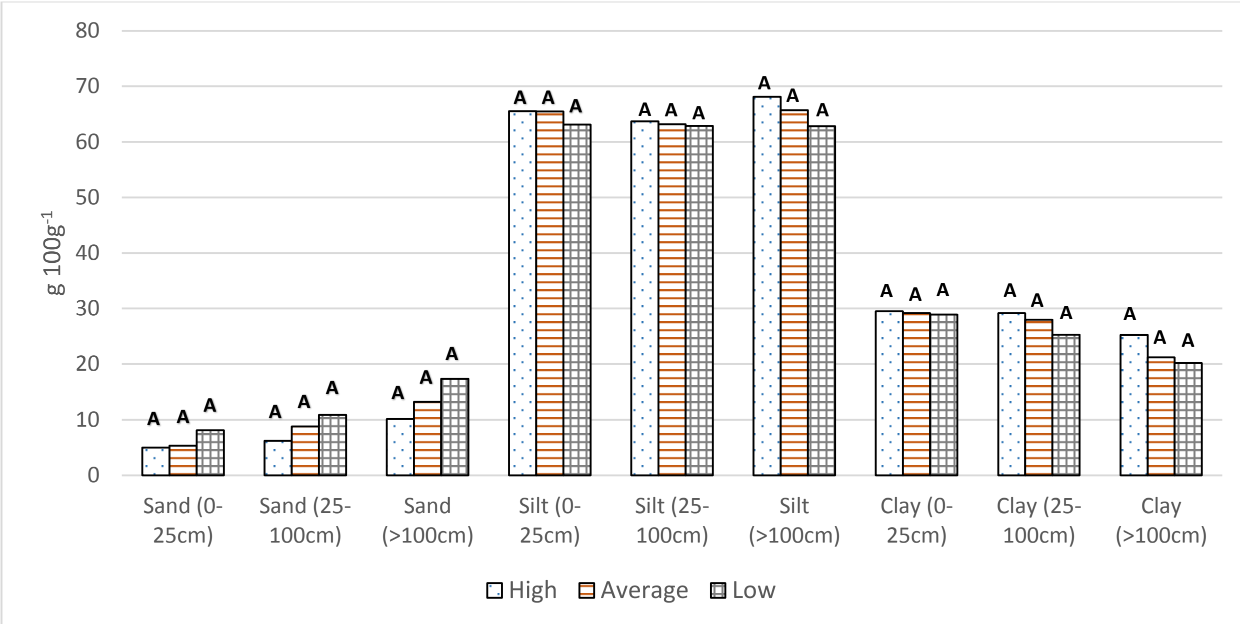

Figure 8. Distribution of sand, silt, and clay as a function of depth class and cluster type. Bars with the same letter are not significantly different ($p<0.05$).

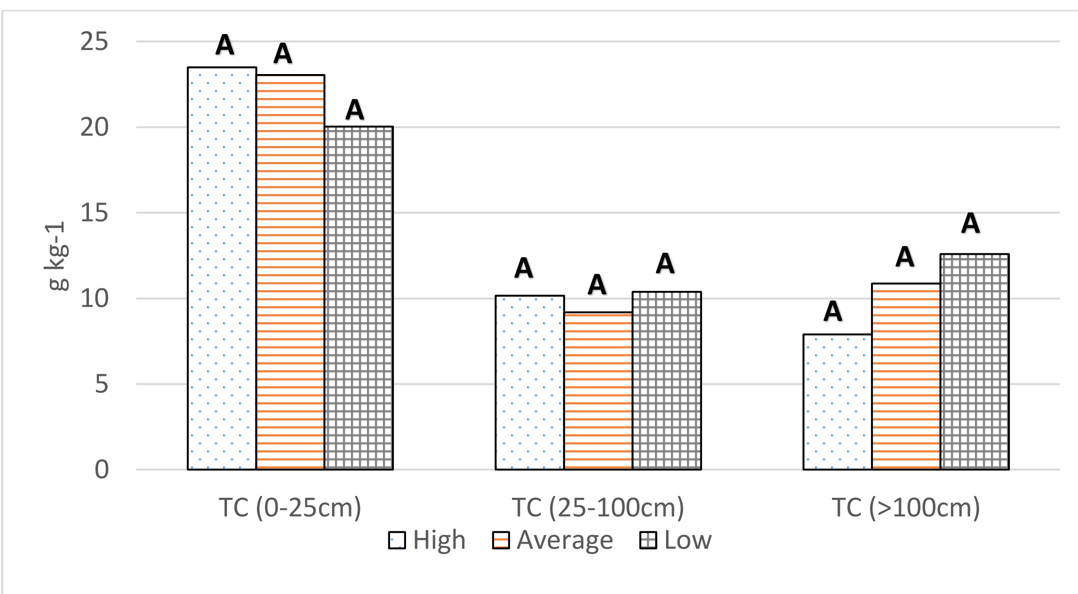

Figure 9. Total carbon (TC) variation as a function of depth class and cluster type. Bars with the same letter are not significantly different ($p<0.05$).

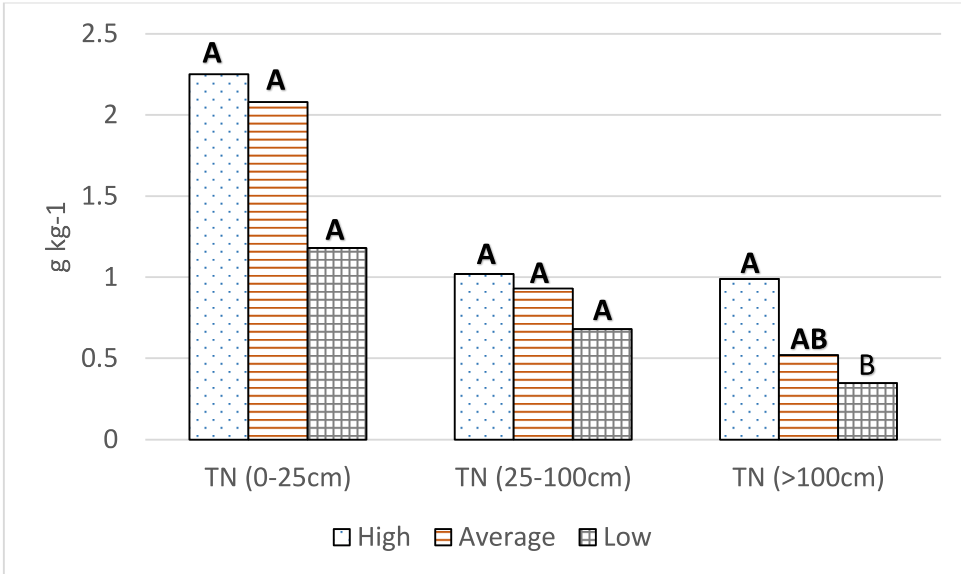

Figure 10. Total nitrogen (TN) variation as a function of depth class and cluster type. Bars with the same letter are not significantly different (p<0.05).

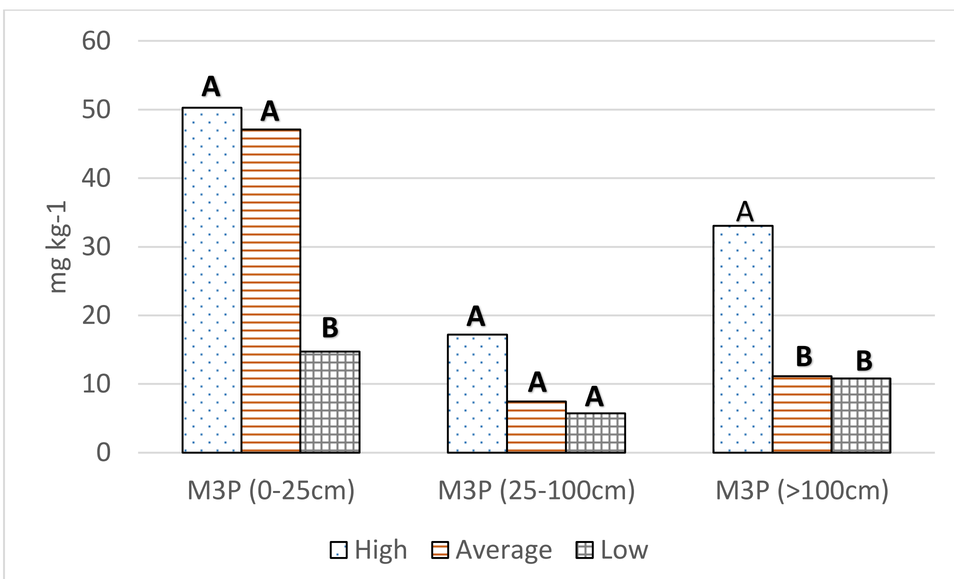

Figure 11. Mehlich 3 phosphorus (MP) variation as a function of depth class and cluster type. Bars with the same letter are not significantly different (p<0.05).

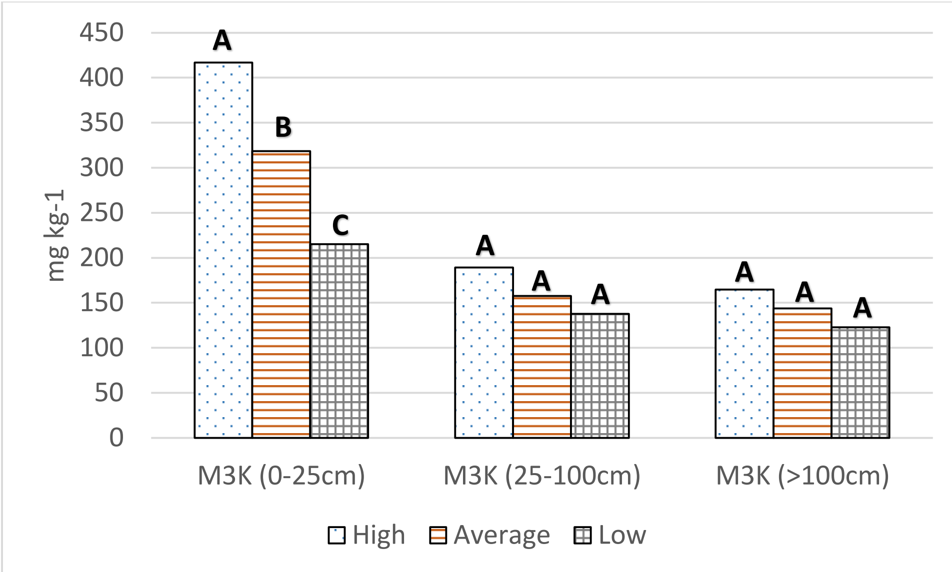

Figure 12. Mehlich 3 potassium (M3K) variation as a function of depth class and cluster type. Bars with the same letter are not significantly different ($p<0.05$).

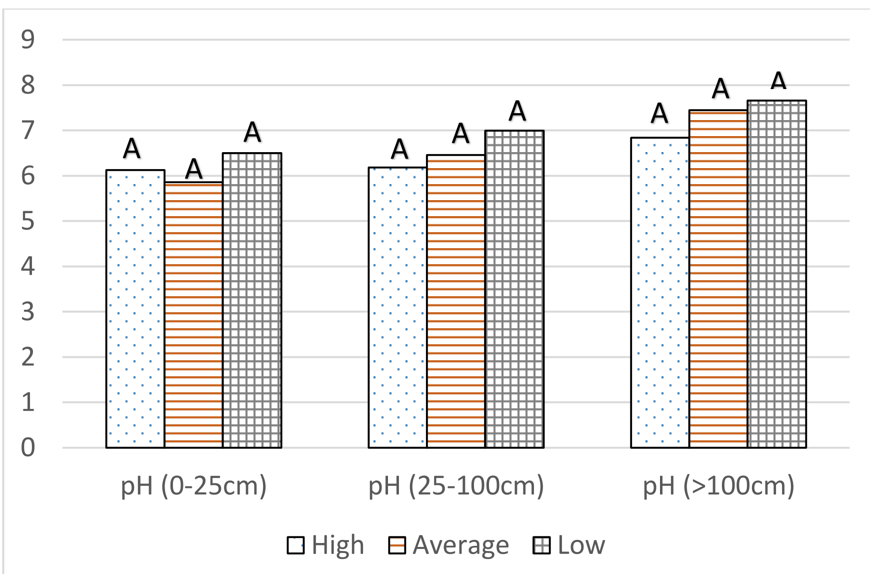

Figure 13. Soil pH variation as a function of depth class and cluster type. Bars with the same letter are not significantly different ($p<0.05$).

CHAPTER 4. GENERAL CONCLUSION

Summary

Producing more with less has become a new paradigm in the agricultural community as precision agriculture is becoming increasingly embraced. The definition for precision agriculture continues to evolve with technology but Robert et al. (1995), Pierce and Nowak (1999) and Miao et al. (2006) define precision agriculture as an integrated information and technology-based management system, designed to manage spatial and temporal variability associated with all dimensions of agricultural production for optimum profitability, sustainability, and protection of the environment. The rationale behind precision agriculture, as explained by Blackmore and Griepentrog (2002), is to identify and manage crop yield variability and the drivers behind it in order to improve existing systems, enhance profitability and minimize any negative impact of agriculture on the environment. The objective of this study was to develop methodology that utilizes years of compiled precision agriculture yield data in order to sustainably, economically, and agronomically improve Iowa agriculture. There were two objectives established in this study.

The first objective was to determine if “Anselin Local Moran’s I cluster analysis tool” (ESRI, 2015) could be used to identify spatially consistent corn yield variability on the loess hills of Northwest Iowa and validate it using a residual method. A 32 hectare site containing multiple years of geo-referenced corn yield data were intensively analyzed. Areas of spatially consistent and significantly high and low yielding clusters were successfully identified. However these spatially consistent clusters of yield variability were relatively small compared to the total area of the site. This may be due to the type of parent material as well as consistent management by the farm operator. Therefore farm managers must consider the amount of time and resources they are willing to invest in order to locate spatially consistent corn yield variability.

The second objective of this study was to determine if any relationships between soil chemical and/or physical characteristics associated with persistent long-term high and low yielding clusters identified using "Anselin Local Moran's I cluster analysis" tool (ESRI 2014) existed. Identifying the relationships between clusters of yield variability and soil chemical and/or physical properties may help in sustainably, economically, and agronomically advancing agriculture in Iowa. The previously identified 32 hectare site contained consistent clusters of corn yield variability that were soil sampled and extensively analyzed for soil chemical and physical properties. The study successfully identified specific quantitative soil characteristics to be significantly different between spatially consistent clusters of corn yield variability.

A follow up study is suggested to test the methodologies used in this study for determining relationships between corn yield variability and soil characteristics at another site where more soil variability exists. The uniformity of the loess parent material may contribute to only finding a small areas of spatially consistent corn yield variability in the study site. Therefore a study conducted in an area where landscape changes more drastically and where multiple parent materials exist in one study site may result in larger clusters of spatially consistent corn yield variability. It may also be beneficial to test other soil chemical and physical properties such as electrical conductivity and water holding capacity to see if these factors contribute significantly to yield variability. The result of identifying relationships between corn yield variability and soil properties can help managers create more economical and sustainable farm operations that more heavily utilize soil characteristics on a zonal basis.

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APPENDIX A. SOIL CORE DESCRIPTIONS

Soil Series: Galva

Core Number: RW1-Avg

Map Unit Symbol: 310C2

Coordinates: x= -96.40104817, Y= 43.0181657 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 391.1 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludoll

Slope Characteristics: 8.2 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap1-- 0-13cm; very dark brown (10YR 2/2); silty clay loam; weak granular structure; friable; common fine roots; very strongly acid; clear smooth boundary.

Ap2 -- 13-22cm; very dark brown (10YR 2/2); silty clay loam; weak subangular blocky structure; friable; common fine roots; very strongly acid; abrupt smooth boundary.

Bw1 -- 22-61cm; dark brown (10YR 3/3); silty clay loam; moderate subangular blocky structure; firm; few fine roots; slightly acid; clear smooth boundary.

Bw2 -- 61-99cm; olive brown (2.5Y 4/3); silty clay loam; moderate subangular blocky structure; friable; slightly acid; clear smooth boundary.

BC -- 99-130cm; olive brown (2.5Y4/4); silty clay loam; weak subangular blocky; friable; neutral; few fine prominent strong brown (7.5YR 4/6) Fe concentrations; few fine distinct grayish brown (2.5Y 5/2) Fe depletions; clear smooth boundary.

C -- 130-144cm; olive brown (2.5Y 4/4); silt loam; massive; friable; neutral; few fine prominent strong brown (7.5YR 4/6) Fe concentrations; few fine distinct grayish brown (2.5Y 5/2) Fe depletions.

Soil Series: Judson

Core Number: RW2-Avg

Map Unit Symbol: 8B

Coordinates: x= -96.400836, Y= 43.017354 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 388.3 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Cumulic Hapludoll

Slope Characteristics: 2.5 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap1 -- 0-18cm; black (10YR 2/1); silt loam; moderate granular structure; friable; common fine roots; slightly acid; clear smooth boundary.

Ap2 -- 18-36cm; black (10YR 2/1); silty clay loam; moderate subangular blocky structure; firm; few fine roots; slightly acid; clear smooth boundary.

A -- 36-68cm; black (10YR 2/1); silty clay loam; moderate subangular blocky structure; friable; slightly acid; clear smooth boundary.

AB -- 68-92cm; very dark brown (10YR 2/2); silty clay loam; moderate subangular blocky structure; friable; gradual smooth boundary.

Bw -- 92-125cm; very dark grayish brown (10YR 3/2); silty clay loam; weak prismatic structure; friable; few fine prominent strong brown (7.5YR 4/6) redoximorphic concentrations; slightly acid; clear smooth boundary.

BC -- 125-141cm; very dark grayish brown (10YR 3/2); silty clay loam; weak subangular blocky structure; friable; few fine prominent strong brown (7.5YR 4/6) redoximorphic concentrations; neutral.

Soil Series: Judson

Core Number: RW3-HH

Map Unit Symbol: 8B

Coordinates: x= -96.400698, Y= 43.017175 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 389.1 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Cumulic Hapludoll

Slope Characteristics: 2.4 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-18cm; black (10YR 2/1); silty clay loam; weak granular structure; friable; common fine and very fine roots; slightly acid; clear smooth boundary.

A -- 18-39cm; very dark brown (10YR 2/2); silty clay loam; weak subangular blocky structure; friable; common fine roots; slightly acid; clear smooth boundary.

AB -- 39-57cm; very dark grayish brown (10YR 3/2); silty clay loam; moderate subangular blocky structure; friable; neutral; clear smooth boundary.

Bw1 -- 57-80cm; dark olive brown (2.5Y 3/3); silty clay loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; abrupt smooth boundary.

Bw2 -- 80-100cm; olive brown (2.5Y 4/3); silt loam; moderate subangular blocky structure; friable; common medium and coarse irregular carbonate concretions; few fine faint grayish brown (2.5Y 5/2) redoximorphic depletions; few fine prominent strong brow (7.5YR 4/6) redoximorphic concentrations and nodules; slightly effervescent; moderately alkaline; clear smooth boundary.

BC -- 100-122cm; olive brown (2.5Y 4/3); silt loam; weak subangular blocky structure; friable common medium irregular carbonate concretions and few medium spherical carbonate concentrations; few fine faint grayish brown (2.5Y 5/2) redoximorphic depletions; few fine prominent strong brown (7.5YR 4/6) redoximorphic concentrations and nodules; strongly effervescent; moderately alkaline; clear smooth boundary.

C -- 122-137cm; olive brown (2.5Y 4/3); silt loam; massive; friable; few fine faint grayish brown (2.5Y 5/2) redoximorphic depletions; few medium prominent strong brown (7.5YR 4/6) redoximorphic concentrations and few fine distinct brown (7.5YR 3/4) redoximorphic nodules; slightly effervescent; moderately alkaline.

Soil Series: Judson

Core Number: RW4-HH

Map Unit Symbol: 8B

Coordinates: x= -96.40052, Y= 43.017047 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 389.9 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludolls

Slope Characteristics: 4.8 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-22cm; very dark brown (10YR 2/2); silty clay loam; moderate subangular blocky structure; firm; common fine roots; moderately acid; abrupt smooth boundary.

A -- 22-38cm; dark brown (10YR 3/3); silty clay loam; moderate subangular blocky structure; firm; few very fine roots; moderately acid; gradual smooth boundary;

AB -- 38-51cm; dark brown (2.5Y 3/3); silty clay loam; moderate subangular blocky structure; friable; moderately acid; clear smooth boundary.

Bw1 -- 51-69cm; olive brown (2.5Y 4/3); silty clay loam; moderate subangular blocky structure; friable; few fine faint grayish brown (2.5Y 5/2) redoximorphic depletions; moderately acid; clear smooth boundary.

Bw2 -- 69-97cm; olive brown (2.5Y 4/4); silty clay loam; moderate subangular blocky structure; friable; few fine distinct grayish brown (2.5Y 5/2) redoximorphic depletions; few fine prominent strong brown (7.5YR 4/6) redoximorphic concentrations; slightly acid; clear smooth boundary.

BC -- 97-133cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; common fine distinct grayish brown (2.5Y 5/2) redoximorphic depletions; common fine prominent strong brown (7.5YR 4/6) redoximorphic concentrations; slightly acid; abrupt smooth boundary.

Cg -- 133-141cm; grayish brown (2.5Y 5/2); silty clay loam; massive; friable; common medium prominent strong brown (7.5YR 4/6) redoximorphic concentrations; slightly alkaline.

Soil Series: Judson

Core Number: RW5-Avg

Map Unit Symbol: 8B

Coordinates: x= -96.400465, Y= 43.017205 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 389.8 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Cumulic Hapludoll

Slope Characteristics: 4.8 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-24cm; black (10YR 2/1); silty clay loam; moderate granular structure; friable; common fine and very fine roots; slightly acid; clear smooth boundary.

A -- 24-40cm; very dark grayish brown (2.5Y 3/2); silt loam; weak subangular blocky structure; friable; few fine and very fine roots; slightly acid; clear smooth boundary.

AB -- 40-62cm; dark olive brown (2.5Y 3/3); silt loam; moderate subangular blocky structure; friable; slightly acid; gradual smooth boundary.

Bw -- 62-89cm; olive brown (2.5Y 4/3); silt loam; weak subangular blocky structure; friable; neutral; abrupt smooth boundary.

BC -- 89-110cm; olive brown (2.5Y 2/2); silt loam; weak subangular blocky structure; friable; coarse medium spherical carbonate concentrations and common medium and coarse irregular carbonate concretions; violently effervescent; moderately alkaline; clear smooth boundary.

Cg -- 110-130cm; grayish brown (2.5Y 5/2); silt loam; massive; friable; common medium spherical carbonate concretions; violently effervescent; moderately alkaline.

Soil Series: Galva

Core Number: RW6-Avg

Map Unit Symbol: 310B2

Coordinates: x= -96.40004, Y= 43.018638 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 395.1 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludoll

Slope Characteristics: 2.8 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-23cm; very dark brown (10YR 2/2); silty clay loam; weak granular structure; friable; common fine and very fine roots; strongly acid; abrupt smooth boundary.

AB -- 23-50cm; very dark grayish brown (10YR 3/3); silty clay loam; weak subangular blocky structure; friable; few fine and very fine roots; slightly acid; clear smooth boundary.

Bw1 -- 50-89cm; brown (10YR 4/3); silty clay loam; moderate subangular blocky structure; slightly acid; gradual smooth boundary.

Bw2 -- 89-110cm; olive brown (2.5Y 4/4); silt loam; moderate subangular blocky structure; neutral; abrupt smooth boundary.

BC -- 110-122cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; few fine spherical carbonate concentrations; few fine distinct light brownish gray (2.5Y 6/2) redoximorphic depletions; slightly effervescent; abrupt smooth boundary; slightly alkaline.

C -- 122-139cm; olive brown (2.5Y 4/4); silt loam; massive; friable; few fine spherical carbonate concentrations and few fine irregular carbonate concretions; few distinct light brownish gray (2.5Y 6/2) redoximorphic depletions; strongly effervescent; moderately alkaline.

Soil Series: Galva

Core Number: RW7-Avg

Map Unit Symbol: 310C2

Coordinates: x= -96.399977, Y= 43.017851 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 394.6 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludoll

Slope Characteristics: 6.9 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-17cm; very dark brown (10YR 2/2); silty clay loam; weak granular structure; friable; common fine and very fine roots; slightly acid; abrupt smooth boundary.

A -- 17-34cm; dark brown (10YR 3/3); silty clay loam; weak subangular blocky structure; friable; few fine and very fine roots; slightly acid; clear smooth boundary.

AB -- 34-51cm; dark brown (10YR 3/3); silty clay loam; moderate subangular blocky structure; friable; slightly acid; clear smooth boundary.

Bw1 -- 51-71cm; olive brown (2.5Y 4/3); silty clay loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; granular smooth boundary.

Bw2 -- 71-99cm; olive brown (2.5Y 4/4); silt loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; abrupt smooth boundary.

BC -- 99-120cm; light olive brown (2.5Y 5/4); silt loam; weak subangular blocky structure; friable; few fine spherical carbonate concentrations; slightly effervescent; slightly alkaline; clear smooth boundary.

C -- 120-136cm; light olive brown (2.5Y 5/4); silt loam; massive; friable; few fine spherical carbonate concentrations; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations; few fine distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; slightly alkaline.

Soil Series: Judson

Core Number: RW8-HH

Map Unit Symbol: 8B

Coordinates: x= -96.399843, Y= 43.017378 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 391.1 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Cumulic Hapludoll

Slope Characteristics: 4.6 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-20cm; black (10YR 2/1); silty clay loam; weak granular structure; friable; common fine and very fine roots; neutral; clear smooth boundary.

A -- 20-42cm; black (10YR 2/1); silty clay loam; weak subangular blocky structure; friable; common fine and very fine roots; moderately acid; clear smooth boundary.

AB -- 42-78cm; very dark grayish brown (10YR 3/2); silty clay loam; moderate subangular blocky structure; firm; few fine roots; strongly acid; clear smooth boundary.

Bt1-- 78-95cm; dark brown (10YR 3/3); silty clay loam; moderate prismatic structure; firm; very few clay films on faces of peds; moderately acid; gradual smooth boundary.

Bt2 -- 95-117cm; dark brown (10YR 3/3); silt loam; weak prismatic structure; firm; very few clay films on faces of peds; moderately acid; gradual smooth boundary.

BC -- 117-138cm; dark brown (10YR 3/3); silty clay loam; weak prismatic structure parting to weak subangular blocky structure; firm; moderately acid.

Soil Series: Judson

Core Number: RW9-HH

Map Unit Symbol: 8B

Coordinates: x= -96.399801, Y= 43.01729 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 391.6 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludoll

Slope Characteristics: 4.6 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap1 -- 0-20cm; black (10YR 2/1); silty clay loam; moderate granular structure; friable; common fine and very fine roots; moderately acid; abrupt smooth boundary.

Ap2 -- 20-31cm; very dark brown (10YR 2/2); silty clay loam; weak subangular blocky structure; friable; common fine and very fine roots; moderately acid; clear smooth boundary.

AB -- 31-57cm; dark olive brown (2.5Y 3/3); silty clay loam; moderate subangular blocky structure; friable; few fine roots; slightly acid; clear smooth boundary.

Bw -- 57-92cm; olive brown (2.5Y 4/3); silt loam; weak prismatic structure parting to moderate subangular blocky structure; firm; slightly acid; clear smooth boundary.

BC -- 92-105cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; few fine prominent strong brown (7.5YR 5/6) redoximorphic concentrations; slightly acid; clear smooth boundary.

C -- 105-130cm; olive brown (2.5Y 4/4); silt loam; massive; friable; few fine prominent strong brown (7.5YR 5/6) redoximorphic concentrations; neutral.

Soil Series: Galva

Core Number: RW10-Avg

Map Unit Symbol: 310B2

Coordinates: x= -96.399344, Y= 43.018045 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 396.4 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludoll

Slope Characteristics: 2.3 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-24cm; very dark brown (10YR 2/2); silty clay loam; weak subangular blocky structure; friable; common fine and very fine roots; slightly acid; abrupt smooth boundary.

AB -- 24-56cm; dark brown (10YR 3/3); silty clay loam; moderate subangular blocky structure; friable; few fine roots; moderately acid; clear smooth boundary.

Bw1 -- 56-70cm; olive brown (2.5Y 4/3); silt loam; weak prismatic structure parting to moderate subangular blocky structure; friable; slightly acid; clear smooth boundary.

Bw2 -- 70-102cm; olive brown (2.5Y 4/4); silt loam; weak prismatic structure parting to moderate subangular blocky structure; friable; few fine distinct grayish brown (2.5Y 5/2) redoximorphic depletions; neutral; abrupt smooth boundary.

BC -- 102-120cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; few medium spherical calcium carbonate concentrations and concretions; few medium distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; slightly alkaline, clear smooth boundary.

C -- 120-136cm; light olive brown (2.5Y 5/4); silt loam; massive; friable; few medium spherical calcium carbonate concentrations and concretions; few medium distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline.

Soil Series: Galva

Core Number: RW11-LL

Map Unit Symbol: 310B2

Coordinates: x= -96.397537, Y= 43.016575 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 399.3 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Typic Hapludoll

Slope Characteristics: 2.9 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap1 -- 0-10cm; very dark brown (10YR 2/); silty clay loam; weak granular structure; friable; common fine and very fine roots; moderately acid; clear smooth boundary.

Ap2 -- 10-21cm; very dark brown (10YR 2/2); silty clay loam; weak subangular blocky structure; firm; common fine and very fine roots; very strongly acid; abrupt smooth boundary.

AB -- 21-48cm; dark brown (10YR 3/3); silty clay loam; weak prismatic structure parting to moderate subangular blocky structure; friable; few fine roots; moderately acid; clear smooth boundary.

Bw1 -- 48-81cm; olive brown (2.5Y 4/3); silty clay loam; moderate prismatic structure; friable; neutral; gradual smooth boundary.

Bw2 -- 81-105cm; olive brown (2.5Y 4/4); silt Loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; clear smooth boundary.

BC -- 105-125cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; few fine distinct dark yellowish brown (10YR 4/6) redoximorphic concentrations; few coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; neutral; abrupt smooth boundary.

C -- 125-140cm; olive brown (2.5Y 4/4); silt loam; massive; friable; few fine spherical calcium carbonate concentrations; few fine distinct dark yellowish brown (10YR 4/6) redoximorphic concentrations; few coarse faint grayish brown (2.5Y 5/2) redoximorphic depletions; slightly effervescent; moderately alkaline.

Soil Series: Galva

Core Number: RW12-LL

Map Unit Symbol: 310B2

Coordinates: x= -96.397362, Y= 43.016491 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 399.8 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Typic Hapludoll

Slope Characteristics: 2.2 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap1 -- 0-10cm; very dark brown (10YR 2/); silty clay loam; weak granular structure; friable; common fine and very fine roots; neutral; abrupt smooth boundary.

Ap2 -- 10-20cm; very dark brown (10YR 2/2); silty clay loam; moderate subangular blocky structure; firm; common fine and very fine roots; strongly acid; abrupt smooth boundary.

AB -- 20-48cm; dark brown (10YR 3/3); silty clay loam; weak prismatic structure parting to moderate subangular blocky structure; friable; few fine roots; moderately acid; gradual smooth boundary.

Bw1 -- 48-84cm; olive brown (2.5Y 4/3); silty Loam; moderate prismatic structure; friable; slightly acid; clear smooth boundary.

Bw2 -- 84-111cm; olive brown (2.5Y 4/4); silt Loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; abrupt smooth boundary.

BC -- 111-126cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; few fine spherical calcium carbonate concentrations; few fine prominent black (N 2/0) Mn redoximorphic concentrations; few medium distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; slightly alkaline; clear smooth boundary.

C -- 126-141cm; olive brown (2.5Y 4/4); silt loam; massive; friable; few fine spherical calcium carbonate concentrations; few fine distinct dark yellowish brown (10YR 4/6) and few fine prominent black (N 2/0) redoximorphic concentrations; few medium faint grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline.

Soil Series: Galva

Core Number: RE13-LL

Map Unit Symbol: 310B2

Coordinates: x= -96.397076, Y= 43.018496 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 398.8 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Typic Hapludoll

Slope Characteristics: 3.1 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-17cm; very dark brown (10YR 2/2); silty clay loam; weak granular structure; friable; common fine and very fine roots; moderately acid; abrupt smooth boundary.

AB -- 17-35cm; dark brown (10YR 3/3); silty clay loam; weak subangular blocky structure; firm; few very fine roots; slightly acid; clear smooth boundary.

Bw1 -- 35-59cm; olive brown (2.5Y 4/3); silt loam; weak prismatic structure parting to moderate subangular blocky structure; friable; slightly acid; gradual smooth boundary.

Bw2 -- 59-85cm; olive brown (2.5Y 4/4); silt loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; clear smooth boundary.

Bw3 -- 85-99cm; olive brown (2.5Y 4/4); silt loam; moderate subangular blocky structure; friable; common coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; neutral; abrupt smooth boundary.

BC -- 99-120cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; common coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; slightly effervescent; moderately alkaline; abrupt smooth boundary.

C -- 120-125cm; light olive brown (2.5Y 5/4); silt loam; massive; friable; few medium distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; slightly alkaline.

Soil Series: Galva

Core Number: RE14-Avg

Map Unit Symbol: 310B2

Coordinates: x= -96.396915, Y= 43.017357 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 400.9 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Pachic Hapludoll

Slope Characteristics: 5.1 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-23cm; very dark brown (10YR 2/2); silty clay loam; moderate granular structure; friable; common fine and very fine roots; slightly acid; abrupt smooth boundary.

A -- 23-43cm; very dark grayish brown (10YR 3/2); silty clay loam; weak subangular blocky structure; friable; few very fine roots; strongly acid; gradual smooth boundary.

AB -- 43-60cm; dark brown (10YR 3/3); silty clay loam; moderate subangular blocky structure; friable; moderately acid; clear smooth boundary.

Bw1 -- 60-81cm; olive brown (2.5Y 4/4); silty clay loam; weak prismatic structure parting to moderate subangular blocky structure; friable; slightly acid; gradual smooth boundary.

Bw2 -- 81-96cm; olive brown (2.5Y 4/4); silty clay loam; moderate prismatic structure; friable; slightly acid; clear smooth boundary.

BC -- 96-122cm; olive brown (2.5Y 4/4); silty loam; weak subangular blocky structure; friable; few fine prominent black (N 2/0) Mn redoximorphic concentrations; few fine distinct grayish brown (2.5Y 5/2) redoximorphic depletions; neutral; clear smooth boundary.

C -- 122-136cm; olive brown (2.5Y 4/4); silt loam; massive; friable; few fine prominent black (N 2/0) and prominent strong brown (7.5YR 4/6) Fe-Mn redoximorphic concentrations; few coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; neutral.

Soil Series: Judson

Core Number: RE15-Avg

Map Unit Symbol: 8B

Coordinates: x= -96.394555, Y= 43.018399 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 400.2 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Cumulic Hapludoll

Slope Characteristics: 4.8 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-27cm; very dark brown (10YR 2/2); silty clay loam; weak granular structure; friable; common fine and very fine roots; strongly acid; clear smooth boundary.

AB -- 27-40cm; very dark grayish brown (10YR 3/2); silty clay loam; weak prismatic structure parting to moderate subangular blocky structure; friable; few very fine roots; slightly acid; clear smooth boundary.

Bt1 -- 40-63cm; dark brown (10YR 3/3); silty clay loam; moderate prismatic structure; friable; few clay films on the faces of peds; slightly acid; clear smooth boundary.

Bt2 -- 63-78cm; olive brown (2.5Y 4/3); silty clay loam; moderate prismatic structure; friable; few clay films on the faces of peds; neutral; clear smooth boundary.

BC -- 78-110cm; olive brown (2.5Y 4/4); silt loam; weak prismatic structure; friable; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations; few medium distinct grayish brown (2.5Y 4/2); redoximorphic depletions; neutral; gradual smooth boundary.

C -- 110-131cm; olive brown (2.5Y 4/4); silt loam; massive friable; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations; few medium and coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; neutral.

Soil Series: Ida

Core Number: RE16-Avg

Map Unit Symbol: 1C3

Coordinates: x= -96.39468, Y= 43.017412 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 405.7 (meters)

Classification: Coarse-loamy, mixed, superactive (calcareous), mesic, Typic Eutrudept

Slope Characteristics: 10 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-11cm; very dark grayish brown (2.5Y 3/2); silt loam; weak granular structure; friable; common fine and very fine roots; common coarse irregular calcium carbonate concretions; violently effervescent; slightly alkaline; abrupt smooth boundary;

Bw1-- 11-34cm; olive brown (2.5Y 4/3); silt loam; weak subangular blocky structure; friable; few very fine roots; common coarse irregular calcium carbonate concretions; strongly effervescent; moderately alkaline; clear smooth boundary.

Bw2 -- 34-52cm; olive brown (2.5Y 4/4); silt loam; moderate subangular blocky structure; friable; strongly effervescent; slightly alkaline; clear smooth boundary.

BC -- 52-70cm; olive brown (2.5Y 4/4); loam; weak subangular blocky structure; friable; few medium prominent strong brown (7.5YR 5/6) redoximorphic concentrations; common coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline; abrupt smooth boundary;

C1 -- 70-92cm; light olive brown (2.5Y 5/4); fine sandy loam; massive; friable; few fine spherical calcium carbonate concentrations; few fine prominent strong brown (7.5YR 5/8) and reddish brown (5YR 4/4) redoximorphic concentrations; common coarse grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline; clear smooth boundary;

C2 -- 92-120cm; light olive brown (2.5Y 5/4); fine sandy loam; massive; friable; few fine prominent strong brown (7.5YR 5/8) redoximorphic concentrations; common coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline.

Soil Series: Ida

Core Number: RE17-LL

Map Unit Symbol: 1C3

Coordinates: x= -96.394201, Y= 43.017786 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 403.5 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Typic Eutrudept

Slope Characteristics: 9.8 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap1 -- 0-12cm; very dark grayish brown (2.5Y 3/2); silt loam; weak granular structure; friable; common fine and very fine roots; slightly alkaline; abrupt smooth boundary.

Ap2 -- 12-24cm; dark olive brown (2.5Y 3/3); silt loam; weak subangular blocky structure; friable; few very fine roots; slightly alkaline; abrupt smooth boundary.

Bw1 -- 24-38cm; olive brown (2.5Y 4/3); moderate subangular blocky structure; friable; slightly alkaline; abrupt smooth boundary;

Bw2 -- 38-58cm; olive brown (2.5Y 4/4); moderate subangular blocky structure; friable; common coarse irregular calcium carbonate concretions; strongly effervescent; moderately alkaline; clear smooth boundary.

BC -- 58-82cm; olive brown (2.5Y 4/4); weak subangular blocky structure; friable; common coarse irregular calcium carbonate concretions; strongly effervescent; moderately alkaline; clear smooth boundary.

C1 -- 82-117cm; olive brown (2.5Y 4/4); massive; friable; few medium spherical calcium carbonate concentrations; strongly effervescent; moderately alkaline; clear smooth boundary.

C2 -- 117-136cm; light olive brown (2.5Y 5/4); massive; friable; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations; few coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline.

Soil Series: Ida

Core Number: RE18-LL

Map Unit Symbol: 1C3

Coordinates: x= -96.393919, Y= 43.01759 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 404.6 (meters)

Classification: Fine-loamy, mixed, superactive (calcareous), mesic, Typic Eutrudept

Slope Characteristics: 6.8 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-18cm; very dark grayish brown (2.5Y 3/2); silt loam; weak subangular blocky structure; friable; common fine and very fine roots; common medium and coarse irregular calcium carbonate concretions; strongly effervescent; slightly alkaline; abrupt smooth boundary.

Bw1 -- 18-37cm; olive brown (2.5Y 4/3); silt loam; moderate subangular blocky structure; friable few fine roots; common medium and coarse irregular calcium carbonate concretions; strongly effervescent; moderately alkaline; clear smooth boundary.

Bw2 -- 37-73cm; olive brown (2.5Y 4/4); silt loam; moderate subangular blocky structure; friable; common medium and coarse irregular calcium carbonate concretions; strongly effervescent; Moderately alkaline; abrupt smooth boundary.

BC -- 73-100cm; light olive brown (2.5Y 5/4); loam; weak subangular blocky structure; friable; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations; few medium distinct gray (2.5Y 5/1) redoximorphic depletions; slightly effervescent; moderately alkaline; clear smooth boundary.

C1 -- 100-116cm; light olive brown (2.5Y 5/4); sandy loam; massive; friable; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations; few medium distinct gray (2.5Y 5/1) redoximorphic depletions; slightly effervescent; moderately alkaline; gradual smooth boundary.

C2 -- 116-132cm; light olive brown (2.5Y 5/4); loam; massive; friable; common coarse prominent yellowish brown (10YR 5/8) redoximorphic concentrations; common coarse distinct grayish brown (2.5Y 5/2) redoximorphic depletions; strongly effervescent; moderately alkaline.

Soil Series: Galva

Core Number: RE19-Avg

Map Unit Symbol: 310C2

Coordinates: x= -96.391632, Y= 43.016506 (GCS: WGS 1984; decimal Degrees)

Elevation: Z= 415.5 (meters)

Classification: Fine-silty, mixed, superactive, mesic, Typic Hapludoll

Slope Characteristics: 7.9 (percent)

Precipitation: Udic Moisture Regime

Date: 12/17/2014

Ap -- 0-18cm; very dark brown (10YR 2/2); silty clay loam; weak granular structure; firm; common fine and very fine roots; neutral; abrupt smooth boundary.

AB -- 18-39cm; dark brown (10YR 3/3); silty clay loam; moderate subangular blocky structure; friable; few fine roots; neutral; clear smooth boundary.

Bw1 -- 39-65cm; olive brown (2.5Y 4/3); silty clay loam; moderate prismatic structure; friable; neutral; gradual smooth boundary;

Bw2 -- 65-97cm; olive brown (2.5Y 4/4); silt loam; weak prismatic structure parting to moderate subangular blocky structure; friable; neutral; abrupt smooth boundary.

BC -- 97-117cm; olive brown (2.5Y 4/4); silt loam; weak subangular blocky structure; friable; few fine prominent yellowish brown (10YR 5/8) and black (N 2/0) Fe-Mn redoximorphic features; common coarse distinct gray (2.5Y 5/1) redoximorphic depletions; strongly effervescent; moderately alkaline; clear smooth boundary.

C -- 117-131cm; olive brown (2.5Y 4/4); silt loam; massive; friable; few fine prominent strong brown (7.5YR 5/6) and black (N 2/0) Fe-Mn redoximorphic concentrations; common coarse distinct gray (2.5Y 5/1) redoximorphic depletions; strongly effervescent; moderately alkaline.

APPENDIX B. SOIL LABORATORY DATA

Units of Soil Parameter Measurements:

Depth:	cm
Sand	g $100g^{-1}$
Silt	g $100g^{-1}$
Clay	g $100g^{-1}$
TC	g kg^{-1}
TN	g kg^{-1}
M3P	mg kg^{-1}
M3K	mg kg^{-1}
pH	-log H^+

Label	depth class	Horizon	depth	tot. C	tot. N	m3P	m3K	pH	sand	cos. Silt	fine silt	clay	tot. silt	Texture
RW1-Avg-1	25	Ap1	13	23.2	2.237	46	220	4.85	6.13	40.82	23.32	29.72	64.14	Silty Clay Loam
RW1-Avg-2	25	Ap2	22	19.8	2.212	13	153	1.8	4.45	38.15	25.78	31.62	63.93	Silty Clay Loam
RW1-Avg-3	100	Bw1	61	8.253	1.282	5	86	6.1	3.4	25.62	38.8	32.18	64.42	Silty Clay Loam
RW1-Avg-4	100	Bw2	99	4.053	1.712	8	145	6.45	5.67	36.45	28.31	29.57	64.76	Silty Clay Loam
RW1-Avg-5	>100	BC	130	2.928	1.229	12	116	6.75	7.46	36.92	29.78	25.84	66.7	Silt Loam
RW1-Avg-6	>100	C	144+	2.546	2.315	33	127	6.95	9.39	43.9	24.98	21.73	68.88	Silt Loam
RW2-Avg-1	25	Ap1	18	24.14	2.24	71	577	6.45	6.15	41.36	26.85	25.65	68.21	Silt Loam
RW2-Avg-2	100	Ap2	36	22.61	2.179	36	288	6.25	5.74	40.26	26.69	27.31	66.95	Silty Clay Loam
RW2-Avg-3	100	A	68	27.04	2.215	6	179	6.15	5.58	36.54	28.94	28.93	65.48	Silty Clay Loam
RW2-Avg-4	100	AB	92	19.42	1.751	6	201	6.05	4.93	35.93	29.89	29.25	65.82	Silty Clay Loam
RW2-Avg-5	>100	Bw	125	10.69	1.119	8	226	6.5	5.09	38.58	29.14	27.19	67.72	Silty Clay Loam
RW2-Avg-6	>100	BC	141+	7.862	0.749	9	221	6.85	5.36	37.24	29.26	28.14	66.5	Silty Clay Loam
RW3-HH-1	25	Ap	18	25.99	2.34	42	369	6.2	6.31	38.15	26.92	28.62	65.07	Silty Clay Loam
RW3-HH-2	100	A	39	22.05	1.998	3	172	6.5	6.26	32.89	30.49	30.36	63.38	Silty Clay Loam
RW3-HH-3	100	AB	57	14.91	1.393	1	160	6.65	7.45	36.93	25.1	30.52	62.03	Silty Clay Loam
RW3-HH-4	100	Bw1	80	8.96	0.999	2	161	7.25	9.88	38.82	23.6	27.7	62.42	Silty Clay Loam
RW3-HH-5	100	Bw2	100	22.72	0.571	1	137	7.9	13.27	42.11	22.85	21.78	64.96	Silt Loam
RW3-HH-6	>100	BC	122	16.65	0.513	2	138	7.9	17.54	45.91	16.63	19.92	62.54	Silt Loam
RW3-HH-7	>100	C	137+	14.98	0.306	2	139	7.95	12.52	46.26	19.6	21.62	65.86	Silt Loam
RW4-HH-1	25	Ap	22	22.79	2.369	34	390	5.75	4.67	36.82	27.84	30.67	64.66	Silty Clay Loam
RW4-HH-2	100	A	38	7.534	0.875	14	208	5.8	3.51	32.88	29.06	34.55	61.94	Silty Clay Loam
RW4-HH-3	100	AB	51	5.642	0.649	24	211	5.95	3.82	30.74	31.6	33.84	62.34	Silty Clay Loam
RW4-HH-4	100	Bw1	69	4.362	0.556	36	206	6	7.36	33.41	27.68	31.55	61.09	Silty Clay Loam
RW4-HH-5	100	Bw2	97	3.316	0.529	47	174	6.15	9.73	38.22	24.31	27.74	62.53	Silty Clay Loam
RW4-HH-6	>100	BC	133	2.837	0.396	26	161	6.35	11.19	72.23	20.07	26.51	92.3	Silt Loam
RW4-HH-7	>100	Cg	141+	4.672	0.296	51	178	7.45	13.62	39.71	16.63	30.04	56.34	Silty Clay Loam
RW5-Avg-1	25	Ap	24	25.13	2.171	24	339	6.35	6.1	40.38	22.61	30.94	62.99	Silty Clay Loam

Label	depth class	Horizon	depth	tot. C	tot. N	m3P	m3K	pH	sand	cos. Silt	fine silt	clay	tot. silt	Texture
RW5-Avg-2	100	A	40	14.58	1.482	2	146	6.15	11.4	35.68	31.72	21.21	67.4	Silt Loam
RW5-Avg-3	100	AB	62	8.086	0.977	2	135	6.5	10.73	39.27	23.99	26	63.26	Silt Loam
RW5-Avg-4	100	Bw	89	5.251	0.71	4	133	7.05	12.75	40.18	22.17	24.89	62.35	Silt Loam
RW5-Avg-5	>100	BC	110	22.41	0.475	1	120	8	11.79	42.06	23.88	22.27	65.94	Silt Loam
RW5-Avg-6	>100	Cg	130+	19.17	0.29	1	123	8.15	9.43	45.93	24.83	19.82	70.76	Silt Loam
RW6-Avg-1	25	Ap	23	21.9	2.235	24	203	5.1	5.14	35.91	29.22	29.72	65.13	Silty Clay Loam
RW6-Avg-2	100	AB	50	8.874	1.055	6	167	6.1	2.34	30.96	32.47	34.24	63.43	Silty Clay Loam
RW6-Avg-3	100	Bw1	89	4.188	0.54	11	158	6.25	4.75	39.12	28.15	27.98	67.27	Silty Clay Loam
RW6-Avg-4	>100	Bw2	110	3.381	0.569	33	155	6.7	8.21	41.55	27	23.23	68.55	Silt Loam
RW6-Avg-5	>100	BC	122	13.58	0.475	6	138	7.8	8.12	47.4	23.92	20.57	71.32	Silt Loam
RW6-Avg-6	>100	C	139+	14.59	0.334	6	134	7.9	10.31	47.3	23.32	19.07	70.62	Silt Loam
RW7-Avg-1	25	Ap	17	21.47	2.195	27	300	6.4	4.28	35.51	30.92	29.26	66.43	Silty Clay Loam
RW7-Avg-2	100	A	34	7.406	1.13	6	159	6.1	3.19	32.71	30.49	33.6	63.2	Silty Clay Loam
RW7-Avg-3	100	AB	51	5.387	0.682	7	162	6.4	4.82	36.51	26.01	32.65	62.52	Silty Clay Loam
RW7-Avg-4	100	Bw1	71	4.072	0.403	11	154	6.65	5.64	40.83	25.22	28.3	66.05	Silty Clay Loam
RW7-Avg-5	100	Bw2	99	3.296	0.431	31	137	6.8	9.45	44	22.13	24.42	66.13	Silt Loam
RW7-Avg-6	>100	BC	120	14.37	0.472	6	126	7.65	8.45	46.63	25.58	19.34	72.21	Silt Loam
RW7-Avg-7	>100	C	136+	19.09	0.328	7	135	7.8	10.29	47.05	23.76	18.91	70.81	Silt Loam
RW8-HH-1	25	Ap	20	24.97	2.283	99	630	6.6	4.95	38.63	28.59	27.84	67.22	Silty Clay Loam
RW8-HH-2	100	A	42	18.33	1.904	10	210	5.7	4.4	38.27	27.6	29.74	65.87	Silty Clay Loam
RW8-HH-3	100	AB	78	8.997	1.021	24	223	5.45	2.64	26.54	32.19	28.63	58.73	Silty Clay Loam
RW8-HH-4	100	Bt1	95	6.449	1.001	43	203	5.6	3.97	38.74	29.02	28.27	67.76	Silty Clay Loam
RW8-HH-5	>100	Bt2	117	6.165	0.725	44	201	5.8	3.91	37.84	31.99	26.45	69.83	Silt Loam
RW8-HH-6	>100	BC	138+	6.049	0.901	48	196	5.6	2.3	31.03	36.27	30.41	67.3	Silty Clay Loam
RW9-HH-1	25	Ap1	20	20.38	1.996	26	279	5.95	3.9	38.09	27.04	30.96	65.13	Silty Clay Loam
RW9-HH-2	100	Ap2	31	11.35	1.296	5	187	5.85	3.78	38.65	28.19	29.38	66.84	Silty Clay Loam
RW9-HH-3	100	AB	57	6.966	0.797	9	203	6.1	5.79	38.42	26.41	29.38	64.83	Silty Clay Loam

Label	depth class	Horizon	depth	tot. C	tot. N	m3P	m3K	pH	sand	cos. Silt	fine silt	clay	tot. silt	Texture
RW9-HH-4	100	Bw	95	3.365	0.386	17	165	6.35	8.95	43.46	22.79	24.81	66.25	Silt Loam
RW9-HH-5	>100	BC	105	2.835	4.08	31	171	6.35	7.49	43.81	23.44	25.26	67.25	Silt Loam
RW9-HH-6	>100	C	130+	2.401	0.303	67	162	6.65	9.88	42.4	22.69	25.02	65.09	Silt Loam
RW10-Avg-1	25	Ap	24	20.23	2.104	14	231	6.15	3.5	37.26	27.08	32.15	64.34	Silty Clay Loam
RW10-Avg-2	100	AB	56	7.096	0.884	3	186	6	3.51	35.32	27.95	33.22	63.27	Silty Clay Loam
RW10-Avg-3	100	Bw1	70	4.304	0.585	5	170	6.4	7.94	47.24	20.11	24.71	67.35	Silt Loam
RW10-Avg-4	>100	Bw2	102	3.577	0.565	11	167	6.65	9.55	46.46	20.91	23.08	67.37	Silt Loam
RW10-Avg-5	>100	BC	120	10.68	0.387	5	149	7.7	9.87	51.45	20.83	17.86	72.28	Silt Loam
RW10-Avg-6	>100	C	136+	15.97	0.558	3	141	7.95	11.01	54.94	17.34	16.71	72.28	Silt Loam
RW11-LL-1	25	Ap1	10	25.49	2.674	51	358	5.75	4.49	39.01	27.52	28.98	66.53	Silty Clay Loam
RW11-LL-2	25	Ap2	21	18.87	2.042	13	174	4.85	3.28	36.73	29.1	30.88	65.83	Silty Clay Loam
RW11-LL-3	100	AB	48	9.67	1.299	3	164	5.8	2.13	30.99	33.74	33.14	64.73	Silty Clay Loam
RW11-LL-4	100	Bw1	81	4.635	0.761	7	178	6.6	3.22	35.09	30.92	30.77	66.01	Silty Clay Loam
RW11-LL-5	>100	Bw2	105	3.456	0.565	27	156	6.7	7.73	42.34	26.29	23.64	68.63	Silt Loam
RW11-LL-6	>100	BC	125	3.169	0.532	58	164	7	7.46	41.46	29.29	24.79	70.75	Silt Loam
RW11-LL-7	>100	C	140+	14.33	0.393	6	135	7.85	9.24	47.32	23.4	20.04	70.72	Silt Loam
RW12-LL-1	25	Ap1	10	23.35	2.412	32	370	6.6	3.96	40.57	24.35	31.12	64.92	Silty Clay Loam
RW12-LL-2	25	Ap2	20	19.29	1.968	11	216	5.25	3.9	37.9	24.03	34.17	61.93	Silty Clay Loam
RW12-LL-3	100	AB	48	7.481	0.97	3	163	5.95	3.67	37.85	26.73	31.76	64.58	Silty Clay Loam
RW12-LL-4	100	Bw1	84	3.93	0.644	7	153	6.45	6.91	41.38	25.66	26.05	67.04	Silt Loam
RW12-LL-5	>100	Bw2	111	3.367	0.387	20	155	6.75	9.48	45.14	21.9	23.48	67.04	Silt Loam
RW12-LL-6	>100	BC	126	13.9	0.416	4	135	7.75	9.75	51.09	17.9	21.26	68.99	Silt Loam
RW12-LL-7	>100	C	141+	15.79	0.485	3	138	7.85	11.41	46.27	20.35	21.98	66.62	Silt Loam
RE13-LL-1	25	Ap	17	19.99	2.006	21	289	5.85	5.19	37.87	25.86	31.08	63.73	Silty Clay Loam
RE13-LL-2	100	AB	35	6.951	0.821	4	166	6.05	4.42	37.41	25.97	32.19	63.38	Silty Clay Loam
RE13-LL-3	100	Bw1	59	4.693	0.675	6	154	6.35	7.41	41.55	25.7	25.34	67.25	Silt Loam
RE13-LL-4	100	Bw2	85	3.67	0.77	14	149	6.6	8.21	43.92	23.76	24.11	67.68	Silt Loam

Label	depth class	Horizon	depth	tot. C	tot. N	m3P	m3K	pH	sand	cos. Silt	fine silt	clay	tot. silt	Texture
RE13-LL-5	100	Bw3	99	3.806	0.617	23	140	7	12.04	44.25	22.09	21.62	66.34	Silt Loam
RE13-LL-6	>100	BC	120	14.79	0.399	3	124	7.85	10.68	47.67	20.63	21.03	68.3	Silt Loam
RE13-LL-7	>100	C	125+	16.05	0.265	3	137	7.6	9.68	46.14	22.17	22.02	68.31	Silt Loam
RE14-AVG-1	25	Ap	23	23.71	2.393	39	390	6.15	3.74	38.13	29.82	28.31	67.95	Silty Clay Loam
RE14-AVG-2	100	A	43	13.37	1.536	7	161	5.4	2.48	35.71	31.76	30.05	67.47	Silty Clay Loam
RE14-AVG-3	100	AB	60	7.132	0.859	5	192	6	2.86	32.64	31.04	33.46	63.68	Silty Clay Loam
RE14-AVG-4	100	Bw1	81	4.713	0.695	5	199	6.25	2.09	34.16	30.13	33.62	64.29	Silty Clay Loam
RE14-AVG-5	100	Bw2	96	3.747	0.454	8	201	6.5	3.47	36.51	28.19	31.83	64.7	Silty Clay Loam
RE14-AVG-6	>100	BC	122	3.197	0.458	18	175	6.65	8.94	40.82	24.27	25.97	65.09	Silt Loam
RE14-AVG-7	>100	C	136	2.798	0.447	39	162	6.65	6.51	43.08	26.09	24.31	69.17	Silt Loam
RE15-AVG-1	100	Ap	27	13.37	1.534	6	153	5.3	3.24	39.78	29.026	27.72	68.806	Silty Clay Loam
RE15-AVG-2	100	AB	40	7.926	0.64	3	166	6.2	2.17	34.2	33.93	29.7	68.13	Silty Clay Loam
RE15-AVG-3	100	Bt1	63	5.548	0.559	3	191	6.45	2.99	34.49	29.46	33.06	63.95	Silty Clay Loam
RE15-AVG-4	100	Bt2	78	3.691	0.516	7	173	6.65	6.65	41.56	24.23	27.56	65.79	Silty Clay Loam
RE15-AVG-5	>100	BC	110	3.228	0.466	12	160	6.9	7.23	43.12	23.48	26.17	66.6	Silt Loam
RE15-AVG-6	>100	C	131+	3.199	0.257	39	143	7	10.88	43.86	23.68	21.58	67.54	Silt Loam
RE16-Avg-1	25	Ap	11	29.75	1.609	15	238	7.55	11.91	41.88	22.73	23.48	64.61	Silt Loam
RE16-Avg-2	100	Bw1	34	15.43	0.433	3	102	7.85	29.01	36.23	16.67	18.1	52.9	Silt Loam
RE16-Avg-3	100	Bw2	52	22.99	0.332	2	113	7.8	13.66	41.79	22.97	21.58	64.76	Silt Loam
RE16-Avg-4	100	BC	70	12	0.079	4	75	8	50.63	26.6	9.54	13.22	36.14	Loam
RE16-Avg-5	100	C1	92	10.16	0.041	4	70	7.95	59.74	20.98	6.22	13.07	27.2	Sandy Loam
RE16-Avg-6	>100	C2	120+	11.1	0.111	5	68	8	64.9	16.53	6.26	12.31	22.79	Sandy Loam
RE17-LL-1	25	Ap1	12	23.42	1.656	11	165	7.7	12.13	42.02	20.11	25.74	62.13	Silt Loam
RE17-LL-2	25	Ap2	24	10.06	0.911	3	133	7.75	11.29	41.63	21.03	26.05	62.66	Silt Loam
RE17-LL-3	100	Bw1	38	7.875	0.754	2	126	7.8	11.43	43.11	20.63	24.83	63.74	Silt Loam
RE17-LL-4	100	Bw2	58	20.06	0.571	1	118	8	11.56	43.5	23.08	21.86	66.58	Silt Loam
RE17-LL-5	100	BC	82	20.61	0.343	1	119	7.9	12.42	45.57	20.87	21.14	66.44	Silt Loam

Label	depth class	Horizon	depth	tot. C	tot. N	m3P	m3K	pH	sand	cos. Silt	fine silt	clay	tot. silt	Texture
RE17-LL-6	>100	C1	117	18.11	0.353	1	115	7.1	11.8	46.07	21.34	20.79	67.41	Silt Loam
RE17-LL-7	>100	C2	136+	20.67	0.326	2	116	8	10.13	47.67	22.45	19.76	70.12	Silt Loam
RE18-LL-1	25	Ap	18	26.6	1.482	10	166	7.7	10.98	42.89	21.82	24.31	64.71	Silt Loam
RE18-LL-2	100	Bw1	37	23.54	0.552	1	101	7.95	11.85	41.71	25.14	21.3	66.85	Silt Loam
RE18-LL-3	100	Bw2	73	19.16	0.35	2	102	8.05	15.01	41.04	22.77	21.18	63.81	Silt Loam
RE18-LL-4	100	BC	100	11.75	0.102	3	65	8.2	50.7	23.57	11.84	13.9	35.41	Loam
RE18-LL-5	>100	C1	116	10.6	0.143	3	68	8.2	53.09	24.22	8.99	13.7	33.21	Sandy Loam
RE18-LL-6	>100	C2	132+	12.88	0.246	3	80	8.15	45.18	27.66	11.8	15.36	39.46	Loam
RE19-Avg-1	25	Ap	18	20.61	1.96	196	470	7.15	3.68	35.81	29.34	31.16	65.15	Silty Clay Loam
RE19-Avg-2	100	AB	39	6.864	0.927	3	192	6.6	2.18	31.86	30.73	35.24	62.59	Silty Clay Loam
RE19-Avg-3	100	Bw1	65	4.613	0.626	6	183	6.75	4.73	37.26	28.3	29.78	65.56	Silty Clay Loam
RE19-Avg-4	100	Bw2	97	3.4	0.581	17	159	7	8.24	42.7	24.98	24.07	67.68	Silt Loam
RE19-Avg-5	>100	BC	117	15.46	0.306	4	135	7.95	9.42	46.62	23.28	20.67	69.9	Silt Loam
RE19-Avg-6	>100	C	131+	16.17	0.285	3	125	8	10.02	46.82	23	20.15	69.82	Silt Loam