A COMPARISON OF SOIL CHARACTERISTICS IN RELATION TO SUCCESS OF A RESTORED PRAIRIE

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by
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A COMPARISON OF SOIL CHARACTERISTICS IN RELATION TO SUCCESS OF A RESTORED PRAIRIE

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ABSTRACT

The Department of Energy's Weldon Spring Site began as an ordinance site and later became a uranium processing facility. Remediation of hazardous waste resulted in an on-site disposal cell and approximately 150 surrounding acres that provided an opportunity to restore a prairie, named Howell Prairie. The 150 acre prairie was established in June, 2002, including the planting of 89 native prairie species. In 2008, a study began to quantify the success of the prairie establishment. Success monitoring shows strong establishment of native prairie species in three of four plots. The fourth plot, Subarea 2C, also showed relatively high cover, but lacked grasses and supported much shorter foliage than the other three plots. It was determined that differences in the soil composition may be the cause of the lack of success in Subarea 2C because it also had light soil color, higher clay content, and lower silt content compared to the other three permanent plots. This study attempts to determine the soil characteristics at Howell

Prairie and how those relate to prairie success by using a stratified sampling regime. Forty-six samples were taken, attempting to maintain a diffuse distribution of sampling points with a bias in Subarea 2C. The study measured soil grain size and texture, compaction and infiltration, nutrients, minerals with a focus on clay minerals, organic matter, soil pH, neutralizable acidity, and cation exchange capacity. Results showed the percent of silt was lower in Subarea 2C. The resulting textures showed that this area's soils were loam and clay loam, with silt loam and silty clay loam in other areas. All samples had quartz in the clay and non-clay fractions. Other non-clay minerals present included potassium feldspar and plagioclase. Of the clay minerals, several were present throughout the study area: illite, interstratified illite-montmorillonite, and kaolinite. Interstratified kaolinite-smectite was found in Subarea 2C. Most nutrients were insignificant, except phosphorus, which was lower, and magnesium was at toxic levels in Subarea 2C. It is hypothesized that a potassium amendment will reduce magnesium uptake and promote success. To demonstrate this, the potassium to magnesium ratio was studied.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the College of Arts and Sciences have examined a thesis titled "A Comparison of Soil Characteristics in Relation to Success of a Restored Prairie," presented by Stephen M. Krabbe, candidate for the Master of Science degree, and certify that in their opinion it is worthy of acceptance.

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LIST OF ABBREVIATIONS

CEC – Cation Exchange Capacity

DOE – U.S. Department of Energy

EPA – U.S. Environmental Protection Agency

NA – Neutralizable Acidity

OM – Organic Matter

SEM – Scanning Electron Microscope

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CHAPTER 1

INTRODUCTION

History and Previous Work

The Department of Energy Weldon Spring Site began as an ordinance site and later became a uranium processing facility. Remediation of hazardous waste from both facilities resulted in an on-site disposal cell and approximately 150 surrounding acres that provided an opportunity to restore a prairie, named Howell Prairie, to be used for education and recreation (Weldon Spring, Missouri 2011).

The 150 acre prairie was completed in June, 2002, including the planting of 89 native prairie species. In 2008, a study began to quantify the success of the prairie establishment (Franson and Scholes 2009). The study also included root sampling for mycorrhizal fungi and soil sampling for various parameters (MDNR 2011a, MDNR 2012). Success monitoring on four permanent plots (Figure 1) shows strong establishment of native prairie species in three of the four plots. The fourth permanent plot, Subarea 2C, also showed relatively high cover, but lacked grasses and supported much shorter foliage than the other three plots (MDNR 2012). Fire and drought are important determinants of cover and species composition; however, they do not explain the lack of grasses and short stature of the plants in Subarea 2C (MDNR 2012).

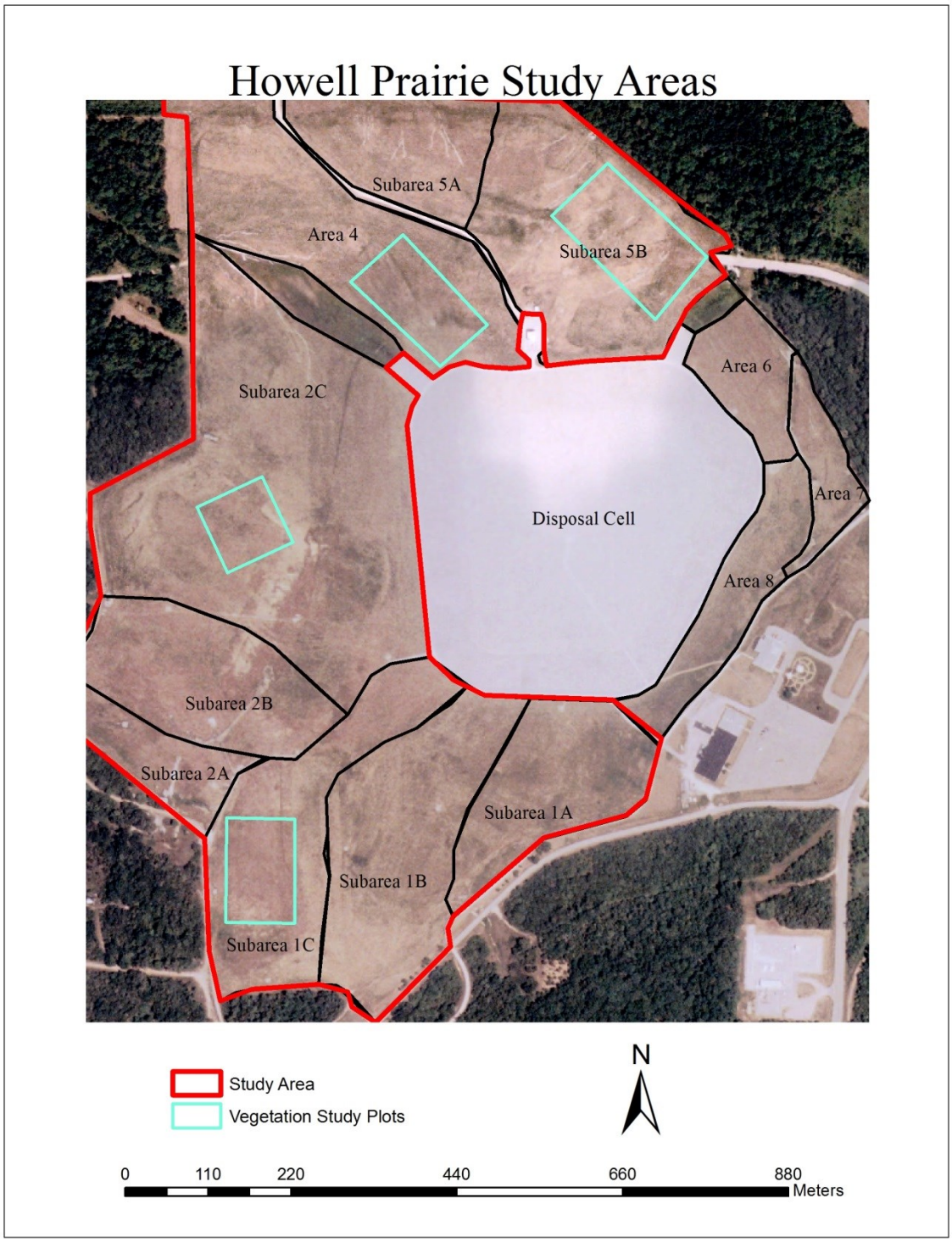


Figure 1. Areas, Subareas, and Vegetation Analysis Plots at Howell Prairie

Since rainfall and atmospheric conditions are the same in each study area, and the seeding and fertilization regimes are assumed to have been consistent across the area (data is not available), it was assumed that differences in the soil composition may be the cause of the lack of success in Subarea 2C (MDNR 2011b). The study also concluded that the soil in this area must be of different origin because of its lighter color and relatively low percentage of clay and relatively higher percentage of silt (MDNR 2011b). This is supported by historical maps showing settling basins in the area before remediation (Figure 2), which would have needed to be drained, remediated, then filled in.

Mycorrhizal fungi, especially Arbuscular Mycorrhizal fungi (AM), are important in the uptake of nutrients by plants, especially phosphorus, and also affect soil structure by holding particles together (MDNR 2011b). Root staining of five plants of five different native prairie plant species (grasses and herbs) all showed fungal colonization. This suggests that mycorrhizal fungi are not limiting plant growth or prairie establishment on Howell Prairie (MDNR 2011a).

Initial soil measurements on Howell Prairie suggest that organic matter (OM) and cation exchange capacity (CEC) are low and that pH is slightly high across Howell Prairie. More importantly, Subarea 2C showed light soil color, higher clay content, and lower silt content compared to the other three permanent plots (MDNR 2012).

The majority of Howell Prairie was established from native soils. However, before remediation, Subareas 2B and 2C contained settling basins that remediation

ultimately required fill soil to bring the area back up to grade (Figure 2). Fill material came from at least half a mile away.

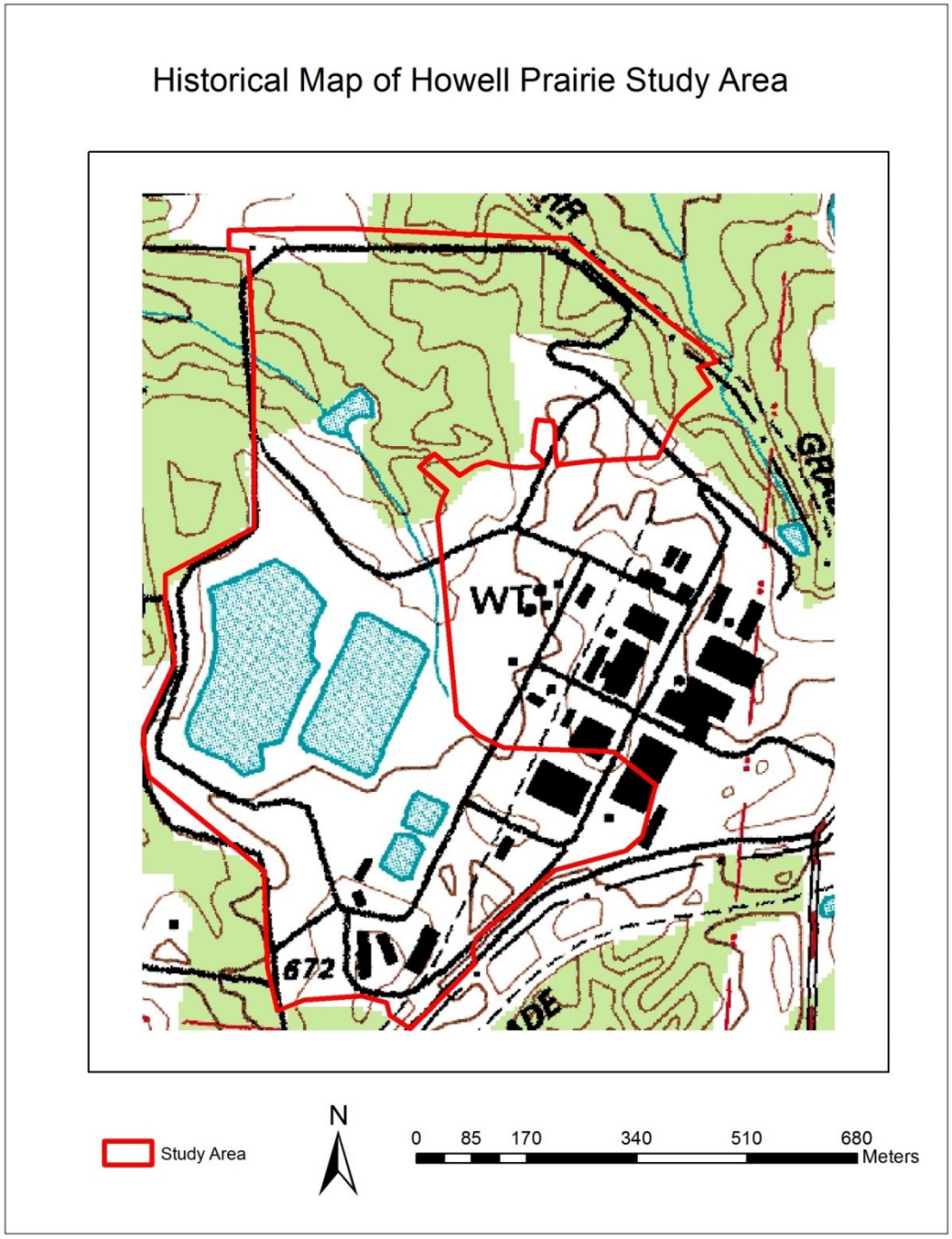


Figure 2. Historical Map of the Weldon Spring Site, showing where settling basins had been located that would need to be filled during construction of the prairie.

Current Study

The current study was designed to answer the question: what are the soil characteristics at Howell Prairie and how do those relate to prairie success? This study measures important characteristics of the soil at Howell Prairie and compares them to the success of prairie establishment of four permanent vegetation plots across the prairie.

Soils have several factors that contribute to the growth and health of plant communities. This study measured soil grain size and texture, compaction and infiltration, nutrients, minerals with a focus on clay minerals, OM, soil pH, neutralizable acidity (NA), and CEC.

For this study, soil samples were taken from the top four inches of soil. The top few inches are where most nutrient cycling happens and, subsequently, where most of the roots of prairie plants reside (Brady 1990). Weldon Spring personnel requested no sampling deeper than six inches. The soil samples were collected to represent the largest five areas of the prairie with a bias toward Subarea 2C. In order to represent the spatial differences in the soil factors, a stratified sampling regime was used across the areas and subareas. The areas and subareas (Figure 1) were established based on slope and aspect as an initial physical zonation of the prairie (Franson and Scholes 2011). From there, 46 samples were taken at non-random points across each subarea of the prairie, selected by taking representative samples, attempting to maintain a diffuse distribution (biased toward Subarea 2C) of sampling points. Once all of the characteristics of the prairie soil were recorded, they were incorporated into a geographic information system (GIS) to determine how they differ across the prairie.

Soil Texture

Soil texture is important because it gives an indication of the physical properties of a soil; a clayey soil will be stickier and more plastic than a loam, while a sandy soil will transfer water more quickly. Too much clay or too much sand both can be detrimental to plant growth. The texture is determined by the percentages of sand (0.05 to 2.0 mm), silt (0.002 to 0.05 mm), and clay (< 0.002 mm) in the soil (Brady, 1990). Initial soil samples showed higher silt in Area 5, while Area 2 was lowest (MDNR 2011a).

Clay and Non-clay Minerals

The nutrients that plants require must also be available to them. Clay minerals are important because they hold water, nutrients, and organic material and determine their availability to plants (Troeh and Thompson 2005). The presence of specific clay minerals was determined by x-ray diffraction for this study. These have not been studied previously at Howell Prairie.

There are a wide variety of clay minerals, which are grouped based on their composition. All clays are composed of silicon and aluminum atoms arranged in layers of tetrahedral and octahedral sheets. The basic form is the kaolin group, consisting of two sheets, one tetrahedral and one octahedral, called a 1:1 layer (Troeh and Thompson 2005). The kaolin group includes kaolinite, dickite, and nacrite, which all form similar hexagonal structures but differ in the arrangement of the layers, and halloysite, which has water between the layers and iron replacing some of the aluminum atoms, making it form a tubular morphology (Murray et al. 1993).

Most of the remaining clay minerals consist of layers of 2:1 sheets, tetrahedral-octahedral-tetrahedral, and differ by their inter-layer composition (Troeh and Thompson 2005). These include the smectites, which expand due to the interlayer presence of water and exchangeable organic compounds, or calcium, magnesium, or potassium ions (Velde 2009). The most common smectites include montmorillonite and bentonite (Troeh and Thompson 2005). They are formed from the decomposition of many igneous rocks (Faure 1998). Illite has anhydrous potassium in the interlayers, does not expand, and can be formed from the decomposition of feldspar or the recrystallization of smectites (Meuner and Velde 2004). Those clay minerals with hydroxy interlayer ions are called the HI clays and include vermiculite and chlorite (Velde 2009). They are partially expanded and do not swell with added water (Troeh and Thompson 2005). Allophane is very fine material that is formed from the complete decomposition of clays or in volcanic ash and can be a source of magnesium and iron (Troeh and Thompson 2005).

Further complicating the study of clay minerals are those that are mixed, where one layer substitutes another (Velde 1995). These interstratified crystals share the properties of those crystals that make them up (Velde 1995). The interstratified clays are thought to be a transition phase of one clay mineral to another and are referred to by the names of those minerals that they are composed of, such as illite-smectite or kaolinite-smectite (Velde 1995).

Non-clay minerals make up the sand fraction of soils (Brady 1990). These include quartz, the primary sand mineral, feldspars, micas, and other minerals (Brady 1990). These are largely inert, but may provide potassium or other nutrients to the soil as

they decompose (Brady 1990). The presence of these was also determined by x-ray diffraction techniques.

Compaction and Infiltration

Compaction and infiltration rates of soil affect the ability of water, air, and roots to move through the soil and can vary depending on how moist the soil is (Troeh and Thompson 2005). Sandy soils that are compact increase the availability of water by increasing fine pore spaces that hold water through adhesion, while uncompact sandy soils have larger pore spaces that allow water to flow through and past most of the roots (Troeh and Thompson 2005). Compacted clayey soils restrict the movement of water and growth of roots (Troeh and Thompson 2005). For this study, compaction was determined in the field using a penetrometry technique during both moist and drought conditions. Infiltration, the rate at which water enters soil, is relevant because low infiltration rates mean that precipitation may runoff the surface and not be available to plants, while high rates mean that precipitation flows through the soil, below the root zone (Troeh and Thompson 2005). For native prairies in the Midwest, infiltration rates of 0.17 to 0.25 cm/min have been reported and are used in this study for comparison (Al-Kaisi 2005).

Nutrients

Plants need specific nutrients for proper growth. The macronutrients, those plants require in large amounts, include nitrogen, potassium, phosphorus, magnesium, calcium, and sulfur (Troeh and Thompson 2005). For this study, nitrogen, potassium, phosphorus, calcium, and magnesium were analyzed with extraction methods. Since little information

is available about the specific requirements of these nutrients for prairie growth, agricultural requirements are used as a proxy for some nutrients.

Nitrogen

Nitrogen is necessary for plant growth and included in most plant compounds (Troeh and Thompson 2005). Nitrogen is made available to plants through microbial activities that break down organic matter and "fix" atmospheric nitrogen and is the most commonly limiting nutrient for terrestrial plant communities (Troeh and Thompson 2005). Since nitrate (NO_3^-) is one form of nitrogen available to plants (Marx et al. 1999), it was used for this study to approximate available nitrogen. For agriculture, amounts greater than 10 ppm are recommended (Marx et al. 1999). There have been no tests of soil nitrate at Howell Prairie.

Potassium

Potassium in soils comes from mineral sources, such as micas and feldspars (Troeh and Thompson 2005). Potassium levels are recommended to be between 80 and 100 ppm for agriculture (Espinoza, Slaton & Mozaffari). Potassium availability is dependent on other soil conditions: acidic soils reduce potassium availability, high calcium content soils increase the availability of potassium to plants, the types and amounts of clay minerals affect the release of potassium under varying conditions (Troeh and Thompson 2005). Potassium is essential for plants because it helps in the movement of other nutrients, photosynthesis, and formation of proteins and carbohydrates (Troeh and Thompson 2005). In a previous study of the Weldon Spring site, potassium averaged 104 ppm, and was lowest in area 2 and highest in area 5 (MDNR 2011a).

Phosphorus

Phosphorus in native soils near the study site usually range from 500 to 900 ppm. Phosphorus is used by plants for nearly all processes and comes from the decomposition of the mineral apatite (Troeh and Thompson 2005). For this study, its content was tested as phosphate, the organic and absorbable phase of phosphorus (Troeh and Thompson 2005). At the study area, phosphorus averaged 11.5 ppm and was not significantly different between areas and subareas (MDNR 2011a). Phosphorus is generally considered to be the second most limiting plant nutrient (Troeh and Thompson 2005)

Calcium

Calcium is used by plants for building cell walls and stimulates the absorption of potassium and nitrogen; therefore, deficiencies lead to stunted growth and weak roots and shoots (Troeh and Thompson 2005). Calcium should be greater than 400 ppm for optimal growth for agricultural uses, including forages (Espinoza, Slaton & Mozaffari). At the study site, calcium has averaged between 2500 and 2600 ppm, with no trends between areas and subareas (MDNR 2011a).

Magnesium

Magnesium is used by plants as a component of chlorophyll and is added to the soil through the decomposition of micas, olivine, and dolomite (Troeh and Thompson 2005). It has an antagonistic relationship with other minerals in plants (Ohno et al. 1985). For instance, an excess of magnesium reduces the uptake of the potassium (Ohno et al. 1985). Increases in potassium, calcium, aluminum, manganese and ammonia have

been known to reduce the amount of magnesium plants absorb (Mayland et al. 1979). Magnesium is normally between 60 and 180 ppm in agricultural soils (Marx et al. 1996). Magnesium was recorded at levels above 180 ppm in a previous study at Howell Prairie (MDNR 2011a).

Nutrient Toxicity and Ratios

Both macro- and micronutrients, while required for plant growth, can also limit plant growth at levels that are too high (Troeh and Thompson 2005). Stunting is a common plant response to nutrient toxicity (Troeh and Thompson 2005).

Since some nutrients are antagonistic to other nutrients, the ratio of one nutrient to another is related to the ability of each nutrient to be absorbed by plants (Ohno et al. 1985). For this study, the ratio of potassium to magnesium was analyzed. Data from the previous studies of Howell Prairie was included because ratios eliminate the seasonality of nutrient cycling.

Organic Matter

Organic matter, from decomposing plants, supplies nitrogen, sulfur, and phosphorus to plants (Troeh and Thompson 2005), so the current study includes the percentage of organic matter in the soil. It also holds nutrients and makes them available to plants (Troeh and Thompson 2005). Initial soil measurements showed low organic matter present at 1.3% across the study area (MDNR 2011a).

Cation Exchange Capacity

Cation-exchange capacity (CEC) is related to the ability of clay and organic components of soil to move nutrients to plant roots and greater numbers indicate an

increased ability to move ions to plant roots (Troeh and Thompson 2005). It is controlled by the charged surfaces of clay minerals and organic compounds (Troeh and Thompson 2005). Initial soil studies at Howell Prairie showed an average of 17 meq/100g, with area 5 having the highest CEC (MDNR 2011a). Typical grassland soils have a CEC of 21 meq/100g (Troeh and Thompson 2005).

Soil pH

Soil pH also affects the uptake of nutrients by controlling the release and absorption of ions from clay minerals and organic compounds (Troeh and Thompson 2005). At Howell Prairie, previous studies show a decline in pH over time, but remaining slightly alkaline (MDNR 2011a). Soil pH is recommended to be between 6.0 and 7.5 for agricultural soils (Marx 1996).

Neutralizable Acidity

Neutralizable acidity (NA) is the amount of hydrogen ions that could be neutralized, often with liming, and can help determine if amendments to the soil would be effective (Nathan et al. 2012). It has not been reported for Howell Prairie.

GIS Analysis

The geographic information system (GIS), ArcGIS 10.0, was used to create thematic maps and calculate statistics for each analyte where appropriate. An aerial photo of the site was used, with boundaries of the areas, subareas, and vegetation sampling plots created for reference. The data was imported from the Excel spreadsheets, and then used to calculate the statistics.

Kriging was used to show the predicted values between sample points (ESRI 2010). It assumes there is a spatial correlation between sample points (ESRI 2010). Kriging creates a statistical model that accounts for the distance and direction between points (ESRI, 2010).

The Cluster and Outlier Analysis (Anselin Local Morans I) script was used to calculate z-scores (to show outliers) and p-values (to show confidence levels) and to produce a graphic representation of those (ESRI 2010).

CHAPTER 2

SITE HISTORY AND PREVIOUS STUDY

Site History

The Howell Prairie and the disposal cell were the final result of the remediation and restoration of the Weldon Spring site, part of an area used by the U.S. Army and U.S. Atomic Energy Commission (AEC) for the production of weapons materials. From 1941 to 1945, the U.S. Army used the site as part of the Weldon Spring Ordinance Works to produce explosives. The site was then unused until 1956, when the AEC built the Weldon Spring Uranium Feed Materials Plant, which was later renamed the Weldon Spring Chemical Plant. The plant was closed in 1967 and transferred back to the U.S. Army. These activities left the area contaminated with low-level radiological and chemical wastes, including 44 buildings, areas where settling basins and ponds had been, and two dump areas in a quarry nearby (Figure 3). (Weldon Spring, Missouri 2011)

Figure 3. Weldon Spring Chemical Plant courtesy of U.S. Department of Energy

Cleanup of the site began in 1984, when the U.S. Department of Energy (DOE) regained control of the site and designated it as a "Major Project". In 1987, the U.S. Environmental Protection Agency (EPA) placed the site on the National Priorities List. From 1988 to 1994, the site was decontaminated and buildings were removed. By 2001, a disposal cell containing 1.48 million cubic yards of material had been constructed, covering 45 acres (Figure 1) (Weldon Spring, Missouri 2011).

In order for the area to be accessible for groundwater monitoring and controlled from erosion, 150 acres surrounding the disposal cell was used to create the Howell Prairie (Weldon Spring, Missouri 2011). The site was graded and by 2004, 89 species (Appendix A) of native prairie plants had been seeded (Figure 4) (Franson and Scholes 2011).

Figure 4. Howell Prairie, courtesy of U.S. Department of Energy

Previous Study of Howell Prairie

Since 2008, studies of Howell Prairie have been conducted to determine the success of the prairie that has established on the prairie, the changes in the prairie over time, and conditions that guide these changes, including the measurement of beneficial mycorrhizal fungi and soil properties which affect the plant communities (MDNR 2011b). Hazardous waste remediation work, such as at the Weldon Spring site, requires the success of the remediation to be demonstrated (Franson and Scholes 2011). Conversely, land restoration work is often performed without measuring success of the work (Franson and Scholes 2011).

Results of vegetation success monitoring at the Howell Prairie demonstrate the success of prairie establishment for most of the prairie. However, they also demonstrated that one area has not had successful prairie establishment. Subarea 2C had high native cover, but very low grass cover (MDNR 2011b). Initial soil measurements suggest that silt was lowest in the soil and clay was highest in Subarea 2C, relative to the other three areas that were studied; Area 4 and Subareas 1C and 5B (MDNR 2012). They also established that organic matter was low in Subarea 2C (MDNR 2012). The researchers hypothesized that the soil in Subarea 2C was significantly different from the rest of the prairie, possibly because borrow material may have come from a different source, and proposed addition of organic material to promote the establishment of grasses and proper growth of other plants (MDNR 2012).

The initial vegetation and soil studies at Howell Prairie led to the current study, which asks, what are the soil characteristics at Howell Prairie and how do those relate to prairie success? The current study attempts to answer this with a bias in Subarea 2C.

CHAPTER 3

METHODS

Sample Collection

On March 12 and 13, 2012, samples and in situ measurements were collected at Howell Prairie (Figure 5). The 46 sampling points were determined by selecting points that were spaced fairly evenly in each Subarea. Subarea 2C and the plots where vegetation analyses had previously been conducted had additional samples taken. The locations were recorded with a Trimble GPS device. On June 16, 2012, additional penetrometry data was collected at points selected in the same manner in order to compare drought conditions to the moist conditions found in March, 2012 (Figure 6).

Penetrometry and Infiltrometry measurements were collected in situ. This data was stored in the GPS and later imported with TerraSync software.

At each sample location of the March, 2012, sampling event, soil samples were collected with a trowel by taking the top 10 cm of soil in a 5 cm by 5 cm square. Each soil sample was placed in a zippered plastic bag and labeled. These were placed in a storage tub and taken to the University of Missouri Extension Soil and Plant Laboratory in Columbia, Missouri, on March 14, 2012. There, the samples were homogenized and subsamples were taken from each sample for analysis of potassium, phosphorus, calcium, magnesium, organic matter content, cation-exchange capacity, pH, and neutralizable acidity. The remainders of the samples were taken to the University of Missouri –

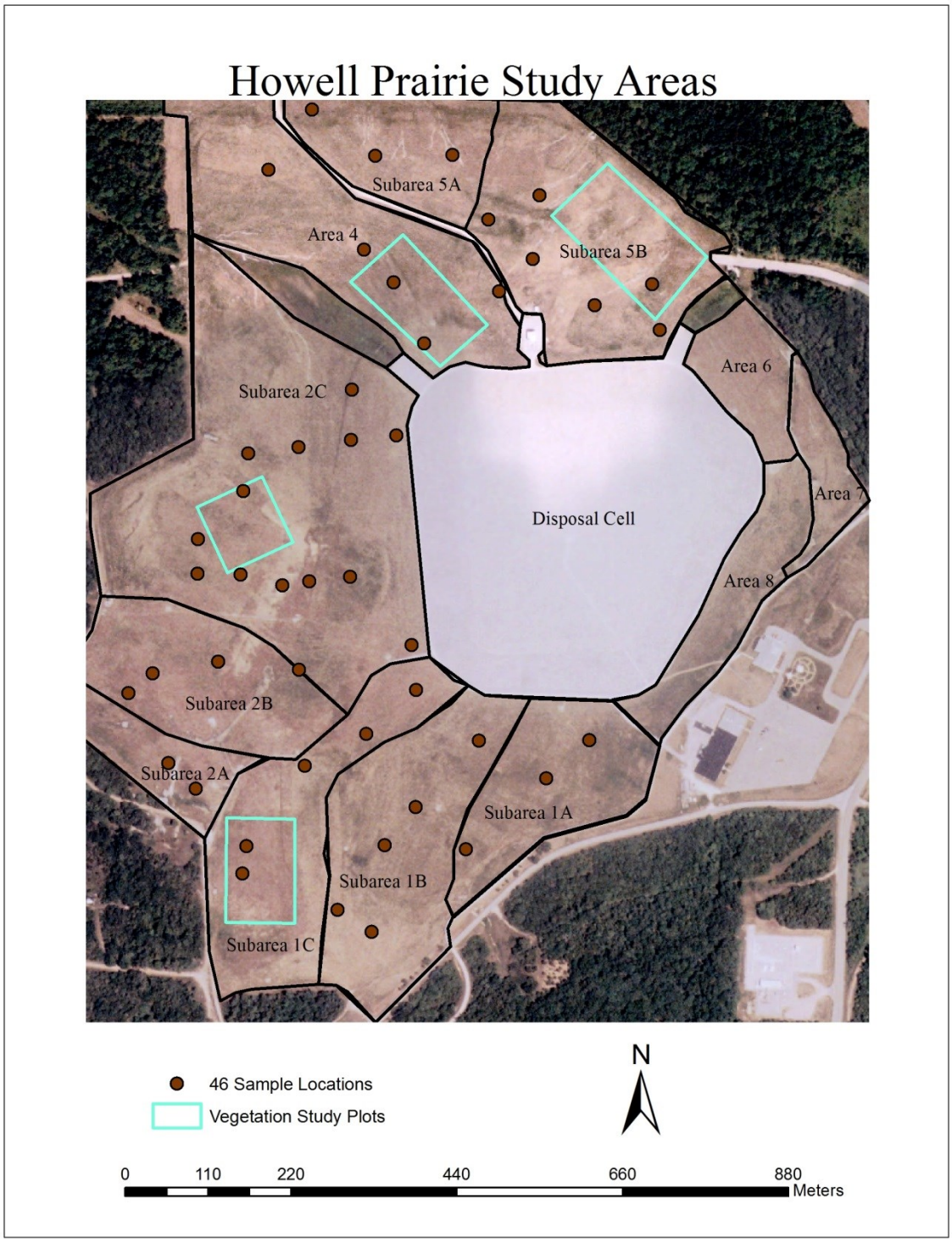


Figure 5. 46 Sample Locations at Howell Prairie, which were analyzed for penetrometry during moist conditions; infiltrometry; non-clay minerals; calcium, magnesium, phosphorus, and potassium content; organic matter content; soil pH; neutralizable acidity; and cation-exchange capacity.

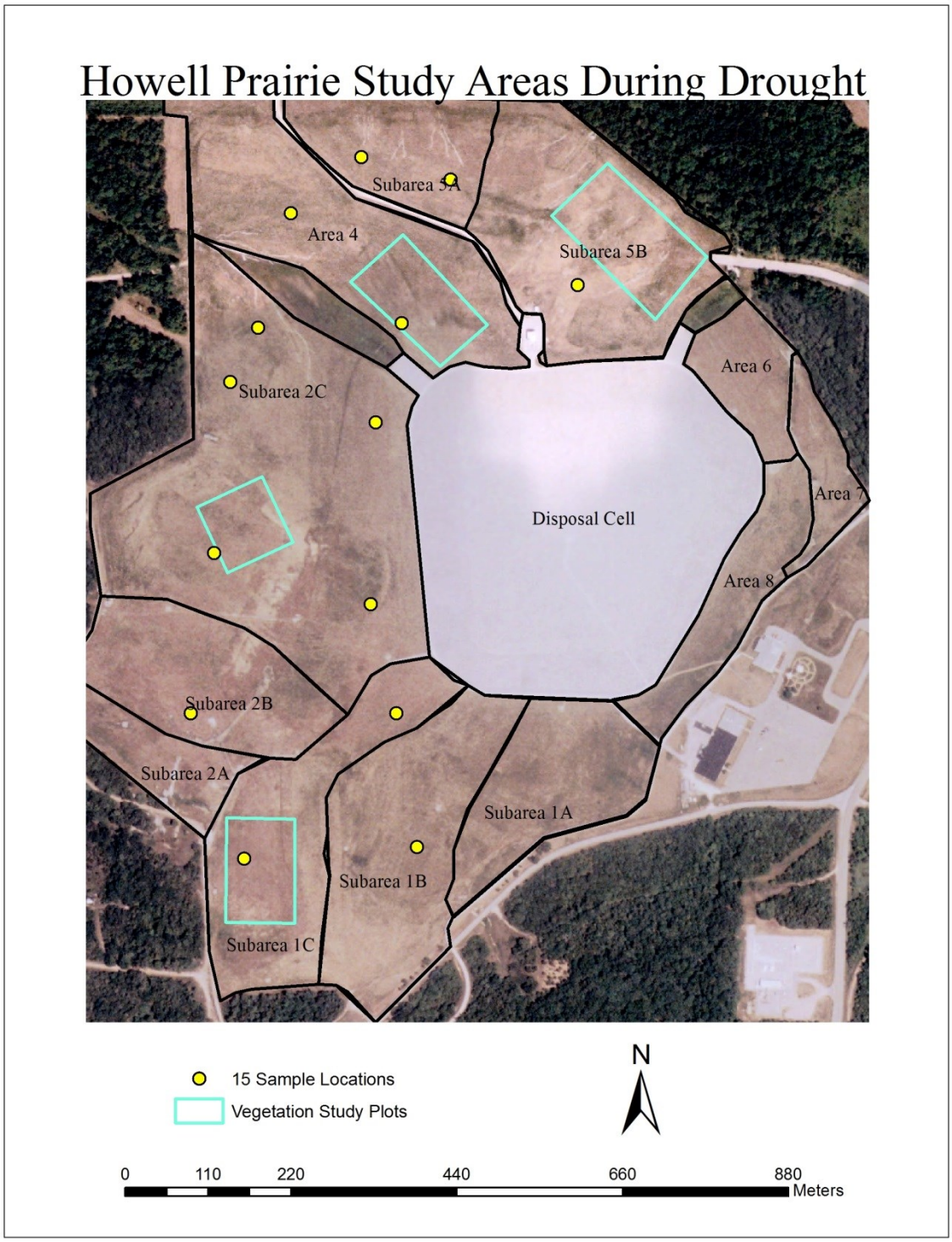


Figure 6. Sample Locations of Penetrometry During Drought Conditions

Kansas City. The non-clay and clay minerals present in the samples were determined using X-ray diffraction and scanning electron microscopy (SEM) analyses. On June 11, 2012, 24 samples were taken to the University of Missouri Extension Soil and Plant Laboratory in Columbia, Missouri, to be analyzed for soil texture and nitrate. These 24 samples were selected to ensure coverage across the site and to include samples from the Subarea 2C and plots established during previous study. These 24 samples were also used for the clay mineral analysis (Figure 7).

Soil Texture Analyses

The soil particle size analysis and soil texture analysis were conducted by the Soil and Plant Testing Laboratory at the University of Missouri Extension Office in Columbia, Missouri, using the hydrometer method with an ASTM 152H-type hydrometer (Nathan et al. 2012). For each sample, 40.0 g of air-dried soil was placed into a mixer and 100 mL of sodium hexametaphosphate solution and 300 mL of deionized water was added to the soil and then mixed for one minute on the low speed setting. The suspension was transferred into the settling cylinder and deionized water was added to bring the volume to 1000 mL (Nathan et al. 2012).

The suspensions were allowed to come to room temperature for approximately two hours. Then, a plunger was inserted into the cylinder and carefully moved up and down to mix the contents. The plunger was removed and the hydrometer was lowered into the suspension. After 30 seconds, the hydrometer reading was recorded as reading #1. Then, the cylinders were covered to protect the samples from foreign materials. After 6 hours, the temperature was recorded as reading #2 (Nathan et al. 2012).

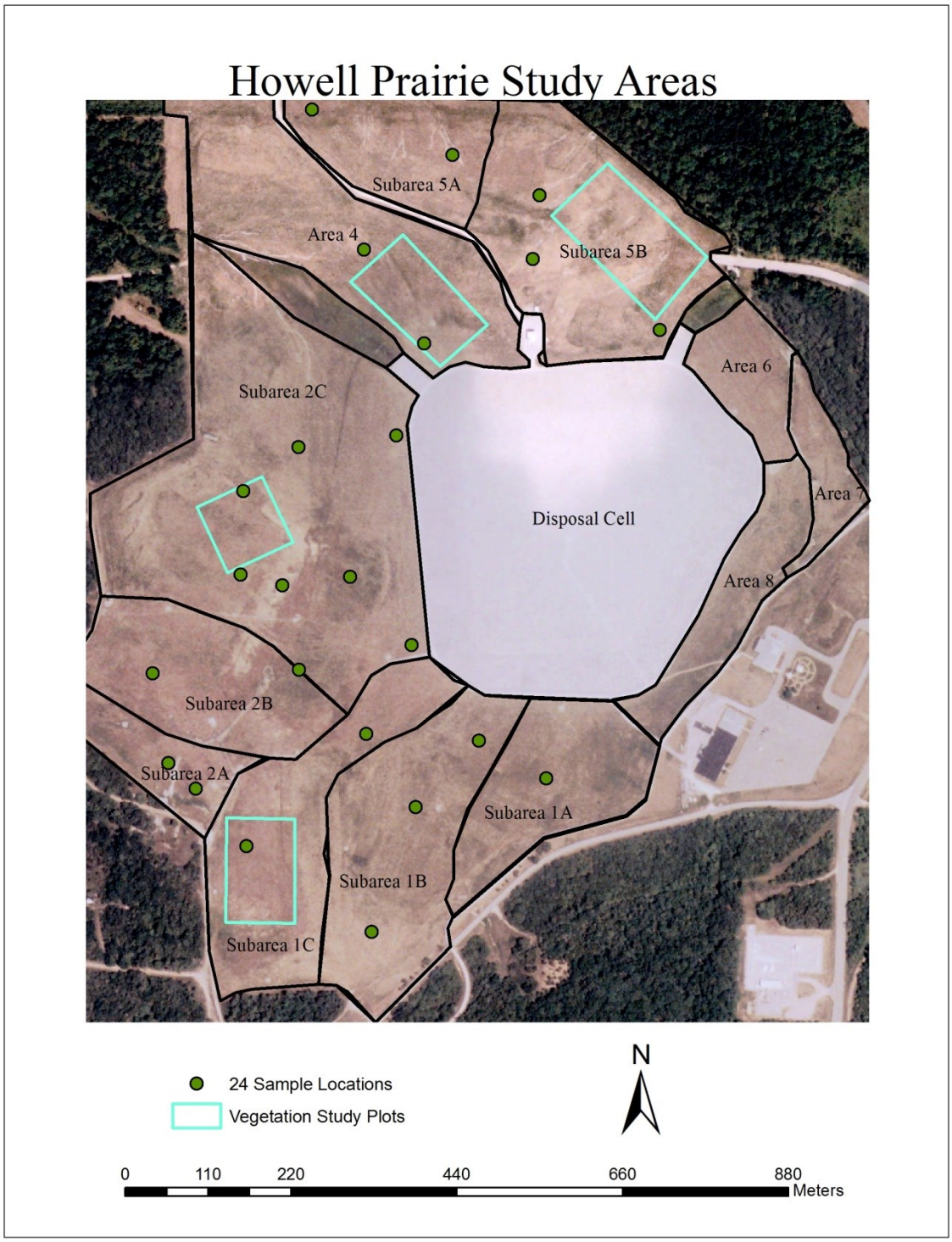


Figure 7. 24 Sample Locations at Howell Prairie, which were analyzed for soil texture, clay minerals, and nitrate content.

Percent of sand, silt, and clay were determined using the following calculations:

%sand = 40-(Reading #1-blank #1)/40 *100

%clay = (Reading #2-blank #2)/40 *100

%silt = 100 – (%sand + %clay)

Soil texture was classified by the guide for textural classification from the USDA Natural Resource Conservation Service. The percentages of sand, silt, and clay were compared to the USDA textural triangle to determine the soil texture (Appendix B) (Nathan et al. 2012).

The percentages of sand, silt, and clay, as well as the soil texture classification of each sample were then entered into a Microsoft Excel spreadsheet for later use in the GIS analysis.

Mineral Identification

Identification of minerals in each soil sample was conducted using X-ray diffraction methods. Random oriented mounts were used to determine non-clay minerals. Clay minerals were identified from preferred orientation mounts after separation from soil samples. Both methods were performed using a Rigaku Miniflex X-ray diffractometer and results were analyzed using JADE 8.0 (MDI, Inc.) software and comparison to example diffractograms of known minerals.

Non-Clay Mineral Identification

Sample Preparation

Approximately 50mg of each homogenized sample was dried for 24 hours at 60° C. These subsamples were then ground into a fine powder with a mortar and pestle. The

powder was placed in sample holders, without compression, so that random orientation of minerals was maximized. The surface of each subsample was smoothed with a spatula to ensure that the sample holder was filled completely and to reduce distortion caused by aggregation in the sample. The sample holders were then placed into a six sample changer, so that multiple samples could be analyzed sequentially.

X-Ray Diffractometer

Each sample was analyzed while spinning on the sample changer and X-rays produced with a copper tube with a nickel filter. Cu Kα radiation was used (30kV, 15mA), with a scan rate of 2° 2θ/min, at angles from 5° to 60° 2θ. The diffractograms produced were imported into JADE for identification of bulk minerals.

With JADE, the search/match feature was used to compare the raw X-ray data to known groups of minerals. In this case, the predetermined group "minerals" was used for comparison. Minerals that were identified were then recorded in a Microsoft Excel spreadsheet for importation into ArcGIS for further analysis of distribution across the study area.

Clay Mineral Identification

Sample Preparation

The same 24 samples used in the nitrate and soil texture analyses were used to determine which clay minerals were present in the different sections of the prairie. In order to identify clay sized minerals in each sample, the clay particles needed to be isolated from the rest of the sample. The decantation method was chosen for this.

Organics had to be removed before decantation could occur. Approximately 30mg of each homogenized sample was placed in 250mL HDPE bottles. Then, 5mL of 30% hydrogen peroxide (H_2O_2) was added, causing a reaction that produced carbon dioxide (CO_2) and water from the decomposition of organic molecules. This was repeated until the subsamples no longer reacted or the bottles were too full to continue. If the bottles were too full, they were placed in a centrifuge and spun for five minutes at 5000 rpm, and the liquid was poured off the top. Then, hydrogen peroxide was added again until reactions no longer occurred.

Once organics were removed, clay minerals could be isolated. Distilled water was added to the bottles until they were approximately 80% full. Approximately 1mg of sodium hexametaphosphate was added to eliminate aggregation of the particles. The bottles were shaken by hand for two to three minutes to evenly distribute the material in the bottles. Then, they were allowed to settle for four hours. After settling, a dropper was used to collect liquid from two to three centimeters below the surface. Ten to twelve drops were placed on glass slides and allowed to evaporate. Shaking, settling, and collection were repeated until a thin, translucent film of clay minerals was on the slides. Four slides from each sample were made.

X-Ray Diffraction of Clay Minerals

The slides were analyzed after air drying, after glycolization, and after heating. Under all conditions, the slides were examined with the X-ray diffractometer under the same settings; stationary mount with a cobalt tube with an iron filter. Co Kα radiation

was used (30kV, 15mA), with a scan rate of 2° 2θ/min, at angles from 4.5° to 40° 2θ at a rate of 2° 2θ/min.

Glycolization was performed by placing one slide of each sample into a glycol chamber for at least 48 hours. The glycol chamber consisted of a glass desiccator with a rack suspending the slides above a pool of ethylene glycol, so that the clay minerals would absorb glycol from the air in the chamber.

Heat treatment was done by heating two slides from each sample; one to 400° C and one to 550° C. The slides were allowed to cool for 10 minutes before scanning.

Once all subsamples had been scanned, with and without treatments, the data was imported into JADE. All four subsamples were displayed in the same graph, so that changes in the crystalline structures could be detected. The results were compared to the USGS Clay Mineral Identification Flow Diagram (see Appendix C) to identify clay minerals.

Four samples that were determined by X-ray diffraction to contain either kaolinite or halloysite were viewed with a Tescan Vega 3LMU scanning electron microscope (SEM). Morphology of the clay minerals was viewed at magnifications of 1100x to 1280x. Points on clay grains were selected from each sample to analyze the elemental composition by EDS. Other grains were selected for analysis due to their high brightness (high average atomic number) in backscattered imagery. The EDS spectra were recorded for each point and an average for each sample was calculated using Bruker Esprit 1.9.3 software. Those were then compared to the known composition of the clay minerals

thought to be present. Clay minerals that were determined to be in each sample were tabulated into a Microsoft Excel spreadsheet for incorporation into ArcGIS.

Compaction and Infiltration

Compaction

. The test for compaction was performed with a custom made penetrometer, which was created from a commonly available grounding rod with a pointed tip and a post setter (Figure 8). The grounding rod was cut to 1.5 meters in length and notched at one centimeter intervals from the point to 30 centimeters from the point. The rod was marked from the point where the bottom of the post setter is when the rod is fully inserted into the post setter (bottom mark) to 10 centimeters above that point (top mark).

At the sample locations, the tip of the penetrometer rod was placed upright on the ground, fully inserted into the post setter to the bottom mark. The post setter was raised to the top mark and dropped three times. The distance that the rod was driven into the ground was recorded to the nearest centimeter, as marked on the rod. The rod was cleaned between each test by scraping off excess soil and rinsing with water. Depth was recorded and the sample location was recorded with the GPS device.

Figure 8. Using the Penetrometer

Infiltration

The test was conducted only during wet conditions because the soil had large cracks under dry conditions that prevented accurate results with the methods used. The test was also performed using a custom made device that was a metal cylinder created by removing both ends of a coffee can with a diameter of 10 cm and a metal ruler (Figure 9).

Figure 9. Infiltrometer

At each sample location, the cylinder was inserted into the ground approximately 3 cm. The ruler was placed vertically into the cylinder, against the wall. Water was poured into the cylinder to approximately 20 cm deep, with the level recorded. After one minute, the level of the water was recorded. That level was subtracted from the starting level to give the infiltrometry reading, which was recorded. The reading was later multiplied by 60 to give infiltration at cm/hr.

Soil Nutrients

The soil nutrients analyses were conducted by the Soil and Plant Testing Laboratory at the University of Missouri Extension Office in Columbia, Missouri, using extraction methods. The results of these analyses were recorded in a Microsoft Excel spreadsheet for incorporation into the GIS analysis.

Nitrate

To determine the available nitrogen, soil nitrate concentration was analyzed using the cadmium reduction method. To extract the nitrate, 10 g of air-dried soil was placed in a flask and 25 mL of 2 M potassium chloride was added then shaken for 5 minutes. Nitrate-free filter paper was used to filter the solution. Approximately 5 mL of the solution was used for the nitrate reduction method through a Lachet Flow Injection Autoanalyzer (using a copperized cadmium column). (Nathan et al. 2012)

To perform this method with a Lachet Flow Injection Autoanalyzer, three reagents were used; a 15 M sodium hydroxide solution, an ammonium chloride buffer at pH 9.5, and a commercially available sulfanilamide color reagent. The analysis was performed with these input data systems parameters:

Sample throughput: 55samples/h, 65 s/sample

Pump Speed: 35

Cycle Period: 65

Analyte Data:

Concentration Units: mg N/L

Peak Base Width: 25 s

% Width Tolerance: 100

Threshold: 7083

Inject to Peak Start: 21 s

Chemistry: Direct

(Wendt 2000)

Bray I Phosphorus

To determine Phosphorus content using the Bray I method, two reagents were used, an extracting reagent and a color developing reagent (Nathan et al. 2012). The extracting reagent was made by dissolving 11.11 g of ammonium fluoride (NH_4F) in 9000 mL of deionized water, then adding 21.6 mL of concentrated hydrochloric acid (HCl) and diluting to 10 L with more deionized water and mixing. The color developing reagent was made by adding 25 mL of acid molybdate stock to 800 mL of deionized water, then adding 10 mL of ascorbic acid stock and diluting to 1 L with more deionized water. The acid molybdate stock was made by dissolving 120 g of ammonium molybdate [$(NH_4)_6 \cdot Mo_7O_{24} \cdot 4H_2O$] in 200 mL of deionized water at 60° C, then cooled. 2.910 g antimony potassium tartrate was added to the aqueous molybdate solution, followed with the addition of 1400 mL of concentrated sulfuric acid (H_2SO_4). After cooling, the solution was diluted to 2 liters. The ascorbic acid stock was made by dissolving 132 g ascorbic acid in one liter of deionized water (Nathan et al. 2012).

To perform the Bray I phosphorus analysis, 20 mL of the extracting reagent was added to 2 g of the soil sample, shaken vigorously for 5 minutes, and then filtered. This

extract was added to the color developing reagent at a 1:4 ratio. In a test tube, 1.5 mL of that solution was mixed with 6 mL of the color developing reagent and allowed to sit for 20 minutes to allow the color to develop. The percent transmittance was read using a spectrophotometer. The percent transmittance was compared to a standard curve in the spectrophotometer to determine the concentration of phosphorus (Nathan et al. 2012).

Calcium, Magnesium, and Potassium

Calcium, magnesium, and potassium content were determined using ammonium acetate extraction with an atomic absorption spectrophotometer. These nutrients were extracted with a solution consisting of 500 mL deionized water, 58 mL of 95.5% acetic acid ($HC_2H_3O_2$), and 70 mL of ammonium hydroxide (NH_4OH). The extractant solution was pH adjusted to 7.0 with either acetic acid or ammonium hydroxide, then diluted to 1000 mL. For calcium and magnesium analysis, an additional solution of lanthanum diluent was used. It was prepared by dissolving 1.2314 g of lanthanum oxide (La_2O_3) in 4 mL of 6 N hydrochloric acid (HCl), then diluting to 1000 mL with deionized water (Nathan et al. 2012).

To extract all three nutrients, 20 mL of the extractant solution was added to 2 g of air dried soil, shaken for 5 minutes, and passed through a filter. The filtrate was collected for analysis. 0.5 mL of the filtrate was set aside for calcium and magnesium analysis. The remainder was used to determine potassium with an atomic absorption spectrophotometer (Nathan et al. 2012).

For calcium and magnesium analysis, 9.5 mL of the lanthanum diluent was added to the 0.5 mL of filtrate that was separated from that used for the potassium analysis.

After mixing, an atomic absorption spectrophotometer was used to determine the calcium and magnesium concentrations (Nathan et al. 2012).

Organic Matter

The soil organic matter (OM) content analysis was conducted by the Soil and Plant Testing Laboratory at the University of Missouri Extension Office in Columbia, Missouri, using the Loss-On-Ignition method. This analysis begins with two grams of air dried soil. The soil was then dried in an oven at 150°C for two hours to remove water bound to minerals and then weighed. The samples were then heated to 360° C for two hours, causing loss of organic material by combustion. After cooling, the sample was weighed again. The organic content, by percent, was calculated as follows, where cw is the weight of the crucible, wt1 is the weight of the sample after heating to 150° C, and wt2 is the weight of the sample after heating to 360°C. The value 95.6 is a correction coefficient based on regression studies (Nathan et al. 2012):

$$\text{Organic\%} = \{[(wt1\text{-}cw) - (wt2\text{-}cw)] / (wt1\text{-}cw)\} * 95.6$$

Cation-exchange Capacity, pH, and Neutralizable Acidity

Cation Exchange Capacity

Cation exchange capacity (CEC) is calculated from the potassium, calcium, magnesium, and neutralizable acidity (NA) results. The calculations are as follows:

$$\text{meq Ca /100 g} = \text{lbs Ca/A} \div 400 \text{ lbs / meq}$$

$$\text{meq K /100 g} = \text{lbs K/A} \div 780 \text{ lbs / meq}$$

$$\text{meq Mg /100 g} = \text{lbs Mg/A} \div 240 \text{ lbs / meq}$$

$$\text{CEC} = \Sigma\ (\text{meq Ca, meq K, meq Mg, NA})$$

(Nathan et al.,2012).

pH

To determine the pH of each soil sample, 5 g of air-dried soil was mixed with 5 mL of distilled deionized water and shaken for 30 minutes. A pH meter was then used to determine the soil pH (Nathan et al. 2012).

Neutralizable Acidity

To determine neutralizable acidity (NA), the new Woodruff buffer method was used (Nathan et al., 2012). A Woodruff buffer solution was made by dissolving 10 g calcium acetate [$Ca(C_2H_3O_2)_2$] and 4.0 g calcium hydroxide [$Ca(OH)_2$] in 500 mL of deionized water. Then, 200 mL of distilled water was heated to 70° C and 12.0 g of para-nitrophenol was dissolved in the hot water. Then, l0.0 g salicylic acid ($C_7H_6O_3$) was added to the acetate-hydroxide solution and mixed vigorously for two minutes. After that, the para-nitrophenol solution was added and mixed. This solution was mixed with deionized water to a final volume of one liter while adjusting the pH to 7.0 ± 0.05 with 6 N sodium hydroxide (NaOH) or 6 N hydrochloric acid (HCl) (Nathan et al. 2012).

Five mL of 0.01 M calcium chloride solution ($CaCl_2$) was added to 5 g of soil. Then, 5 mL of the Woodruff buffer solution was added and the solution was stirred intermittently for 30 minutes. The pH of this solution was measured with a pH meter and recorded as pH_b. The following calculations were used to find NA:

$$NA = (pH\ 7.0 - pH_b) * 10$$

(Nathan et al. 2012)

GIS Analysis

Data Collection

In order to be able to visually see differences of all soil parameters across the study area, geographic analysis was performed. ESRI's ArcMap 10.0 and ArcCatalog 10.0 were used to perform the Geographic Information System (GIS) analysis. All layers were created with spatial reference North American Datum (NAD) 1983 and the Universal Transverse Mercator (UTM) zone 15N coordinate system.

A base map was created for all parameters by clipping a raster image of St. Charles County, downloaded from the National Agriculture Imagery Program (NAIP), to cover the Weldon Spring Site area (Ortho_1-1 2007). Based on the topography of the study area, the area and subarea boundaries were digitized (Franson and Scholes 2011). The project area boundary was also digitized to limit the extent of kriging for analysis of each parameter.

On-site locational data was collected using the UTM zone 15N coordinate system and NAD83 datum with a Trimble Global Positioning System (GPS), which included locational data, the sample identification number, and penetrometry and infiltrometry data. The information from the March, 2012, sampling event was extracted from the Trimble GPS with Terrasync software and copied into a Microsoft Excel spreadsheet because the soil test data was to be added to it. The data from the June, 2012, sampling event was exported as a point data shapefile because it only included penetrometry data.

The spreadsheets (Appendices D, E and F) were edited to add data from all soils tests and locational data for each point. The penetrometry, infiltrometry, soil nutrients

(including the potassium/magnesium ratios), CEC, pH, NA, and OM were added as the numerical results of their respective analyses. The soil texture results were added as percent of sand, silt, and clay. Soil texture classifications were assigned an arbitrary number, where Loam is 1, Clay Loam is 2, Silt Loam is 3, and Silty Clay Loam is 4.

Three separate spreadsheets were created. The first (Appendix D), included all of the sample locations from the March, 2012, sampling event, penetrometry, infiltrometry, pH, NA (meq/100g), OM (%), Bray I phosphorus (ppm), calcium (ppm), magnesium (ppm), potassium (ppm), CEC (meq/100g), and the non-clay minerals. The second spreadsheet (Appendix E), included information from the 24 samples that included clay minerals; percentages of sand, silt, and clay; texture classification, based on USDA standard classification; and nitrate. The third spreadsheet (Appendix F) included the potassium to magnesium ratios from this study and previous studies.

The completed spreadsheets were added to the map in ArcMap. They were georeferenced by displaying the XY data, with easting assigned to X and northing assigned to Y, while keeping the same datum and coordinate system. The resulting dataset was then exported as a featureset in the geodatabase.

Statistical Analysis

Kriging was used for each parameter to get a statistical and visual representation of the occurrence of each soil parameter across the study area. Ordinary kriging was used with a spherical semivariogram model. A 6 point, variable search radius was used due to the distance and distribution between points. The Raster Analysis mask was set

to the project area polygon feature and Mean Coincident Points were used for the Geostatistical Analysis settings.

The Cluster and Outlier Analysis (Anselin Local Morans I) script was used to calculate z-scores (to show outliers) and p-values (to show confidence levels) and to produce a graphic representation of those. Inverse-Distance was used for Conceptualization of Spatial Relationships and Euclidian Distance for the Distance Method. The Raster Analysis mask was set to the project area polygon feature. Z-scores and p-values were acquired and incorporated into the appropriate spreadsheet (Appendices D, E, and F).

CHAPTER 4

RESULTS

Soil Texture Analysis

Sand

Percent sand had a mean of 21.5% and standard deviation of 5.8 across the whole prairie. It was highest Subarea 2C, at 26.1%. It was lowest in Subareas 5A and 5B at 12.5% for both (Table 1 and Figure 10). Kriging showed highest levels in Subarea 2C and lowest values in Subarea 5B. Cluster and Outlier Analysis showed two points in Subarea 5B and one in Subarea 5A with low z-scores and a 99% confidence level. It also had three points in Subarea 2C with high z-scores at a 99% confidence level (Figure 11).

Table 1.--Percent Sand

	n	Mean	Standard Deviation	Standard Error
Total	24	21.46	5.75	1.15
Subarea 1A	1	22.50		
Subarea 1B	3	21.67	1.44	0.83
Subarea 1C	2	21.25	1.77	1.25
Subarea 2A	2	22.50	3.54	2.50
Subarea 2B	2	22.50	0.00	0.00
Subarea 2C	7	26.07	5.93	2.24
Area 4	2	21.25	1.77	1.25
Subarea 5A	2	12.50	5.30	3.75
Subarea 5B	3	12.50	5.00	2.89

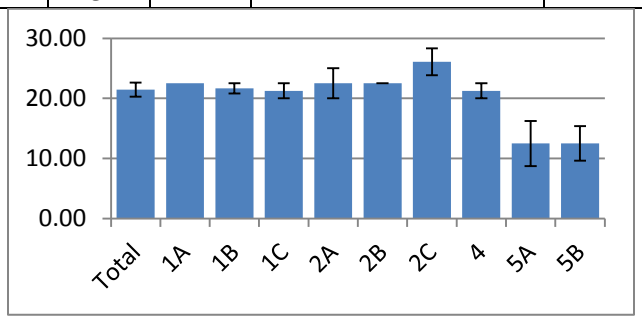


Figure 10. Percent Sand vs. Subarea, Error bars are s.e. of the mean

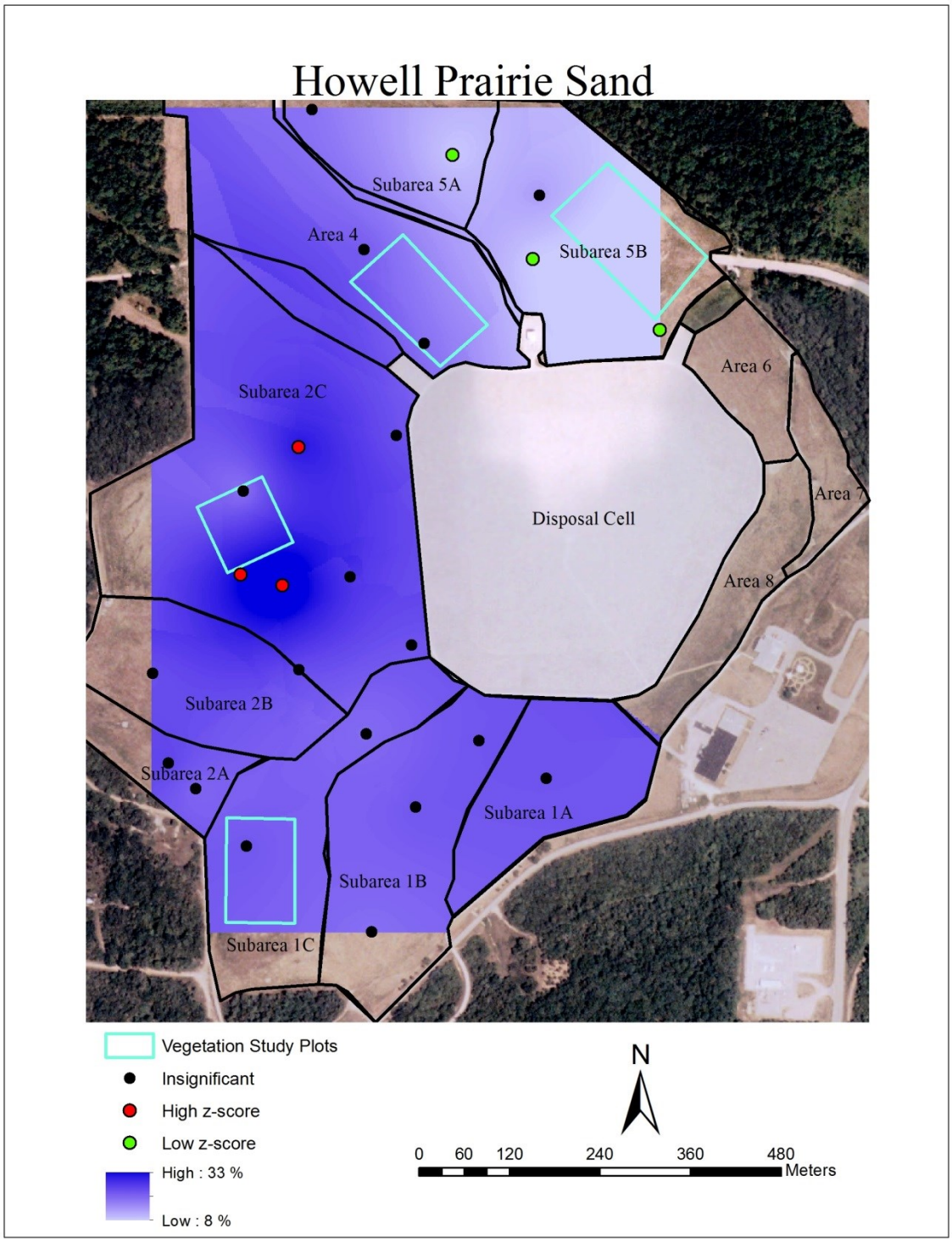


Figure 11. Map of Howell Prairie Percent Sand, showing significantly high levels in Subarea 2C and significantly low areas in Subareas 5A and 5B.

Silt

Percent silt was fairly consistent across the study area, nearly 55%, except in Subarea 2C, which had 46% (Table 2 and Figure 12). Kriging showed lowest levels in Subarea 2C. Cluster and Outlier Analysis resulted in four points in Subarea 2C which had high z-scores at a 99% confidence level (Figure 13).

Table 2.--Percent Silt

	n	Mean	Standard Deviation	Standard Error
Total	24	53.23	6.19	1.24
Subarea 1A	1	55.00		
Subarea 1B	3	55.00	2.50	1.44
Subarea 1C	2	55.00	0.00	0.00
Subarea 2A	2	55.00	0.00	0.00
Subarea 2B	2	53.75	1.77	1.25
Subarea 2C	7	47.14	8.59	3.25
Area 4	2	56.25	1.77	1.25
Subarea 5A	2	57.50	3.54	2.50
Subarea 5B	3	57.50	2.50	1.44

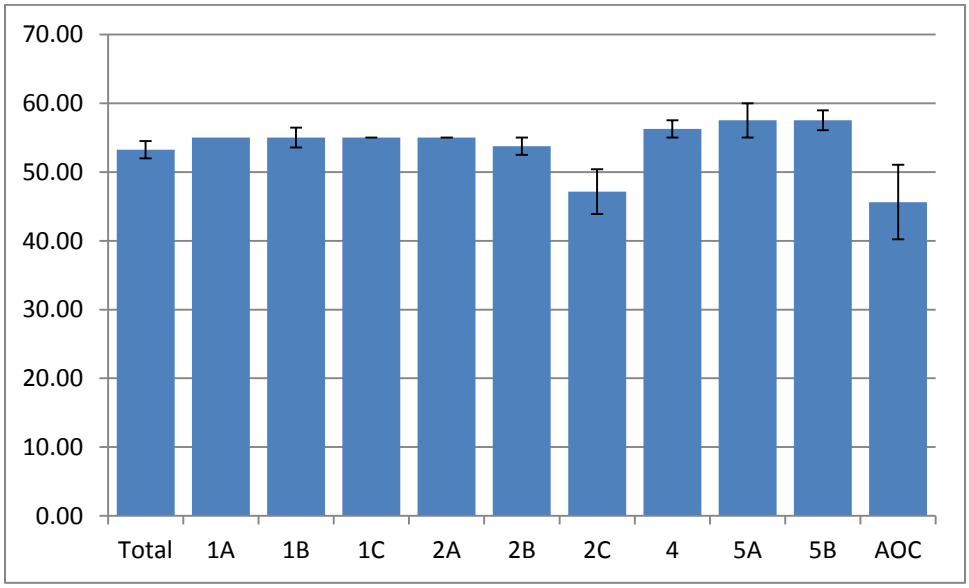


Figure 12. Percent Silt vs. Subarea, Error bars are s.e. of the mean

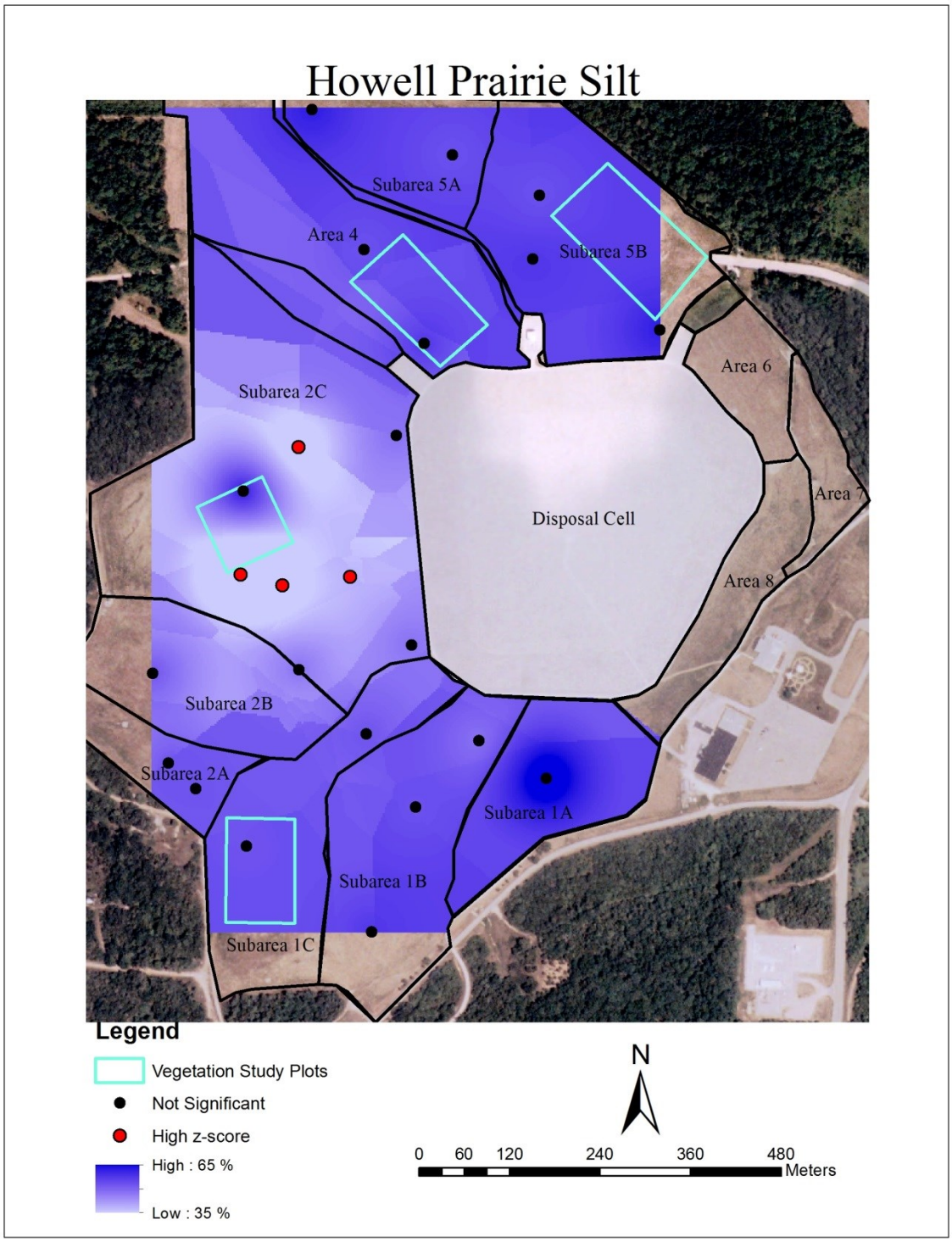


Figure 13. Map of Howell Prairie Percent Silt, showing significantly low values in Subarea 2C

Clay

Percent clay for the study area had a mean of 22.5% and a standard deviation of 3.9. Percent clay was highest in Subareas 5A and 5B, though Subarea 5A was not statistically significant due to a standard deviation of 8.84. The areas with the lowest were Subareas 1A and 2A, with 22.5% (Table 3 and Figure 14). However, only one sample in Subarea 1A makes it insignificant. Kriging results showed a trend of high values in the north part of the study area to low values in the south. Cluster and Outlier Analysis resulted in two points in Subarea 5B which had high z-scores at a 99% confidence level (Figure 15).

Table 3.--Percent Clay

	n	Mean	Standard Deviation	Standard Error
Total	24	25.52	3.90	0.78
Subarea 1A	1	22.50		
Subarea 1B	3	23.33	1.44	0.83
Subarea 1C	2	23.75	1.77	1.25
Subarea 2A	2	22.50	3.54	2.50
Subarea 2B	2	23.75	1.77	1.25
Subarea 2C	7	26.79	4.01	1.52
Area 4	2	25.00	3.54	2.50
Subarea 5A	2	30.00	8.84	6.25
Subarea 5B	3	30.00	2.50	1.44

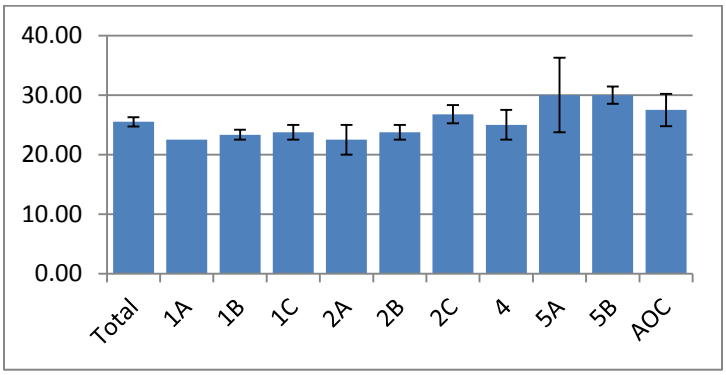


Figure 14. Percent Clay vs. Subarea, Error bars are s.e. of the mean

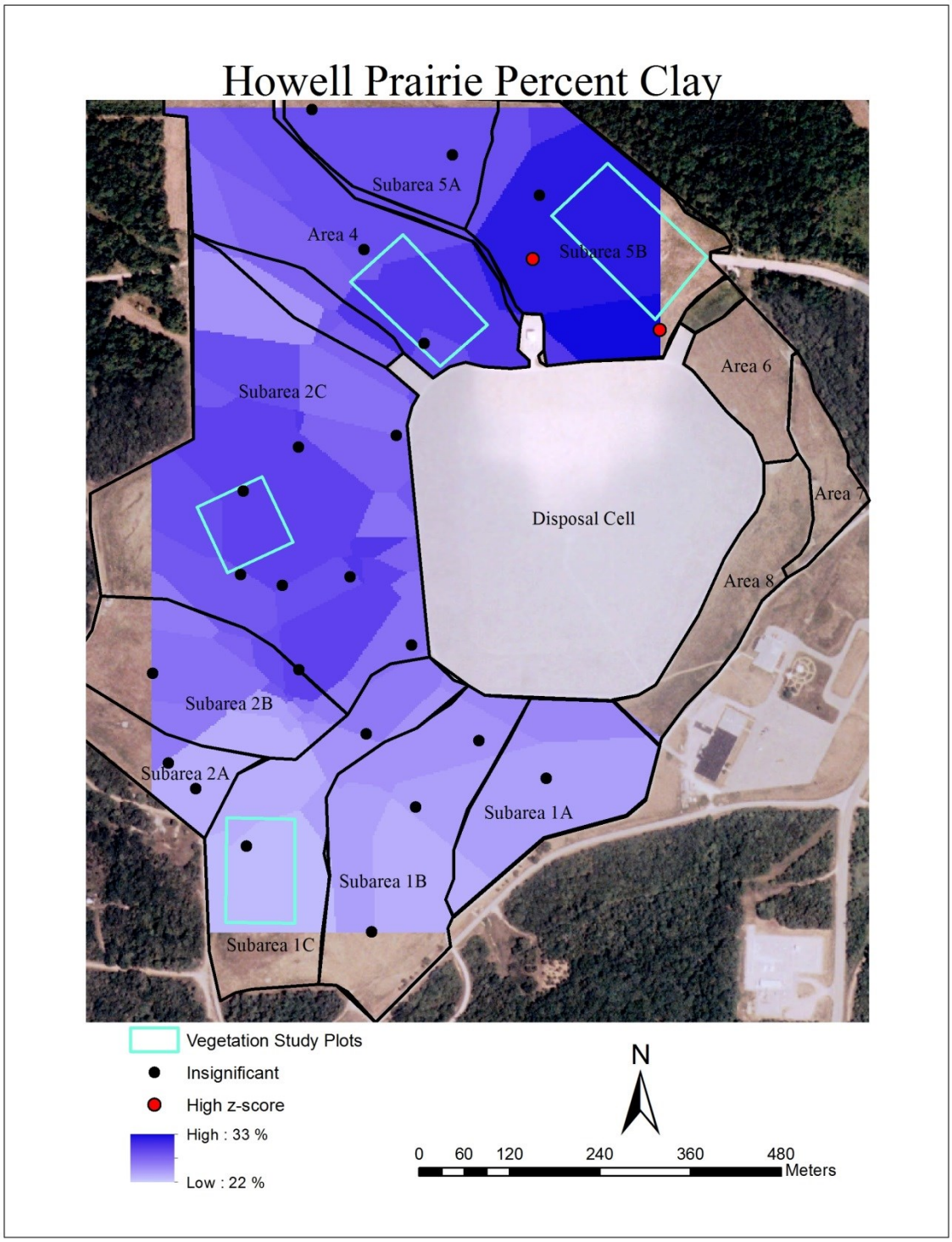


Figure 15. Map of Howell Prairie Percent Clay, showing significantly higher values in the north to low values in the south.

Soil Texture Classification

With these results, soil texture varied across the study area when compared to the USDA soil texture triangle (Figure 16). Most of Area 5 and the eastern half of Area 4 soils were Silty Clay Loam. The western half of Area 4, all of Area 1, and Subareas 2A and 2B were Silt Loam. Most of Area 2C was Clay Loam, while there was a small area in 2C that was Loam (Figure 17).

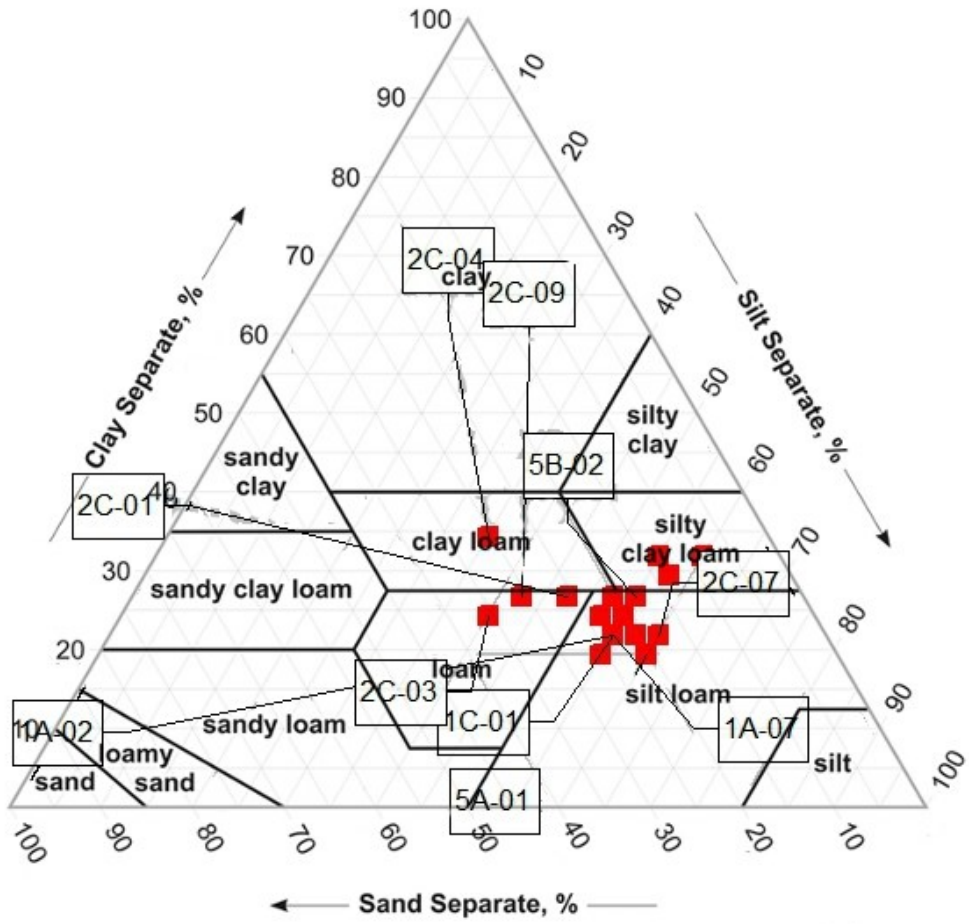


Figure 16. Soil Texture on USDA Soil Texture Triangle, showing samples in Subarea 2C as clay loam or loam, while all other samples were silty clay loam or silt loam.

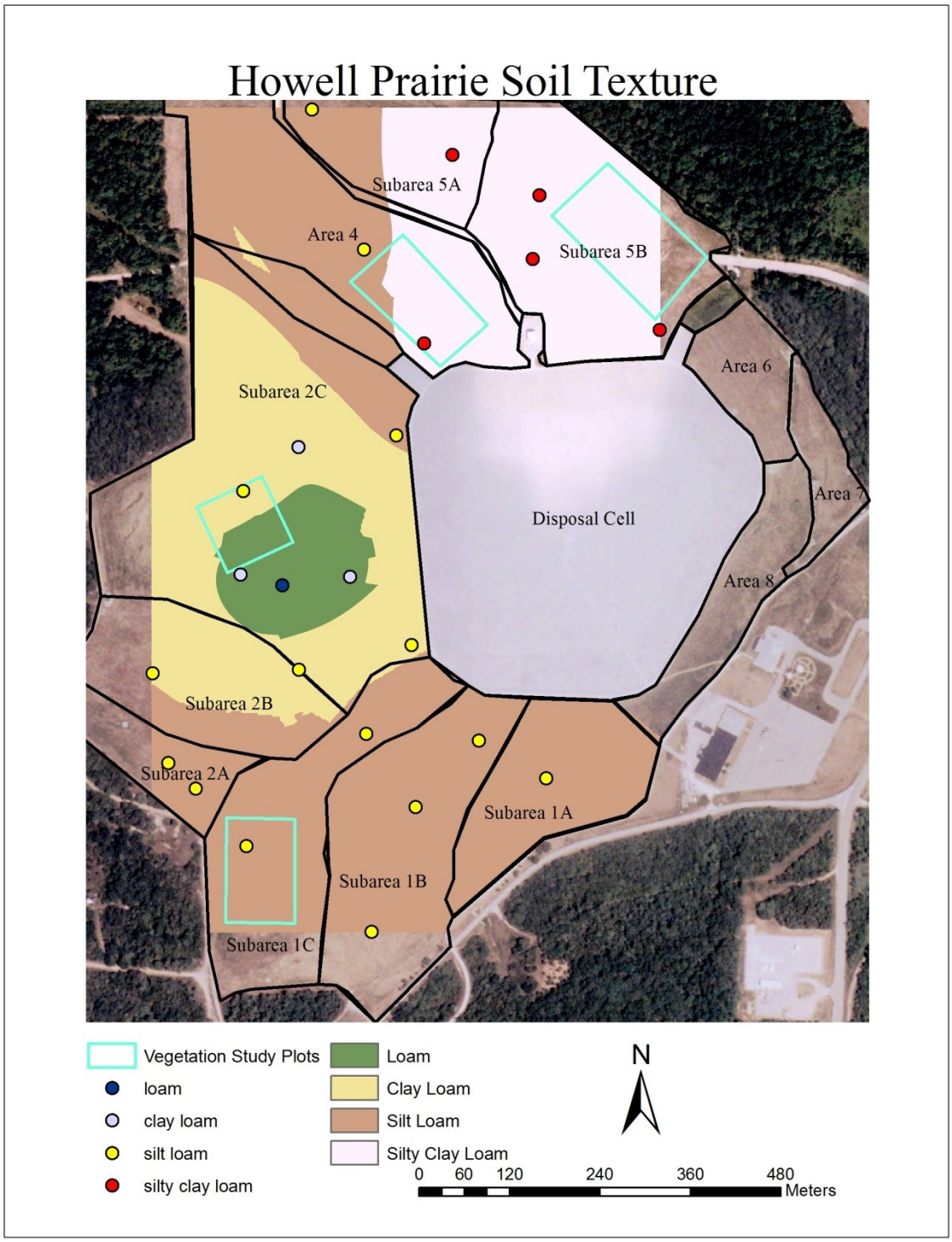


Figure 17. Soil Texture Map, showing loam and clay loam in Subarea 2C, silt loam to the north and south of Subarea 2C, and silty clay loam in Area 5.

Mineral Identification

Clay Minerals

Clay minerals varied across the study area, although all samples had clay-sized quartz crystals present, with all diffractograms having peaks at 3.34 Å and 4.25 Å. Illite was also present throughout the prairie, shown with 10 Å peaks that did not change with treatments. Interstratified illite-montmorillonite was also shown in all samples with a broad peak from 10 Å to 14 Å that expanded when treated with glycol, then collapsed to 10 Å under heat treatment, intensifying the 10 Å peak from illite. Kaolinite or halloysite was present throughout the study area. Kaolinite and/or halloysite were seen by a sharp peak at 7 Å air-dried that was not affected by glycol treatment and destroyed when heated to 550° C. Interstratified kaolinite-smectite was present only in Subarea 2C (Figure 18), indicated by a broad peak between 7 Å and 10 Å after glycol treatment. Examples of these diffractograms are shown in Figures 19 to 24.

Visually comparing scanning electron micrographs of the clay minerals did not produce conclusive results to determine the difference between kaolinite or halloysite (Figures 25 and 26). Quartz grains were seen in subarea 2C (Figure 26). Elemental spectrum analysis showed proportions of oxygen, aluminum, and silicon that are consistent with clay minerals at most points. These also had low percentages of potassium, titanium, magnesium, iron, and sodium, which are consistent with illite-montmorillonite and kaolinite-smectite (Figures 27 and 28 and Appendix G). There were several grains that had high brightness (high average atomic number) in backscattered

electron imagery, that included zircon, silver, barium, and very low amounts of heavy metals. The low occurrence of these is considered detrital (Figure 29).

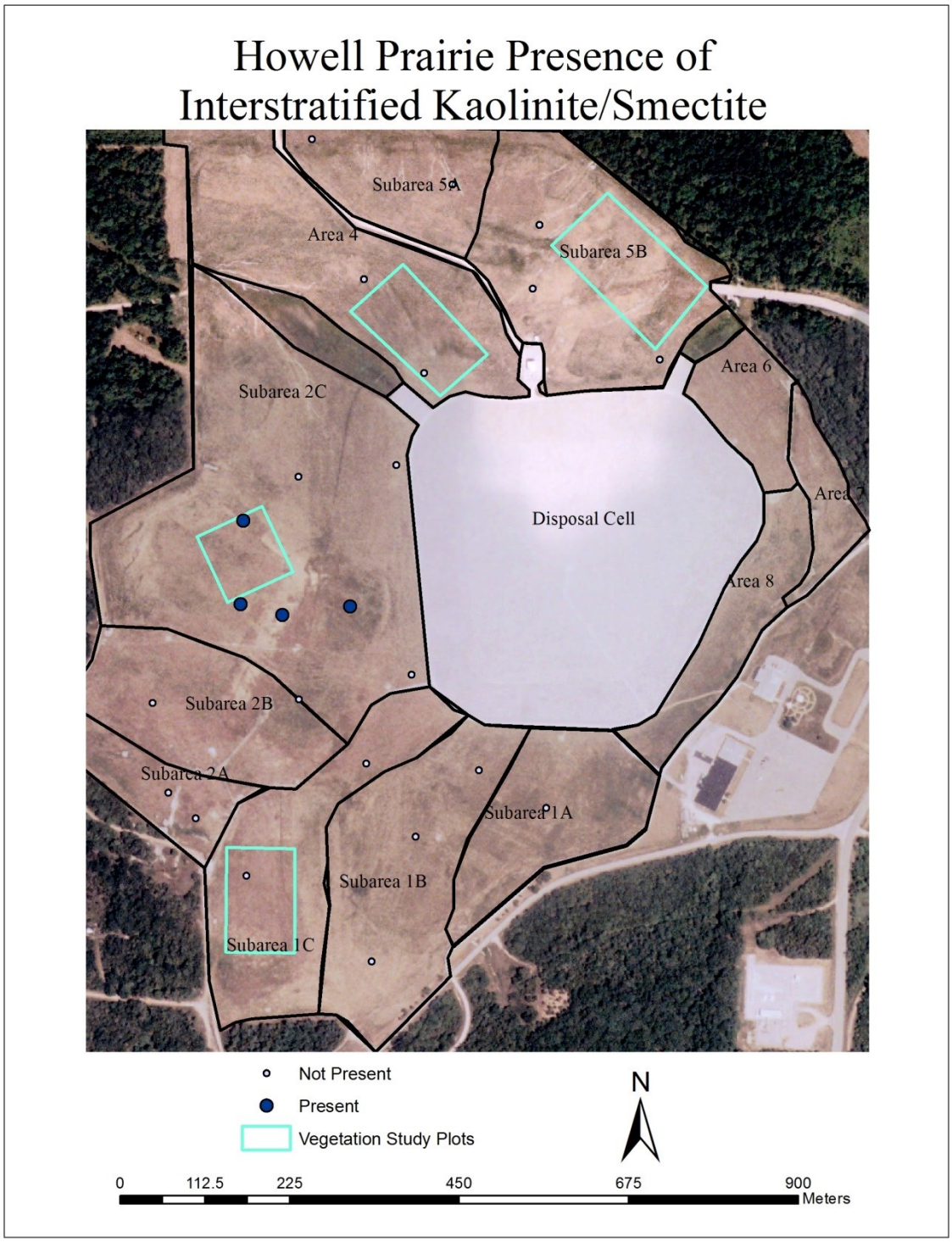


Figure 18. Map of Howell Prairie Presence of Interstratifie Kaolinite-Smectite, showing the mineral present only in Subarea 2C.

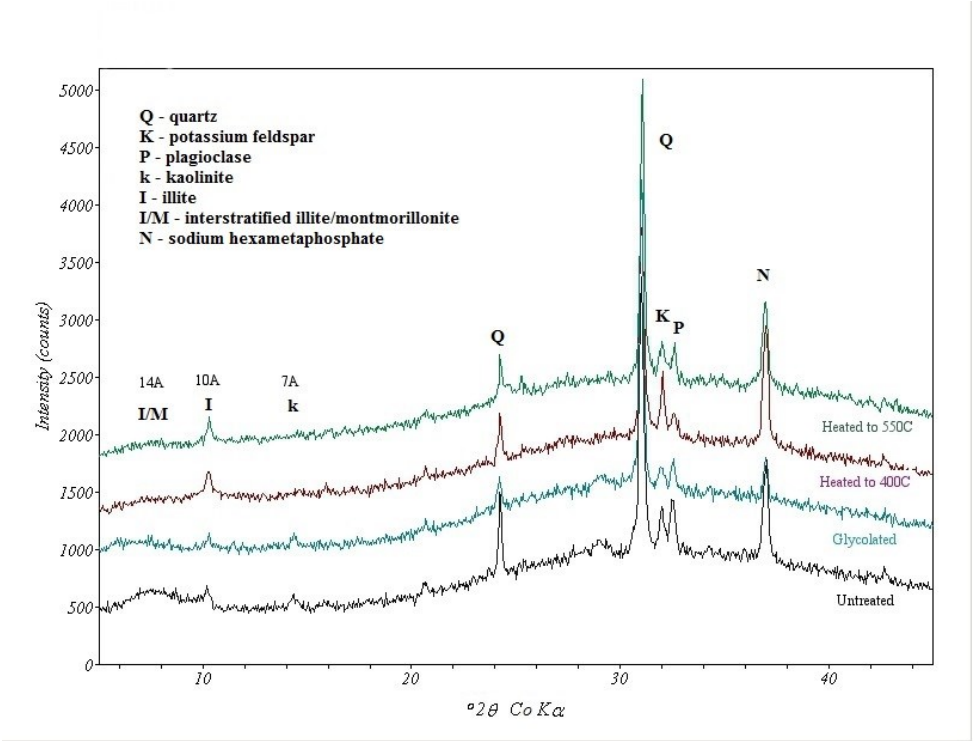


Figure 19. Diffractogram of Oriented Clay Mount Subarea 1A Sample 2

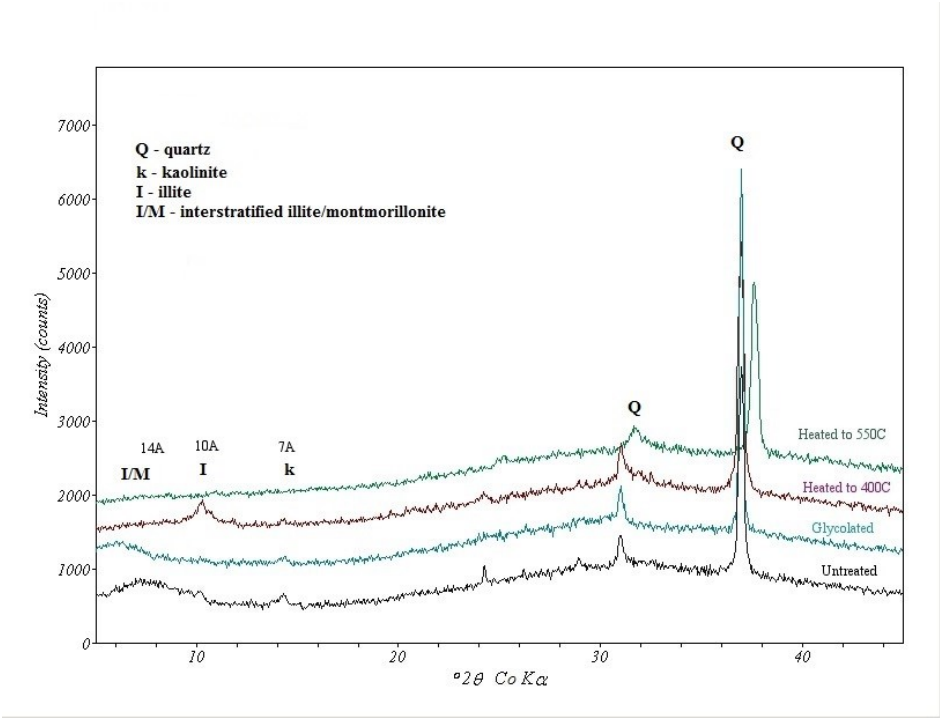


Figure 20. Diffractogram of Oriented Clay Mount Subarea 1C Sample 4

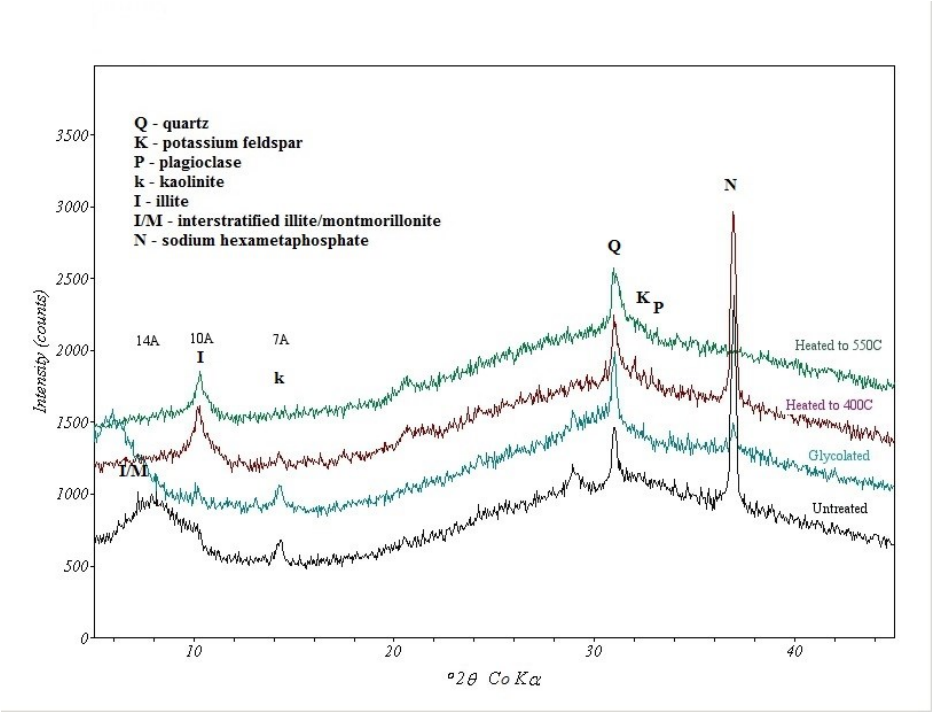


Figure 21. Diffractogram of Oriented Clay Mount Subarea 2B Sample 2

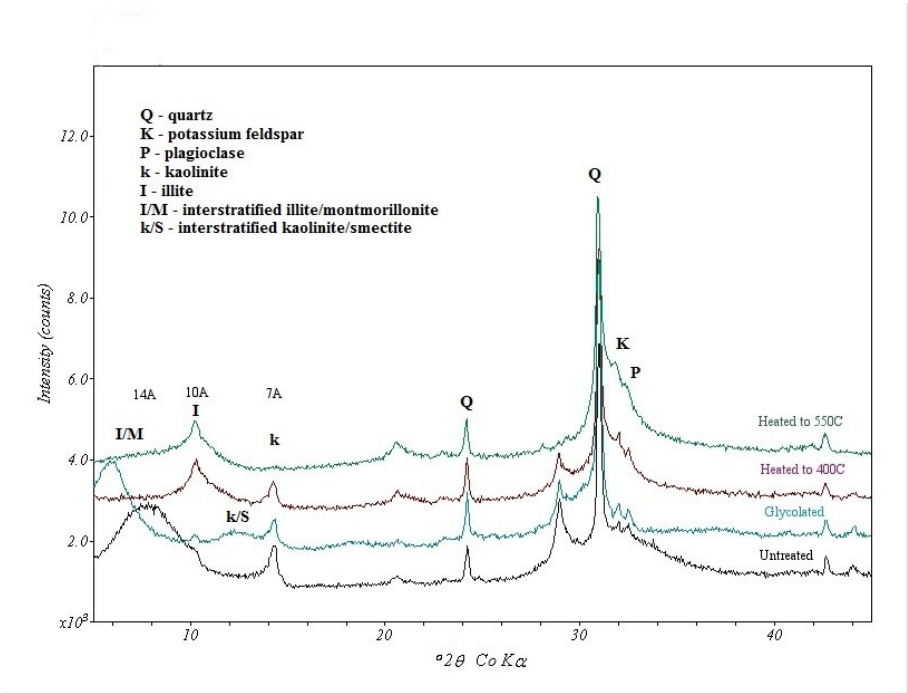


Figure 22. Diffractogram of Oriented Clay Mount Subarea 2C Sample 4

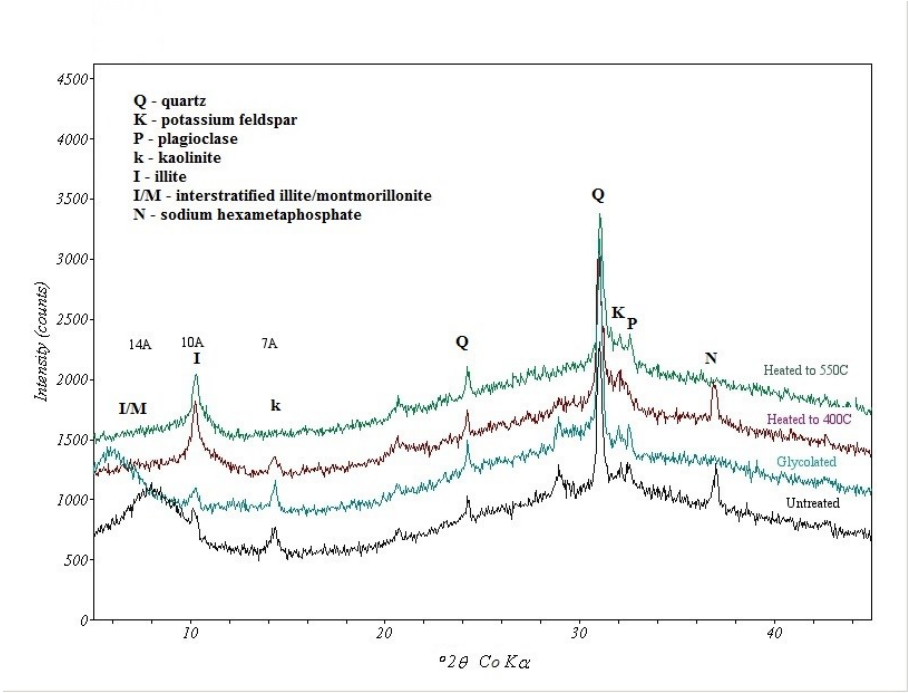


Figure 23. Diffractogram of Oriented Clay Mount Area 4 Sample 3

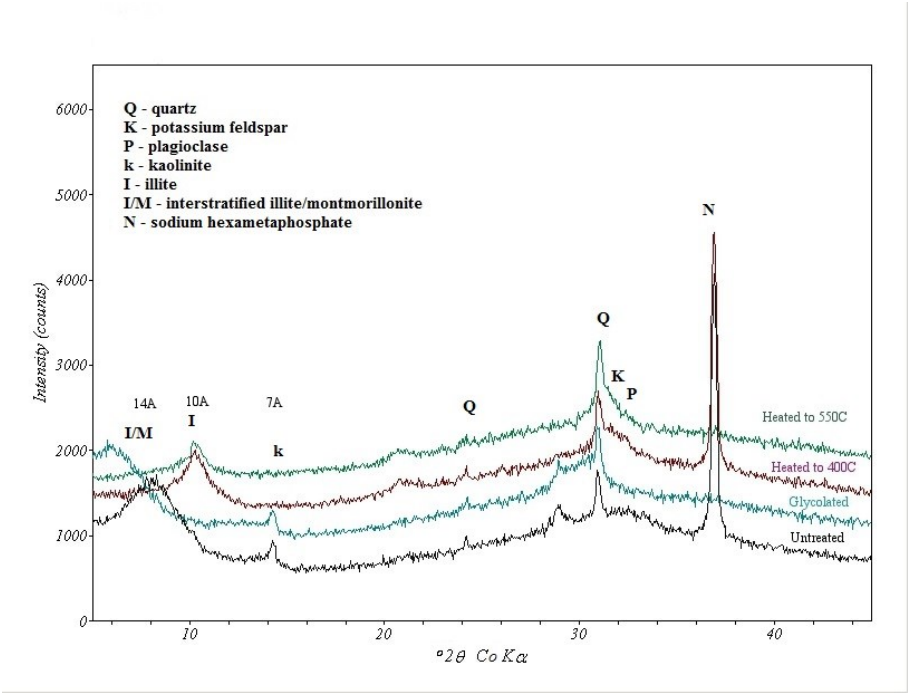


Figure 24. Diffractogram of Oriented Clay Mount Subarea 5B Sample 3

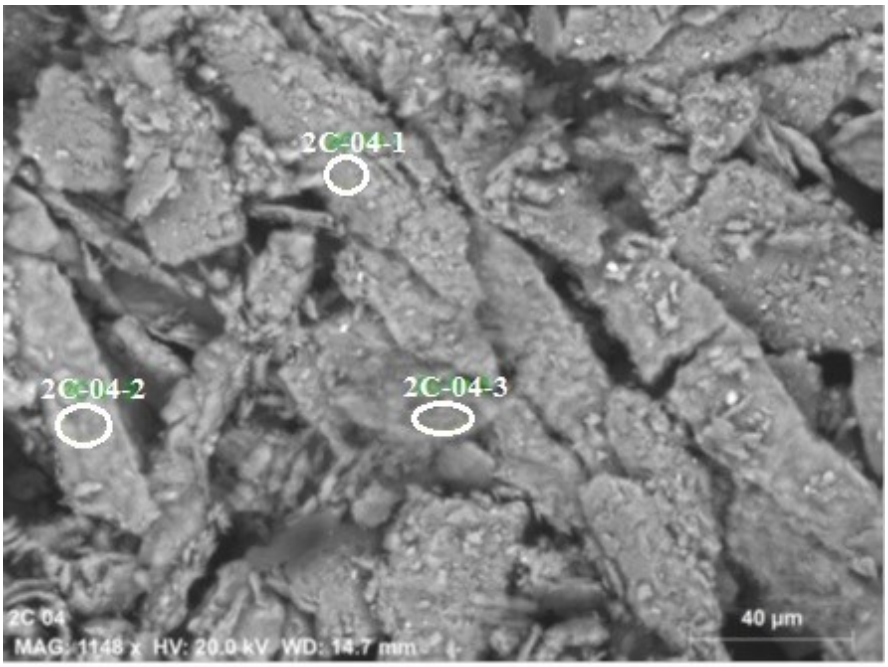


Figure 25. Scanning Electron Micrograph of Sample 2C-04, showing areas where elemental spectra were analyzed.

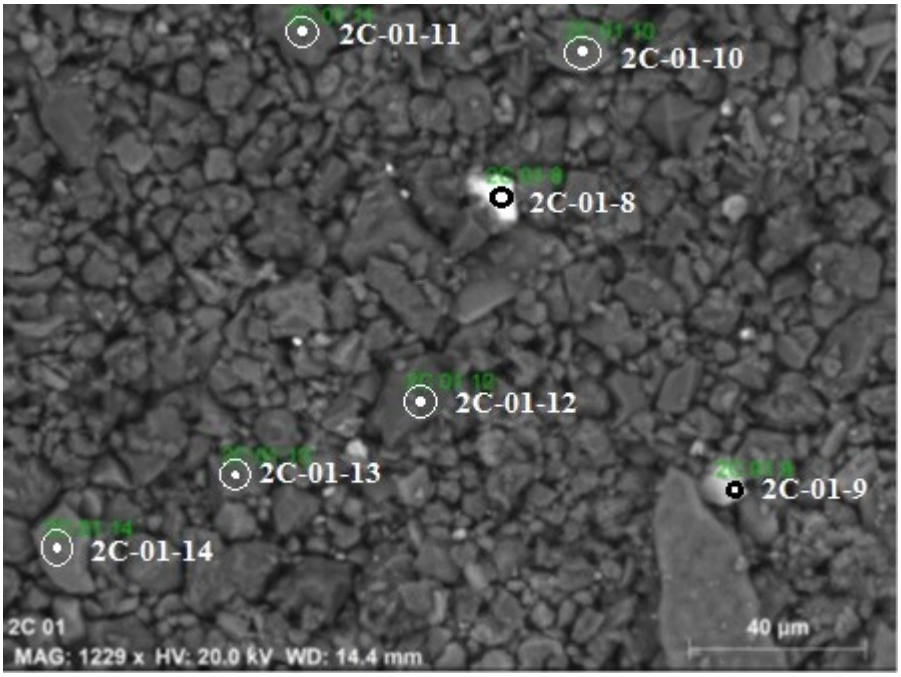


Figure 26. Scanning Electron Micrograph of Sample 2C-01, showing points and areas where elemental spectra were analyzed. Sample points 10 to 14 had elemental spectra that were consistent with alumino-silicate clay minerals. Sample points 8 and 9 were sampled because of high brightness (high average atomic number) in back scattered electron imagery. Sample point 8 had zircon present.

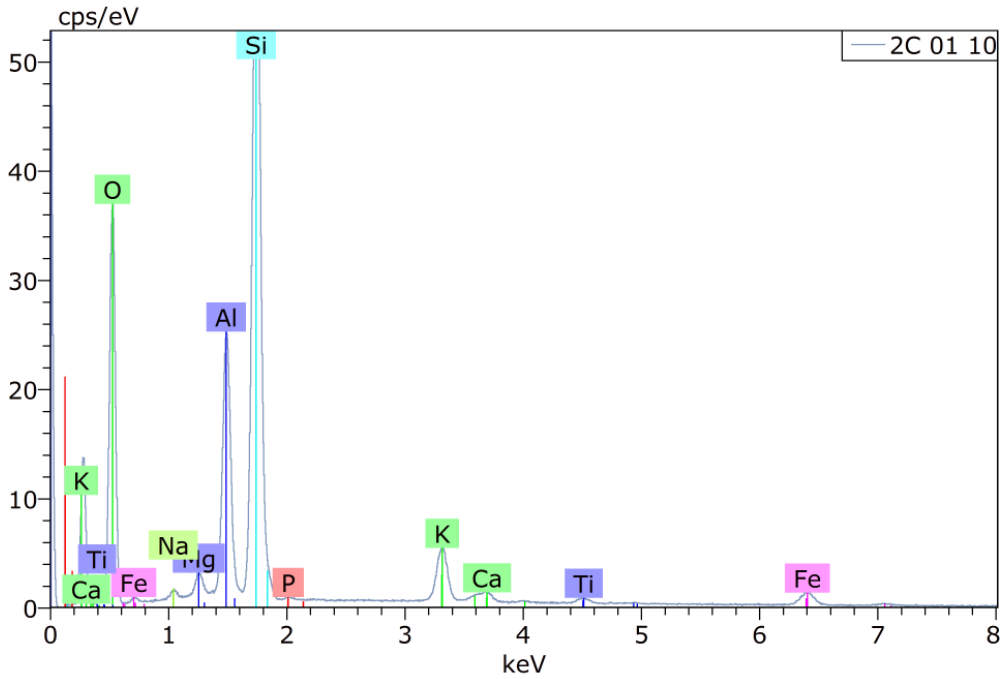


Figure 27. Elemental Spectrogram of Sample 2C-01, sample point 10, with results consistent with interstratified illite-montmorillonite.

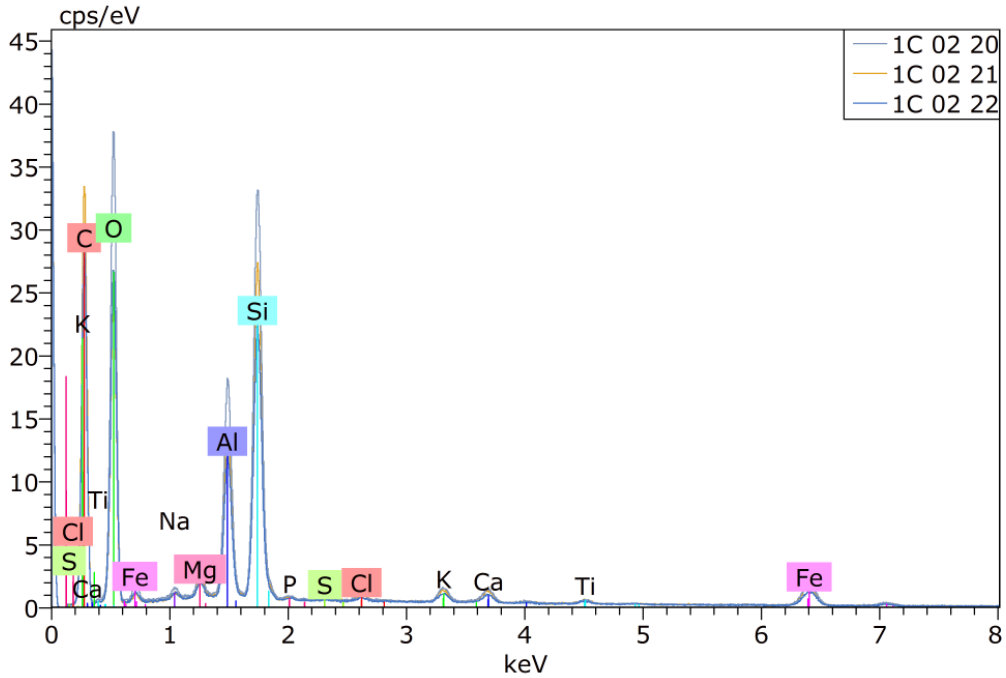


Figure 28. Elemental Spectrogram of Sample 1C-02, sampling points 20, 21, and 22, with results consistent with interstratified illite-montmorillonite and potassium feldspar. Carbon is included as a result of the carbon tape used to hold the sample.

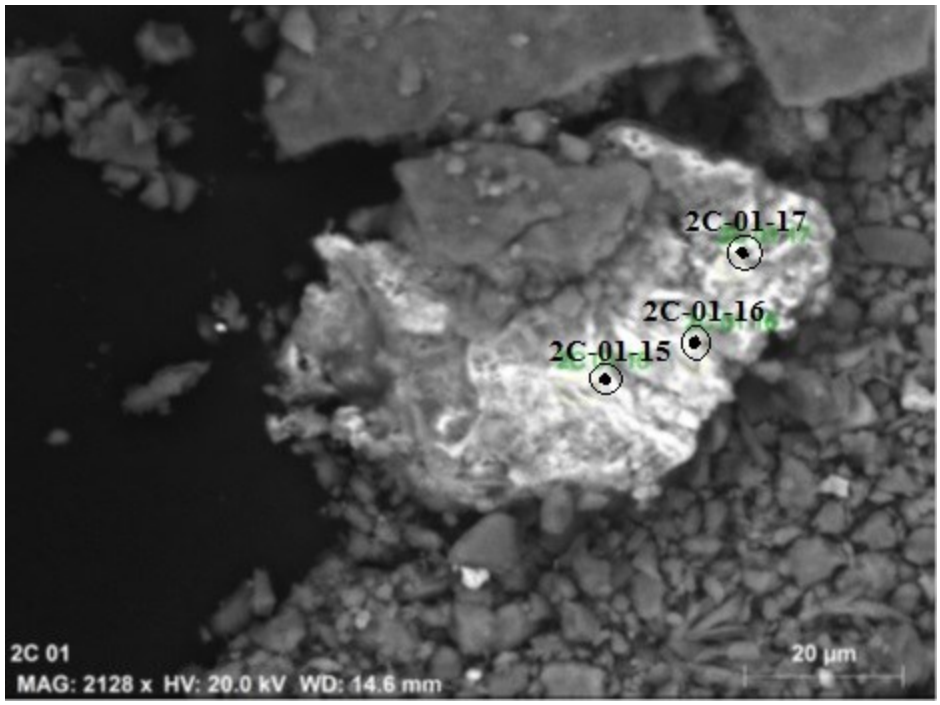


Figure 29. Scanning Electron Micrograph of Sample 2C-01 Detrital Phase. It shows points that were sampled because of high brightness (high average atomic number) in back scattered electron imagery.

Non-Clay Minerals

All samples had quartz, potassium feldspar, and plagioclase present. No significant differences were found in any of the subareas (Figure 30).

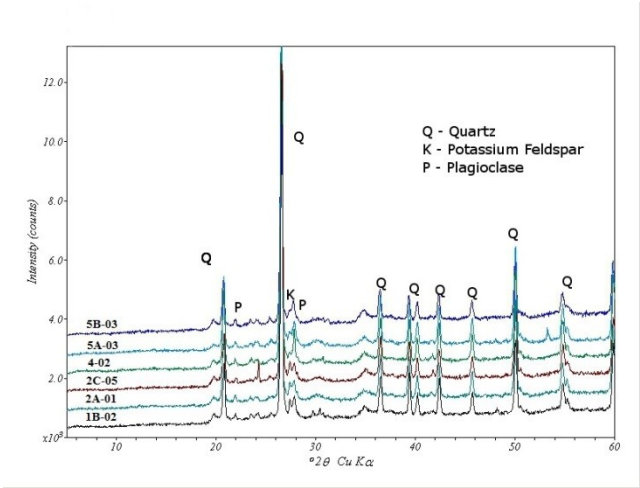


Figure 30. Diffractogram of Random Mounted Samples – Non-Clay Fraction, showing consistency of non-clay minerals across the study area.

Compaction and Infiltration

Compaction

Compaction by penetrometry across the whole study area under moist conditions ranged from 10cm to 27cm, with a mean of 16.5cm. The median was 16.0cm, and the standard deviation was 4.0cm. Penetrometry under moist conditions was highest in Area 4. It was lowest in Area 2A (Table 4 and Figure 31). Kriging shows highest values in Subarea 2C. Cluster and Outlier Analysis shows three points in the southern part of 2C that had high z-scores (Figure 32).

Table 4.--Depth (cm) with Penetrometer Under Moist Conditions

	n	Mean	Standard Deviation	Standard. Error
Total	46	16.48	4.00	0.58
Subarea 1A	3	14.67	1.53	0.88
Subarea 1B	5	15.00	3.46	1.55
Subarea 1C	5	14.40	2.70	1.21
Subarea 2A	2	11.50	2.12	1.22
Subarea 2B	4	18.50	1.91	0.96
Subarea 2C	13	18.46	4.37	1.21
Area 4	5	19.80	4.66	2.08
Subarea 5A	3	14.67	3.79	2.19
Subarea 5B	6	14.67	2.42	0.99

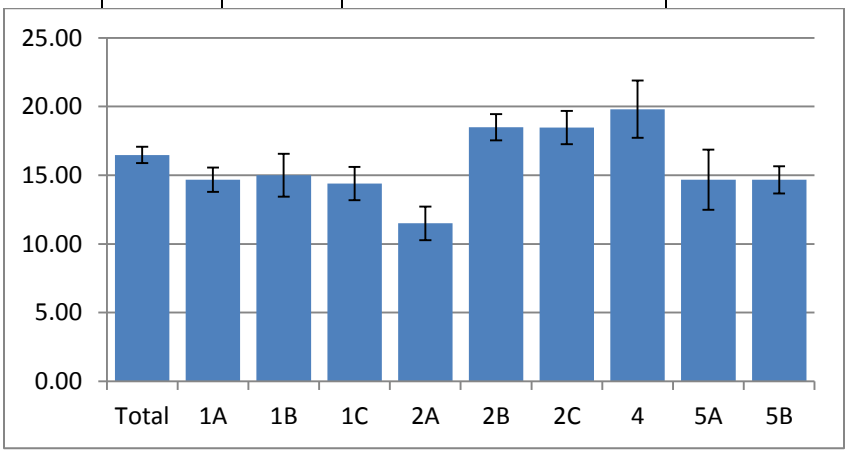


Figure 31. Depth (cm) with Penetrometry Under Moist Conditions vs. Subarea, Error bars are s.e. of the mean.

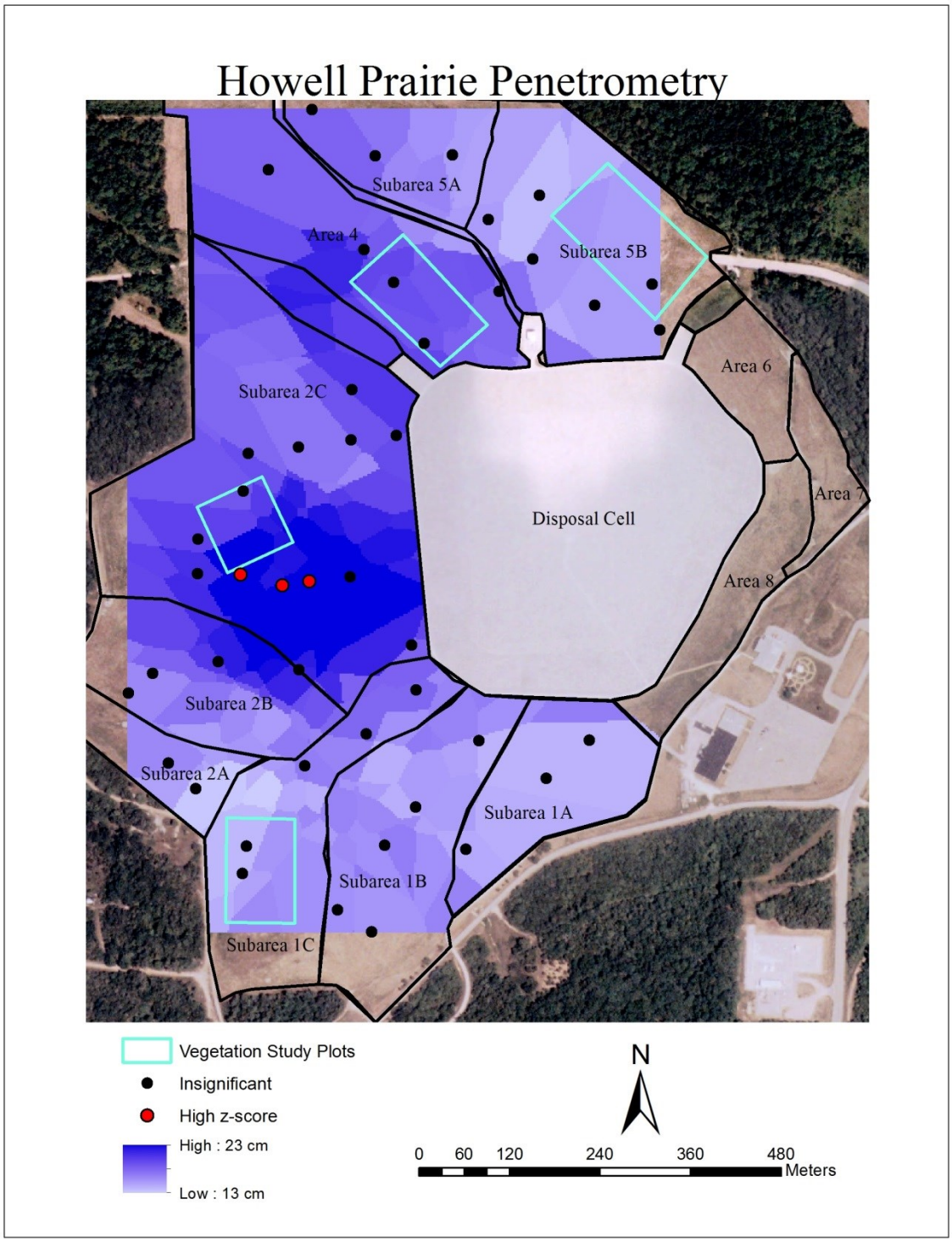


Figure 32. Map of Penetrometry of Howell Prairie During Moist Conditions, showing significantly high values in Subarea 2C.

Penetrometry across the whole study area under drought conditions ranged from 0cm to 5cm, with a mean of 1.63 cm and standard deviation of 1.06 cm (Table 5). Due to the low sample size, these numbers are statistically insignificant. Kriging and Cluster and Outlier Analysis could not be run due to the small sample set.

Table 5.--Penetrometry (cm) During Drought

Sample	Depth	Sample	Depth
1b-1	1	2c-5	4
1c-1	3	4-1	3
1c-2	1	4-2	1
2b-1	3	5a-1	3
2c-1	2	5a-2	5
2c-2	1	5b-1	1
2c-3	0	Mean	1.63
2c-4	2	Std. Dev	1.06

Infiltration

Infiltrometry ranged from 0 to 120 cm/hr across the study area, with a mean of 27.4 cm/hr, and standard deviation of 24.5 cm/hr. It was lowest in Subarea 2B and highest in Subareas 5A and 5B (Table 6 and Figure 33). Kriging showed highest values in Subarea 5B. Cluster and Outlier Analysis showed two points in Subarea 5B with high z-scores with a 99% confidence level (Figure 34).

Table 6. Infiltration Rates (cm/hr)

	n	Mean	Standard Deviation	Standard Error
Total	46	27.39	24.45	3.57
Subarea 1A	3	26.00	12.49	7.21
Subarea 1B	5	19.20	10.73	4.80
Subarea 1C	5	27.60	21.88	9.79
Subarea 2A	2	39.00	21.21	12.25
Subarea 2B	4	12.00	6.93	3.46

Table 6 Continued

Subarea 2C	13	24.00	20.49	5.68
Area 4	5	16.80	13.01	5.82
Subarea 5A	3	59.00	21.63	12.49
Subarea 5B	6	59.00	41.64	17.00

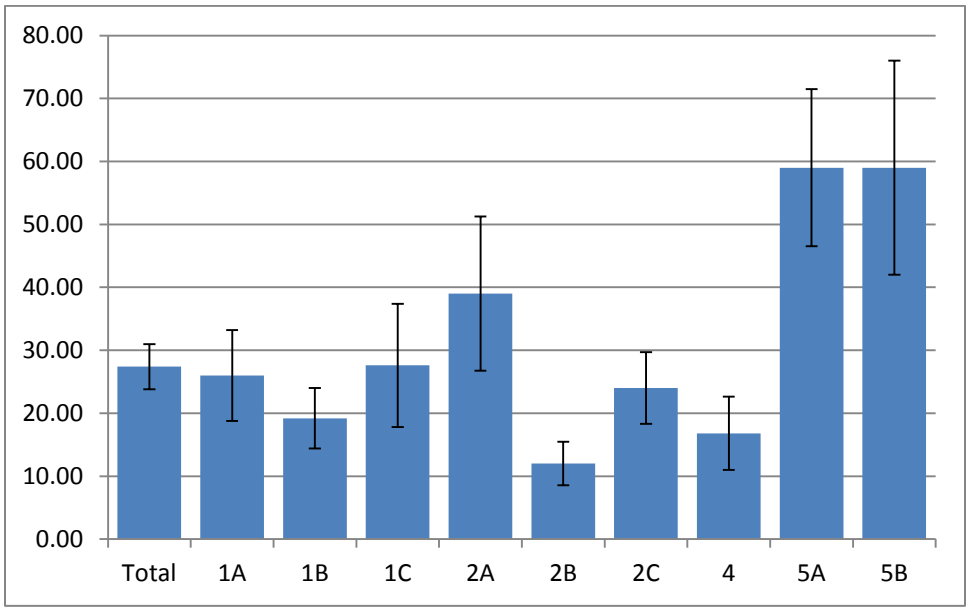


Figure 33. Infiltration Rates (cm/hr) vs. Subarea, Error bars are s.e. of the mean.

Soil Nutrient Analyses

Nitrate

Nitrate ranged from 25.6 ppm to 105.9 ppm, with a mean of 105.9 ppm and standard deviation of 61.9 ppm. Nitrate was highest in Subarea 2A, and lowest in Subarea 1C. The AOC was near the mean with a large standard error (Table 7 and Figure 35). Kriging shows highest levels in 1C and 4 with low areas dispersed throughout the study area; however, the low sample size does not provide enough data to draw conclusions. Cluster and Outlier Analysis resulted in one point in Subarea 2C with

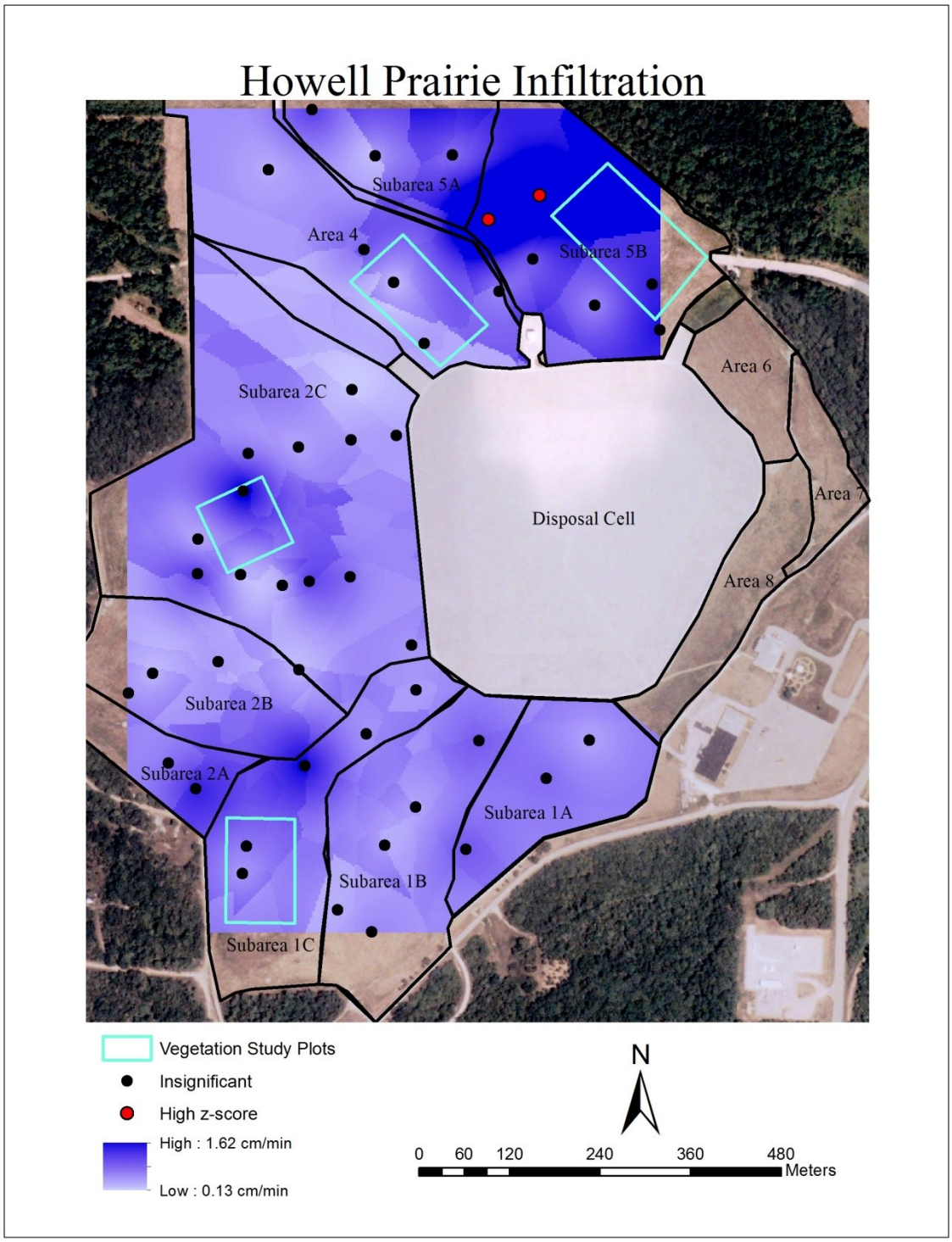


Figure 34. Map of Infiltration Rate of Howell Prairie Soil, showing significantly high values in Subarea 5B.

a large negative z-score at the 99% confidence level (Figure 36). The low number of samples with high variability makes these results insignificant.

Table 7.--Nitrate Content (ppm)

	n	Mean	Standard Deviation	Standard Error
Total	24	105.90	61.92	12.38
Subarea 1A	1	67.60		
Subarea 1B	3	118.90	28.91	16.69
Subarea 1C	2	54.50	29.13	20.60
Subarea 2A	2	159.10	75.52	53.40
Subarea 2B	2	75.55	70.64	49.95
Subarea 2C	7	95.36	64.98	24.56
Area 4	2	96.30	22.20	15.70
Subarea 5A	2	122.13	80.89	57.20
Subarea 5B	3	122.13	102.48	59.17

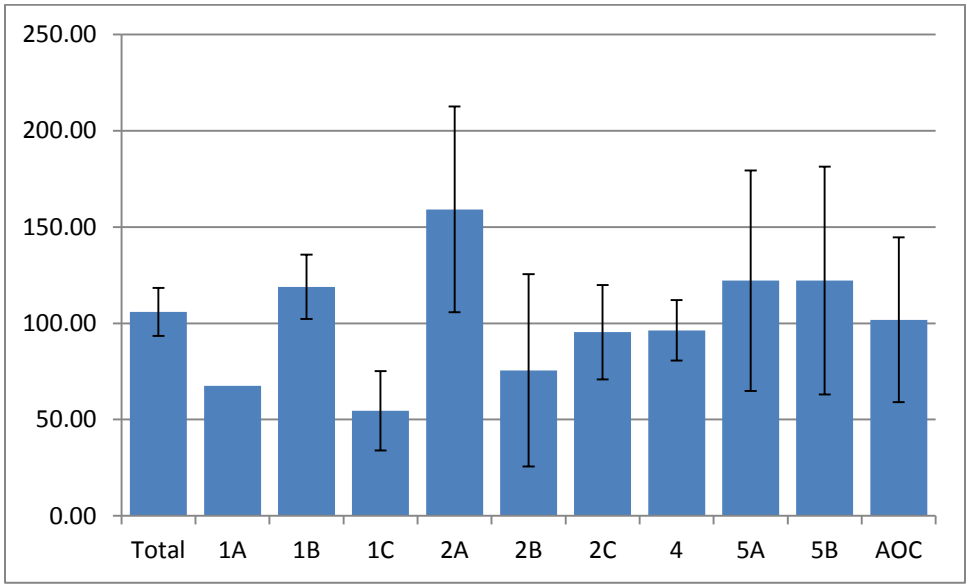


Figure 35. Nitrate Content (ppm) vs. Subarea, Error bars are s.e. of the mean.

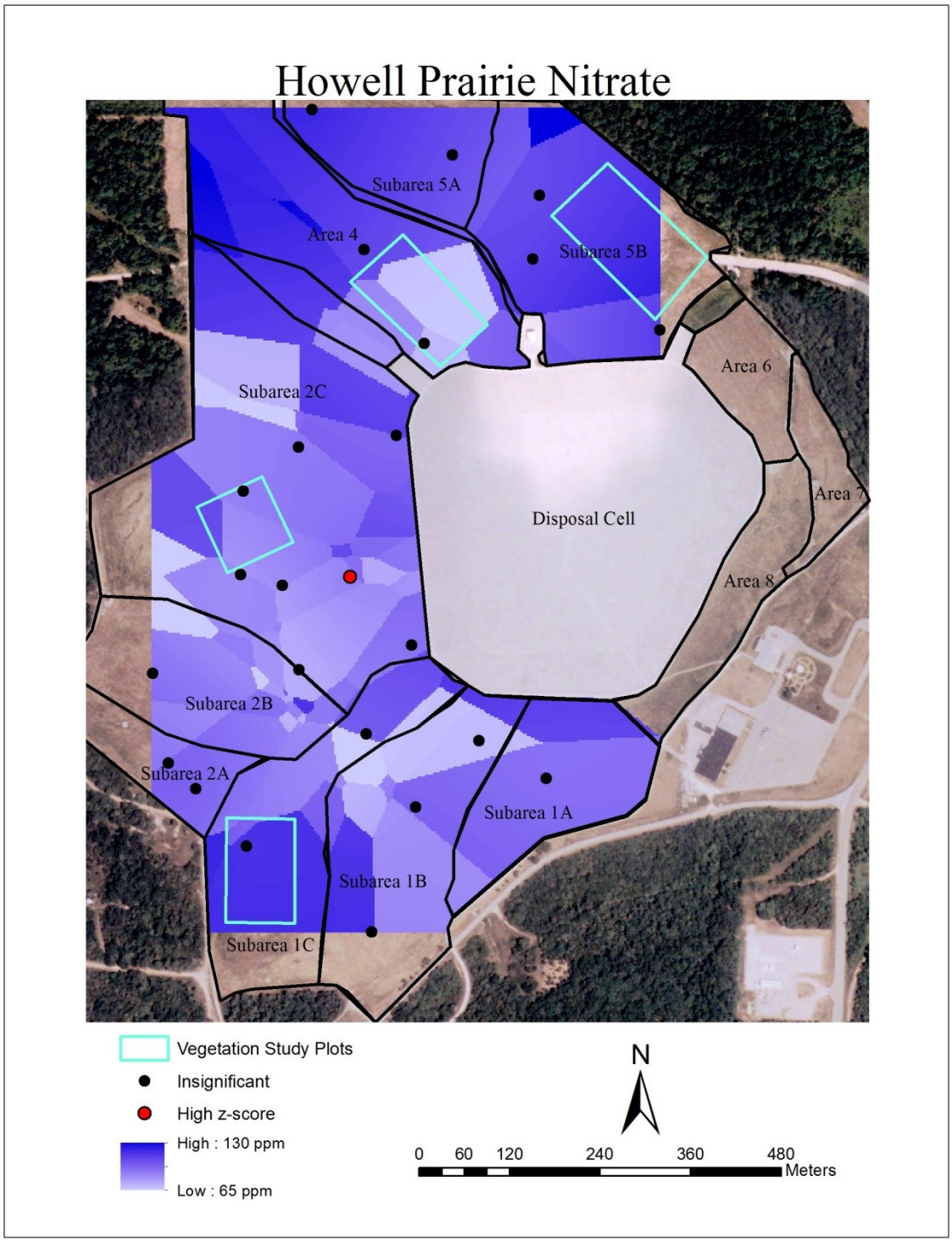


Figure 36. Map of Nitrate Concentration in Howell Prairie Soil. The low sample size did not provide enough data to draw conclusions.

Potassium

Potassium ranged from 53.5 ppm to 189 ppm across the study area, with a mean of 93.1 ppm and standard deviation of 27.1 ppm. It was highest in Subarea 2A. Subarea 4 was also higher than the study area (Table 8 and Figure 37). All other subareas were not significantly different than the study area. Kriging showed highest levels in Area 4 and lowest in Subarea 2C. Cluster and Outlier Analysis resulted in one point each in Area 4 and Subarea 2A with high a z-score with a 99% confidence level (Figure 38).

Table 8. Potassium Content (ppm)

	n	Mean	Standard Deviation	Standard Error
Total	46	93.11	27.07	3.95
Subarea 1A	3	91.17	12.05	6.95
Subarea 1B	5	95.70	13.12	5.87
Subarea 1C	5	90.60	30.81	13.78
Subarea 2A	2	139.50	33.23	19.19
Subarea 2B	4	83.50	20.70	10.35
Subarea 2C	13	84.62	18.43	5.11
Area 4	5	116.40	45.26	20.24
Subarea 5A	3	81.67	27.74	16.01
Subarea 5B	6	81.67	23.43	9.56

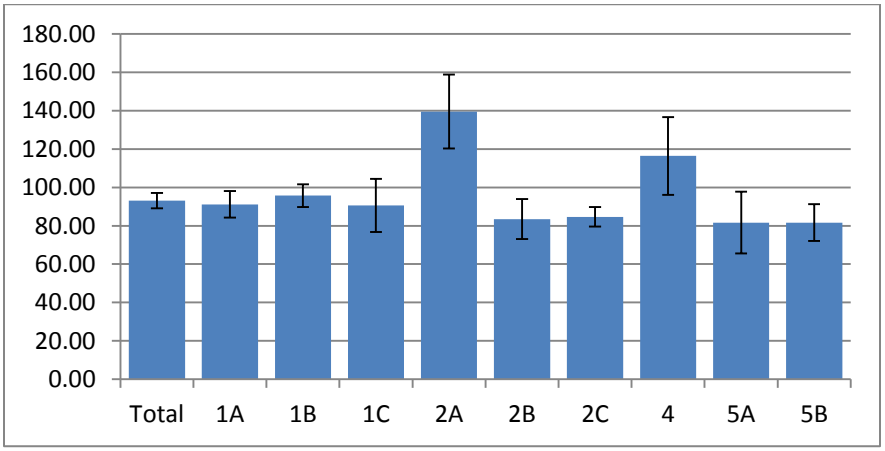


Figure 37. Potassium Content (ppm) vs. Subarea, Error bars are s.e. of the mean.

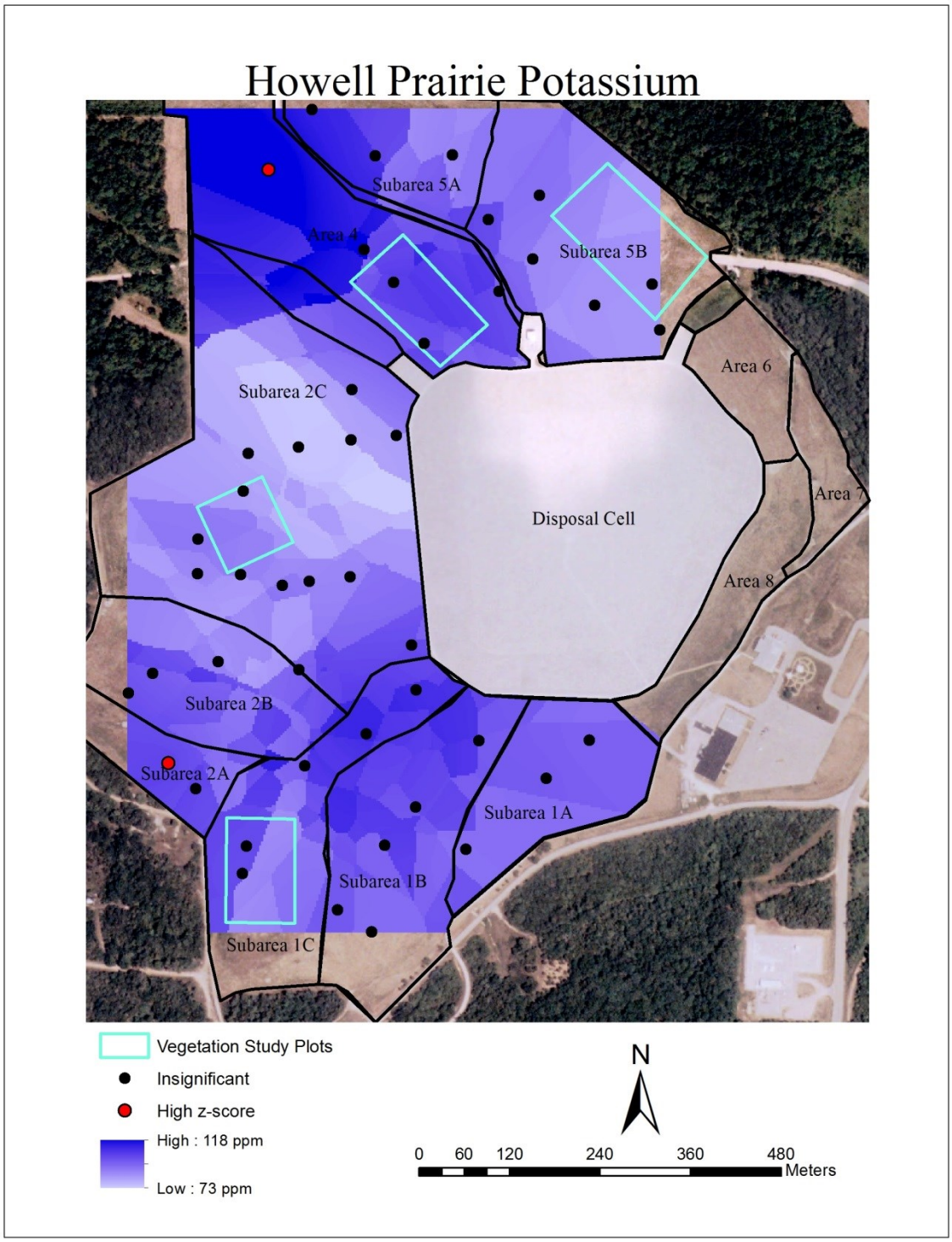


Figure 38. Map of Potassium Content in Howell Prairie Soils, showing points in Subarea 2A and Area 4 with significantly high values. Subarea 2C has lower values than the rest of the study area.

Phosphorus

Phosphorus content across the study area ranged from 1.5 ppm to 33.5 ppm, with the mean of 14.0 ppm and standard deviation of 7 ppm. Phosphorus was highest in Subareas 2A and 2B and lowest in Subarea 2C (Table 9 and Figure 39). Kriging showed lowest levels in Subarea 2C, but high levels in 2A, 2B, and 4. Cluster and Outlier Analysis showed two points in the southern portion of Subarea 2C with high z-scores at 99% confidence level and one in 2C with a high z-score at 95% confidence level (Figure 40).

Table 9.--Phosphorus Content (ppm)

	n	Mean	Standard Deviation	Standard Error
Total	46	13.99	7.00	1.02
Subarea 1A	3	16.50	7.05	4.07
Subarea 1B	5	15.00	5.45	2.44
Subarea 1C	5	14.10	4.74	2.12
Subarea 2A	2	17.25	6.01	3.47
Subarea 2B	4	16.50	1.96	0.98
Subarea 2C	13	11.69	8.08	2.24
Area 4	5	15.50	4.90	2.19
Subarea 5A	3	11.08	15.77	9.10
Subarea 5B	6	11.08	6.87	2.81

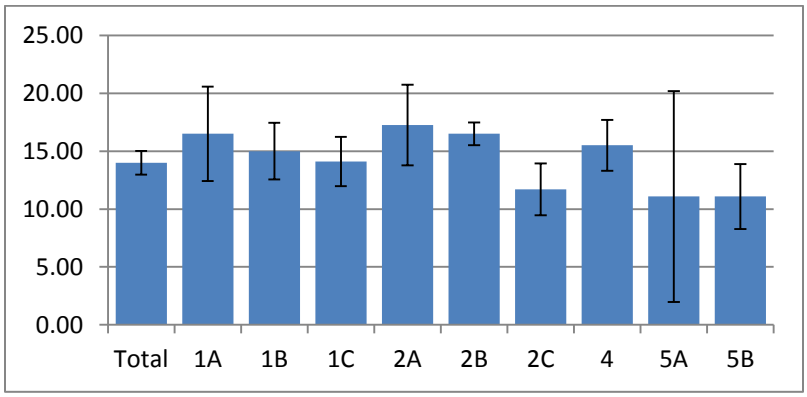


Figure 39. Phosphorus Content (ppm) vs. Subarea, Error bars are s.e. of the mean.

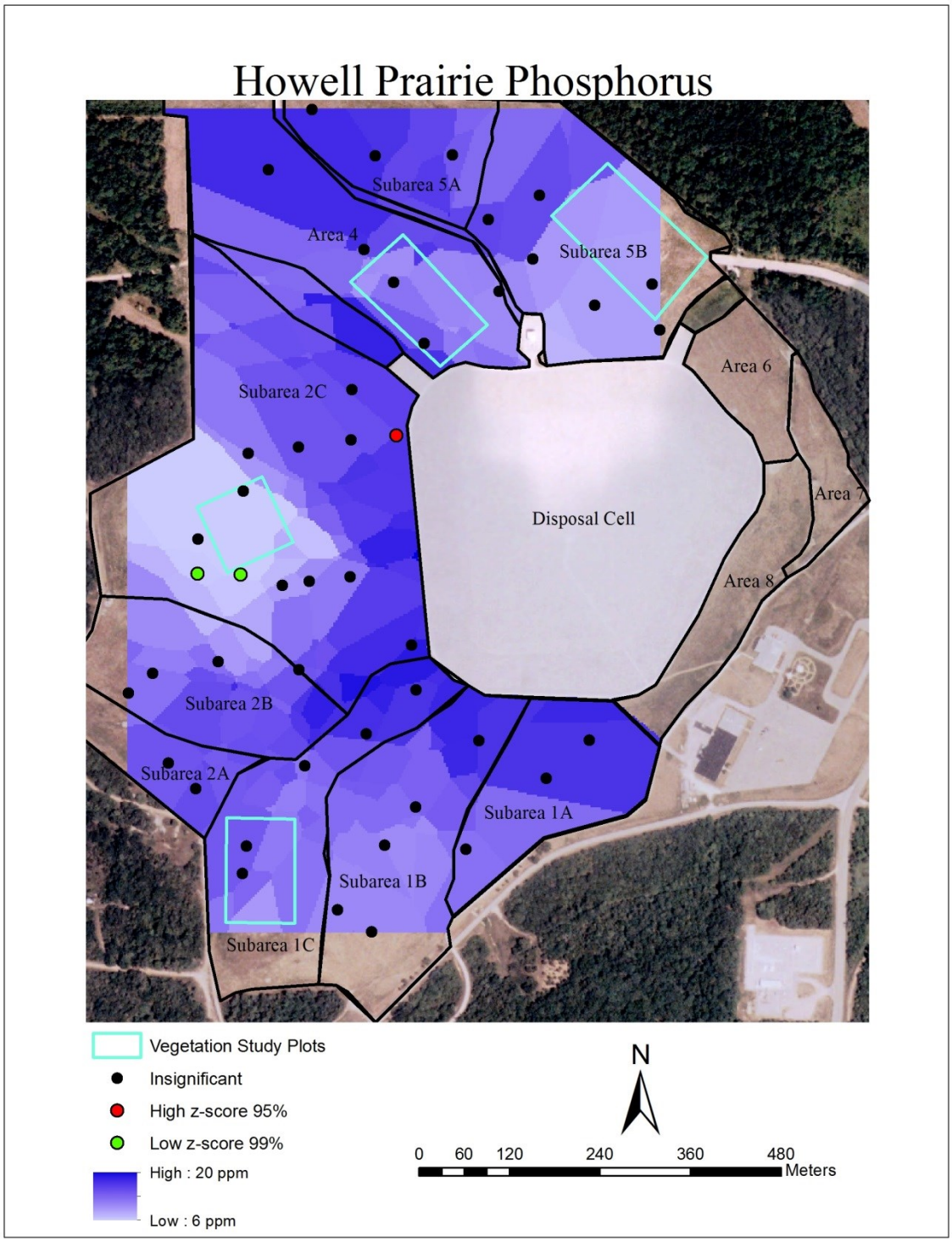


Figure 40. Map of Phosphorus Content in Howell Prairie Soils, showing significantly lower values in Subarea 2C.

Calcium

Calcium ranged from 1041.5 ppm to 4451 ppm across the study area, with a mean of 2177.3 ppm and standard deviation of 611 ppm. It was highest in Subarea 2A and lowest in Subarea 5B (Table 10 and Figure 41). Kriging showed highest values in Subarea 1B and lowest in 2C. Cluster and Outlier Analysis had two points in Subarea 1B with high z-scores and 99% confidence levels (Figure 42).

Table 10.—Calcium Content (ppm)

	n	Mean	Standard Deviation	Standard Error
Total	46	2177.29	610.96	89.12
Subarea 1A	3	2226.00	310.71	179.39
Subarea 1B	5	2586.70	221.13	98.89
Subarea 1C	5	2427.70	878.26	392.77
Subarea 2A	2	2747.25	733.62	423.56
Subarea 2B	4	1876.38	146.85	73.43
Subarea 2C	13	2077.73	426.07	118.17
Area 4	5	1964.60	369.99	165.46
Subarea 5A	3	1630.58	1320.41	762.34
Subarea 5B	6	1630.58	313.29	127.90

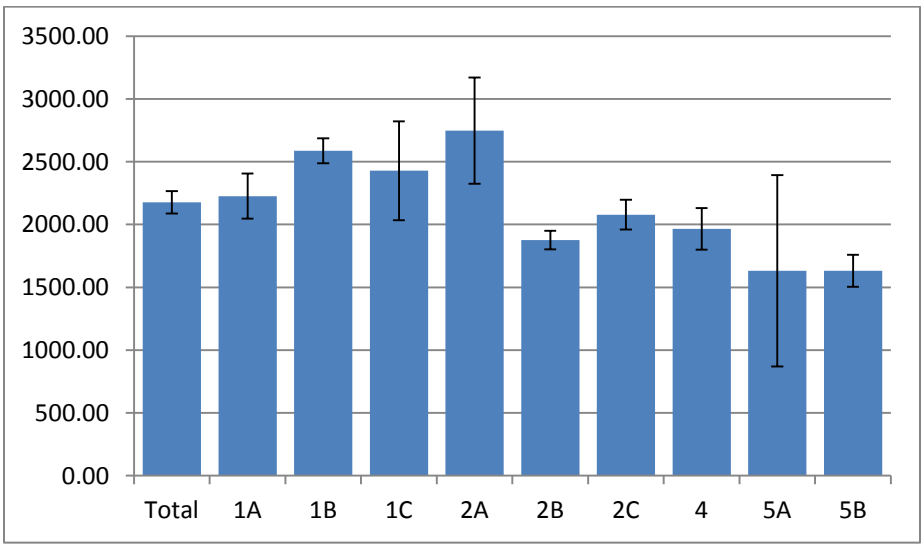


Figure 41. Calcium Content (ppm) vs. Subarea, Error bars are s.e. of the mean.

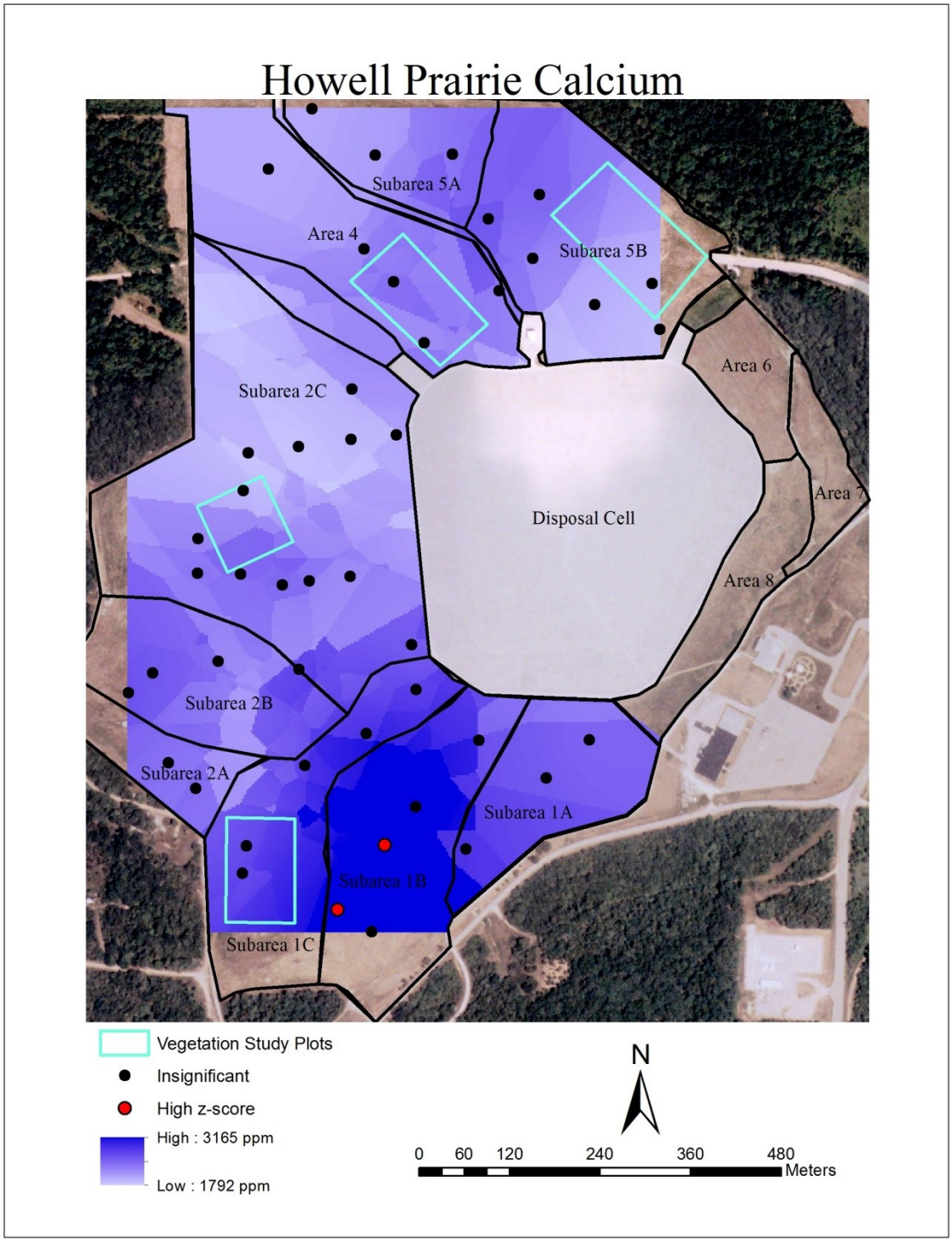


Figure 42. Map of Calcium Content in Howell Prairie Soils, showing significantly high values in Subarea 1B.

Magnesium

Magnesium ranged from 141.5 ppm to 616 ppm across the study area, with a mean of 356.1 ppm and standard deviation of 93.4 ppm. It was highest in Subarea 2C and Area 4. It was lowest in Subarea 2B (Table 11 and Figure 43). Kriging showed highest levels in Subarea 2C and lowest in Subareas 2B and 1C. Cluster and Outlier Analysis results showed three points in the southern portion of Subarea 2C with high z-scores at the 99% confidence level (Figure 44).

Table 11.--Magnesium Content (ppm)

	n	Mean	Standard Deviation	Standard Error
Total	46	356.10	93.42	13.63
Subarea 1A	3	309.83	21.95	12.67
Subarea 1B	5	364.60	49.01	21.92
Subarea 1C	5	314.50	67.96	30.39
Subarea 2A	2	398.50	101.12	58.38
Subarea 2B	4	286.13	26.94	13.47
Subarea 2C	13	394.81	110.08	30.53
Area 4	5	394.20	114.12	51.04
Subarea 5A	3	320.42	114.84	66.30
Subarea 5B	6	320.42	104.16	42.52

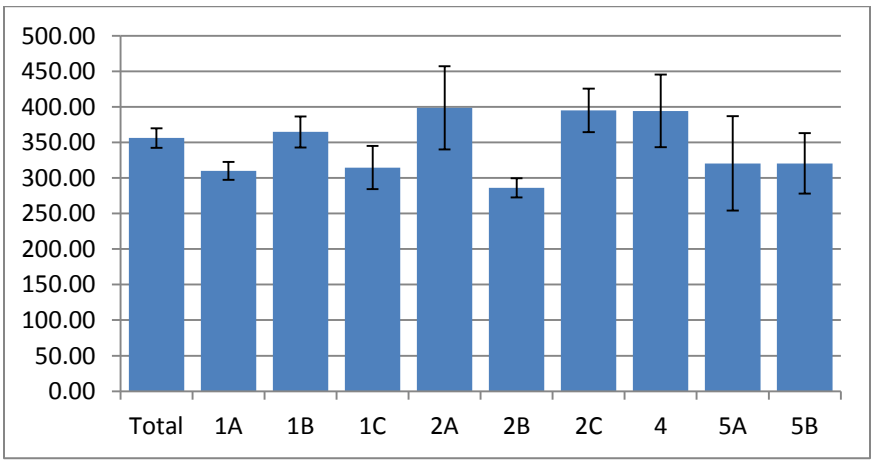


Figure 43. Magnesium Content (ppm) vs. Subarea, Error bars are s.e. of the mean.

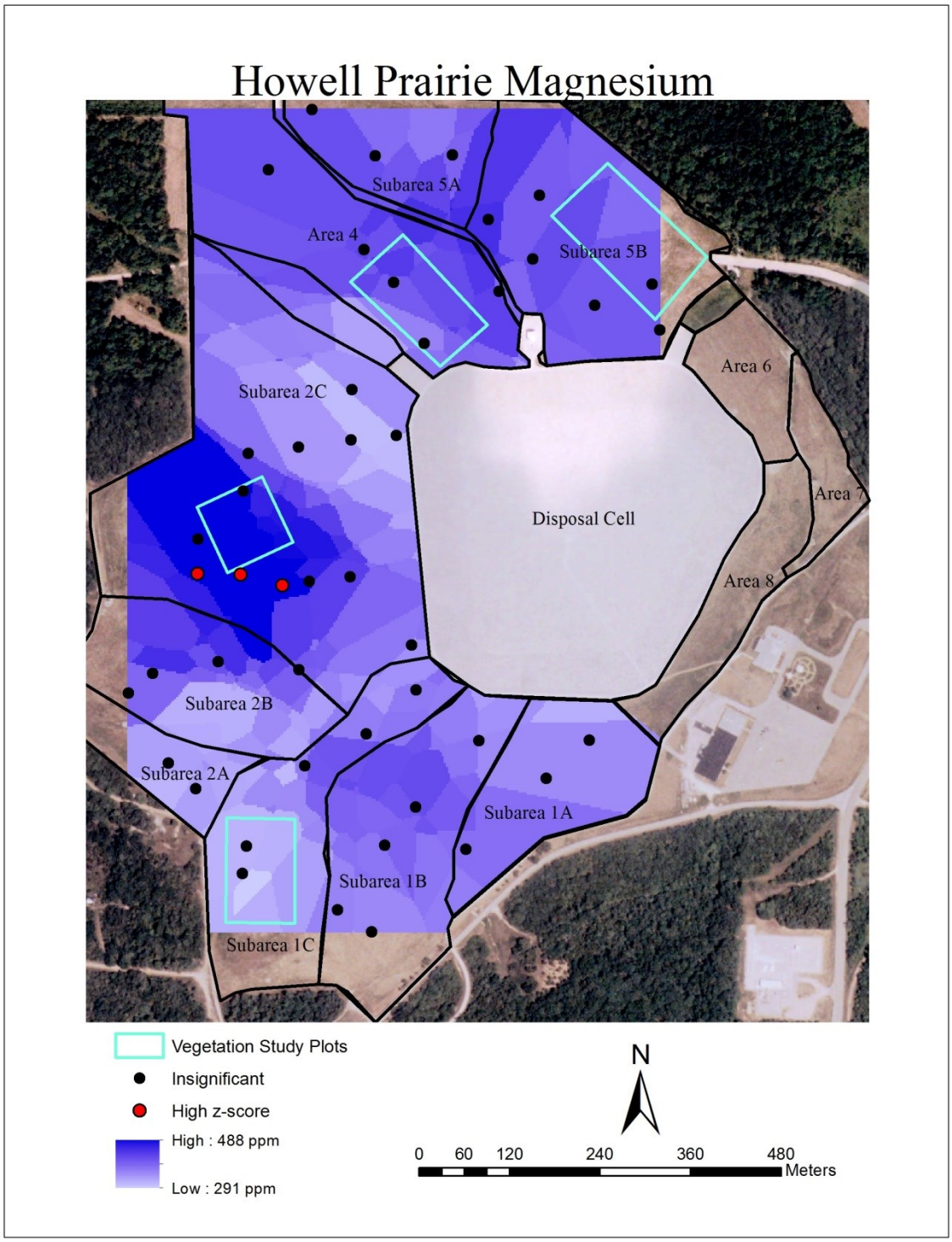


Figure 44. Map of Magnesium Content in Howell Prairie Soil, showing significantly high values in Subarea 2C.

Potassium to Magnesium Ratio

The ratio of potassium to magnesium ranged from 0.140 to 0.390 across the study area (including data from June and August, 2010), with a mean of 0.262 and a standard deviation of 0.0774. The potassium to magnesium ratio was highest in Subarea 2A and lowest in Subarea 2C (Table 12 and Figure 45). Kriging showed lowest levels in the southern part of Subarea 2C and highest levels in Subarea 5A. Cluster and Outlier Analysis showed a cluster of lowest values in the Subarea 2C at the 99% confidence level (Figure 46).

Table 12.—Potassium to Magnesium Ratio

	n	mean	standard deviation	standard error
Total	58	0.262	0.0774	0.0102
Subarea 1A	4	0.273	0.0707	0.0354
Subarea 1B	5	0.263	0.0142	0.0019
Subarea 1C	6	0.269	0.0537	0.0219
Subarea 2A	3	0.349	0.0756	0.0099
Subarea 2B	4	0.293	0.0696	0.0348
Subarea 2C	21	0.216	0.0603	0.0132
Area 4	5	0.300	0.0922	0.0412
Subarea 5A	3	0.305	0.1720	0.0993
Subarea 5B	7	0.284	0.0855	0.0323

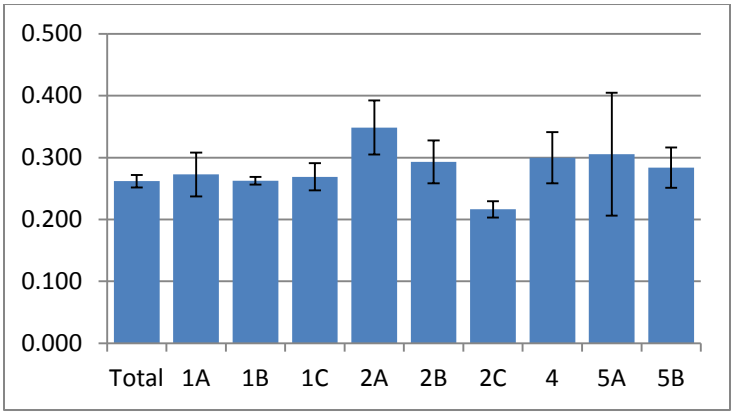


Figure 45. Potassium to Magnesium Ratio vs. Subarea, Error bars are s.e. of the mean.

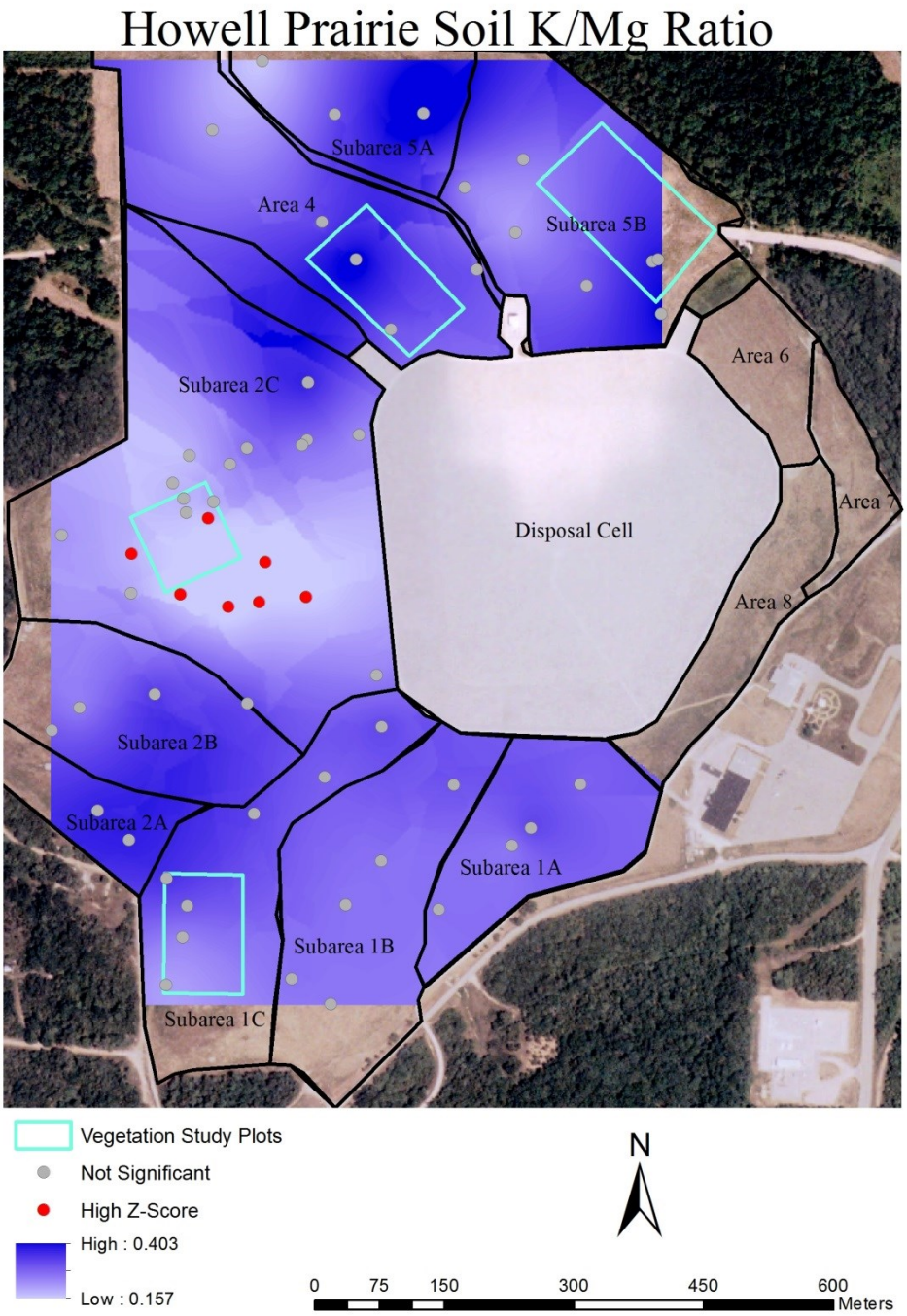


Figure 46. Map of Potassium to Magnesium Ratios in Howell Prairie Soils, showing a cluster of significantly low values in Subarea 2C. This includes data from previous studies of Howell Prairie soils. The ratio accounts for seasonal variability of nutrient cycling.

Organic Matter Content

Organic matter ranged from 0.4% to 3.5% across the study area, with a mean of 2.1%, and a standard deviation of 0.7%. Organic content was highest in Subarea 2A and lowest in Subarea 1A and Area 4 (Table 13 and Figure 47). Kriging results showed the highest levels in the eastern portion of Subarea 2C and lowest in the western portion of 2C and a general trend of low to high from north to south. Cluster and Outlier Analysis resulted in two points in the southern part of Subarea 2C with large negative z-scores at the 95% confidence level (Figure 48).

Table 13.--Percent Organic Matter

	n	Mean	Standard Deviation	Standard Error
Total	46	2.07	0.67	0.10
Subarea 1A	3	1.77	0.23	0.13
Subarea 1B	5	2.24	0.53	0.24
Subarea 1C	5	1.98	0.45	0.20
Subarea 2A	2	2.80	0.99	0.57
Subarea 2B	4	2.35	0.21	0.10
Subarea 2C	13	1.95	0.78	0.22
Area 4	5	1.78	0.80	0.36
Subarea 5A	3	2.15	1.00	0.58
Subarea 5B	6	2.15	0.70	0.29

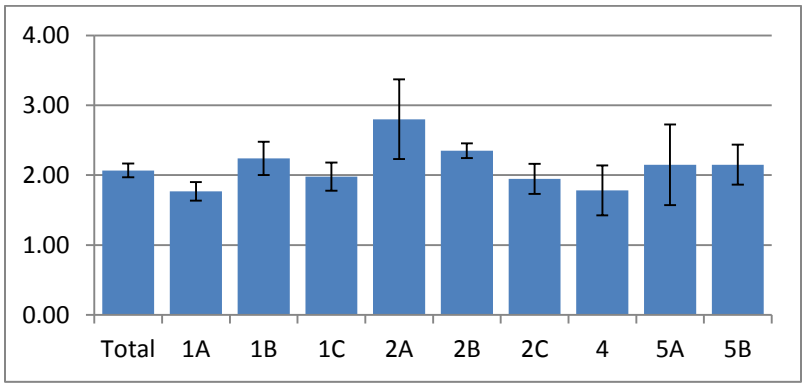


Figure 47. Percent Organic Matter vs. Subarea, Error bars are s.e. of the mean.

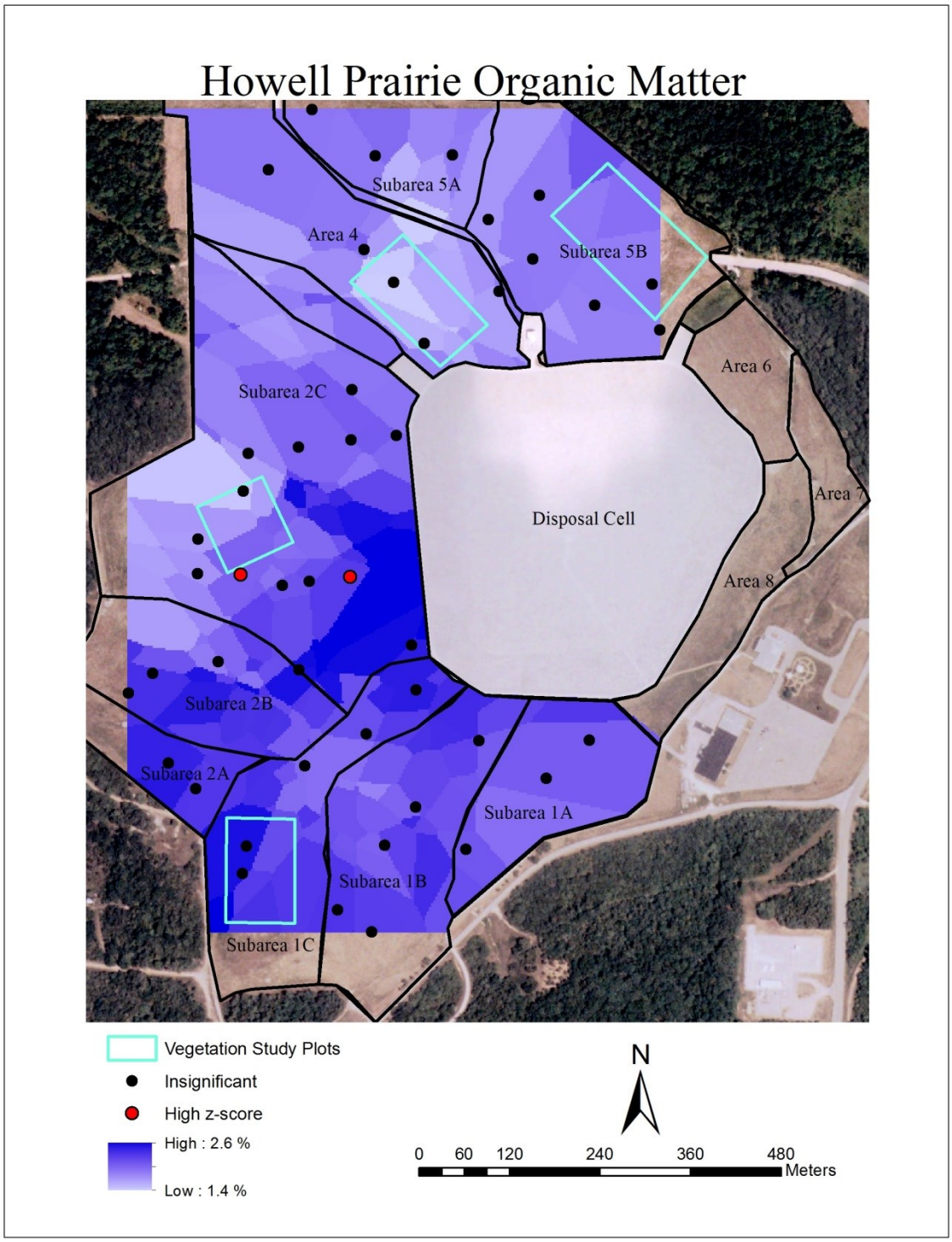


Figure 48. Map of Organic Matter Content in Howell Prairie Soils, showing highest levels in the eastern part of Subarea 2C and lowest levels in the western part of Subarea 2C. A general trend of low values in the north to high values in the south is also shown.

Cation-exchange Capacity, pH, and Neutralizable Acidity

Cation Exchange Capacity

Cation Exchange Capacity (CEC) ranged from 7.5 meq/100g to 24.7 meq/100g, with a mean of 14.2 meq/100g and standard deviation of 3.3 meq/100g. CEC was highest in Subarea 2A. It was lowest in Subareas 5A and 5B, though the variability in Subarea 5A makes it insignificant (Table 14 and Figure 49). Kriging showed highest CEC in Subarea 1B and lowest in the northern half of Subarea 2C. Cluster and Outlier Analysis resulted in two points in Subarea 1B with high z-scores at a 99% confidence level (Figure 50).

Table 14--Cation Exchange Capacity (meq/100g)

	n	Mean	Standard Deviation	Standard Error
Total	46	14.22	3.25	0.47
Subarea 1A	3	13.93	1.48	0.86
Subarea 1B	5	16.24	1.37	0.61
Subarea 1C	5	15.00	4.93	2.21
Subarea 2A	2	17.45	2.76	1.59
Subarea 2B	4	12.00	0.62	0.31
Subarea 2C	13	14.08	2.54	0.71
Area 4	5	13.42	2.78	1.24
Subarea 5A	3	11.45	5.72	3.30
Subarea 5B	6	11.45	2.15	0.88

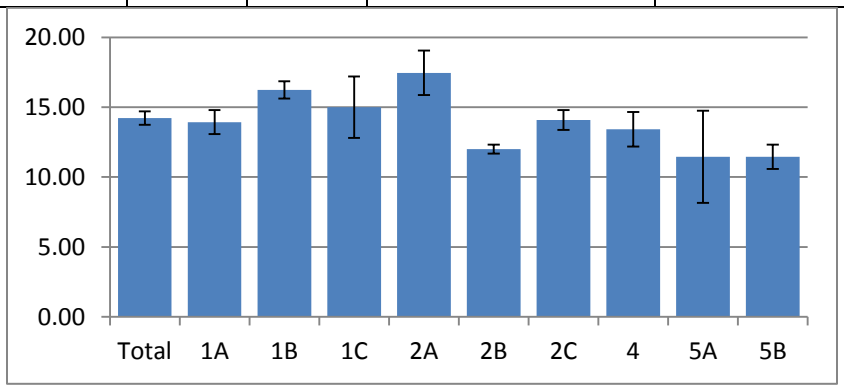


Figure 49. CEC (meq/100g) vs. Subarea, Error bars are s.e. of the mean.

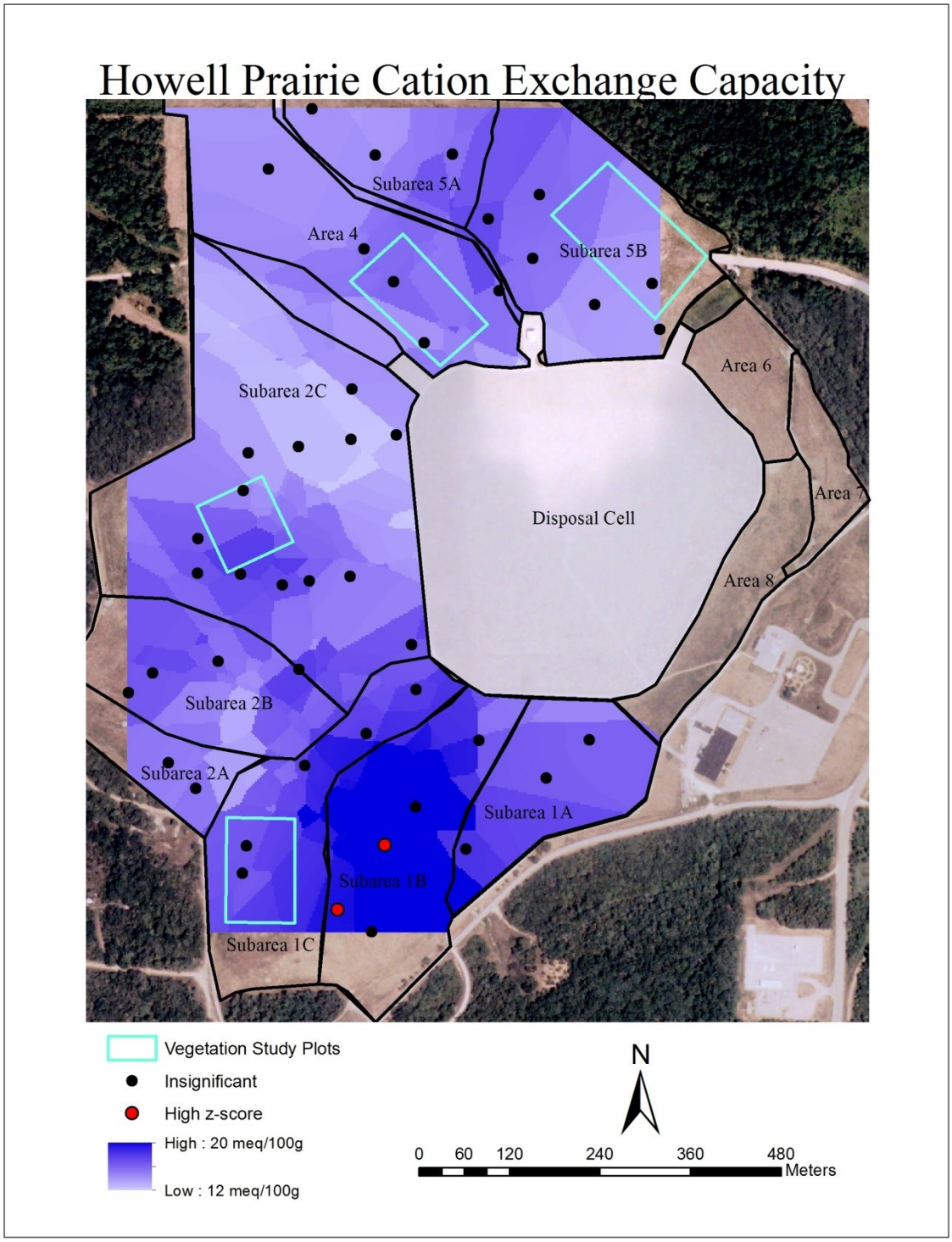


Figure 50. Map of Cation Exchange Capacity of Howell Prairie Soils, showing highest values in Subarea 1B.

pH

The pH ranged from 6.0 to 7.7 across the study area, with a mean of 7.3. Subarea 1B was highest at 7.6, while Subarea 5B was lowest at 6.8 (Table 15 and Figure 51). Kriging showed the lowest pH in Subareas 2C and 5B and highest in Subareas 1A and 1B. Cluster and Outlier Analysis could not be run with confidence because of the logarithmic scale of pH (Figure 52).

Table 15.--pH

	n	Mean
Total	46	7.32
Subarea 1A	3	7.51
Subarea 1B	5	7.56
Subarea 1C	5	7.48
Subarea 2A	2	7.40
Subarea 2B	4	7.33
Subarea 2C	13	7.19
Area 4	5	7.25
Subarea 5A	3	7.41
Subarea 5B	6	6.78

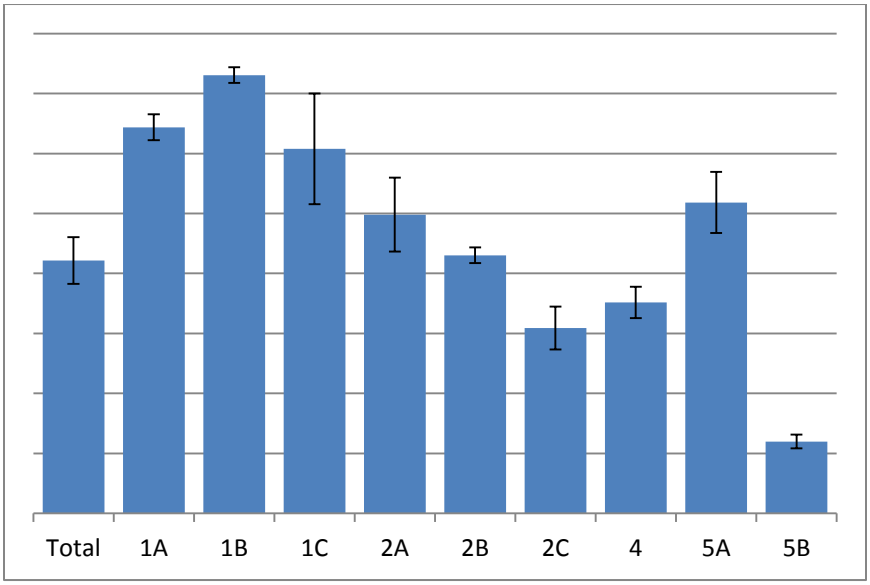


Figure 51. pH vs. Subarea

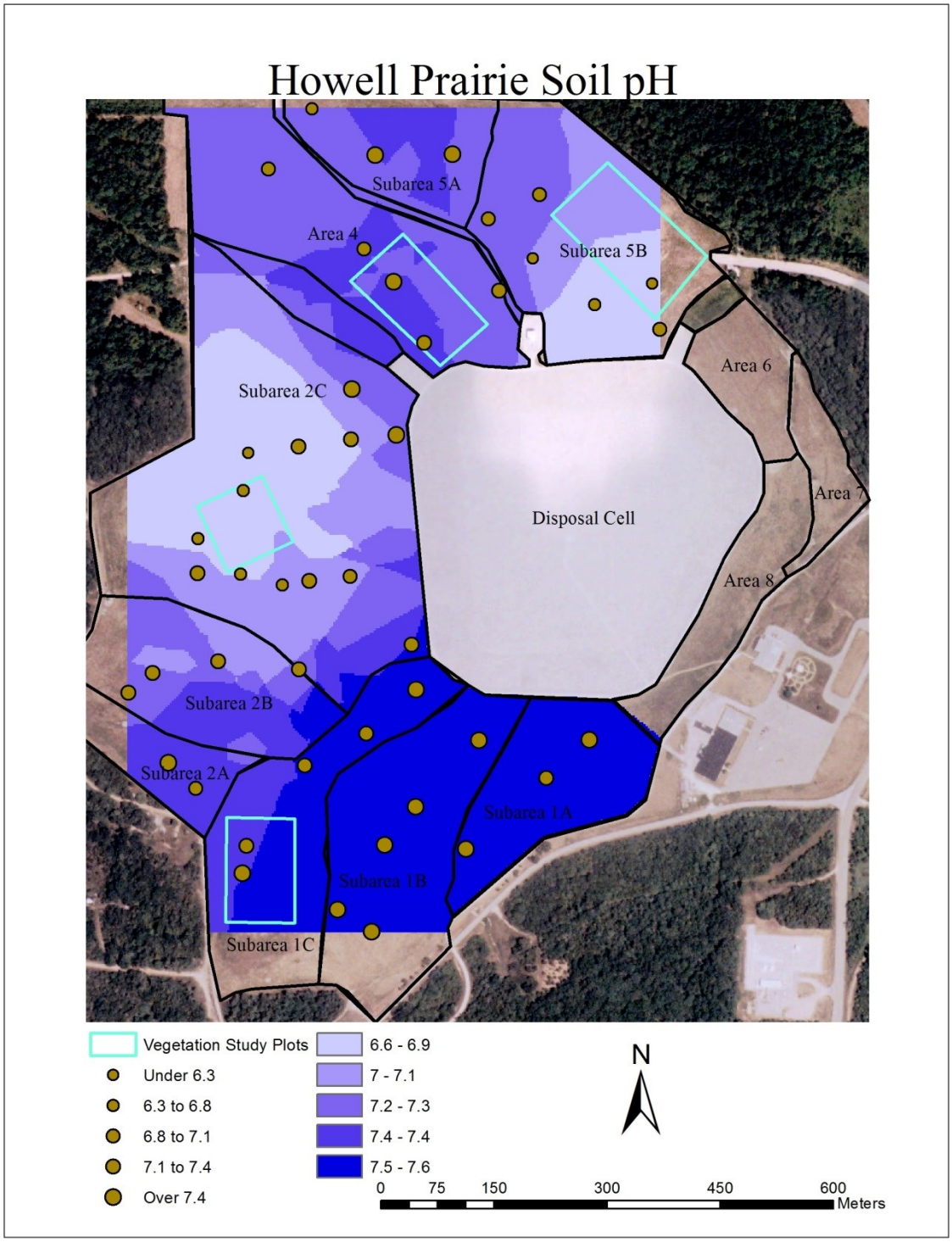


Figure 52. Map of Howell Prairie Soil pH, showing lowest values in Subareas 2C and 5B and highest values in Area 1.

Neutralizable Acidity

Neutralizable acidity was zero across most of the study area. The mean was 0.1 meq/100g and standard deviation was 0.32. Subareas 5A and 5B were the highest at 0.42 meq/100g (Table 16 and Figure 53). Kriging showed high NA in Subarea 2C and Subarea 5B. Cluster and Outlier Analysis resulted in two points in Subarea 2C and two points in Subarea 5B with high z-scores at a 99% confidence level (Figure 54).

Table 16--Neutralizable Acidity (meq/100g)

	n	Mean	Standard Deviation	Standard Error
Total	46	0.12	0.32	0.05
Subarea 1A	3	0.00	0.00	0.00
Subarea 1B	5	0.00	0.00	0.00
Subarea 1C	5	0.00	0.00	0.00
Subarea 2A	2	0.00	0.00	0.00
Subarea 2B	4	0.00	0.00	0.00
Subarea 2C	13	0.19	0.43	0.12
Area 4	5	0.00	0.00	0.00
Subarea 5A	3	0.42	0.29	0.17
Subarea 5B	6	0.42	0.49	0.20

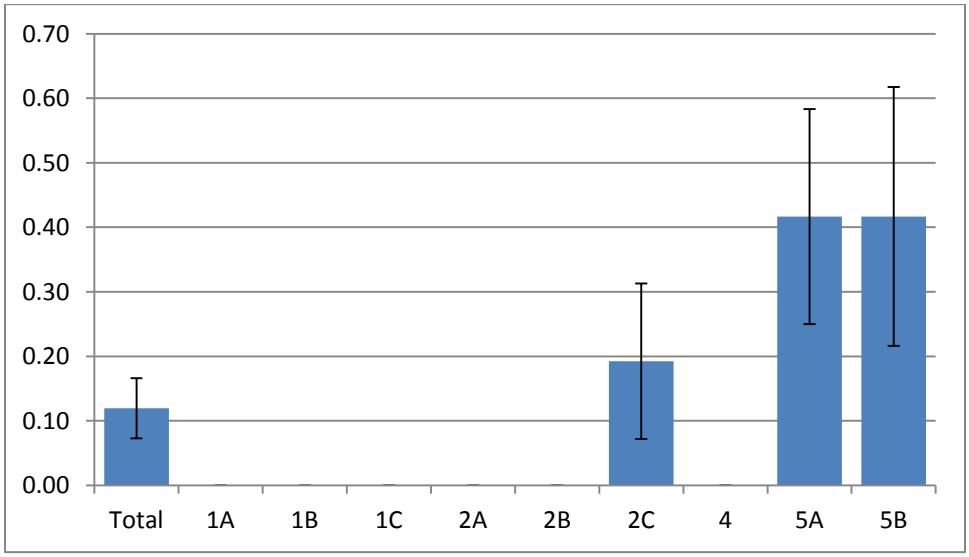


Figure 53. Neutralizable Acidity vs. Subarea, Error bars are s.e. of the mean.

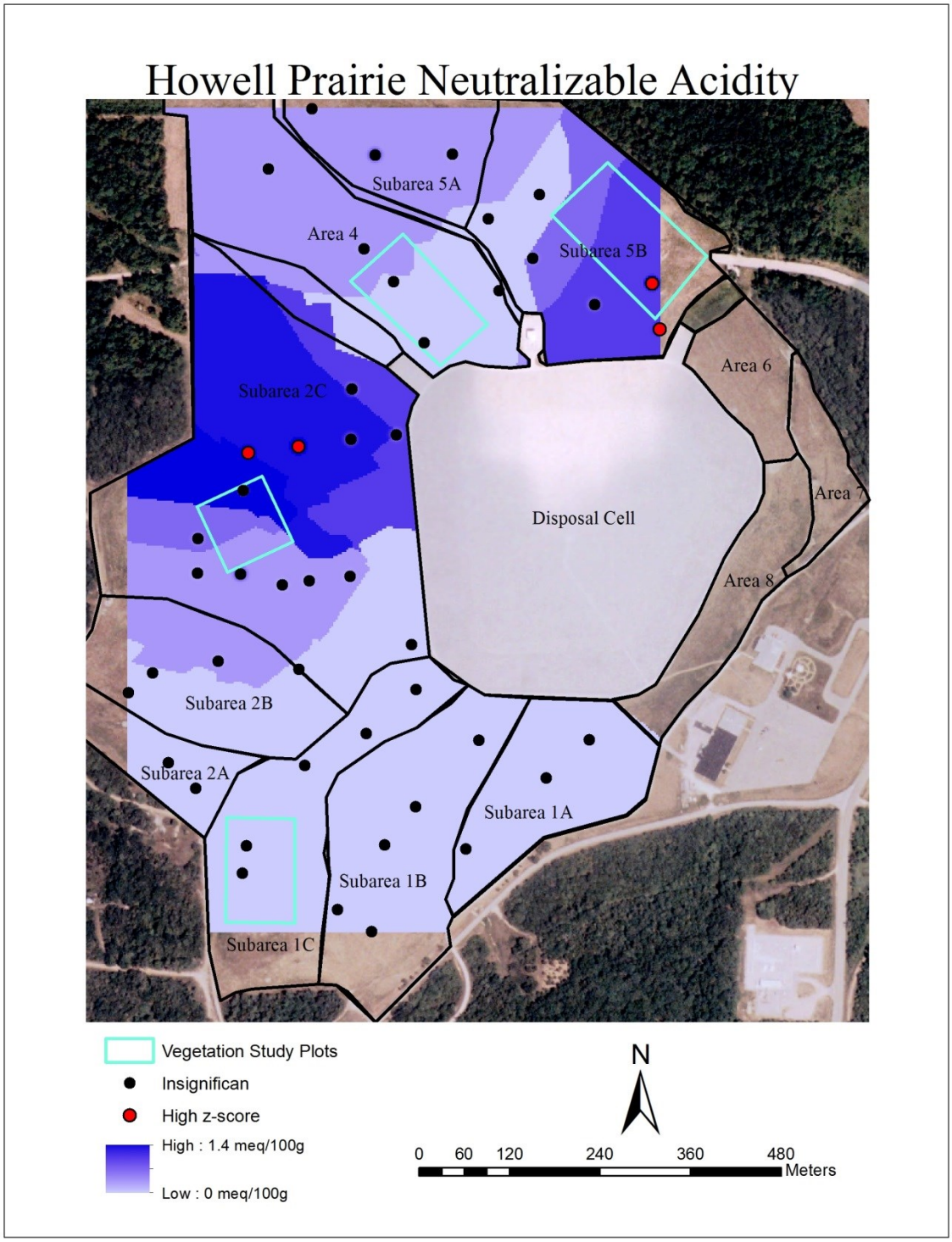


Figure 54. Map of Neutralizable Acidity of Howell Prairie Soils, showing highest values in Subareas 2C and 5B. This is insignificant since the majority of the soils at Howell Prairie are alkaline.

CHAPTER 5

DISCUSSION

Plant communities, especially prairie communities, depend on many factors for healthy growth. On Howell Prairie, a restored prairie at the Weldon Spring site, initial studies have shown that three of the four areas studied have successful prairie establishment. However, Subarea 2C has few grasses (native or nonnative) with the existing plants showing stunted growth, suggesting that there is a significant difference in the soil in that area due to lighter color, low organic matter content, low silt content, and high clay content (MDNR 2011b). For this study, comparisons were made across the whole study area which include soil texture (including percentages of sand, silt, and clay), clay and non-clay minerals, compaction by penetrometry under moist and drought conditions, infiltrometry, soil nutrients (calcium, magnesium, potassium, phosphorus, and nitrate) including the ratio of potassium to magnesium, organic matter content, cation exchange capacity (CEC), pH and neutralizable acidity (NA).

Soil texture differs across the study area. The percent of silt was lower in the southern portion of Subarea 2C, replaced with larger amounts of sand and clay. The resulting textures, based on the USDA classification, showed that this area's soils were loam, surrounded by clay loam, with silt loam to the north in Area 4 and to the south in Area 1 and Subareas 2A and 2B, followed by silty clay loam in Area 5. These differences coincide with compaction, where Subarea 2C is less compact (higher

penetrometry readings), which is expected for higher sand content. These results support the previous work at Howell Prairie.

The minerals in the soil are also very important to the species of plants that grow in it. These have not been studied at the site before. Due to the methods used, amounts of minerals could not be established; however, the presence of different minerals is still important.

All samples had quartz in the clay and non-clay fractions. Other non-clay minerals present included potassium feldspar and plagioclase. Both of these are sources of nutrients; potassium feldspars release potassium while degrading to kaolinite and plagioclase provides calcium (Velde 2009). This coincides with sufficient potassium and calcium throughout the whole study area.

Of the clay minerals, several were present throughout the study area: illite, interstratified illite-montmorillonite, and kaolinite. Since the methods used were not able to distinguish proportions of each of these minerals, conclusions can only be based on presence, limiting the ability to make recommendations. However, the minerals that are present give some insight into the soil at Howell Prairie.

The presence of illite and interstratified illite-montmorillonite throughout the study area affects nutrient availability. Illite is most likely the primary natural source of potassium to the soil (Dixon 1998). Interstratified illite-montmorillonite is of significance at this study site, since it is found mostly in prairie soils, produced from the effects of prairie plants and their natural environment on illite (Meunier and Velde 2004). Interstratified illite-montmorillonite also has a higher cation exchange capacity than illite

because it absorbs organic matter and water, making it expansive (Meunier and Velde 2004).

Kaolinite is also present throughout the study area. Feldspars are the main parent material of kaolinite and their concurrence is expected in most soils in the Midwest (Meunier and Velde 2004). Since there are no interlayer sites in kaolinite, it holds little water and few ions (Newnham 1961). It is assumed that the presence of other clay minerals prevents this from limiting plant growth.

The presence of interstratified kaolinite-smectite in the southern portion of Subarea 2C is significant. It has the ability to hold a variety of ions in its interlayers, commonly magnesium, and releases those through decomposition (Hughes et al. 1993). It occurs as a result of the decomposition of smectite minerals to kaolinite, but is usually in quantities that are undetectable when other clay minerals are present (Hughes et al. 1993). Since it was detected in multiple samples in the southern portion of Subarea 2C, there is a sufficient quantity to impact the soil chemistry, suggesting this is the source of excessive magnesium.

Compaction and infiltration showed no significant differences when comparing the whole study area to the smaller areas and subareas. Penetration under moist conditions suggests that it is not limiting root growth. Penetration under drought conditions was not relevant due to sample size. Infiltration rates also suggest this is not a limiting factor. Penetration and infiltration have not been studied at Howell Prairie before. Further study of these parameters may lead to reliable conclusions.

Some trends in the concentrations of nutrients were shown. However, nitrate content was not statistically relevant due to low sample size. It has also not been previously tested at Howell Prairie, so no comparisons could be made over time.

Potassium was between the recommended guidelines of 80 to 100 ppm (Espinoza, Slaton and Mozaffari) throughout the study area, except in Subarea 2A and Area 4, which were both higher at 139.5 ppm and 116.4 ppm respectively. Subarea 2C was lowest, but should not affect plant growth, which is consistent with previous studies at Howell Prairie (MDNR 2011a). However, the high levels of magnesium in the southern part of Subarea 2C may limit the amount of potassium that the plants uptake.

For optimal growth, phosphorus should be between 36 and 50 ppm (Espinoza, Slaton and Mozaffari). All areas were low, but the southern part of Subarea 2C was lowest, with two outliers. This is not consistent with previous work, which showed no statistical differences.

Calcium concentrations showed a trend of increasing levels from north to south. General guidelines show that calcium should be greater than 400 ppm for optimal growth for agricultural uses, including forages (Espinoza, Slaton and Mozaffari). The levels across the study area exceed those and there does not appear to be a change over time.

Magnesium was at a higher concentration in the southern portion of Subarea 2C than the rest of the study area, with three contiguous outliers that exceed the tolerance levels from experimental data, at 502.6 ppm. Kobayashi et al. showed that this level is toxic to 11 out of 12 grasses in their study. The concentrations of magnesium in the remainder of the prairie were below the thresholds in this study (Kobayashi et al. 2004).

Magnesium toxicity has been known in agriculture since the 1800's. Reports of lime derived from dolomites, which are partly composed of magnesium, were shown to inhibit growth of many crop plants as early as the 1840's (Davy 1846). Excessive Magnesium in soils has been shown to restrict growth in both C3 and C4 grasses (Kobayashi et al. 2004). High levels of magnesium have also been shown to limit the uptake of other nutrients, such as calcium and potassium (Jayaganesh 2011).

Due to the toxic levels of magnesium and the antagonistic relationship of potassium and magnesium, the ratio of these two nutrients was also analyzed. This analysis included data from previous studies at Howell Prairie because it is assumed that even though nutrients vary seasonally, the ratios will remain constant as nutrients are cycled. This assumption was supported by the results. A cluster with a low ratio of potassium to magnesium was shown and included points from the current study and previous studies.

Organic content was not significantly different throughout the study area. A previous study showed that organic matter was low (MDNR 2011a), but within the recommended range of 0.5 to 5.0% for agricultural soils (Espinoza, Slaton and Mozaffari). The results of this study show that organic matter is still within that range and may be increasing from 1.3% in previous study to 2% with the current study.

Cation exchange capacity was highest in Subarea 1B and lowest in Subarea 5B with a general trend of highest in the south to lowest in the north. Over time, there has been no apparent change in CEC.

The pH level throughout the study area remains slightly alkaline, except Subarea 5B and part of Subarea 2C, which were slightly acidic. Kriging showed the western part of Subarea 2C as slightly acidic. However, the levels detected during this study are continuing the trend of decreasing pH over time. NA is related to pH in that it shows how well the pH could be adjusted to raise acidic soils. Since most of the soils in the study area are alkaline, there is no NA. Those areas that did show NA levels coincided with pH, but are not relevant since the pH is within the recommended range of 6.0 to 7.5.

CHAPTER 6

CONCLUSIONS

Many analytes varied across the prairie without impacting successful establishment of prairie species. However, it was soil texture along with available magnesium, the ratio of potassium to magnesium, and the magnesium containing mineral, kaolinite-smectite that were found to be significant only in Subarea 2C.

One of the most important parameters of this study was the differences in soil type. The southern part of Subarea 2C has soil that is loam to clay loam. However, it is assumed these differences in soil type should not affect the growth of grasses on Howell Prairie since they are near silt loam and silty clay loam on the USDA textural triangle.

The apparent toxic levels of magnesium and the low potassium to magnesium ratio in the southern portion of Subarea 2C are of greatest importance. It would be difficult to take the magnesium out of the soil artificially. However, amendments to the soil could reduce the uptake of magnesium by the plants in this part of the prairie. Adding an antagonistic nutrient, such as potassium, would prevent magnesium from being absorbed and, through maintenance, allow time for the excessive magnesium to leach out.

The presence of interstratified kaolinite-smectite in Subarea 2C is probably the source of the magnesium. Since it is a transition phase in the decomposition of smectite to kaolinite, it could be assumed that the soil from this part of Subarea 2C is from a nearby source that has not weathered as much, perhaps from a lower soil layer as often occurs when soil is imported from borrow pits.

In order to establish a method to promote the establishment of grasses and prevent dwarfism in other plants in Subarea 2C, more research is needed. Finding the extent of the affected area is necessary. The area of concern should be able to be delineated simply by measuring potassium and magnesium levels in soil samples and calculating these nutrients' ratios to determine the extent of the affected area. This could also be used to verify the kriging methods used in the current study. Once the extent is determined, a solution could be found. I hypothesize that adding a potassium amendment to the soil and allowing sufficient time for magnesium to leach from the upper layer of the soil will promote new growth of grasses in the affected area.

APPENDIX A

TABLE OF NATIVE SPECIES SEEDED

Plant Family	**Botanical Name**	**Common Name**
Apiaceae	*Zizia aurea*	Golden Alexander
Apiaceae	*Polytaenia nuttallii*	Prarie Parsley
Apiaceae	*Oxypolis rigidior*	Cowbane
Apiaceae	*Cicuta*	Water Hemlock
Apiaceae	*Eryngium yuccifolium*	Rattlesnake Master
Asclepiadaceae	*Asclepias hirtella*	Tall Green Milkweed
Asclepiadaceae	*Asclepias incarnata*	Swamp Milkweed
Asclepiadaceae	*Asclepias sullivantii*	Sullivant's Milkweed
Asclepiadaceae	*Asclepias tuberosa*	Butterfly Milkweed
Asteraceae	*Aster nova-angliae*	New England Aster
Asteraceae	*Aster oolentangiensis*	Sky Blue Aster
Asteraceae	*Bidens aristosa*	Bidens
Asteraceae	*Coreopsis grandiflora*	Large Flowered Coreopsis
Asteraceae	*Coreopsis lanceolata*	Sand Corepsis
Asteraceae	*Coreopsis tripteris*	Tall Coreopsis
Asteraceae	*Echinacea pallida*	Pale Purple Coneflower
Asteraceae	*Echinacea paradoxa*	Yellow Coneflower
Asteraceae	*Echinacea purpurea*	Purple Cone Flower
Asteraceae	*Eupatorium rugosum*	Snakeroot
Asteraceae	*Helianthus laetiflorus*	Showy Sunflower
Asteraceae	*Helianthus sp*	Sunflower

TABLE OF NATIVE SPECIES SEEDED (Continued)

Plant Family	**Botanical Name**	**Common Name**
Asteraceae	*Heliopsis helianthoides*	False Sunflower
Asteraceae	*Liatris aspera*	Rough Blazing Star
Asteraceae	*Liatris punctata*	Button Blazing Star
Asteraceae	*Liatris pycnostachya*	Prarie Blazing Star
Asteraceae	*Parthenium integrifoilum*	Wild Quinine
Asteraceae	*Ratibidia pinnata*	Grey Head Coneflower
Asteraceae	*Rubeckia subtomentosa*	Sweet Black Eyed Susan
Asteraceae	*Rudbeckia hirta*	Black Eyed Susan
Asteraceae	*Siliphium intergrifolium*	Rosin Weed
Asteraceae	*Siliphium laciniatum*	Compass Plant
Asteraceae	*Siliphium terebinthinaceum*	Prarie Dock
Asteraceae	*Solidago rigidia*	Stiff Goldenrod
Asteraceae	*Solidago speciosa*	Showy Goldenrod
Asteraceae	*Veronia baldwinii*	Missouri Ironweed
Asteraceae	*Veronia sp*	Ironweed
Boraginaceae	*Verbena hastata*	Blue Vervain
Caryophyllaceae	*Silene regia*	Royal Catchfly
Campanulaceae	*Lobelia cardinalis*	Cardinal Flower
Commelineaceae	*Tradescantia ohiensis*	Spiderwort
cyperaceae	*Carex vulpinoidea*	Fox Sedge
cyperaceae	*Scirpus atrovirens*	Green Bulrush
Euphorbiaceae	*Euphorbia corollata*	Flowering Spurge

TABLE OF NATIVE SPECIES SEEDED (Continued)

Plant Family	**Botanical Name**	**Common Name**
Fabaceae	*Amorpha canscens*	Lead Plant
Fabaceae	*Astralagus sp*	Milk Vetch
Fabaceae	*Bapitisia bracteata*	Cream Wild Indigo
Fabaceae	*Baptisia alba*	White Wild Indigo
Fabaceae	*Baptisia australis*	Blue Indigo
Fabaceae	*Chamaecrista fasciculata*	Partridge Pea *Cassia fasiculata*
Fabaceae	*Dalea candida*	White Prarie Clover
Fabaceae	*Dalea pueourea*	Purple Prarie Clover
Fabaceae	*Desmanthus illinoensis*	Illinois Bundle Flower
Fabaceae	*Desmodium sp*	Tick Trefoil
Fabaceae	*Lespedeza capitata*	Round Headed Bush Clover
Fabaceae	*Mimosa quadrivalvis*	Sensitive Plant
Fabaceae	*Senna marilandica*	Maryland Senna
Fabaceae	*Strophostyles sp*	Wild Bean
Fabaceae	*Tephrosia vinginiana*	Goats Rue
Labiatae	*Monarda fistulosa*	Wild Bergamot
Lamiaceae	*Physostegia augustofolia*	Spring Obedient
Lamiaceae	*Physostegia virginiana*	Obedient Plant
Lamiaceae	*Pycnanthemum tenuifolium*	Slender Mountain Mint
Lamiaceae	*Salvia azurea*	Blue Sage
Lamiaceae	*Teucrium canadense*	Germander
Liliaceae	*Melanthium vinrinicum*	Bunch Flower

TABLE OF NATIVE SPECIES SEEDED (Continued)

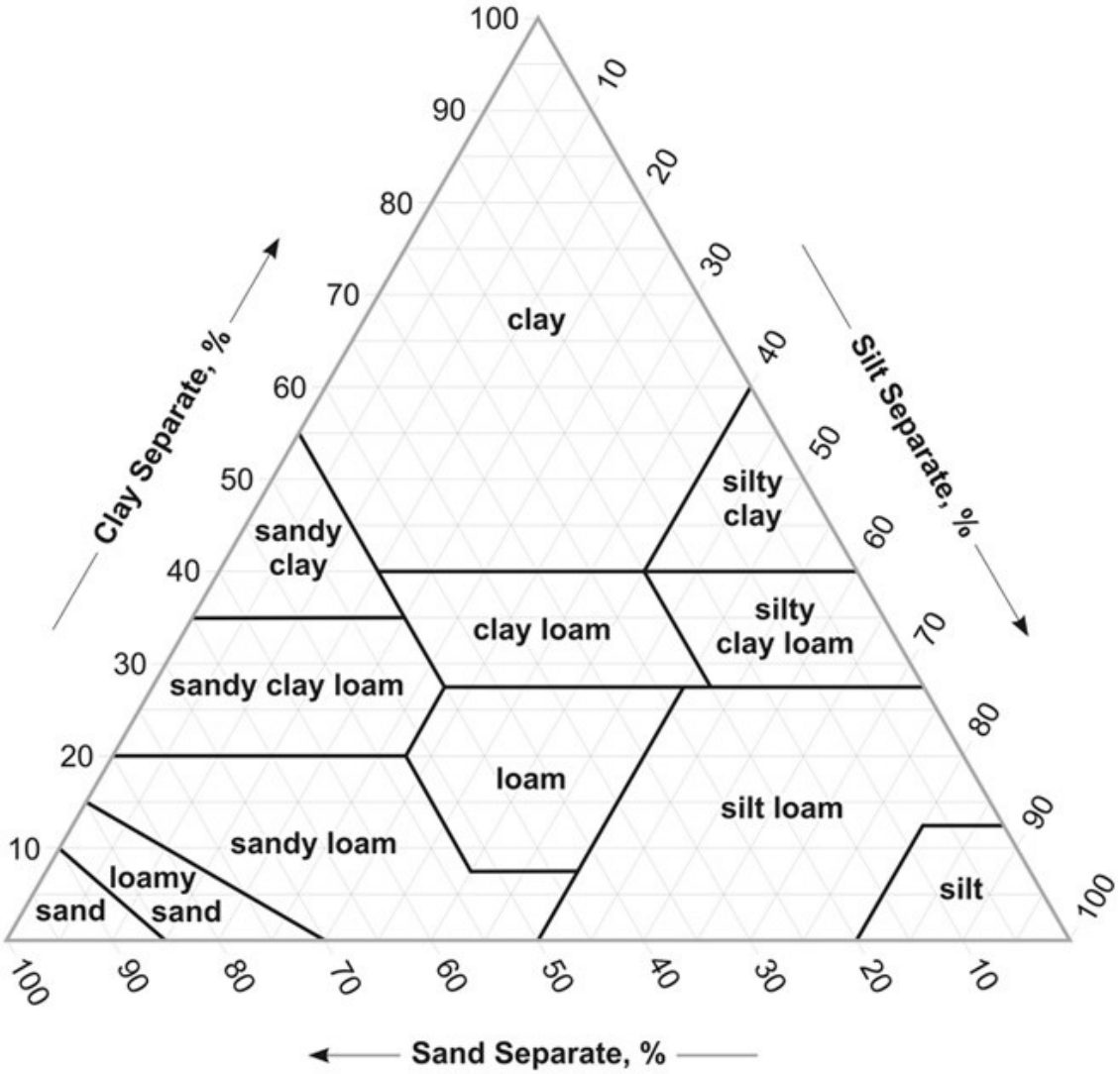
Plant Family	**Botanical Name**	**Common Name**
Liliaceae	*Camassia scilloides*	Prarie Hyacinth
Poaceae	*Andropogon gerardii*	Big Blue Strem
Poaceae	*Andropogon ternarius*	Splitbeard Bluestream
Poaceae	*Andropogon virginicus*	Broom Sedge
Poaceae	*Aristida sp*	Three Awn Grass
Poaceae	*Bouteloua curtipendula*	Side Oats Grama
Poaceae	*Elymus virginicus*	Virginia Wild Rye
Poaceae	*Koeleria cristata*	June Grass
Poaceae	*Schizachyrium scoparium*	Little Blue Stem
Poaceae	*Scleria triglomerata*	Tall Nut Grass
Poaceae	*Sorghastrum nutans*	Indian Grass
Poaceae	*Sporobolus heterolepus*	Prarie Dropseed
Poaceae	*Tridens flavus*	Purple Top
Poaceae	*Chasmanthium latifolium*	Sea Oats
Primulaceae	*Dodecatheon*	Midland Shooting Star
Onagraceae	*Oenothera macrocarpa*	Missouri Primrose
Onagraceae	*Ludwigia alternifolia*	Seed Box
Onagraceae	*Gaura sp*	Gaura
Rosaceae	*Potentilla sp*	Cinquefoil
Rosaceae	*Rosa sp*	Rose
Rhamnaceae	*Ceanothus americanus*	New Jersey Tea
Saxifragaceae	*Heuchera richardsonii*	Prarie Alum Root

TABLE OF NATIVE SPECIES SEEDED (Continued)

Plant Family	**Botanical Name**	**Common Name**
Schrophulariaceae	*Meadia*	Indian Paintbrush *Castilleja*
Schropulariaceae	*Pedicularis canadensis*	Wood Betony
Schropulariaceae	*Penstemon digitalis*	Fox Glove Beard Toung

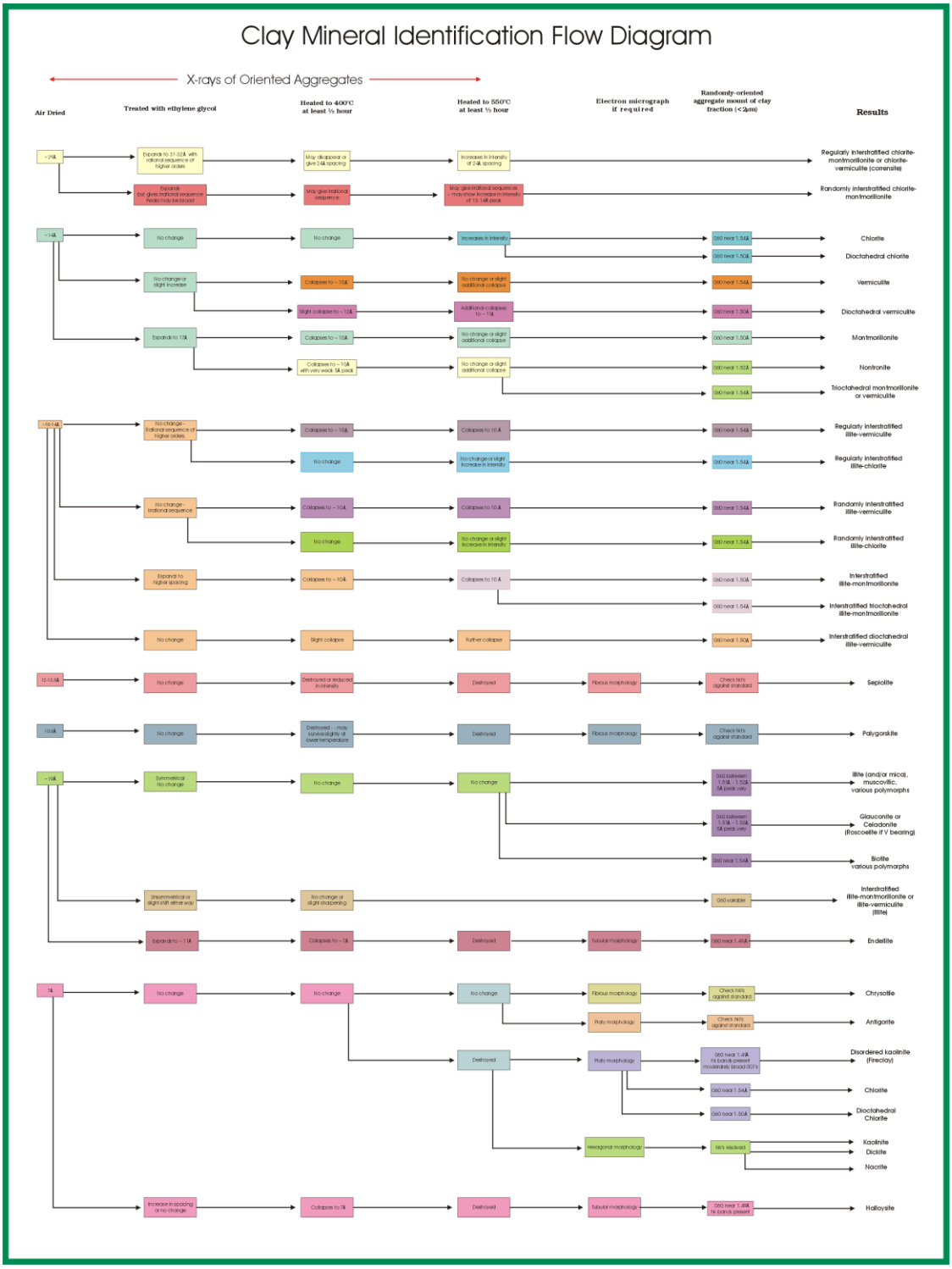
APPENDIX B

USDA SOIL TEXTURE TRIANGLE



APPENDIX C

USGS CLAY MINERAL IDENTIFICATION FLOW DIAGRAM



APPENDIX D

SPREADSHEET OF 47 SAMPLE RESULTS

Sample ID	Pen. (cm)	Infil. cm/hr	pH	NA (meq/100g)	OM %	P (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	CEC (meq/100g)
1a-01	13	12	7.5	0	1.5	10	1874.5	323	83	12.3
1a-02	15	30	7.4	0	1.9	24	2339.5	284.5	105	14.3
1a-03	16	36	7.6	0	1.9	15.5	2464	322	85.5	15.2
1b-01	14	24	7.5	0	2.2	8.5	2401.5	330	82	15
1b-02	20	12	7.6	0	2.3	16.5	2865	358.5	96.5	17.6
1b-03	17	12	7.5	0	1.5	11	2746.5	447.5	113.5	17.8
1b-04	12	12	7.6	0	3	16.5	2575	326	84	15.8
1b-05	12	36	7.6	0	2.2	22.5	2345.5	361	102.5	15
1c-01	17	24	7.4	0	2.4	15.5	1977.5	235	70.5	12
1c-02	11	12	7.5	0	1.6	6	1953	263	57.5	12.1
1c-03	12	66	7.3	0	2.2	15.5	1995.5	349	107	13.2
1c-04	16	18	7.4	0	1.4	18.5	2226	320	83	14
1c-05	16	18	7.7	0	2.3	15	3986.5	405.5	135	23.7
2a-01	13	54	7	0	3.5	13	2228.5	470	163	15.5
2a-02	10	24	7.6	0	2.1	21.5	3266	327	116	19.4
2b-01	17	18	7.4	0	2.3	14	2019.5	247	74	12.3
2b-02	19	6	7.3	0	2.1	17.5	1949	307.5	60	12.5
2b-03	17	18	7.2	0	2.4	18.5	1857	299	107	12.1
2b-04	21	6	7.4	0	2.6	16	1680	291	93	11.1
2c-01	14	30	6.9	0	3.4	10	2513	429	73	16.3
2c-02	27	48	7.2	0	2.7	7.5	2458	496.5	99.5	16.7
2c-03	24	6	6.6	0.5	0.4	1.5	1982.5	538.5	75	15.1
2c-04	21	6	6.7	0	1.8	5	2604.5	616	103.5	18.4
2c-05	17	48	7.2	0	1.5	9	1920	376.5	89.5	13
2c-06	17	6	6.8	0	2	8.5	2228.5	469	88	15.3
2c-07	18	72	6.5	0.5	1.9	11.5	1520.5	339	78	11.1
2c-08	12	24	6	1.5	1.6	4	1287.5	342.5	60	10.9
2c-09	19	12	7.3	0	2.8	30.5	2216	323	99	14
2c-10	19	18	7.4	0	2.3	21.5	1474.5	209.5	63	9.3
2c-11	14	18	7.5	0	1.1	11	2474	318	67.5	15.2
2c-12	15	6	7.6	0	2.3	11	2265	319	124.5	14.3
2c-13	23	18	7.4	0	1.5	21	2066.5	356	79.5	13.5
4-01	26	18	7.2	0	1.2	16	2531	527.5	129	17.4
4-02	19	0	7.5	0	3.1	23	1836	421	189	13.2

SPREADSHEET OF 47 SAMPLES RESULTS (Continued)

Sample ID	Pen. (cm)	Infil. cm/hr	pH	NA (meq/100g)	OM %	P (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	CEC (meq/100g)
4-03	16	36	7.1	0	1.8	12.5	1760.5	294.5	77	11.5
4-04	23	12	6.9	0	1.1	10	2113.5	468.5	102.5	14.7
4-05	15	18	7.3	0	1.7	16	1582	259.5	84.5	10.3
5a-01	16	48	6.8	0.5	1.2	2	2083.5	480	67	15.1
5a-02	17	6	7.6	0	2.2	33.5	2254	357.5	105	14.5
5a-03	10	18	7.5	0	3.2	16.5	4451	250.5	121	24.7
5b-01	15	120	6.9	0	2	4.5	1855	397	73	12.8
5b-02	17	96	7	0	1.9	14	1774	301	75.5	11.6
5b-03	13	24	6	1	2.2	6.5	1726	446.5	83	13.6
5b-04	12	12	6.7	0.5	1.5	9.5	1526.5	311.5	80.5	10.9
5b-05	18	48	6.3	1	1.8	8.5	1041.5	141.5	53.5	7.5
5b-06	13	54	7	0	3.5	23.5	1860.5	325	124.5	12.3

APPENDIX E

SPREADSHEET OF 24 SAMPLE RESULTS

Sample ID	N (ppm)	Sand %	Silt %	Clay %	Texture	Kaolinite-Smectite
1A-02	67.6	22.5	55	22.5	silt loam	
1B-01	151	20	57.5	22.5	silt loam	
1B-04	110.8	22.5	55	22.5	silt loam	
1B-05	94.9	22.5	52.5	25	silt loam	
1C-01	33.9	22.5	55	22.5	silt loam	
1C-04	75.1	20	55	25	silt loam	
2A-01	212.5	20	55	25	silt loam	
2A-02	105.7	25	55	20	silt loam	
2B-02	125.5	22.5	55	22.5	silt loam	
2B-04	25.6	22.5	52.5	25	silt loam	
2C-01	226.3	25	47.5	27.5	clay loam	
2C-03	52	35	40	25	loam	X
2C-04	40.6	30	35	35	clay loam	X
2C-07	88.4	17.5	60	22.5	silt loam	X
2C-09	118.7	30	42.5	27.5	clay loam	
2C-11	43.3	22.5	52.5	25	silt loam	X
2C-13	98.2	22.5	52.5	25	silt loam	
4--01	80.6	20	57.5	27.5	silty clay loam	
4--03	112	22.5	55	22.5	silt loam	
5A-01	213.5	20	60	20	silt loam	
5A-03	99.1	12.5	55	32.5	silty clay loam	
5B-02	37.3	17.5	55	27.5	silty clay loam	
5B-03	93.1	12.5	57.5	30	silty clay loam	
5B-06	236	7.5	60	32.5	silty clay loam	

APPENDIX F

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES

	Calcium			Potassium		
Sample ID	ppm	Z-Score	P-Value	ppm	Z-Score	P-Value
1a-01	1874.5	-0.092	0.927	83.0	-0.162	0.871
1a-02	2339.5	0.006	0.995	105.0	-0.218	0.827
1a-03	2464.0	0.383	0.702	85.5	-0.212	0.832
1b-01	2401.5	1.154	0.248	82.0	-0.451	0.652
1b-02	4451.0	3.173	0.002	121.0	-0.710	0.478
1b-03	2932.5	3.442	0.001	77.0	-0.771	0.441
1b-04	2746.5	1.128	0.259	113.5	-0.521	0.603
1b-05	2575.0	0.196	0.845	84.0	-0.181	0.856
1c-01	1995.5	0.272	0.786	107.0	-0.700	0.484
1c-02	1977.5	0.206	0.837	70.5	-0.468	0.640
1c-03	2226.0	-0.011	0.991	83.0	-0.622	0.534
1c-04	3986.5	0.446	0.656	135.0	0.045	0.964
1c-05	2345.5	0.257	0.797	102.5	0.314	0.754
2a-01	1953.0	0.124	0.901	57.5	-3.802	0.000
2a-02	2228.5	0.030	0.976	163.0	-2.402	0.016
2b-01	3266.0	-0.596	0.551	116.0	0.325	0.745
2b-02	2019.5	-0.494	0.621	74.0	-0.171	0.864
2b-03	1949.0	0.382	0.702	60.0	0.322	0.748
2b-04	1857.0	0.345	0.730	107.0	-0.699	0.485
2c-01	2066.5	-0.147	0.883	79.5	0.316	0.752
2c-02	2513.0	0.052	0.958	73.0	0.265	0.791
2c-03	2458.0	0.072	0.943	99.5	-0.268	0.789
2c-04	1982.5	-0.189	0.850	75.0	0.012	0.991
2c-05	2604.5	-0.420	0.675	103.5	-0.196	0.844
2c-06	1920.0	-0.119	0.905	89.5	0.052	0.958
2c-07	2228.5	0.054	0.957	88.0	0.247	0.805
2c-08	1520.5	1.267	0.205	78.0	0.581	0.561
2c-09	1287.5	1.041	0.298	60.0	0.944	0.345
2c-10	2216.0	0.085	0.932	99.0	-0.453	0.651
2c-11	1474.5	-0.261	0.794	63.0	0.492	0.623
2c-12	2474.0	-0.595	0.552	67.5	1.126	0.260
2c-13	1680.0	-0.164	0.869	93.0	0.026	0.979

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Calcium			Potassium		
Sample ID	ppm	Z-Score	P-Value	ppm	Z-Score	P-Value
4-01	2265.0	0.053	0.958	124.5	1.802	0.072
4-02	2531.0	-0.447	0.655	129.0	0.612	0.540
4-04	1836.0	0.589	0.556	189.0	-2.345	0.019
4-05	2113.5	0.093	0.926	102.5	-0.252	0.801
4-06	1582.0	-0.562	0.574	84.5	-0.445	0.656
5a-01	1760.5	0.596	0.551	77.0	-1.261	0.207
5a-02	2083.5	0.178	0.859	67.0	0.133	0.894
5a-03	2254.0	0.040	0.968	105.0	-0.361	0.718
5b-01	2515.0	0.146	0.884	89.0	0.043	0.966
5b-02	2865.0	-0.039	0.969	96.5	-0.058	0.954
5b-03	1855.0	-0.162	0.872	73.0	0.071	0.943
5b-04	1774.0	1.342	0.180	75.5	0.689	0.491
5b-05	1726.0	1.330	0.184	83.0	0.347	0.729
5b-06	1526.5	1.487	0.137	80.5	0.378	0.705

	Magnesium			Bray I Phosphorus		
Sample ID	ppm	Z-Score	P-Value	ppm	Z-Score	P-Value
1a-01	323.0	0.454	0.650	10.0	-0.757	0.449
1a-02	284.5	0.622	0.534	24.0	-0.227	0.821
1a-03	322.0	-0.431	0.667	15.5	-0.080	0.936
1b-01	330.0	0.533	0.594	8.5	-0.284	0.776
1b-03	483.5	0.192	0.848	2.0	0.204	0.838
1b-04	447.5	0.773	0.440	11.0	0.480	0.631
1b-05	326.0	0.338	0.736	16.5	0.863	0.388
1c-05	361.0	0.065	0.948	22.5	0.741	0.459
1c-04	405.5	-0.145	0.885	15.0	0.320	0.749
1c-03	320.0	-0.211	0.833	18.5	0.164	0.869
1c-01	349.0	0.350	0.726	15.5	-0.002	0.998
1c-02	235.0	0.287	0.774	15.5	0.097	0.923
2a-01	263.0	-1.120	0.263	6.0	-0.015	0.988
2a-02	470.0	-1.440	0.150	13.0	0.076	0.940
2b-01	327.0	0.378	0.706	21.5	0.053	0.958
2b-02	247.0	0.925	0.355	14.0	0.103	0.918

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Magnesium			Bray I Phosphorus		
Sample ID	ppm	Z-Score	P-Value	ppm	Z-Score	P-Value
2b-03	307.5	1.019	0.308	17.5	0.311	0.756
2b-04	299.0	0.507	0.612	18.5	0.419	0.675
2c-13	291.0	0.059	0.953	16.0	0.465	0.642
2c-01	356.0	-0.110	0.913	21.0	-0.939	0.348
2c-02	429.0	1.328	0.184	10.0	0.405	0.686
2c-03	496.5	2.370	0.018	7.5	0.896	0.370
2c-04	538.5	5.766	0.000	1.5	3.134	0.002
2c-05	616.0	3.842	0.000	5.0	2.050	0.040
2c-06	376.5	0.526	0.599	9.0	1.466	0.143
2c-07	469.0	-0.294	0.768	8.5	0.884	0.377
2c-08	339.0	-0.202	0.840	11.5	0.468	0.639
2c-09	342.5	0.084	0.933	4.0	-1.027	0.304
2c-10	323.0	0.783	0.434	30.5	-0.579	0.563
2c-11	209.5	1.265	0.206	21.5	2.054	0.040
2c-12	318.0	0.809	0.418	11.0	-0.619	0.536
4-01	319.0	-0.932	0.351	11.0	-0.107	0.915
4-02	527.5	-2.353	0.019	16.0	0.061	0.951
4-04	421.0	-0.483	0.629	23.0	-0.194	0.846
4-05	468.5	0.551	0.582	10.0	0.658	0.510
4-06	259.5	-2.171	0.030	16.0	0.142	0.887
5a-01	294.5	-1.060	0.289	12.5	0.060	0.952
5a-02	480.0	-0.782	0.434	2.0	-3.238	0.001
5a-03	357.5	-0.058	0.953	33.5	-3.663	0.000
1b-02	250.5	-0.297	0.766	16.5	-0.563	0.574
5b-01	386.5	0.208	0.835	12.5	-0.043	0.966
5b-02	358.5	0.002	0.999	16.5	-0.384	0.701
5b-03	397.0	0.254	0.799	4.5	0.312	0.755
5b-04	301.0	-0.283	0.777	14.0	-0.056	0.955
5b-05	446.5	-0.824	0.410	6.5	0.487	0.626
5b-06	311.5	-0.193	0.847	9.5	0.524	0.600

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Penetrometry			Infiltrometry		
Sample ID	cm	Z-Score	P-Value	cm/min	Z-Score	P-Value
1a-01	13	0.352	0.725	0.2	-0.048	0.962
1a-02	15	0.555	0.579	0.5	-0.001	0.999
1a-03	16	0.160	0.873	0.6	-0.213	0.831
1b-01	14	-0.536	0.592	0.4	0.117	0.907
1b-02	20	-0.420	0.675	0.2	0.308	0.758
1b-03	17	-0.035	0.972	0.2	0.621	0.535
1b-04	12	-0.006	0.995	0.2	0.233	0.816
1b-05	12	0.438	0.661	0.6	-0.038	0.970
1c-01	17	-0.184	0.854	0.4	0.064	0.949
1c-02	11	-0.160	0.873	0.2	0.117	0.907
1c-03	12	0.160	0.873	1.1	-0.625	0.532
1c-04	16	0.139	0.889	0.3	-0.303	0.762
1c-05	16	-0.047	0.962	0.3	0.181	0.856
2a-01	13	1.287	0.198	0.9	-0.186	0.853
2a-02	10	1.255	0.209	0.4	-0.091	0.928
2b-01	17	0.029	0.977	0.3	0.389	0.698
2b-02	19	0.144	0.886	0.1	0.514	0.607
2b-03	17	0.195	0.845	0.3	0.544	0.586
2b-04	21	0.174	0.862	0.1	0.383	0.702
2c-01	14	-2.036	0.042	0.5	0.064	0.949
2c-02	27	4.232	0.000	0.8	-0.798	0.425
2c-03	24	4.919	0.000	0.1	-0.220	0.826
2c-04	21	2.646	0.008	0.1	0.152	0.879
2c-05	17	0.141	0.888	0.8	-1.085	0.278
2c-06	17	0.148	0.882	0.1	-0.883	0.377
2c-07	18	-0.182	0.856	1.2	-1.490	0.136
2c-08	12	-0.759	0.448	0.4	-0.129	0.897
2c-09	19	-0.142	0.887	0.2	-0.047	0.962
2c-10	19	-0.129	0.897	0.3	0.492	0.623
2c-11	14	-0.158	0.874	0.3	0.374	0.708
2c-12	15	-0.108	0.914	0.1	0.770	0.441
2c-13	23	-0.177	0.859	0.3	0.181	0.856
4-01	26	1.561	0.118	0.3	0.484	0.629
4-02	19	0.812	0.417	0.0	-0.071	0.943

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Penetrometry			Infiltrometry		
Sample ID	cm	Z-Score	P-Value	cm/min	Z-Score	P-Value
4-04	23	-0.177	0.859	0.2	-0.543	0.587
4-05	15	0.388	0.698	0.3	-0.766	0.444
4-06	16	-0.055	0.957	0.6	-0.398	0.691
5a-01	16	-0.125	0.900	0.8	-0.929	0.353
5a-02	17	-0.135	0.893	0.1	-0.266	0.790
5a-03	10	0.329	0.742	0.3	-0.849	0.396
5b-01	15	0.541	0.588	2.0	4.970	0.000
5b-02	17	-0.083	0.934	1.6	8.361	0.000
5b-03	13	0.768	0.443	0.4	-0.360	0.719
5b-04	12	0.856	0.392	0.2	-0.706	0.480
5b-05	18	-0.507	0.612	0.8	0.479	0.632
5b-06	13	0.306	0.760	0.9	0.447	0.655

	Organic Matter		
Sample ID	OM %	Z-Score	P-Value
1a-01	1.5	0.188	0.851
1a-02	1.9	-0.018	0.986
1a-03	1.9	0.188	0.851
1b-01	2.2	0.549	0.583
1b-03	1.7	-0.110	0.913
1b-04	1.5	0.481	0.631
1b-05	3.0	0.114	0.909
1c-05	2.2	0.488	0.625
1c-04	2.3	-0.183	0.855
1c-03	1.4	-0.415	0.678
1c-01	2.2	0.124	0.901
1c-02	2.4	0.191	0.849
2a-01	1.6	-1.493	0.135
2a-02	3.5	-1.298	0.194
2b-01	2.1	0.185	0.853
2b-02	2.3	0.102	0.919
2b-03	2.1	0.121	0.904
2b-04	2.4	0.095	0.924

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Organic Matter		
Sample ID	OM %	Z-Score	P-Value
2c-13	2.6	0.280	0.779
2c-01	1.5	-2.021	0.043
2c-02	3.4	-0.818	0.414
2c-03	2.7	0.258	0.796
2c-04	0.4	-2.184	0.029
2c-05	1.8	0.849	0.396
2c-06	1.5	1.354	0.176
2c-07	2.0	0.070	0.944
2c-08	1.9	0.119	0.905
2c-09	1.6	0.042	0.966
2c-10	2.8	-1.126	0.260
2c-11	2.3	0.096	0.923
2c-12	1.1	-1.173	0.241
4-01	2.3	-0.555	0.579
4-02	1.2	0.289	0.773
4-04	3.1	-0.589	0.556
4-05	1.1	0.622	0.534
4-06	1.7	0.701	0.484
5a-01	1.8	-0.091	0.928
5a-02	1.2	0.099	0.921
5a-03	2.2	-0.364	0.716
1b-02	3.2	0.066	0.947
5b-01	1.6	0.258	0.796
5b-02	2.3	-0.204	0.838
5b-03	2.0	0.091	0.927
5b-04	1.9	0.103	0.918
5b-05	2.2	-0.191	0.849
5b-06	1.5	-0.073	0.942

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Cation Exchange Capacity			Neutralizable Acidity		
Sample ID	meq/100g	Z-Score	P-Value	meq/100g	Z-Score	P-Value
1a-01	12.3	0.082	0.935	0.0	0.161	0.872
1a-02	14.3	0.061	0.951	0.0	0.227	0.820
1a-03	15.2	0.247	0.805	0.0	0.161	0.872
1b-01	15.0	0.508	0.611	0.0	0.161	0.872
1b-03	18.9	3.785	0.000	0.0	0.223	0.823
1b-04	17.8	1.377	0.168	0.0	0.227	0.820
1b-05	15.8	0.051	0.959	0.0	0.230	0.818
1c-05	15.0	0.167	0.867	0.0	0.275	0.784
1c-04	23.7	-0.017	0.986	0.0	0.230	0.818
1c-03	14.0	-0.506	0.613	0.0	0.161	0.872
1c-01	13.2	0.492	0.623	0.0	0.207	0.836
1c-02	12.0	0.386	0.700	0.0	0.161	0.872
2a-01	12.1	-0.037	0.970	0.0	0.217	0.828
2a-02	15.5	0.016	0.987	0.0	0.216	0.829
2b-01	19.4	-0.869	0.385	0.0	0.210	0.834
2b-02	12.3	-0.808	0.419	0.0	0.216	0.829
2b-03	12.5	0.752	0.452	0.0	0.229	0.819
2b-04	12.1	0.553	0.581	0.0	0.161	0.872
2c-13	11.1	-0.141	0.888	0.0	0.161	0.872
2c-01	13.5	-0.260	0.795	0.0	0.223	0.824
2c-02	16.3	0.291	0.771	0.0	0.048	0.962
2c-03	16.7	0.351	0.725	0.0	-0.085	0.933
2c-04	15.1	0.251	0.802	0.5	-1.059	0.290
2c-05	18.4	-0.323	0.746	0.0	-0.204	0.838
2c-06	13.0	-0.554	0.580	0.0	-0.066	0.948
2c-07	15.3	-0.361	0.718	0.0	-1.160	0.246
2c-08	11.1	0.613	0.540	0.5	4.373	0.000
2c-09	10.9	0.752	0.452	1.5	2.112	0.035
2c-10	14.0	0.329	0.742	0.0	-0.845	0.398
2c-11	9.3	0.069	0.945	0.0	0.227	0.821
2c-12	15.2	-0.306	0.759	0.0	-0.663	0.507
4-01	14.3	-0.051	0.959	0.0	0.161	0.872
4-02	17.4	-1.092	0.275	0.0	0.225	0.822
4-04	13.2	0.457	0.648	0.0	0.161	0.872

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Cation Exchange Capacity			Neutralizable Acidity		
Sample ID	meq/100g	Z-Score	P-Value	meq/100g	Z-Score	P-Value
4-05	14.7	0.021	0.983	0.0	0.224	0.822
4-06	10.3	-1.256	0.209	0.0	0.161	0.872
5a-01	11.5	0.228	0.820	0.0	-0.248	0.804
5a-02	15.1	-0.095	0.924	0.5	-0.752	0.452
5a-03	14.5	0.026	0.979	0.0	-0.251	0.802
1b-02	24.7	2.584	0.010	0.0	0.218	0.828
5b-01	16.0	0.180	0.858	0.0	0.327	0.744
5b-02	17.6	0.011	0.991	0.0	0.229	0.819
5b-03	12.8	-0.160	0.873	0.0	0.324	0.746
5b-04	11.6	1.179	0.239	0.0	-1.014	0.311
5b-05	13.6	0.507	0.612	1.0	3.393	0.001
5b-06	10.9	0.975	0.330	0.5	4.010	0.000

	Nitrate		
Sample ID	ppm	Z-Score	P-Value
1A-02	67.6	0.13781	0.89039
1B-01	151	0.10503	0.91635
1B-04	110.8	0.06369	0.94921
1B-05	94.9	0.21386	0.83065
1C-01	33.9	-1.6951	0.09006
1C-04	75.1	0.5212	0.60223
2A-01	212.5	-0.6878	0.49156
2A-02	105.7	0.06711	0.94649
2B-02	125.5	0.03458	0.97241
2B-04	25.6	0.47978	0.63138
2C-01	226.3	-3.2101	0.00133
2C-03	52	0.50669	0.61237
2C-04	40.6	0.63324	0.52658
2C-07	88.4	0.15113	0.87987
2C-09	118.7	-0.0491	0.96083
2C-11	43.3	0.22413	0.82266
2C-13	98.2	0.12793	0.8982
4--01	80.6	0.39842	0.69032

SPREADSHEETS OF STATISTICS FOR ALL ANALYTES (Continued)

	Nitrate		
Sample ID	ppm	Z-Score	P-Value
4--03	112	0.02521	0.97989
5A-01	213.5	-0.1533	0.8782
5A-03	99.1	0.09939	0.92083
5B-02	37.3	0.33754	0.73571
5B-03	93.1	0.16389	0.86982
5B-06	236	-0.4063	0.68449

	Sand			Silt			Clay		
Sample ID	Sand %	Z-Score	P-Value	Silt %	Z-Score	P-Value	Clay %	Z-Score	P-Value
1A-02	22.5	0.113	0.910	65.0	-0.024	0.981	22.5	0.478	0.632
1B-01	20.0	-0.003	0.998	57.5	0.176	0.861	22.5	0.674	0.501
1B-04	22.5	0.081	0.936	55.0	0.315	0.753	22.5	0.759	0.448
1B-05	22.5	0.133	0.894	52.5	-0.135	0.892	25.0	0.243	0.808
1C-01	22.5	0.092	0.927	55.0	0.130	0.896	22.5	0.809	0.419
1C-04	20.0	-0.005	0.996	55.0	0.068	0.946	25.0	0.189	0.850
2A-01	20.0	-0.109	0.913	55.0	0.147	0.883	25.0	0.326	0.744
2A-02	25.0	0.002	0.998	55.0	0.146	0.884	20.0	1.028	0.304
2B-02	22.5	0.304	0.761	55.0	-0.157	0.875	22.5	0.053	0.958
2B-04	22.5	0.555	0.579	52.5	0.622	0.534	25.0	0.008	0.993
2C-01	25.0	1.808	0.071	47.5	3.001	0.003	27.5	0.491	0.624
2C-03	35.0	4.326	0.000	40.0	6.323	0.000	25.0	-0.155	0.877
2C-04	30.0	3.760	0.000	35.0	6.151	0.000	35.0	-0.897	0.370
2C-07	17.5	-2.231	0.026	60.0	-4.074	0.000	22.5	-1.410	0.158
2C-09	30.0	2.030	0.042	42.5	2.829	0.005	27.5	0.314	0.754
2C-11	22.5	0.236	0.814	52.5	0.213	0.832	25.0	-0.037	0.971
2C-13	22.5	0.357	0.721	52.5	0.366	0.715	25.0	0.103	0.918
4--01	20.0	0.225	0.822	57.5	0.263	0.792	27.5	0.082	0.935
4--03	22.5	-0.171	0.864	55.0	0.197	0.844	22.5	-1.219	0.223
5A-01	20.0	0.468	0.640	60.0	0.259	0.796	20.0	-2.606	0.009
5A-03	12.5	2.168	0.030	55.0	0.306	0.760	32.5	-0.092	0.927
5B-02	17.5	1.683	0.092	55.0	0.201	0.841	27.5	1.121	0.262
5B-03	12.5	3.685	0.000	57.5	0.606	0.544	30.0	2.468	0.014
5B-06	7.5	4.082	0.000	60.0	0.650	0.516	32.5	2.197	0.028

APPENDIX G

SPREADSHEET OF POTASSIUM TO MAGNESIUM RATIOS INCLUDING DATA COLLECTED IN PREVIOUS STUDIES AT HOWELL PRAIRIE

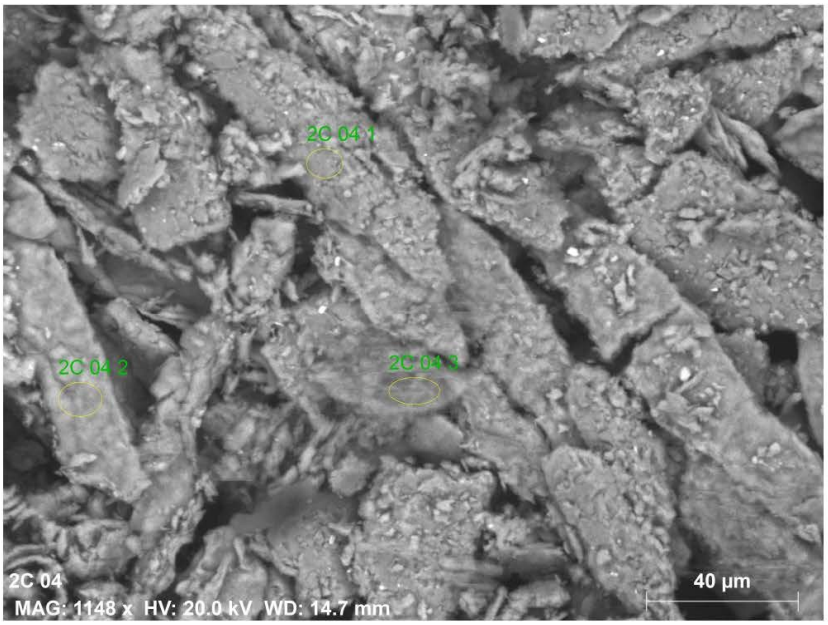
SampleID	Mg	K	K/Mg ratio	Date	Z-score	P-value
1a-01	323	83	0.257	3/13/2013	-0.017	0.987
1a-02	284.5	105	0.369	3/13/2013	-0.931	0.352
1a-03	322	85.5	0.266	3/13/2013	0.015	0.988
1A-1-08-10	447	89	0.199	8/23/2010	-1.092	0.275
1b-01	330	82	0.248	3/13/2013	0.001	0.999
1b-02	358.5	96.5	0.269	3/13/2013	0.004	0.996
1b-03	447.5	113.5	0.254	3/13/2013	0.024	0.981
1b-04	326	84	0.258	3/13/2013	0.028	0.977
1b-05	361	102.5	0.284	3/13/2013	0.273	0.785
1c-01	235	70.5	0.300	3/13/2013	0.202	0.840
1c-02	263	57.5	0.219	3/13/2013	-0.197	0.844
1c-03	349	107	0.307	3/13/2013	0.000	1.000
1c-04	320	83	0.259	3/13/2013	-0.008	0.993
1c-05	405.5	135	0.333	3/13/2013	-0.224	0.823
1C-8-06-10	408	80	0.196	6/16/2010	0.213	0.831
2a-01	470	163	0.347	3/13/2013	1.931	0.053
2a-02	327	116	0.355	3/13/2013	1.505	0.132
2A-1-12-10	282	97	0.344	Dec-10	0.771	0.441
2b-01	247	74	0.300	3/13/2013	-0.158	0.875
2b-02	307.5	60	0.195	3/13/2013	-0.836	0.403
2b-03	299	107	0.358	3/13/2013	-0.219	0.827
2b-04	291	93	0.320	3/13/2013	0.962	0.336
2c-01	429	73	0.170	3/13/2013	2.457	0.014
2c-02	496.5	99.5	0.200	3/13/2013	2.184	0.029
2c-03	538.5	75	0.139	3/13/2013	3.922	0.000
2c-04	616	103.5	0.168	3/13/2013	3.545	0.000
2c-05	376.5	89.5	0.238	3/13/2013	0.520	0.603
2c-06	469	88	0.188	3/13/2013	2.013	0.044
2c-07	339	78	0.230	3/13/2013	0.900	0.368
2c-08	342.5	60	0.175	3/13/2013	1.785	0.074
2c-09	323	99	0.307	3/13/2013	-0.744	0.457
2c-10	209.5	63	0.301	3/13/2013	-0.231	0.817
2C-10-06-10	671	91	0.136	6/16/2010	3.101	0.002

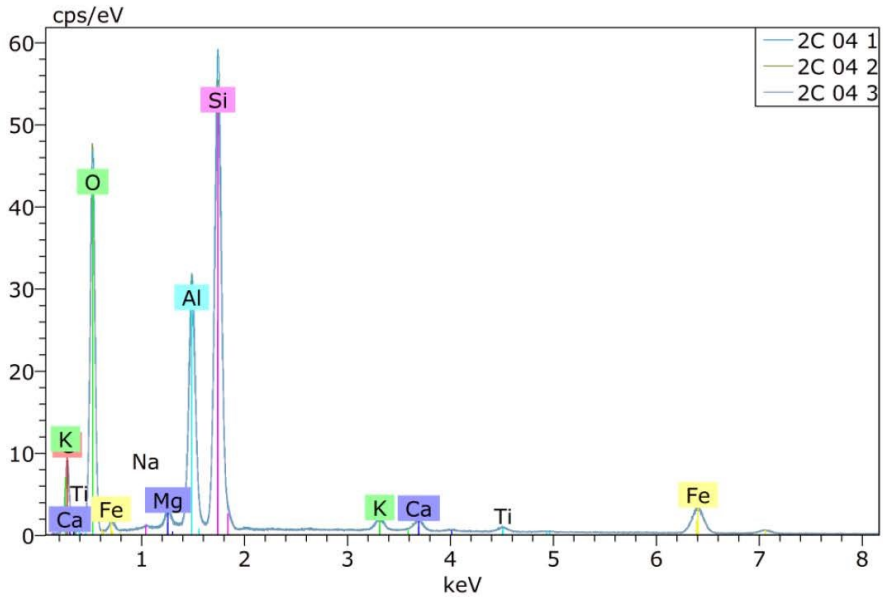
SPREADSHEET OF POTASSIUM TO MAGNESIUM RATIOS INCLUDING DATA COLLECTED IN PREVIOUS STUDIES AT HOWELL PRAIRIE (Continued)

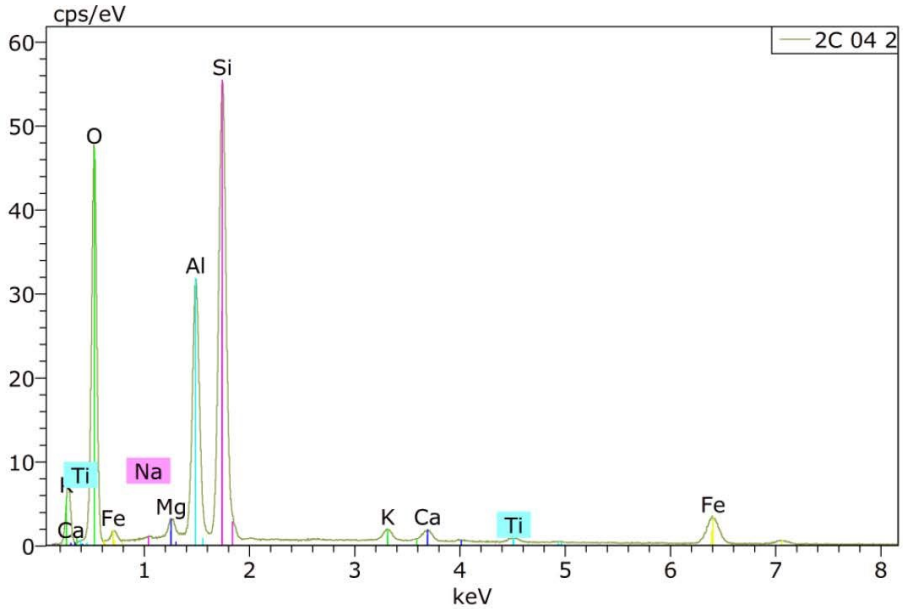
SampleID	Mg	K	K/Mg ratio	Date	Z-score	P-value
2c-11	318	67.5	0.212	3/13/2013	-0.453	0.650
2C-11-06-10	518	98	0.189	6/16/2010	1.833	0.067
2c-12	319	124.5	0.390	3/13/2013	-0.194	0.846
2C-12-06-10	329	53	0.161	6/16/2020	3.535	0.000
2c-13	356	79.5	0.223	3/13/2013	-0.447	0.655
2C-2-08-10	324	77	0.238	8/23/2010	0.327	0.744
2C-3-08-10	396	77	0.194	8/23/2010	1.621	0.105
2C-4-08-10	415	89	0.214	8/23/2010	0.740	0.459
2C-5-08-10	468	99	0.212	8/23/2010	-0.385	0.700
2C-9-06-10	464	121	0.261	6/16/2010	0.080	0.936
4-01	527.5	129	0.245	3/13/2013	-0.530	0.596
4-02	421	189	0.449	3/13/2013	-0.284	0.776
4-03	294.5	77	0.261	3/13/2013	0.008	0.994
4-04	468.5	102.5	0.219	3/13/2013	0.911	0.362
4-05	259.5	84.5	0.326	3/13/2013	-1.134	0.257
5a-01	480	67	0.140	3/13/2013	0.219	0.826
5a-02	357.5	105	0.294	3/13/2013	0.420	0.675
5a-03	250.5	121	0.483	3/13/2013	-1.270	0.204
5b-01	397	73	0.184	3/13/2013	-1.013	0.311
5b-02	301	75.5	0.251	3/13/2013	0.229	0.819
5b-03	446.5	83	0.186	3/13/2013	0.095	0.925
5b-04	311.5	80.5	0.258	3/13/2013	-0.041	0.967
5b-05	141.5	53.5	0.378	3/13/2013	1.925	0.054
5b-06	325	124.5	0.383	3/13/2013	2.690	0.007
5B-6-06-10	159	55	0.346	6/15/2010	1.853	0.064

APPENDIX H

Application Note
Company / Department



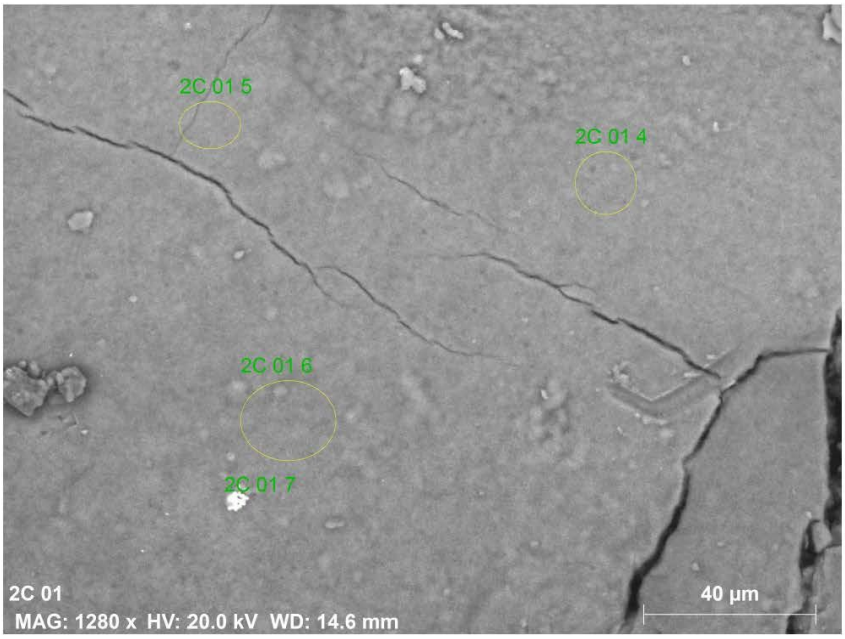


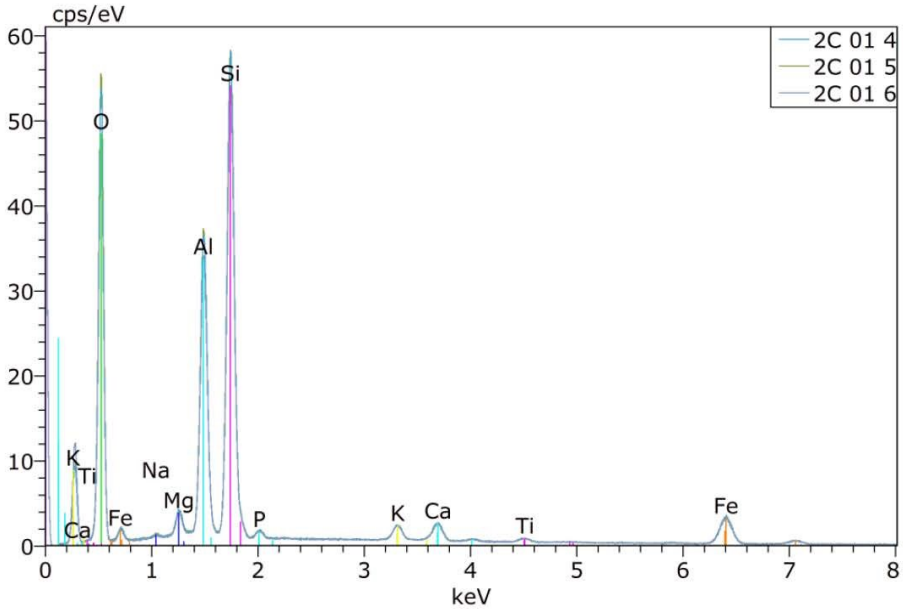


Spectrum: 2C 04 2

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	41.12	52.58	67.92	4.55
Na	11	K-series	0.14	0.17	0.16	0.04
Mg	12	K-series	0.81	1.03	0.88	0.07
Al	13	K-series	10.29	13.15	10.08	0.52
Si	14	K-series	17.84	22.81	16.79	0.79
K	19	K-series	0.83	1.06	0.56	0.05
Ca	20	K-series	0.96	1.23	0.63	0.06
Ti	22	K-series	0.50	0.63	0.27	0.04
Fe	26	K-series	5.73	7.33	2.71	0.18
		Total:	78.22	100.00	100.00	

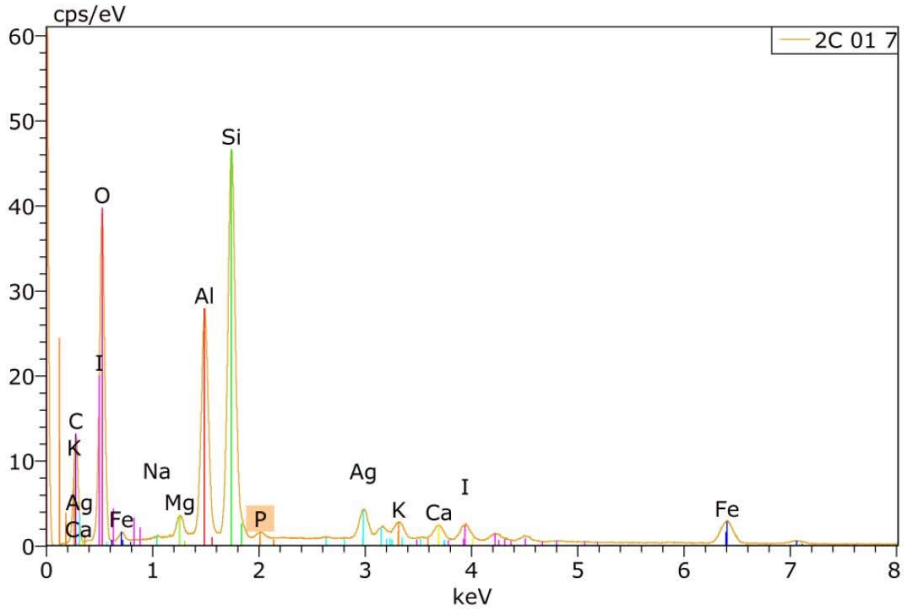
F


2C 01 5
2C 01 4
2C 01 6
2C 01 7
2C 01
MAG: 1280 x HV: 20.0 kV WD: 14.6 mm
40 µm


cps/eV
2C 01 4
2C 01 5
2C 01 6
O
Si
Al
K
Ti
Ca
Na
Mg
Fe
P
K
Ca
Ti
Fe
keV

Mass percent (%)

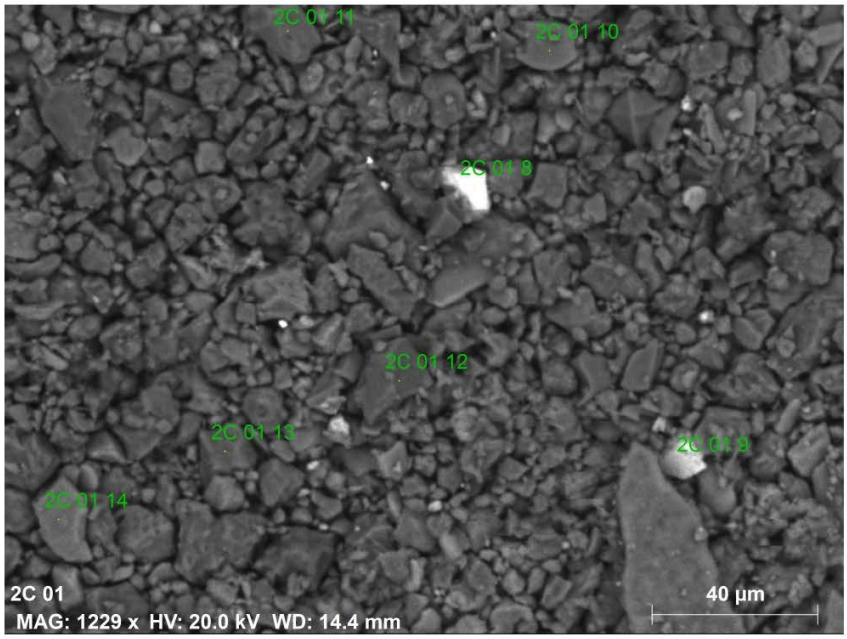
Spectrum	O	Na	Mg	Al	Si	P	K	Ca	Ti	Fe
2C 01 4	53.61	0.10	1.13	12.88	20.34	0.51	1.39	2.00	0.61	7.42
2C 01 5	53.91	0.17	1.15	12.84	20.16	0.48	1.34	1.88	0.52	7.54
2C 01 6	52.84	0.13	1.18	13.02	20.56	0.51	1.40	1.96	0.59	7.80
Mean value:	53.45	0.14	1.15	12.92	20.36	0.50	1.38	1.94	0.57	7.59
Sigma:	0.56	0.03	0.03	0.09	0.20	0.02	0.03	0.06	0.05	0.19
Sigma mean:	0.32	0.02	0.01	0.05	0.12	0.01	0.02	0.04	0.03	0.11



F

Spectrum: 2C 01 7

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
C	6	K-series	24.06	23.02	34.85	2.93
O	8	K-series	43.18	41.31	46.96	4.82
Na	11	K-series	0.19	0.18	0.14	0.04
Mg	12	K-series	1.01	0.97	0.72	0.08
Al	13	K-series	8.73	8.35	5.63	0.44
Si	14	K-series	13.10	12.53	8.11	0.58
P	15	K-series	0.24	0.23	0.14	0.04
K	19	K-series	1.05	1.01	0.47	0.06
Ca	20	K-series	1.24	1.19	0.54	0.06
Fe	26	K-series	4.17	3.99	1.30	0.14
Ag	47	L-series	4.03	3.85	0.65	0.15
I	53	L-series	3.52	3.37	0.48	0.13
		Total:	104.53	100.00	100.00	



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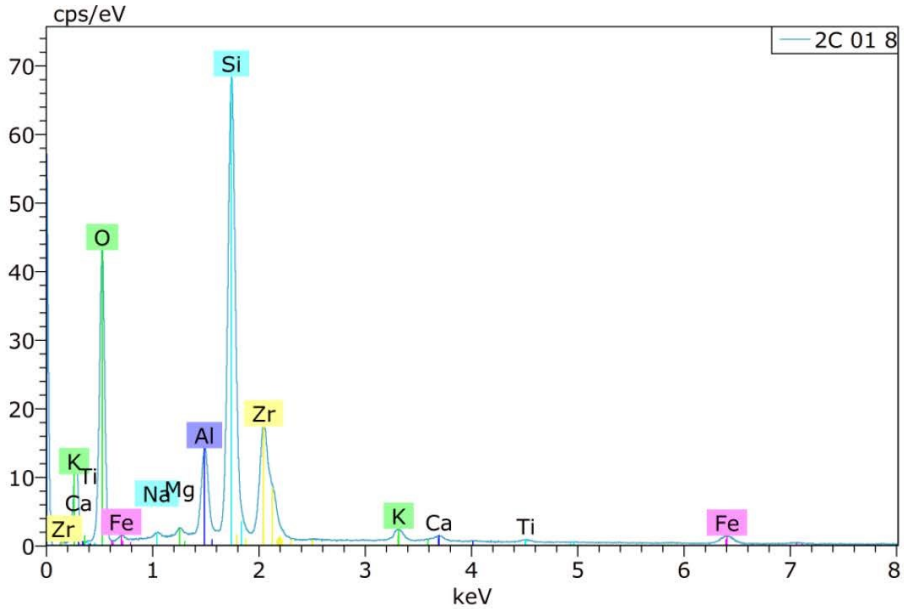
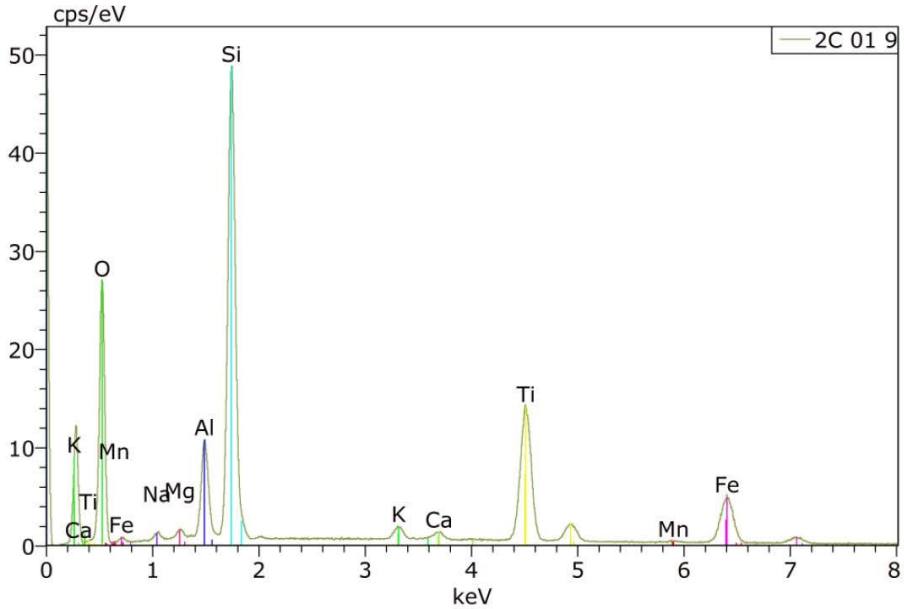


Spectrum: 2C 01 8

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	40.53	51.34	72.72	4.50
Na	11	K-series	0.29	0.37	0.36	0.05
Mg	12	K-series	0.29	0.37	0.34	0.04
Al	13	K-series	3.30	4.19	3.52	0.18
Si	14	K-series	15.61	19.77	15.95	0.69
K	19	K-series	1.06	1.34	0.78	0.06
Ca	20	K-series	0.56	0.72	0.40	0.04
Ti	22	K-series	0.32	0.41	0.19	0.04
Fe	26	K-series	1.94	2.45	1.00	0.08
Zr	40	L-series	15.03	19.04	4.73	0.60
		Total:	78.94	100.00	100.00	

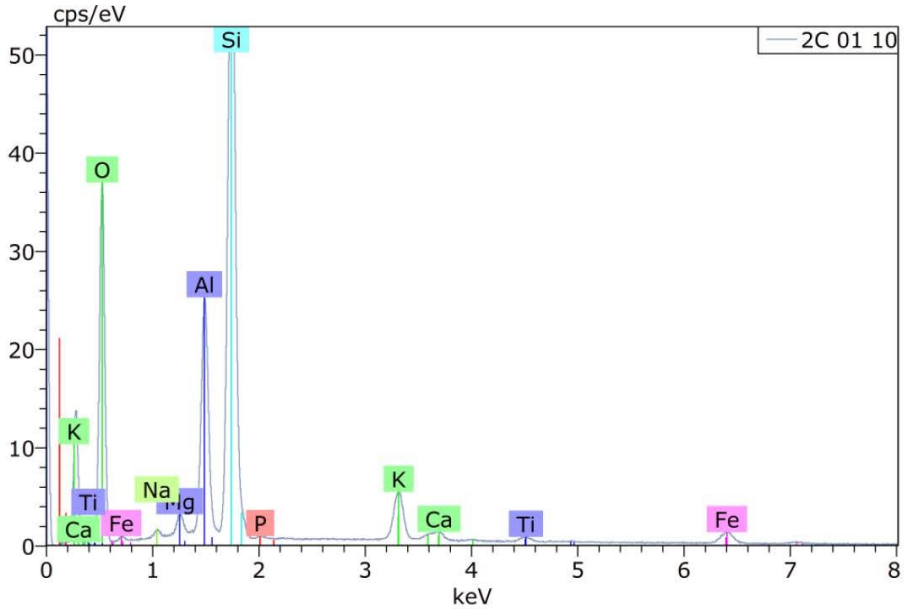
F



Spectrum: 2C 01 9

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	44.40	46.76	65.97	5.05
Na	11	K-series	0.70	0.74	0.72	0.07
Mg	12	K-series	0.56	0.59	0.54	0.06
Al	13	K-series	4.94	5.20	4.35	0.26
Si	14	K-series	19.72	20.77	16.69	0.87
K	19	K-series	0.79	0.84	0.48	0.05
Ca	20	K-series	0.51	0.53	0.30	0.04
Ti	22	K-series	14.21	14.96	7.05	0.42
Mn	25	K-series	0.22	0.23	0.10	0.03
Fe	26	K-series	8.91	9.38	3.79	0.27
		Total:	94.96	100.00	100.00	

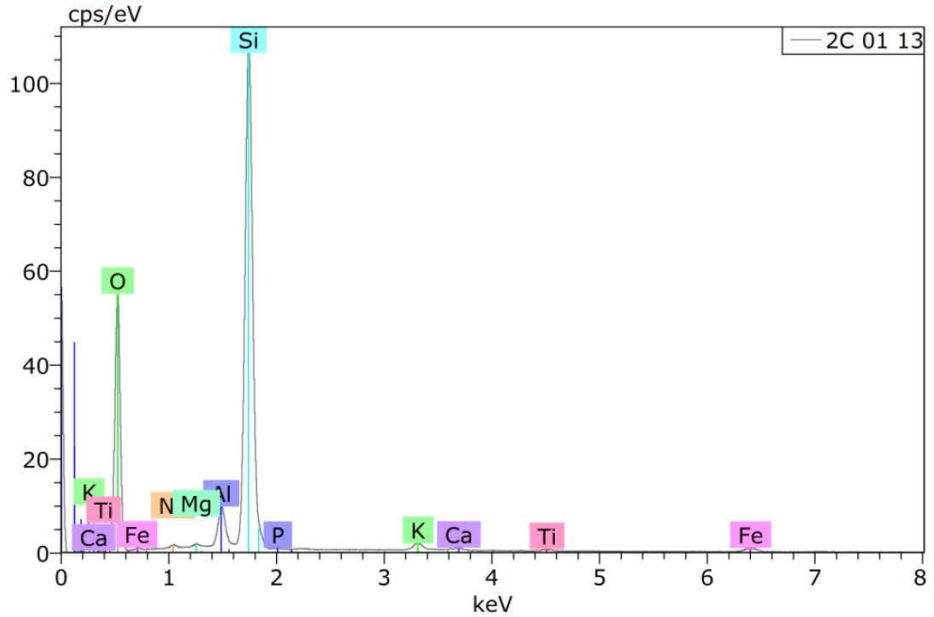
F



Spectrum: 2C 01 10

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	38.62	50.23	65.09	4.32
Na	11	K-series	0.40	0.52	0.47	0.05
Mg	12	K-series	0.84	1.09	0.93	0.07
Al	13	K-series	8.31	10.81	8.30	0.42
Si	14	K-series	21.84	28.41	20.97	0.96
P	15	K-series	0.12	0.16	0.11	0.03
K	19	K-series	3.34	4.34	2.30	0.13
Ca	20	K-series	0.73	0.95	0.49	0.05
Ti	22	K-series	0.48	0.63	0.27	0.04
Fe	26	K-series	2.21	2.87	1.07	0.09
		Total:	76.88	100.00	100.00	

F



Spectrum: 2C 01 13

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	40.08	55.68	69.51	4.40
Na	11	K-series	0.22	0.31	0.26	0.04
Mg	12	K-series	0.15	0.21	0.17	0.03
Al	13	K-series	2.24	3.12	2.31	0.13
Si	14	K-series	26.20	36.40	25.88	1.14
P	15	K-series	0.09	0.12	0.08	0.03
K	19	K-series	0.95	1.32	0.68	0.06
Ca	20	K-series	0.34	0.47	0.24	0.04
Ti	22	K-series	0.28	0.39	0.16	0.04
Fe	26	K-series	1.43	1.98	0.71	0.07
		Total:	71.98	100.00	100.00	

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VITA

Stephen Michael Krabbe was born in Kansas City, Missouri, on March 13, 1975. He was educated in the Hickman Mills School District, graduating from Hickman Mills Senior High School in January, 1993, in the top ten percent of his class. He attended Northwest Missouri State University as an Undeclared Major from January, 1993, to May, 1994.

In March, 1992, Mr. Krabbe enlisted in the United States Army Reserve, 308th Psychological Operations Company, in Belton, Missouri. He attended Primary Leadership Development Course, achieving the rank of Sergeant in March, 1995, at 20 years of age. From May, 1996, to February, 1997, he was deployed to Bosnia-Herzegovina in support of Operation Joint Endeavor. From October, 2000, to September, 2001, Sgt. Krabbe served in the Missouri National Guard as a Heavy Equipment Operator.

From 1995 to 2000, Mr. Krabbe worked various jobs in the Insurance and Mortgage industries. From 2000 to 2005, he worked as an Equipment Operator for the Johnson County Landfill and Shawnee Rock Company.

From the fall 2005 through spring 2006, Mr. Krabbe attended Longview Community College, graduating with an Associates of Arts degree.

Beginning in the summer of 2006, he attended the University of Missouri – Kansas City, graduating in December, 2008, with a Bachelor of Science in Environmental Studies, with Minors in Geology and Geography. He was a member of Alpha Sigma Lambda Honor Society, served as the Supplemental Instructor for

Understanding the Earth (Environmental Science 110), and worked as a lab assistant in the Geosciences Department.

In June, 2007, Mr. Krabbe began working for the Missouri Department of Natural Resources as a part-time employee. From January, 2008, to the present, he has continued to work for the Missouri Department of Natural Resources as an Environmental Specialist. He has worked in the Solid Waste, Hazardous Waste, and Water Pollution sections, where he inspects facilities to ensure compliance with applicable regulations.

Mr. Krabbe began work toward his Master of Science in Environmental and Urban Geosciences, emphasis in Environmental Geology, in January, 2009. Upon completion of the degree requirements, he plans to continue working for the Missouri Department of Natural Resources and begin working toward a Ph.D., with research in the environmental education field.