Identifying Differences in Illinois Dry Prairies by Examining Soil Factors and their Effects on Plant Species Composition

Abstract

Illinois is home to a wide array of prairie remnants that have been preserved from the period of westward expansion. Of these, dry prairies are known to be among the most species rich. Within the class of dry prairies there are three major types in Illinois: dolomite prairies, gravel hill prairies, and sand prairies. For years these prairies have only been differentiated by their substrate as each of their names imply, but no work has been done to confirm whether or not the substrate does differ significantly, and if that difference alters the environment enough to change the plant community. This study was conducted to deepen the understanding of the factors setting these prairie types apart. To accomplish this 18 remnant prairies representing a mixture of the three site types were examined. At each of these locations soil properties were analyzed including nutrient availability, infiltration rates, and soil texture. In addition, a survey was performed to determine plant composition at each study site. Soil nutrients differed among the different prairie types, with significant differences between sand prairies, and dolomite and gravel prairies. These differences were most evident in nitrogen, potassium, magnesium, and calcium. Other important nutrients such as phosphorous, iron, and copper were not significantly different between all three types. Infiltration rate was not significantly different between sand and either of the two other site types, but dolomite and gravel hills varied significantly from each other. Soil texture was also found to vary significantly between dolomite and the other two site types with much higher proportions of clay and silt in dolomite prairies. The plant surveys were analyzed in R using an ordination to graphically display the plant species as they relate to the three prairie types. The results of this analysis suggest there is a significant difference in floral community of sand prairies compared to the other two prairie types, whereas gravel hill and dolomite prairies do not differ significantly from each other based on the plant community. This research suggests there are some significant differences between the soils of these prairies, and there is a significant difference in species composition which can also differentiate these sites from each other. Additionally, gravel hill and dolomite prairies may not be two distinct types of prairies based on their species composition and soil properties. Considering these two prairie types as a single type instead would allow management agencies to use time and resources more effectively by managing these sites together.

Introduction

Before America was settled by Europeans most of the country was covered in vast areas of forest and prairies. Since the 1800s and the expansion westward these once vast wild areas have been reduced to a fraction of their former expansive size. While the eastern forests were cut down to supply the wood necessary to construct buildings and to power the blossoming industrial revolution, the Midwestern states were treated very differently. As settlers pushed west they found flat lands with tall grasses and forbs that burned frequently but had incredible deep and rich soil. This was perfect land for farming to feed the growing American, and soon world, population.
American plows have been working the majority of this once immense prairie land for over 100 years in many cases. As such the prairie is one of the greatest cases of habitat loss in the world with less than 1% of the original prairie land left undisturbed (Robertson and Schwartz, 1994). Illinois, which is known as the prairie state, was once covered almost entirely by prairies. Today it is one of the hardest hit of the Midwestern states for loss of original prairie land and because of this loss it is hardly recognized as the prairie state any longer. Most would say that the corn and soybean state is a more apt description.

While much of this once expansive habitat is lost there are still many examples of isolated remnant prairies throughout the state that survive today. These remnants are often small and isolated plots on the edges of farm fields, secluded in inaccessible locations, or preserved in natural areas that maintain the unique character of the original prairies that used to cover the state. These remnants are often rich in species diversity and represent some of the only virgin, or uncultivated, land left in the country. Many of these have set the precedent for what conservation agencies are attempting to recreate when they begin a prairie habitat restoration. These restored prairies are areas that have been used for some other purpose by people, but are now being converted back to their natural condition through managed fires, reseeding, and weed control. In many cases these efforts can be successful in restoring much of what was lost.

During restoration projects it is important to identify the type of prairie that one is trying to restore. Plant communities are dependent on several factors including light, water, and nutrient availability and prairies are no different. They come in a variety of types which are usually identified along a gradient determined by water availability and the type of soil they are growing on. The scale for moisture runs from the very dry or xeric prairies, to mesic, which have an optimal balance of water available, to hydric or very wet prairies. The very wet prairies contain the lowest amounts of plant species diversity. As one moves to progressively drier environments the species diversity increases, and reaches its pinnacle in the dry-mesic prairies (Curtis, 1959). These drier prairies are of special concern to researchers since they harbor the greatest levels of plant diversity and thus act to preserve the largest number of species that thrive in prairie environments. Within this dry-mesic category the type of soil conditions are used to further differentiate the prairies from one another. The three major categories of dry prairies are dolomite, gravel hill, and sand prairies. These dry prairie types, as the names suggest, have different soil particles that make up the major part of their composition. The major type of soil particles are sand, silt and clay, each being smaller than the last. Dolomite prairies are defined by a layer
of dolomite bedrock very close to the surface or even exposed at the surface with very thin soil. Gravel hills were formed by glacial activity and are made up of deposits of glacial till, which is mostly comprised of multiple sizes of interlocking gravel, sand, and some soil and are unique in their topography of having elevation whereas the other prairies are generally flat. Sand prairies are composed primarily of different size grains of sand and can be the secondary community forming on dunes or on glacial deposits of sand.

While the unique character, high species diversity, and extreme habitat loss are enough to motivate the conservation and restoration of these types of communities there are still details regarding soil, the plant community, and interactions between them that are unknown. One of the major factors in water storing capacity, and thus soil moisture availability, in the type of soil that is found in an area. In prairies the ability of plants to access and efficiently use water can be the deciding factor between life and death. For this reason the soil that plants grow on is often specific to the species since they adapt to the environment in which they have evolved. One of the major unanswered questions about prairies is if the plant species composition shifts as the soil factors change.

In this study the effects of soil composition on the plant species found in these dry remnant prairies is examined, and attempts to find out if there are links between the soils found in a prairie and the variety of plants that are able to grow there. Additionally it is the goal of this study to quantify the difference between these types of dry prairies to better understand differences and similarities of these prairie communities. This work, and other studies like it, could be critical in the future to helping conservation scientists understand differences in plant communities of each prairie as they attempt to preserve and restore them. Only when they better understand the factors that separate the types of prairies and motivate different plant communities to grow and thrive will this kind of conservation and restoration be truly successful.

**Literature Review**

Prairies were once the largest, continuous environment in the US. One of the most commonly accepted ways of defining what a prairie is that of a level or rolling grassland, especially which can be found in North America. This definition can be extended by understanding other characteristics, such as that the vegetation is composed mainly of perennial grasses, along with many species of flowering plants from the pea and composite families. Most authorities recognize three basic subtypes of prairie: tallgrass prairie; midgrass, or mixed-grass, prairie; and shortgrass prairie, or shortgrass plains. These prairies once dominated much of the United States West of the Appalachian Mountains all the way to
the edge of the deserts in the rain shadow of the Rocky Mountains. This made it one of the most dominant environments in the United States, covering approximately 40% of the country, which is about 170 million acres according to the National Park Service. Today, less than 1% of the land area that was once prairie still exists today in an untouched state and it is considered the most highly fragmented ecosystem in North America (Robertson and Schwartz, 1994; Samson and Knopf, 1996). In the Chicago Region of northeastern Illinois, before European settlement, over 80% of the landscape was composed of prairie that covered about 1.6 million acres (McBride, Bowles, and Petersen). Today this once vast area of the Illinois Landscape has been reduced to only 0.2% of its former area (White and Glenn-Lewin, 1984).

The traditional distinction of tallgrass/shortgrass has been used for many years, but to build upon this simplified distinction Curtis (1959) found that there was an edaphic gradient related to the soil moisture determined by the drainage qualities of Wisconsin's natural areas. He examined this gradient by creating a compositional index based on the indicator species for different drainage types ranging from dry to wet. Similar studies have also been conducted in order to look deeper into the moisture classes of prairie communities, such as by Dix and Smeins who used moisture as the major ecological gradient for landscape analysis of North Dakota prairie vegetation (Dix and Smeins, 1967). This moisture gradient ranges from the extreme dry, or xeric conditions, to the extremely wet, or hydric, conditions. Bowles and Jones (2007) conducted a study creating a floristic ordination and gradient analysis of prairie to wetland communities in the Chicago region by examining plant communities across 6 different moisture classes consisting of dry, dry-mesic, mesic, wet-mesic, wet, and hydric. These studies have all found significant relationships between the level of soil moisture and drainage and the resulting levels of plant diversity and the community composition in any location. He found that extremely dry environments have low diversity and that as moisture increased in the soil the species diversity would increase up to a threshold in dry-mesic environments, and then it would steeply drop off. Most significantly though they found that this relationship exists across a gradient with the plant communities dynamically responding and changing across the gradient (Curtis, 1959; Bowles and Jones, 2007). This is important to note because it means that plant populations are the most diverse in the drier prairies, which have traditionally been the most disturbed by man, and thus have led to the greatest amount of species loss.

Within the moisture gradient classification, there is also the effect of substrate on a prairie system. On the wet-mesic to hydric side of the gradient there are the marshes, bogs, fens, sedge
meadows, and seeps springs which are high in moisture and often have standing water. On the opposite side of the gradient there are the sand, gravel, and dolomite prairies (Bowles and Jones, 2007). The dry prairies are more commonly defined by their soil properties than by any other feature, as their names suggest. The major reason for this characterization is that it is a major point of difference between the prairies. The dolomite prairies occur over dolomitic bedrock that is very near the surface, and is often exposed, leaving comparatively thin soil for plants to grow on. Gravel hill prairies are formed from windblown loess and glacial deposits of gravel and soil in random locations on the landscape. Sand prairies too are left over glacial deposits in many cases, or form on the along river and lake shores where sand is deposited in large quantities (Evers, 1955; Curtis, 1959). Each of these environments presents a different set of conditions and challenges to the plants that live in them and so plants have to adapt to the challenges of these unique environments. This process of adaptation may have led to the high levels of diversity found within these communities.

Prairies traditionally are thought of as flat grasslands but actually have a wide array of plants adapted to the unique set of conditions found there (Evers, 1955). Grasses often are dominant members of the plant community within prairies, with many different species found in each prairie (Bowles and Jones 2007). Other dominant plant families include the fabaceae and the compositae or asteraceae, which both have many individuals adapted to dry environments. (Figure 1) (Curtis and Greene, 1949; Bowles and Jones, 2007; Kraszewski and Waller, 2008). These species have several above ground adaptations to help them survive in the dry conditions. Many have a thicker waxy cuticle on the leaves that helps to minimize water loss, as well as thinner leaf blades that minimize the amount of direct sun exposure. They also tend to have hoary or tomentos leaves and stems, meaning they are covered in small white hairs which diffract sunlight minimizing its intensity before it hits the leaves photosynthetic tissue. In addition many of the true prairie grasses (Poaceae) have an alternative method of photosynthesis, called C4 photosynthesis, which allows the plant to more efficiently turn carbon dioxide into sugar under high heat, low water, and low nitrogen conditions. This method conserves water by allowing the plant to keep stomates closed more often and concentrate atmospheric carbon dioxide into the bundle sheath cells. To complement these above ground adaptations there are also several below ground adaptations, or rooting strategies employed by prairie plants. Some send out a deep taproot that can reach 12 or more feet into the soil anchoring the plant and allowing it to draw water and nutrients from very deep, such as prairie dock. Others have fibrous root systems that greatly increase surface area and allow them to more effectively absorb water and nutrients in a small area, capitalizing on the periodic summer rains, which is a common strategy among succulents like prickly pears. The third
strategy is a rhizomatic root structure, which gives the plant a strong cloning ability, as well as providing a storage center for nutrients and water that can become more scarce during the dry parts of the year, which is a common feature among the major prairie grasses like big blue stem. All of these strategies involve a heavy root investment, which is a hallmark of prairie species that evolved with persistent disturbance from fire. This allows the surface to burn off, liberating nutrients into the environment, which resprouting plants can then use for new surface growth.

<table>
<thead>
<tr>
<th>Gramminoids</th>
<th>Forbs</th>
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<tbody>
<tr>
<td><strong>Common Name</strong></td>
<td><strong>Latin Name</strong></td>
</tr>
<tr>
<td>Little Blue Stem</td>
<td><em>Andropogon scoparius</em></td>
</tr>
<tr>
<td>Big Blue Stem</td>
<td><em>Andropogon gerardii</em></td>
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<tr>
<td>Indian Grass</td>
<td><em>Sorgastrum nutans</em></td>
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<tr>
<td>Side Oats Gramma</td>
<td><em>Bouteloua curtipendula</em></td>
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<tr>
<td>Switch Grass</td>
<td><em>Panicum virgatum</em></td>
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<tr>
<td>Needle Grass</td>
<td><em>Stipa spartea</em></td>
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**Figure 1** This table includes some of the major species of grasses and forbs found within the various dry prairie environments.

There are three factors that are critical to the growth of all plants. These are water, light, and nutrients. Any of these factors can become limiting in the environment especially when they are in short supply. In the dry prairie environment the most limiting factor is water availability. Water is critical for all life on earth, and it becomes more important in water scarce environments since so many life processes depend on water to function (Curtis, 1959). Since dry prairie plants have many adaptations to minimize water loss and maximize water use efficiency. These qualities make the plants more competitive in this water limited environment. Light is not as limiting in prairies. Since there are fewer tall species that shade out the others light is usually intense, and most species have to cope with an excess of light and heat that can increase evaporation rates, cause damage to photosynthetic tissue, or cause photoinhibition which decreases the efficiency of photosynthetic processes. Those plants that are smaller in stature have to compete for light and often emerge early in the growing season, and thrive after disturbance clears away competitors (Tilman, 1988; Givnish and Leach, 1996). The final critical factor for plant life is availability of nutrients in the soil. Of the nutrients found in soil, some of the most critical are considered to be nitrogen, phosphorous, calcium. Sometimes others nutrients such as potassium and magnesium can be limiting depending on the location. Fire in prairies is known to alter the balance of these nutrients, volatilizing nitrogen but releasing phosphorous into the soil in ash (Ojima et al., 1994; Givnish and Leach, 1996; Tilman, Wedin, and Knops, 1996). The plant community changes in
response to this disturbance selecting for those plants able to efficiently use nitrogen or those that can produce it though nitrogen fixing bacteria (Deyn, Raaijmakers, and Putten, 2004).

These factors that limit prairie environments can be examined in multiple ways to better understand how the environments differ from one another, and thus they can be differentiated more clearly. When considering the soil and the water available to plants it is important to understand how soil and water interact. Precipitation can bring small or large amounts of water to an area, but depending on the soil it can be lost very quickly, like water forming runoff along a paved road, or it can be absorbed into the soil and held there. The process of infiltration, whereby water permeates into the soil, is critical for plants, because they do not have access to water until it enters the soil where their roots can absorb it. Infiltration is strongly influenced by texture and microstructure of soil, which determines how many pores are formed in soil. These tiny pockets in the soil leave space for water to fill in, and act as tiny reservoirs for water once it infiltrates into the soil (Rawls, L., and Saxton, 1982). The rate of infiltration can be measured by observing the time it takes for water to be absorbed into a particular type of soil. This rate can be used to determine if there are differences in the structure and texture of soil.

Soil texture has wide ranging effects on the properties of a soil type. Texture is classically defined by three main soil particle sizes. These sizes are, from largest to smallest, sand, silt, and clay. Texture classes are assigned to soils based on the proportions of these three particle sizes. Sand particles are the largest of the three, and create loose soils with large pore spaces. Silt is intermediate in size and often the major component in some of the most productive soils, creating a finer texture with smaller pore spaces but not becoming overly compact. Clay particles are the smallest, and thus have extremely high surface to volume ratios, allowing the clay to effectively bind to itself. This can often lead to an impermeable layer in soil, and will prevent the infiltration of water if a layer of clay if formed (Abdel-Magid, Schuman, and Hart, 1987). Most soils have some combination of these three particles that make up the average composition. Sand, gravel, and dolomite prairies each have unique composition of the major particles that make up the soil, in addition to large chunks of gravel and bedrock in gravel and dolomite prairies. Sand prairies are have the strongest association with sand as the major particle composing the soil. This makes sand prairies unique in that they have coarse soils that have large pore spaces, and tend to be less stable. Dolomite and gravel prairies have varying levels of all three particles sizes, but have the additional influence of larger pieces of rock and gravel, which interrupt the microstructure of the soil. This also alters the total water storage capacity of the soil since
In addition to soil texture, available nutrients in the soil is another influential factor in the ability of plants to successfully grow and reproduce in any location. Nutrient availability, along with light and water, is often a driving force behind competition in a prairie (Tilman, 1982). Since plants are unable to move to find resources for their growth, they have to rely on the soil to provide what they need to grow. Some of the most critical nutrients for plant growth are known to be nitrogen, phosphorous, potassium, and calcium, but a host of other nutrients are necessary for complex biological processes except in lower quantities. These nutrients are absorbed by the roots of a plant and are then distributed throughout the other tissues (Deyn, Raaijmakers, and Putten, 2004). Rooting strategies among prairie plants differ, with some forming fibrous networks of root, others rhizome, and some deep taproots. These different strategies have formed over millions of years to make the plants competitive with each other, but also distributes the amount of nutrients being pulled from the soil along a vertical gradient to minimize the competition in any single layer of the soil (Rajaniemi, Allison, and Goldberg, 2003). These strategies also vary to take advantage of differing amounts of water availability. Shallower roots are able to absorb even the slightest rainfall, while deep taproots can often extend several feet into the soil and find underground sources of moisture. Some species like Andropogon gerardii have mychorrhizal root associations which is a symbiotic association that supplies A. gerardii with additional water and nutrients in exchange for sugars (Schultz et al., 2001). It has also been found that as levels of nutrients shift, the plant community development is affected. This effect can be positive in the cases of poor soils that have nutrients added, and negative if the nutrient load becomes too high (Deyn, Raaijmakers, and Putten, 2004). One area that is not highly understood about soil nutrients is how they vary with soil texture. For example, if sand increases is there a positive or negative correlation with the amount of potassium in that soil? By examining nutrient contents of different textured soils the relationship between texture and nutrients can be clarified.

Many factors affect the plant life that can grow in a prairie. Dry prairies in particular present challenges to the plant life residing in them since they not only are limited by water, but also have the effects of varying soil texture and nutrient availability to contend with. While studies in the past have looked at differences in species composition, most have focused primarily on the differences in moisture gradients alone as indicators of different plant communities, such as in the studies conducted by Curtis.
This approach neglects to look at another major factor in the plants life and development though, by assuming nutrient availability and soil texture have no significant effect. Clearly different soil textures and nutrient restriction have altered the types of plants that can grow in other environments, such as the low nitrogen and water logged conditions in bogs, which favor carnivorous plants, and so determining the effect of texture and nutrients should be a priority for prairies. Additionally, dry prairie types have classically been defined by the type of soil that is found in them, so it should be tested whether these distinctions have a quantifiable difference.

This study will test what soil factors vary between sand, dolomite, and gravel hill prairies. In addition, it also will test for differences in the plant composition to determine if the prairies are in distinct prairie types bases on plant species. The main hypotheses under consideration were that all three prairies will vary significantly in soil composition based on soil texture, nutrient availability, and infiltration rate of water into the soil, with dolomite prairies having the most diverse soil condition and the greatest available nutrients, followed by gravel hills, and then sand prairie, based on the assumption that smaller soil particles like silt and clay will allow the soil in dolomite and gravel hills to hold more nutrients and water in their pores then the larger pore spaces of soil rich in sand. Additionally, the plant community will distinguish these sites from one another by showing three separate classes of plant communities that correspond to the different prairie types because the plants able to grow in each of the prairies will respond to the texture of the soil and available water and nutrients therein.

This was accomplished by surveying 17 Illinois dry prairies and identifying the vegetation growing in them, as well as measuring the nutrient availability of the soil in these prairies, the infiltration rate, and the soil texture. These factors will then be examined to determine if patterns exist between the plant diversity seen, and the measured soil factors. Relationship, both positive and negative were looked for in order to determine the correlations between these factors. The plant communities were compared based on the presence and absence of the species found, as well as the importance of each to the environment in which it was found. Taken together these analyses were used to draw conclusions about these relationships.
Methods

Study Area

The study area was located in Northeastern Illinois and spanned Lake, Will, Kane, Cook, DuPage and McHenry counties. A total of sixteen dry prairie sites were located within these counties and chosen on the basis of being remnant or restored dry prairies. There were a total of four dolomite, six gravel hill, and six sand prairies sampled across the counties which can be seen in Figure 2, which shows a map of all the study sites. One of the dolomite locations and one of the sand locations were much larger than the rest and had a more dynamic landscape. As a result and were sampled in two different locations within the prairie instead of one. Land managers, state and county ecologists, and township representatives were contacted to obtain permits for the sampling being done and to get a background of the site, understand some of the site history, and to find out about what sections of the different prairies or natural areas were most similar to the dry prairie being looked for. These qualities varied depending on the type of prairie. Dolomite prairies needed to have shallow soil with at least some exposed bedrock. Sand prairies needed to have soil majorly composed of sand that was not wet when examined. Gravel hills were needed to have some slope that set them up higher than the surrounding landscape, and have soil with a larger amount of gravel imbedded near the surface or just below the surface, and generally were thought to have a more patchy vegetative cover. All sites were examined for how close they were to any human influence, including roads and trails. Sites further from these areas were favored, except when it was unavoidable to do so. Water sources, and plant species indicting moist conditions, such as cattails and reeds, were also avoided to ensure sample areas were in dry conditions.
Figure 2: A map of northeastern Illinois with all study sites marked on it. Dolomite sites are indicated by yellow pins, gravel hills by green pins, and sand prairies by red pins.
Field Methods

Plot Selection

The study sites ranged in size and topography. Before a plot was established the local naturalist or ecologist working on the site was contacted in order to find the most characteristic location in the site. Then based on the recommendation received and satellite photos, which were used as a reference to see large portions of the prairies and some of the features within them, we entered the site and examined all the most pristine and characteristic areas of the dry prairie. The characteristic areas were those that matched descriptions made by previous studies on remnant prairies. The features that were looked for involved topography, plant composition and density, and isolation within the site to minimize edge effect, which distorts the population by having additional invading exotic and weedy species and human impact. The areas with the least disturbance and the most characteristic features was then chosen for comparison. When a plot was selected its approximate location was marked on a map and a GPS coordinate was taken in addition to the site being sketched out for later reference. The sketches included the orientation of the plot, reference points on the landscape, and some topographical notes to aid in characterizing the site later, or returning to it.

Plots were 20m by 20m and were kept as square as possible. A 50m measuring tape was used to measure out each side of the plot. One corner of the plot was marked and the tape secured at the end and the end of the tape was stretched out twenty meters to the south. This was repeated for each of the four sides, and at the four corners flags were placed to mark the location. In order to make sure the plot was square the sides were remeasured after the four sides were placed. From each corner the 5 meter marks were also flagged along the edges and into the interior of the plot to create the grid pattern show in figure 3.

Figure 3: Example of plot used for plant surveys.
Nutrient Probes

PRS probes, or plant root simulator probes, which are shown in Figure 4a, were used to measure the available soil nutrients in each plot. The probes were constructed of a plastic casing with a resinous membrane exposed in an opening of the casing. This membrane was exposed to the soil upon burial and absorbed nutrients from the soil over time. There were two different types of soil probes; one set of probes were used to collect anions from the soil, and an alternate set were used to collect cations.

The PRS probes were arranged in pairs, one orange that collected anions and one purple that collected cations per pair. These were buried in the soil of the 20m by 20m plot at the marked locations five meters down and five meters in from the corner. The probes each had orange flagging tied to their ends to make relocation easier. This was done four times in every 20m² plot at each of the four corners five meters in from the edges of the plot. After the probes were placed one pint of distilled water was poured over the area to begin facilitating the ion exchange in the soil since 2012 had an exceedingly dry summer and drought conditions throughout the Midwest. The probes had to be left in for a minimum of two weeks in order for the ion exchange to have sufficient time to happen. Two weeks was used as a minimum time to collect soil nutrients because the probes act as plant root simulators and gradually uptake soil nutrients as shown in Figure 4b which diagrams the uptake by the probes, and is the burial time recommended by Western Ag Innovation, the manufacturer of the probes. One site was visited per day over two and a half weeks. During a visit plots were laid out and the soil probes were put into the soil to begin collecting ions. Each site was returned to on average three weeks after the initial visit to collect the soil probes and conduct the rest of the field procedures.

![Figure 4a: PRS probes from Western Ag Innovations used to measure nutrient availability in the soil. Figure 4b: Diagram of the relationship between nutrient uptake and ion activity. It should be noted the relationship is non-linear so the final results cannot be divided into smaller segments of time. Taken from Western Ag Innovation - http://www.westernag.ca/innov/](image)
Infiltration Tests

At each location a measure of the infiltration rate of water into the soil was taken by using a double ring infiltrometer as shown in figure 5. This is a metal tool with an inner ring enclosed by an outer ring, both of which are filled with water. The outer ring helps to prevent lateral outflow of the water in the central ring, giving a more accurate measure of the water’s movement into the soil straight downward. The infiltrometer was placed near two of the locations where the PRS probes had been so the nutrient and infiltration data would be from as close to the same locations as possible. Before starting a soil sample was taken to measure soil moisture back in the lab. This was used as a correction for the infiltration rate by giving an indication of ambient soil moisture levels which would vary from site to site. After the sample was collected the infiltrometer was pushed into the ground enough to prevent water from escaping out from the sides, which was about 2cm’s deep. The two rings were then filled with water, which was approximately 1L of water. The time it took for the water to descend into the ground was recorded by taking a reading of the time for every 5 or 10mm the water descended. The descent of the water was measured by a bobber that floated on the water and was attached to a rod that ran up the infiltrometer and next to a ruler. The rod had an indicator that would point to the depth to which the water had descended. Once the water had descended far enough to only have one centimeter of water left in it the rings were refilled two more times to get a longer and more accurate measure of the infiltration.

Figure 5: Double ring infiltrometer used to measure infiltration rate of water into the soil at field locations.
Plant Surveys

In each 20m by 20m plots a thorough plant survey was conducted systematically in smaller subplots or quadrats. This was done by marking out five meter intervals along the edges of the outer plot with flags and then marking out all the inner lines as well, setting up a grid in the plot. Sampling was initiated in one of the corners by designating that corner quadrat number 1. Inside of the 5m by 5m quadrat every plant was identified to species level if possible using several plant identification guides, personal experience with the plants, and a dichotomous key of The Flora of the Chicago Region. Then the percent cover of that species was determined in the quadrat using a cover class system. These cover classes were determined using classes 1-7, where each number denoted a percentage of cover. For example, 1 denoted 0-1% cover, 2 denoted 1-5% cover, 3 denoted 5-25%, 25-50%, 50-75%, 75-95%, 95-99%, 99-100%.

After the 5m by 5m quadrat was surveyed a smaller 0.5m² quadrat was surveyed by using a quadrat made out of PVC piping to mark out the smaller subset in 2 opposite corners of the quadrat. In these corners all the species in the area were again identified. The cover classes were recorded as well as the number of individual plants within the area. This was done in a differently depending on the species. For tussock forming or clumping grass each tussock was counted as an individual. In the rhizomatic grasses an estimation of the number of stems was made using a stem class. For forbs and woody species the actual number of individual plants was counted. These processes were repeated in at least four of the 5m by 5m quadrats in the larger plot. If time permitted a fifth quadrat was surveyed. Figure 6 shows a detailed diagram of the survey method.
Laboratory Methods

Soil Texture Analysis

The soil collected before the infiltration tests was put into tightly sealed plastic Ziploc bags. In the lab the samples were taken out and an initial "wet" weight was taken by using an analytical balance to measure the mass. We dried the samples for 24-48 hours in a drying oven at 100 degrees Fahrenheit. Drying time was decided by the schedule followed for field work, and when someone was available to process the soil samples. Once dry, the soil was reweighed on the same analytical scale to get a "dry" weight. The amount of water weight lost for the different locations was then used as a correction for the infiltration rate as discussed in the infiltration section, by subtracting it as an initial soil moisture level since weather varied over the course of the sampling period. The dried soil from each location was then sifted using soil sieves with screen sizes of 4.75mm, 2.0mm and 1.0mm to remove the particles larger than coarse sand and any excess plant roots or other debris. The spacing and interwoven mesh of these sieves caught any particles larger than their size spacing and thus removes them from the sample. Each of the sieves contents was collected for each sample and weighed to find the percent composition of the total mass these particles made up.

For the particles smaller than 1.0mm a soil texture reading was taken using the hygrometer method. A hygrometer is a glass device precisely weighted with lead inside the glass bell so that it floats at a particular depth in pure water at standard conditions of temperature, 25 degrees Celsius, and 1atm of pressure. When suspended particles are in the solution they cause the hygrometer to float higher in the water and this reading can be used to calculate the percent sand, silt, and clay in the suspension. The reading was standardized by running a blank, which used the same water source as the rest of the tests. 100mL of sodium hexametaphosphate was mixed with 900mL of water in a 1000mL graduated cylinder and the temperature and hygrometer reading were recorded. Sodium hexametaphosphate is used to break up the soil particles that would otherwise cling to each other. To perform the soil texture 40.000g of the soil, or as close to this as possible, was precisely measured out in a transparent cup and the actual weight recorded. This cup was used to begin thoroughly mixing the soil. This was done by adding 100mL of a 5% solution of sodium hexametaphosphate to the soil in the cup. This was then mixed using a spoon until the soil was broken up. The contents of the cup were quantitatively transferred into a metal malt mixing cup for a standard Hamilton Beach Malt machine. The transparent plastic allowed for any small particles to be seen and transferred into the mixer. Enough water was used
to rinse every soil particle into the metal cup. This was then very well mixed using the malt mixer which broke up all the soil clods that were left and suspended all the particles.

After about 2 minutes of mixing the mixer was shut off and the contents again quantitatively transferred into a 1000mL graduated cylinder by rinsing all the particles into the cylinder with water. The cylinder was then filled with just under 1000mL of water. A "plunger" was then used to remix the suspension and as it was pulled out it was rinsed off until the cylinder was at 1000mL of water. The hygrometer was then put into the solution and a reading was taken after 40 seconds, which is the time it takes for all the sand to settle out. The temperature was also recorded in degrees Celsius. A second hygrometer and temperature reading for the blank and the texture were taken at two hours to measure how much silt had settled out of solution. The remaining portion after this measure was clay and is determined by subtraction of the other two amounts from the original mass.

Data Analysis

Data collected from all tests and surveys was collected and organized using Microsoft Excel. Excel was also used to create graphs of the infiltration rate of the different sites. To create ordinations of the species to the site types the statistical program R was used, specifically the Vegan package. Making an ordination involved organizing the data into a matrix that showed the presence or absence of a species, with 0 indicating absence, and 1 indicating presence. This matrix was then analyzed by the program and produced importance values, ranking species based on the number of times it occurred within a site. Species that occurred in less than 5% of sites were excluded from the final matrix and the ordination diagram to correct for possible misidentification, species that could not be identified, or other sources of error. The Vegan package was also used to perform a K-means clustering which reordered the sites based on the species importance values, but with a more thorough examination from higher standards of scrutiny. This K-mean clustering also created a new ordination diagram, grouping the prairies based on the multi-level clustering and considering the importance values. For additional statistical analysis SPSS was used to perform ANOVA analyses to determine if there were significant differences between the sites in the nutrient levels and the soil texture. The ANOVA data only determined if there was a difference between the three groups of data, or the three prairies, but did not determine which site or sites were different. To determine which sites were significantly different ANOVA contrasts were also performed to compare two sites together against the other site to test which site was varying from the others. This involved conducting a standard one way ANOVA, but the contrast test requires assigning two of the three groups a grouping value, and the third the inverse of
the other two. This meant assigning gravel hills and dolomite sites a value of 1, and sand prairies -2. The program then runs the ANOVA, and then conducts a posttest that looks for variation between the assigned groupings. This was chosen so that it could be determined which site, or sites were varying from the others. This method was also able to group dolomite and gravel hill sites together while still analyzing them separately first, which allowed the soils to be examined for the same relationship found in the plant community.

Results

Nutrients

There was a significant difference between the different prairie types for several of the nutrients measured by the soil probes. The most significant differences were found between nitrogen, calcium, magnesium, and manganese. Nitrogen was found to be most available in the gravel hill prairies on average, and the amount of nitrogen between the prairie types was significantly different (ANOVA P-value 0.002). Dolomite and gravel prairies were not found to vary significantly from one another. When grouped together in an ANOVA Contrast against sand prairies, and were found to vary significantly from sand prairies. (ANOVA Contrast P-value: 0.0004) Figure 7 for is a box plot displaying the nutrient data on nitrogen in the prairies. The average and spread within the gravel prairies is the greatest by a large amount. Dolomite prairies were also spread across a wide range because of two prairies outside the 1st and 3rd quartiles, shown as (*) on the box plot, but otherwise grouped tightly together. Despite the difference in spread and average, the two prairie types were not significantly different when compared using a 2-tailed t-test, which showed a p value of 0.029. Sand however had a very low average for nitrogen availability in contrast to the variable levels found in gravel and dolomite prairies.
Figure 7: Box plot display of the average nitrogen availability in the three types of prairies. The average is shown for each site type by the black bar in the box plot. This shows the average amount of nitrogen available, as well as the range of the data collected. Nitrogen was most abundant in gravel hills and least abundant in sand prairies. Gravel and dolomite were not significantly different from one another. Dolomite prairies also had what appeared to be outlier values for two prairies, on opposite ends of the amount of availability. These values are indicated by stars, and are pointed out because they fell outside the first and third quartiles.
Calcium was found to be significantly different between the prairie types. Gravel and dolomite sites did not vary significantly from one another, while sand varied significantly from both of them. (ANOVA P-value: 0.001, ANOVA Contrast p-value: 0.0004) Figure 8 shows a box plot and p-value data on calcium from the ANOVAs used to analyze the differences. Dolomite sites have a large spread of values, as can be seen by the large inter-quartile range depicted by the spreading arms. Gravel hills had a much smaller spread in the amount of available calcium, but the average, 2075.6µg/10cm^2 was very close to that of dolomite, 2347.24µg/10cm^2, and it fell within the values of the dolomite prairies. Sand was much poorer in available calcium, and had very small spread, with all values between 300 and 500.

Figure 8: Box plot of average calcium data by prairie type. This shows the average amount of calcium available, as well as the range of the data collected. Calcium was most abundant dolomite on average and least abundant in sand prairies. Gravel and dolomite were not significantly different from one another but were significantly different from sand prairies.
Magnesium, like nitrogen, was the most abundant in gravel hill prairies. There was a significant difference between the three prairies types, shown by an ANOVA p-value of 0.002. Gravel and dolomite sites were not found to vary significantly from one another, but together varied significantly from sand sites shown by an ANOVA Contrast p-value of 0.002. Figure 9 shows the average and range of the magnesium availability in the three types of prairies. Dolomite sites varied the most greatly between locations, with more of the variability found in values greater than the mean. Gravel hills and sand prairies had little variability but showed opposite level of magnesium availability.

Figure 9: Box plot of average magnesium data by prairie type. This shows the average amount of magnesium available, as well as the range of the data collected. Magnesium was most abundant in gravel hills on average and least abundant in sand prairies. Dolomite prairies had a very large spread of available magnesium. Gravel and dolomite were not significantly different from one another but were significantly different from sand prairies.
Manganese was another nutrient that showed a significant difference between the three prairies, and like most of the nutrients sand prairies proved to have lower availability as shown in Figure 10. There was a significant difference between the three sites, ANOVA p-value of 0.017, but there was no significant difference between dolomite and gravel hill prairies. There was a significant difference again between dolomite and gravel hill prairies grouped together, and sand prairies, ANOVA Contrast p-value of 0.001. In all three prairie types this was a much less abundant element in the soil. Additionally, all three prairies exhibited more spread in the availability measured than in most other measure nutrients, but sand showed the least spread.

Figure 10: A box plot displaying the three types of dry prairies and the corresponding nutrient availability, as well as the ANOVA values for data comparison. The diagram shows the average availability of manganese, as well as the range of the data between the first and third quartile. Gravel hills and dolomite prairies showed very similar values and were not significantly different from each other, while sand varied significantly from both the other prairie types.
Unlike the majority of the rest of the key nutrients, potassium showed the opposite relationship between prairie types as shown in Figure 11. There was still a significant difference between the prairies, and between dolomite and gravel together compared to sand, but the availability of potassium was much higher in this sand prairies. (ANOVA p-value: 0.179, ANOVA Contrast p-value: 0.117) There was also a much larger range in the amount of available potassium in sand prairies compared to the other nutrients, while dolomite and gravel hills have very small ranges.

Figure 11: Box plot of average potassium data by prairie type. This shows the average amount of potassium available, as well as the range of the data collected. Potassium was most abundant in sand prairies on average and least abundant in dolomite. Sand prairies had a very large spread of available potassium. Gravel and dolomite were not significantly different from one another but were significantly different from sand prairies.
Phosphorous showed no significant difference between the three prairie types, as shown in Figure 12. The box plot in Figure 12 displays this, showing there is little difference between the prairie types, and statistically tested by an ANOVA showing a p-value of 0.806, indicating that there is little difference between the prairie's nutrient availability for phosphorous. Additionally, when sites were grouped together and compared there was still not a significant difference between them, ANOVA contrast p-value of 0.576. In this case there was also a large spread for the nutrient availability for all three prairie types, not just one or two as in previous soil nutrients.

Figure 12: Box plot of average phosphorous data by prairie type. This shows the average amount of phosphorous available, as well as the range of the data collected. Phosphorous showed no significant difference in availability in any of the prairies. Sand prairies had a lightly larger spread of available phosphorous. Gravel and dolomite were not significantly different from one another and were not significantly different sand either.
Infiltration

The results of the infiltration tests were aggregated together for each prairie type. The infiltration was measured as a function of depth of water absorbed into the soil over a period of time. The cumulative total time it took water to infiltrate into the soil was then converted into an average rate of infiltration for each prairie type, as shown below in Figure 13. The average infiltration rate was found to be fastest in dolomite prairies, followed by sand prairies, and infiltration was slowest in gravel hills. Gravel and dolomite prairies were found to have significantly different rates of infiltration, while sand was not found to be significantly different from either dolomite or gravel prairies. Sand prairies also varied the most in the rate of infiltration, as shown by the much larger standard deviation in values around the average rate compared to dolomite or gravel hills.

![Average Infiltration Rate of Gravel Hill, Sand, and Dolomite Prairies](image)

**Figure 13:** Graph showing the average infiltration rate of the three types of prairies. Dolomite, in blue, had the fastest infiltration rate, followed by sand in orange, and gravel hills had the slowest infiltration on average, shown in purple. The error bars on the graph shows the standard deviation for each of the prairie types.
Plant Community

The initial assessment of the plant community was done by comparing the species found in the prairies to their importance to any particular prairie sampled, coded for by the type of prairie. In Figure 14 the ordination of the species found, based on importance values, is depicted showing the interrelationship of the prairies sampled to all species that occurred in at least 5% of the sampled quadrats. Sand prairies are indicated by the blue squares, gravel hills by yellow circles, and dolomite by red triangles. The closer these markers are placed on the ordination the more similar the prairies are to one another in terms of species composition, and the farther apart they are the more differences there were observed between them. In sand prairies there are two main clusters of sites, one near the top center, and another down and to the right. There is a large separation between these sites and are shown to have few overlapping important species between them. The dolomite sites were the most tightly clustered on the ordination, indicating the closest relationship between this site type and the species found there. Gravel hills were widely distributed in the ordination, showing lower association with specific species found in them. There is also overlap between the dolomite and gravel hill sites, which suggests that they share some important species. There are also two gravel hills that cluster less with the gravel and dolomite sites and more with the lower group of sand prairies, indicating those five sites may be very similar in species composition. The results found in this ordination led to additional questions, which are: Regarding relationship between gravel and dolomite species composition, are they actually overlapping, indicating that they are the same in terms of species composition? and what is the cause of the gravel and sand cluster?
Figure 14: This figure shows the ordination of the dry prairies based on species importance values. Sand prairies are shown in blue, dolomite in red, and gravel hills in green. The three dashed ovals outline the basic assortment of species with the highest importance values to that prairie type. Sand prairies show a grouping that divides into two major clusters. Dolomite sites cluster together in one small area and show the strongest association to each other and the species found in them. Gravel hills have a very wide spread and overlap with dolomite on one side, and nearly intersect the lower cluster of sand sites.
The initial ordination was examined and it was determined that the data may be suggesting relationships that were not clearly being shown. To further scrutinize the relationship between plant species and the prairies they associate with a K means clustering was performed. This analysis performs a more rigorous examination, and is not biased by previous determinations of site types, so the outcome does not cluster sites based on their determined type, but will cluster them based on the species importance values. This new clustering also shows what the breakdown would be if a coarser or finer scale were used to separate the sites. This second operation yielded the ordination shown in Figure 15, which more clearly represents the results and helps to answer the questions left by the previous ordination. Sand prairies cluster together in a group near the top of the figure in a true dry sand prairie cluster (Cluster B). The dolomite and all but two gravel prairies cluster together as well, Cluster A, indicating that there is little or no difference in the highly important plant species that are found in dolomite and gravel prairies. The final cluster was not clearly outlined in the initial ordination. This third cluster consists of a mix of sand and dolomite prairies that are unlike the other sand and dolomite prairies in species composition, and are more closely related to each other then they are to the other sand and gravel sites. These sites, were determined to be outlier prairies for this reason and were excluded from other forms of analysis in order to attain more accurate results in comparing the sand, dolomite and gravel prairies.
Figure 15: This is the second ordination produced comparing dry prairie types based on species importance values. This version was created using a K means clustering operation, restructuring the comparison and using a more strict analysis. Sand sites are shown in blue, gravel in green and dolomite in red. The three clusters shown in the ordination are cluster A, which consists of the closely related gravel and dolomite prairies. Cluster B is made up of only sand sites which had a unique set of species with high importance values. Cluster C is unlike both of the other clusters, and is made up of sand and gravel sites with species composition unlike that of the other sand and gravel prairies.
Soil Texture

Soil texture was determined using the hygrometer method to separate the sand, silt, and clay from the soils and determining the percentage that each particle sizes contributed to the soil composition. This was done for each prairie sampled, and the values were averaged together and the results are displayed in Figure 16. Dolomite prairies had the most even distribution of soil particle sizes having close to even amounts of sand silt and clay. Silt was the most abundant in dolomite prairies, followed by sand and clay. Gravel hills and sand prairies were very similar in texture, both being mainly composed of sand, and having similar percentages of clay and silt. Gravel hills, on average had more silt and clay and slightly less sand, while sand prairies were mainly composed of sand, and had low amounts of silt and clay.

Figure 16: This stacked bar graph shows the average percent composition of the different prairies. Clay is depicted in blue and was the least abundant. Silt is depicted in green and was second most abundant except in dolomite prairies where it was the most abundant particle. Sand is depicted in tan and is the most abundant soil particle, except in dolomite site. Dolomite prairies were significantly different in composition than the sand and gravel hill prairies.
Discussion

It was found that dry prairies do differ from one another both in species composition and soil factors. But dolomite and gravel hill prairies do not vary from one another in the plant species and in the majority of soil factors examined in this study. From this data it was concluded that while the dry prairies are different based on these factors, all three varieties may not be completely unique environments. By testing what soil factors vary between sand, dolomite, and gravel hill prairies, it was found that some nutrients, such as nitrogen, calcium, magnesium and manganese are significantly different in availability in sand prairies then in dolomite and grave hills, which do not vary from one another significantly. Differences in the plant composition were also found to exhibit this same pattern, with sand prairies having a different composition that dolomite and gravel hills, which were not significantly different from each other.

The hypothesis that all three prairie types will vary significantly from one another was not supported as it was stated. The main feature found in the soils of the three prairies was that dolomite and gravel hills are very similar in most instances, while sand prairies were significantly different from these two. The relationship was found to be dolomite and gravel prairies being richer in nutrients than the sand prairies. This trend is likely due to the similar parent material of the soils of dolomite and gravel hills. Dolomite is a calcium rich bedrock, and gravel hills were deposited by glaciers that scoured the land and scraped up a large amounts of this same rock and deposited it in locations all at once leaving hills behind. This similar ancestry may be the common link behind some of these similarities. Additionally, dolomite and gravel hill prairies are also comprised of larger percentages of silt and clay. These smaller particles are thought to be better able to hold on to ions in the soil because of their greater surface to volume ratio, and the creation of more tiny pores in soil, which also leave room to better hold on to water. These factors combined would allow for more nutrients to be held in the soils compared to the incredibly sandy soils in the sand prairies.

Another major factor influencing this trend would be the plant community. Plants have long term impacts on the soil in multiple ways. By drawing up nutrients into their tissues plants can selectively alter the amounts of nutrients in the soil by drawing more of certain nutrients into their roots then others. Like all organisms, plants have specific nutrient requirements for growth and maintenance of their tissues. Phosphorous and nitrogen are the two major nutrients that plants must find in the soil. Phosphorous was not significantly different between prairie types, so it is likely not influenced as
strongly by the varied plant community. Dolomite and gravel prairies however had significantly more nitrogen available in their soils, which could mean two things. The first is that there is a higher number of nitrogen fixing plants growing in these environments. These types of plants have bacterial root associations that allow them to use nitrogen from the atmosphere that is normally unavailable for use. Sand prairies then may have a small proportion of these plants, and in turn the soils stored nitrogen is more rapidly consumed by the plants. A possible alternative to this is related to fire regime. When fires burn through a prairie, nitrogen is liberated into the atmosphere while other nutrients like phosphorous are returned to the soil. The more often a prairie burns the less nitrogen there will be in the soils (Givnish and Leach, 1996; Reich, Hungate, and Luo, 2006). This lack of nitrogen in the soil also increases the competitive advantage of nitrogen fixing plants since their investment in the process is returned by their ability to grow in more fire disturbed areas where competition with other plant species will be lower. This in turn would also help to describe some of the differences in the plant community between dolomite and gravel prairies when compared to sand prairies, since sand prairies are much poorer in nitrogen, N-fixing plants would likely be more competitive and thus more abundant as compared with the other prairies.

The differences in the infiltration rate were also measured for all three prairie types. In comparing the differences dolomite prairies had the fastest infiltration, sand had a wider range of infiltration rates but on average was in between dolomite and gravel hills, which had the slowest infiltration. This outcome was not exactly as expected from the initial hypothesis. Sand prairies were expected to drain the most quickly because of the larger size soil particles, such as can be seen with water draining into sand on the beach. The sand is not able to hold water as effectively as soils rich in clay and silt and thus drains away. In field observations it was noted though that the size of the sand grains varied from one prairie to the next. Some locations had much coarser sand, which proved to drain quickly, while others had very soft, fine grained sand that drained more slowly. There were also locations that fell between these two extremes, both in sand particle size and infiltration rate. The location of sites also varied, with some sand prairies located in the middle of forests creating a clearing, and other locations being found in residential areas, or next to agricultural fields. These prairies had a higher input of organic material from tree leaves and other organic debris, and are subject to much less frequent fires since the prairie is preserved with the forest. These sites were also much less subject to compaction, which is a process where pressure collapses the structure of the soil, removing air spaces and small pores in the soil creating a hard, rocklike soil instead. This is likely due to their isolation from human impact. Most of the gravel hills were very close to human influences, often occurring next to
farmers fields, or in one case as an undeveloped portion of a neighborhood. This proximity to human impact, and the origin of the hills coming from glacial deposits may be the cause of higher soil compaction and the slower infiltration rate in gravel hill prairies. Farmers and developers both use heavy machinery, and these tools leave behind marks on the soil. Over time, even brief periods when heavy machinery is involved, soils can become extremely hard and compressed, and it takes a long time for plants to reestablish and break through this kind of soil. There is also the glacial history, where these hills may have had a mile of ice pressing down on top of them at some point in the past, causing extreme compaction, interlocking the gravel that makes up a large portion of the hills, and then the little bit of space left was slowly filled in with other glacial outwash and windblown sand, silt and clay.

Dolomite prairies on the other hand have very thin soils, richer in organic matter, and low in sand. This allows the dolomite soils to act more like a sponge, with water being soaked in and held in the soil that is there, and when it hits the bedrock just underneath, the water moves laterally outward. Despite these differences, the pattern of infiltration does not reflect the other trends seen in the plant community, and it may then not be very influential to the composition of the prairies. This is not to say that water is not vital, but water does still penetrate into the soil. The plants living in these communities are already adapted to dry conditions, and so even if the water takes longer to reach them, they are highly specialized to make the best use of the water that is there.

Dolomite prairies were the most diverse in soil texture, showing more equal amounts of sand silt and clay. Gravel hills and sand prairies were not the same in soil texture, but were not as different as originally thought, especially when considering the types of prairies are distinguished by this main feature. Infiltration rates did support the original hypothesis, since all three types of prairies displayed differing levels of infiltration, even though the way this occurred was different than expected. Soil nutrients were highly variable between the three prairie types as well, but the variability was also not as hypothesized. Dolomite and gravel hills often varied together and were more nutrient rich then sand prairies, which was expected. The main difference from the original hypothesis is that gravel hills had the highest average nutrient availability much of the time. This was not the case with all nutrients though. Several nutrients, like phosphorous, did not vary significantly between the prairies. A few, such as potassium exhibited a reverse trend, in which sand prairies were the most rich in that nutrient. This does show the high variability of the different prairies, but also shows there is some kind of pattern to the nutrients within the soil that deserves further investigation. It is also true that the plant community was able to be used to distinguish the different site types, but again not as was expected. Initially is was thought that each prairie type would have a unique set of plants, or different dominant plants that
would distinguish one prairie type from the other. This proved true in the case of the sand prairies, which showed a unique set of plants with high importance values, that allowed them to be distinguished from the others. Dolomite and gravel hills had a different outcome. These two prairies shared dominant species, and showed a very similar overall plant species composition. This was similar enough that based on the plants alone the two types of sites would likely not be distinguishable from one another.

These results are unique in that, based on the results of nutrients and plant species composition, it appears that there is a correlation between the presence of certain nutrients and composition of the plant community. In his studies on the different plant communities of Wisconsin Curtis found that water availability was the most influential factor in determining the plant community of an area, and using his data, based an entire classification system on it to determine the environmental conditions based on the plant community (Curtis and Greene, 1949). In his consideration he looked at nutrients in the soil as well, but determined that this was not a significant factor compared with water availability. This study suggests otherwise. Curtis had a valid point in saying that water was the most important factor in describing species composition across environmental gradients, but when looking into a specific part of that gradient, such as in dry prairies, all the prairies are dry, and so the difference in available water between them is negligible. Since there are still differences observed between these environments there must be some other factors influencing these differences. As was seen in this study, specific biologically important nutrients such as nitrogen, calcium, magnesium, and manganese all vary together with prairie type. The prairies in turn have different species composition, and so it follows that the soil, if the not water, is affecting that difference.

This differential response to soil nutrients has been observed by others scientists in specific species. Schultz et al. found that *Andropogon gerardii* responded to soil nutrients differently from Illinois to Kansas. In their particular experiment, they noted that *A. gerardii* would form mycorrhizal root associations in the poorer soils found in Kansas, whereas in Illinois' rich soil the trade off of sugars for added nutrients was not as beneficial (Schultz et al., 2001). This shows that there are local adaptations to the environment by plants, but it also shows that some plants have mechanisms to remain productive in a wider array of conditions (Chapin Iii, 1980). These generalist species, such as *A. gerardii*, were found in almost every plot that was sampled over the course of this study, and so do not show a strong affinity for a single prairie type. Other species, which are more restricted in their ability to form such fugal associations, or which have very specific nutrient requirement may be more limited, and would respond to the local conditions found in a prairie more strongly. This seems to be the case for most of the species.
seen in this study that associated more strongly with a single prairie type, but closer investigation of this local adaptation would be an interesting avenue for further research.

In a study conducted on the Palouse Prairies of Washington state and Idaho, there was a strong association between the biophysical aspects of a prairie and the structure of the plant community growing there (Hanson et al., 2008). In these western prairies, which are also critically endangered, slope and aspect were found to be the strongest factor in predicting the diversity of a site and the structure of its plant community. On these sites, which are mostly found on more rugged terrain and in much hillier country than Illinois, this effect of slope and aspect is probably more exaggerated, especially since most of the remaining remnants there are found on steep north facing slopes, isolated from, or inaccessible to farming, and are less desirable for grazing. Illinois' prairies, by contrast, are mostly flat in the northeastern portion of the state. In these locations the effects of aspect and slope would be negligible. However, in the gravel hill prairies this effect of slope would likely have some effect on the community, but altered to match the local climate conditions and underlying soils. This trend of slope and aspect effecting prairie diversity was also observed in the southwestern hill prairies of Illinois that form along the banks of the Mississippi River (Evers, 1955; Leach, 1990; Dufrene and Legendre, 1997). In these prairies, as in the Palouse, there is a strong correlation between the aspect of a hill, the steepness of the slope, and the diversity of species that were found growing there. This shows that the effect does present itself in the conditions found in Illinois, and an examination of the effect of aspect and slope on gravel hills in northeastern Illinois would indicate whether this effect is seen in these prairies as well, and could show a possible distinction between north and south facing slopes.

An additional question that has been examined by others is the effects of other soil biota, combined with nutrients on the plant community. Deyn et al. found that there is a strong correlation between plant community development and the availability of soil nutrients. They found that soil biota including bacteria, root feeding nematodes and other omnivorous arthropods reduced the effects of plant dominance in soils with high nutrient availability (Deyn, Raaijmakers, and Putten, 2004). In this examination they were able to determine that in higher nutrient conditions grasses would often become dominant, lowering diversity. When soil biota were abundant, higher diversity was maintained, with lowered grass dominance and increases in forbs. This may have implications for this study. It was observed that gravel and dolomite prairies tended to be richer in nutrients, and have similar plant communities with similar abundant species. Sand prairies were poorer in most of the nutrients, and showed a very different plant community by comparison. This difference, while effected by the nutrient
availability of the soil, may also be effected by differing soil biota which could be a factor in influencing this different assemblage of plants.

Interesting to note is that there have been many recorded changes in the species composition of prairies over time. In the pre-settlement Midwest, hundreds of thousands of square miles were covered with prairies. During that time there was much greater species diversity, as fragmentation had not yet caused local extinctions, and great loss in genetic diversity. In their recensuses of fifty four Wisconsin prairie, Leach and Givnish found that 8-60% of species were lost from individual prairies over a 32-52 year period. They also found that small plants, nitrogen fixers, and those with small seeds that need bare ground to germinate were the most subject to local extinction (Givnish and Leach, 1996). This is of note in this study because these findings may indicate that the prairies are being homogenized by human influences. The main factors that Givnish and Leach found to be effecting the species loss that found were lack of fire regime, limited seed dispersal due to loss of pollinators and seed carrying animals and insects. They also found that fragmentation of prairies increased edge effect and caused the prairies to be susceptible to invasion by exotic and invasive species. Similar results were also seen by Kraszewski and Waller, who also reexamined the dry prairie remnants in south-central Wisconsin (Kraszewski and Waller, 2008). In this study however, they found not only a loss of the original species, but an overall gain in species and diversity due to invasion by weeds, invasive species, and tall woody shrubs that crowded and shaded out many of the original species. It was found in this study that gravel hills and dolomite prairies do not significantly differ from one another in their plant community, but that does not mean they have always been that way. It is possible that over time these areas have been effected by human factors that have lowered diversity and since they share similar properties, both now contain similar plant species that are able to survive under this altered condition.

As with all things, there were setbacks with this study, and there are several area that have room for improvement. The summer of 2012, was exceptionally dry, with many states facing drought conditions across the Midwest. This effect of climate was seen in dramatic terms in most of the sites studied for this experiment. The effects of the drought were further exaggerated by the prairies already being dry, and so even well adapted plant species faced a challenging growing season. Many of the locations showed effects of this drought, with species flowering outside of their usual schedule, as well as many plants not flowering at all. There was also a high level of plant mortality observed, as many plants could not deal with the hot dry conditions. In grasses, many went into dormancy, waiting for more favorable conditions to return. These conditions highlighted the variability of climate and showed
that sampling of the plant community is subject to these climatic shifts. In order to mitigate this effect, sampling over multiple summers, and compiling the data would have provided a more accurate representation of the plant community. Additionally, having a sampling in the spring, summer, and fall would allow for the full range of plants to be observed, and allow for the most plants to be seen and identified during their often brief flowering periods, allowing the most accurate identification possible. Not having this extra data does not invalidate the results of this study, but the results could be further supported by this additional information.

Another area that happened to be of some significant impact is that of the Illinois Beach sand prairie on the ordination, and consequently on the analysis of the soil nutrients and soil texture. Illinois beach clustered with the other sand prairies in the initial ordination, but in the ordination based on the K means operation, Illinois beach was actually indicated to be part of the cluster with dolomite and gravel hills. This was a problem for conducting the analysis on the soils then, because Illinois Beach had to be classified with one of the three prairie types. In terms of the plant community, it appeared to be a sand or gravel site, but all of the nutrient and the soil texture was like that of the sand prairies. The ANOVAs used to compare the data were performed three different times, with Illinois beach grouped as a sand, gravel, and dolomite prairie. When Illinois beach was anything but sand, almost all of the ANOVA p-values dropped below the level of being significant. When it was grouped as a sand prairie though, the significance was again apparent. Because the Illinois Beach soil data most closely reflected that of the other sand prairies, especially in that the soil is over 95% sand since it is a successional dune environment, it was grouped with the sand prairies for statistical analysis. A possible explanation for the difference in the plant community is the high level of human management in the area. The Illinois DNR regularly burns the dry prairie at Illinois Beach in order to manage invasive weeds, the black oak population, and to keep the natural prairie in good condition. On top of this, Illinois Beach was the only habitat sampled that was near to Lake Michigan. This is a significant difference from the other inland prairies, which are not affected by lake effect snow and rain, nor do they have the influence of the almost constant wind off of the lake. These differences from other sand prairies may then be responsible in whole or in part for the observed difference in the plant community.

While Illinois Beach did show that there are some more dynamic influences on the plant community, there is still a clear link between the plant community seen in an area, and the combined effects of soil nutrients and texture. The texture influences the soils ability to hold nutrients, and the varying effects of the of the nutrients alter what plants grow in a prairie, and which are most abundant.
This has implications for management of these prairies, in that gravel and dolomite appear to be very similar to one another. This link is seen both in the availability of nutrients, and in the plant community, which suggests the two are connected. These prairies could then be managed together in order to preserve these locations, and the plant life that is seen in them. Managers currently have to do site by site management, based on the type of prairie. By grouping these two prairie types together for management purposes the agencies responsible for these prairies would be able to save on time, manpower, and paperwork, allowing more attention to be given to each prairies individual needs, such as weed and invasive species control, prescribed burns, and mowing. All of these activities help to promote prairie health, and maintain the character of the prairies. By eliminating an entire separate category of prairies that needs a separate evaluation and management plan the process could be streamlined, and similar practices could be used for the maintenance of both prairie varieties.

Another implication of this work is the identification of the outlier prairies. These prairies, which county botanists and other managers are responsible for, seem to be degraded from their original character. All seventeen of the sites sampled were previously recognized as dry prairies, and efforts should have been aimed at maintaining the integrity of these now rare environments. At least four location seem to have been altered by some processes, whether natural or manmade, that have pushed them to have plant communities that are no longer characteristic of dry sand or gravel hill prairies. These alterations could be due to natural variation, misidentification of the locations by people in the past, or ineffective management and protection efforts. Prairie remnants are extremely rare, and any that are still in existence are worth preserving. If they become so degraded from their original state that they no longer harbor the diversity and species that prairies are known for, it be a great loss for an already dwindling natural resource. To help prevent further degradation, these sites should be evaluated, and compared to historical records to determine if they have been altered. If they have, then plans can be made to help restore them, or to prevent further loss or degradation in the future.

The question remains as to the definite causes of the variation in the plant community between sites of the same type, and between the different prairie types. It seems that nutrients and other soil factors are able to influence the plant community significantly, but it remains to be seen exactly how much these factors can vary until a different enough environment is formed that the plant community will shift in response. This is one avenue of further research that should be pursued to clarify the gradient of nutrients as it exists in a prairie environment, and allow for better understanding of how the plant community will shift with soil nutrients. This would be ideal to do in a field setting, but replicating
prairies in controlled conditions, and submitting them to alternate nutrient regimes would also be an informative avenue of research. This sort of research may then allow for prairies to be more effectively monitored and maintained by keeping nutrients available at levels which create the ideal growing conditions for native plants, and could possibly be used to control the invasion and spread of invasive species by keeping natives abundant and healthy, and adjusting nutrients so invasive species are unable to become established.

Another extension of this work that should be done is to resample all the prairies involved over a larger sample area, at multiple times during the year, and even over a few years. This additional data would allow for a much more rigorous examination of the prairies plant life and would make the likelihood of missing species that are actually present much less probable. This would also allow for rare plant species, and those that are early blooming, or late blooming to also be accounted for in sampling. Having this more comprehensive list of species would also increase the detail at which the prairies themselves could then be compared. Many of the prairies had overlap in generalist species, but varied in the abundance of these. If smaller and more rare plants can be found, then the different prairies would be more definitely associated by having more overlapping rare species, or they could prove to be differentiated from one another by this more detailed examination. In either scenario, this again would have management implications. If the dolomite and gravel hill prairies prove to harbor many of the same rare species, these and other dolomite and gravel hill prairies could be managed together and targeted as areas that need further preservation efforts. They could also provide sources to promote genetic diversity between sites by seed collection and pollen transfer between site, or preservation of these seeds in seed banks for future restoration efforts. If these sites turned out to be different in rare and other plant species, this would indicate another strategy is needed. Identifying the species that are found in each would allow for a comprehensive list to be created, and each could then be managed and protected based on the rarity of the species found. It may also be the case that some sites, while similar in generalists, and more common species, are not ideal habitat for rarer, and possibly more sensitive plants. If this is the case, these locations could be managed to try and promote greater diversity, or those that are harboring these species could be more intensely focused on to preserve them. By repeating this study with these additional elements the outcome of this study can be confirmed, or adjusted to best possible understanding of the relationship that exist between dry prairie plant communities and the soils in which they grow. This clearer understanding would then not only provide better insights into possible management strategies, but also a deeper understanding of one of the most critically endangered ecosystems in the world, which then may be better preserved for the future.
References


