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Comparison of Physical and Chemical Soil Properties in Restored Coniferous and Prairie Ecosystems

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Comparison of Physical and Chemical Soil Properties in Restored Coniferous and Prairie Ecosystems

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Abstract: Soils provide many important services for ecosystems and humans, primarily through vegetative feedbacks. Many factors can alter soil properties which in turn alter the quality of services that soil provide for their ecosystem. This study compared a variety of physical and chemical properties between restored coniferous and prairie ecosystems. In addition, a comparison was made between plots of the same ecosystem type at different lengths of restoration. Soil properties tested included pH, percent organic matter, and nutrient concentrations, among other tests. Percent organic matter and nitrate and phosphate concentrations were found to be similar among the prairie and coniferous sites. In comparison, the percent moisture, pH, litter depth and ammonium concentration were different between the ecosystems. The only soil properties that varied based on length of restoration were the soil pH in the prairie plots and the percent organic matter in the coniferous plots. The qualitative trends from the physical and chemical properties varied in what would be expected from similar sites. Primarily, nitrogen and phosphorus levels were lower than optimal levels. The prairie ecosystem was found to have much higher concentrations of ammonium and phosphorus, suggesting better nutrient levels for plant growth. In addition, a higher percent moisture and pH in the prairie plot's soil suggest a more supportive ecosystem for a broader range of vegetative growth.

Introduction:

Soil properties can vary drastically due to a variety of interactions with organisms, climate, parent material and topography. These many interactions can greatly affect many soil characteristics. These characteristics are broken into physical, chemical and biological traits. Among the most important of these properties is nitrogen availability, the most common limiting factor in plant growth (Xu et al. 2012). Other factors, like pH and the amount of moisture and organic material in the soil also greatly affect soil's productive capacity. This productive capacity is manifested in the many ecosystem services that soils provide. Soils can indirectly provide every type of ecosystem service, including provisioning, regulatory, cultural and supporting services. It is necessary to measure and study soil properties because these ecosystem services can vary in quality based on soil types (Palm et al. 2007).

Vegetative feedbacks from soil are among the most important ecosystem services that that soil provides. This field of study has gained enormous attention in the past few decades. According to (Ehrenfeld et al. 2005), no papers linking the words "plant" and "soil" were found in the Biosis database until the year 1985. Since then, there has been an influx of papers on this topic, appearing at a rate of roughly 3500 each year. This research has delved into the many indirect effects of plant growth due to soil quality. For instance, numerous studies have found that soil is a prominent component of the ecological response to global environmental changes (Ehrenfeld et al. 2005). A study in 1997 used a general circulation and equilibrium model to quantify the effects of both physiological and structural vegetation feedbacks on a doubled CO2 climate (Betts et al. 1997). The study found that vegetation feedbacks from soil provided significant regional-scale climate effects.

It is clear that soil characteristics can differ and that these differences can have great effects on their ecosystem and also humans. It is thus important to quantify how soil properties can change in different parts of the world, specifically in different ecosystems. Therefore, this study's goal was to quantify the possible differences in soil quality between a coniferous and prairie ecosystem. The study's location in southeastern Minnesota included multiple coniferous and prairie plots that were all restored from agriculture. The site chosen provided a great opportunity to compare two different ecosystems for a number of reasons. First, the sites were very close in proximity and would therefore have the same climatic influences. Second, both ecosystems were restored from the same farming landscape which allowed a baseline to compare differences in the soil properties that may have developed. Theoretically, the sites would all have contained the same soil properties, so I was interested in investigating the extent to which changes may have occurred between the two ecosystem types.

Many soil properties can be tested to measure soil quality. One of the main soil properties tested for was soil pH. PH can change drastically in certain ecosystems, especially when there are prominent vegetative and human interactions with the soil. According to the Natural Resource Conservation Service the most important effect of pH in soil is on ion solubility, which in turn affects microbial and plant growth. My study also included analyzing the depth of the litter layer at each site to compare its possible effects on soil properties. A study performed in a deciduous forest ecosystem measured the effects of detritus alterations on soil carbon concentrations and soil respirations. It was found that altered litter quantities greatly impacted soil microclimate with removal of litter causing a decline in soil carbon stocks (Fekete et al. 2014). Percent organic matter content in the soil was also tested. This property affects the soil's capacity to retain and release nutrients for plant growth. Organic matter in soil also store and release water and affect the exchange of gasses with the atmosphere (Palm et al. 2007). Finally I tested for the concentrations of nitrates, ammonium and phosphates. Phosphorus and nitrogen are vital for plant growth. It was necessary to measure ammonium and nitrate concentrations because plants can use nitrogen from either source. It was these primary factors and other characteristics that I compared between the two different ecosystems and the two time lengths of restoration.

Goals for this study were centered on investigating:

(1) The possible variation in coniferous and prairie soil properties

(2) The magnitude of change in soil properties due to length of restoration in prairie and coniferous ecosystems from a similar soil baseline

Methods:

The location of this study took place in the St. Olaf Natural Lands which are adjacent to the St. Olaf College campus in southeastern Minnesota. Four plots from the natural lands were included in the study, consisting of two coniferous and two prairie plots. The two coniferous and two prairie plots were broken into plots that different in length of restoration. This included prairie plots restored in 1993 (P93) and 1998 (P98) as well as coniferous plots restored in 1993 (C93) and 1999 (C99).

Data Collection

Soil data was collected at three random locations in each of the four plots resulting in 12 soil samples. Seven soil properties were tested for with each of the 12 samples. The first variable tested was (1) litter depth which was recorded at each location. Soil was then collected using a soil core sampler and the samples were brought back to the lab to test for physical and chemical properties. (2) Soil pH was calculated using standard procedures with a pH machine. (3) Percent moisture was calculated by drying a determined mass of soil in an oven at 105° C for 24 hours and calculating the difference in weight and dry mass. (4) Percent organic matter used the same soil that was dried in the 105° C oven, which was then dried in a 500° C muffler oven for 4 hours. The actual percent organic matter was calculated using this equation:

Percent organic matter = (weight after 105° C – weight after 500° C) / weight after 105° C

Soil extractions were performed in the lab in order to calculate the concentrations of ammonium, nitrates and phosphates (5-7). First, a 2M KCl extractant was made for nitrate and ammonium extractions using standard procedures. An approximate weight of soil was weighed out (about 5g) and mixed and shaken with 25mL of KCl for 45 minutes. After being shaken, the soil solutions were filtered using Whatman 42 filter paper. The same procedures were done for extracting phosphates; however a solution of Mehlich 3 extract was used in replace of KCl. Chemical analysis of nitrates and phosphates was done using a SmartChem 200 (Discrete Analyzer). Chemical analysis of ammonium was performed using a spectrophotometry process with the development of a standard curve for accuracy.

Statistical Analysis

Statistical analysis was done in the form of one-way ANOVA tests using R Commander (R Core Team 2014). ANOVA tests were performed in order to compare the average values for each soil property and to see if the averages were statistically similar. Two ANOVA tests were done for each soil property in order to test for possible variance due to length of restoration. This included a test comparing the average values between C93 and C99 and also P93 and P98. A third ANOVA test was done for each soil property to compare the two ecosystem types. This test compared the two prairie plots averaged together with the two coniferous plots averaged together.

Results:

Comparing ecosystem type

The prairie plots were found to have much larger concentrations of ammonium and phosphorus from phosphates than the coniferous plots. Ammonium levels in the prairie plots were on average 250% higher than the coniferous plots (Table 1). Both prairie and coniferous had large concentrations of phosphorus, prairie concentrations averaged 17.132 mg/kg of soil and coniferous averaged 14.18 mg/kg. In comparison, ammonium and N from Nitrates which all had concentrations of less than .25mg/kg. The coniferous soil pH of 4.14 was much lower than the prairie's pH of 6.33. The percent organic matter was roughly the same in both ecosystem types while percent moisture was on average 250% higher in the prairie. Litter depth also varied considerably, with coniferous litter depths 9cm deeper on average.

ANOVA tests revealed that the average percent organic matter and phosphate and nitrate concentrations were statistically similar between the prairie and coniferous plots. All of these tests produced p-values well over 0.05. The largest p-value was for 0.924 from comparing nitrates, suggesting the greatest similarity between the two ecosystems (Table 2). In comparison, percent moisture, pH, litter depth and ammonium concentrations were found to be statistically different. All of the p-values were well below 0.05, with the highest value being 1.50×10^{-6} which percent moisture and ammonium concentration both got. Statistically, all of these soil properties were very different when comparing the two ecosystem types. It should also be noted that the standard deviation from averaging the phosphates was unusually high (Table 3), suggesting extreme variance in the data.

Comparing length of restoration

Only soil moisture differed by length of restoration for both ecosystem types. Percent moisture had p-values less than 0.05 for both prairie and coniferous sites; however the coniferous site was not very different with a p-value of 0.045. In comparison, litter depth and nitrate and phosphate concentrations were similar based on restoration length for both ecosystems. Ammonium concentration was close to being similar in both ecosystems with a p-value of 0.045 when comparing coniferous sites. Overall the most similar averages overtime were between litter depths, with both p-values above 0.6. The greatest difference was in pH in the prairie plots with a p-value of 4.7×10^{-4}.

Discussion:

When studying soil properties, the most important conclusions come from comparing the results found to what would normally be expected for optimum levels. For example, a study on a 55 year old coniferous stand found that soil pH was 4.3 on average (Binkley and Sollins 1993). This is very similar to my findings of a coniferous pH of 4.14. Similarly, a study on prairies found soil pHs as low as 5.42 in a native prairie and pHs as high as 6.38 in a restored prairie (Bliss 1964). Once again, my finding of a pH of 6.38 in the prairie soil is well in the normal range. A study in 2014 compared soil factors analyzed for moisture, pH and nutrients under stands of oak and pine species (Pitman et al. 2014). The study revealed that soil pH rose with tree age in pine stands and N levels in the soil rose with tree age for both tree species. Nitrogen levels increased with time in my findings, however pH was found to decrease with stand age. Optimum percent organic matter is usually found above 2.0%. All of the sites tested were well above this threshold. In regards to nutrient levels, all of the tested sites were lower than expected. The optimum concentration of phosphorus for most row crops and forages is between 36-50 mg/kg of soil

(Leo Espinoza). Phosphorus levels in this study were 50% lower than optimum concentrations. Similarly, nitrogen levels for medium fertility are usually between 10-20 mg/kg (Allan Fulton 2011), which is extremely high compared to the findings from this study. Overall, findings from this study varied in comparison to normal levels, with nutrient concentrations much lower than expected.

There are many factors that could have influenced the results that were found in this study. First, the extreme difference in soil pH in the coniferous plots was due to the decomposition of pine needles. Pine needles have a pH between 3.2 and 3.8 and greatly affect soil pH when they break down in the soil (Williams 2010). Conifers depend on low soil pH due to conifers' reduced ability to take in nutrients as pH rises. Phosphates were found to be similar among the sites tested which could be credited to the fact that the sites were very close in proximity. Phosphorus is derived from bedrock deep underground. Therefore, the plots would most likely have similar levels of phosphorus because they are closed located geographically and would thus have the same bedrock. A thinner litter layer among the prairie plots could have also promoted higher percent moisture and organic matter because material and moisture would more easily penetrate the litter layer. Percent organic matter and thus nitrate levels would also be higher in the prairie plots due to the frequent planned burnings that happen on the natural lands. Fire would break down plant material and accelerate decomposition which would this add more material into the soil. For this reason it would be expected that higher percent organic matter would have been found in the prairie plots. Surprisingly, equal levels of organic matter were found among the sites. This suggests that decomposition rates may be higher in the prairie plots which would lower percent organic matter in the soil at a given time. Finally, the prevalent issue of low nutrient and phosphorus levels may be attributed to the intensive farming that was done on the land pre-restoration. Intensive farming uses up many of the nutrients that are required for plant growth, so low nutrient levels may be a remnant impact of farming.

There are many implications from this study revolving around the differences in ecosystem type. One implication could be that lower nitrogen levels in the prairie would result in more legume biomass and lower grass biomass (Piper 1995). Soil pH can also affect the emissions of N_2O, a potent greenhouse gas. A decrease in soil pH translates to an increase in N2O emissions (Robinson et al. 2014) which suggests that the coniferous plots would be release more of a particular greenhouse gas. Soil pH is also the most important factor to investigate when investigating nutrient problems in conifer trees (Cregg 2005). A normal pH among the plots tested implies that the conifers are getting adequate access to nutrients. The most important implications from this study are a result of nitrogen and phosphorus concentrations. The prairie ecosystem was found to have much larger concentrations of ammonium and phosphorus, suggesting better nutrient levels for plant growth. In addition, higher percent moisture and pH in the prairie plots' soil suggest a more supportive ecosystem for a broader range of vegetative growth. In respect to optimum nutrient levels, both coniferous and prairie ecosystems were still lower than expected, most likely as a result of pre-restoration farming. In regards to length of restoration, there were a few notable differences in soil properties. This is an important finding due to the small difference in restoration lengths tested.

There is a lot of potential for further research to compliment the findings in this study. First, more soil properties could be tested. This could include soil density and water filtration and macro and microorganisms found in the soil. This would expand the basis for which soil properties and function change between ecosystems. It would also be important to do further tests on length of restoration with greater differences in time. Finally, it would be very interesting to investigate more remnant effects of farming and the speed and extent to which each ecosystem affects these variables.

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Table 1: Average values combined between prairie and coniferous plots

	Prairie	Coniferous
Litter Depth (cm)	4.3	13.883
% Moisture	24.678	9.989
% Organic Matter	6.672	6.428
pH	6.33	4.14
NH4 (mg/kg)	0.247	0.1
N - from Nitrates(mg/kg)	0.093	0.096
P - from Phosphates (mg/kg)	17.132	14.18

Table 2: P-values from ANOVA tests from comparing coniferous plots (C) by time, prairie plots (P) by time, and combined coniferous plots with combined prairie plots (C/P).

	C - time comparison	P - time comparison	C/P - ecosystem comparison
Litter Depth	0.649	0.665	**1.97E-09**
pH	0.463	**4.70E-04**	**1.12E-08**
% Moisture	**0.045**	**0.0305**	**1.50E-06**
% Organic Matter	**0.0289**	0.298	0.709
Nitrates	0.105	0.22	0.924
Phosphates	0.434	0.0923	0.676
Ammonium	**0.045**	0.152	**1.50E-06**

Table 3: Standard deviations by plot.

	P93	**P98**	**C93**	**C99**
Litter Depth (cm)	0.874	0.874	1.168	0.557
% Moisture	1.348	2.067	1.268	1.211
% Organic Matter	0.733	1.198	0.937	0.111
pH	0.064	0.062	0.14	0.025
NH4 (mg/kg)	0.028	0.091	0.013	0.001
N - from Nitrates(mg/kg)	0.028	0.075	0.073	0.014
P - from Phosphates (mg/kg)	0.139	16.041	10.14	3.546

Table 4: Average values by plot.

	P93	P98	C93	C99
Litter Depth (cm)	4.467	4.133	14.067	13.7
% Moisture	22.34	27.014	11.448	8.531
% Organic Matter	6.188	7.155	5.518	7.337
pH	6.603	6.06	4.107	4.173
NH4 (mg/kg)	0.257	0.354	0.114	0.085
N - from Nitrates(mg/kg)	0.059	0.126	0.142	0.051
P - from Phosphates (mg/kg)	6.93	27.335	11.49	16.871