Spring 5-13-2018

Comparison of Soil Development Rate in Reclaimed and Un-reclaimed Grassland Soil

Abdullah Allahyani
Pittsburg State University, aallahyani@gus.pittstate.edu

COMPARISON OF SOIL DEVELOPMENT RATE IN RECLAIMED AND UN-RECLAIMED GRASSLAND SOIL

A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the Degree of Master in Science

Abdullah Allahyani

Pittsburg State University

Pittsburg, Kansas

May 2018

COMPARISON OF SOIL DEVELOPMENT RATE IN RECLAIMED AND UN-RECLAIMED GRASSLAND SOIL

Abdullah Allahyani

APPROVED:

Thesis Advisor____
Dr. Dixie Smith, Department of Biology

Committee Member ____
Dr. Phillip Harries, Department of Biology

Committee Member ____
Dr. Kevin Elliott, Department of Technology and Workforce Learning

Acknowledgments

I would like to thank my advisor Dr. Dixie Lee Smith for their unmeasurable support during the research and compilation of this thesis. They were always available when I needed their support and guidance. They provided me with guidelines towards developing my own original work by steering me to the right direction through prompt replies to my questions and request for guidance. Their utmost support directed my efforts towards producing a professionally crafted thesis.

I would also like to acknowledge the members of the thesis committee. Specifically, I would like to thank Dr. Philip Harries and Dr. Kevin Elliot for their high level of professionalism and skepticism that raised the bar higher for me to address issues clearly and concisely. Their passionate participation pushed me to produce at my level best. They showed their commitment through reading the thesis and providing me with valuable comments that facilitated my final work.

I would also like to thank the Graduation and continuous studies at the Pittsburg state University for the opportunity to present my capability in taking this academic and professional leap. I would also like to thank the Saudi cultural mission whose work ensures that the country has a continuous flow of qualified and well-educated graduates. Through their support, I am part of that continuous flow of graduates.

Most importantly, I would like to thank my family members who have provided me with moral and physical support in my quest to complete this thesis. I would express my profound gratitude to them for their continuous encouragement throughout the process.

This accomplishment would not have become a reality without the help, guidance, and support of the aforementioned persons. Thank you.

COMPARISON OF SOIL DEVELOPMENT RATE IN RECLAIMED AND UN-RECLAIMED GRASSLAND SOIL

An Abstract of the Thesis by
Abdullah Allahyani

Soil formation is a process that entails the breakdown of rock particles otherwise known as weathering. It is a process that is determined by various factors such as time, climate, parent materials, topography, and biota. The exposure of the rock particles to these factors affects the process of soil formation in that more exposure accelerates soil development. To establish the rate of soil development, we based our research on reclaimed and un-reclaimed regions. According to the results, soil developed at a rate of 10-24cm per annual while on the un-reclaimed land it was 0.05-0.06cm per annual. The difference in the two areas is explained by the fact that in the reclaimed land it is hospitable for the growth of microbes that supports soil development microbes and invertebrates. This is because of the presence of organic matter that energizes microbes thus increasing the rate of decomposition. Again, reclaimed soil develops faster than un-reclaimed soil because of the presence of small, uniform particles, which offers a large surface area for chemical reactions. In other words, the reclaimed land is hospitable and prepared for maximum weathering. On the contrary, the un-reclaimed sites weathers slowly because it does not support the growth of plants and microorganisms. This is because the mining leftovers are acid and have not organisms that would provide energy for the growth of microbes. However, the parent materials for the reclaimed sites offers the unconsolidated material that could cause rocks and small particles to weather at a higher rate. In general, the biotic action is essential in soil development since organisms are responsible for the process and breakdown of the existing organic matter. The purpose of this paper is to examine the rate of soil development in reclaimed and un-reclaimed grassland soil.

Table of Contents

List of Figures

Chapter I

Introduction

Surface mining for coal is one of the mining methods that is highly visible. It leads to temporary removal of large rocks, soil and plants that leads to a permanent change of soil structure and topography. In extreme cases surface mining, can lead to loss of water in stream channels, diverting or increasing water flow. (Pond et al, 2014) Surface mining sites can create or open porous geological recharge area where infiltrating water percolates and may end up in a stream (Siskind, et al., 2007). When mine tailings are exposed to water and air, the percolating water can become acidic. In Southeast Kansas, extensive strip mining in the past century has resulted in nearly all these scenarios in places across the region, and the subsequent disturbance and /or destruction of the original soil. This proposal will look at the rate of soil development in places where the obvious destruction of surface soils was addressed by restoration.

One of the sites used in this project is an extreme example of damage resulting from strip mining. The Monahan mining site consists of 156 acres, bought by the late Francis A. Monahan and donated to PSU Biology Department in the year 1988. The major mining method used in the area was strip mining for coal, which had an adverse impact on the environment. The site was also shaft mined between the years 1910 and 1920. Following the mining, the site was a collection site for tipple. Tipple is the residue left after vehicles carrying coal were emptied, washed and screened. The tipple collection resulted in complete destruction of the topsoil and plant community. Therefore, in order to restore this area to something like its original community, it was first necessary to restore a functioning soil. In 1984, the site reclamation began, and soil has been developing there since 1987. The fact that the site was used to collect tipple makes it an especially damaged site.

Soil develops through a process called weathering which entails fracturing and breakdown of rocks into soil particles. This process varies in speed depending on the intensity of different factors. Soil is a mixture of mineral particles, decomposed organic substances, humus and other mineral elements subjected to water and air. For soil to be fully formed, these various particles will develop horizons with more consistent properties then seen in the early soil.

In this project, understanding soil horizons is very important because the soils horizons did not form naturally. There are O and A horizons, recently developed, and they contain most of the OM accumulated so far. Later, a B-horizon will develop from the A-horizon as clay-sized particles leach out with the movement of water and collect below the A. However, it takes a long time for a B-horizon to develop. At these sites, there is no B-horizon yet because it is new soil and there has not been enough time for leaching out of the A. In addition, natural C- horizons are the parent material (rock), but at the sites in this study, the parent material is mining leftovers and residues.

Five soil-forming factors

This project looks at the rate of development of the A horizon, or the soil layer that is at the surface of the soil. This is where weathering of the soil parent material begins and whether the soil was reclaimed or not, weathering occurred at the surface at all of the sites once it was no longer subjected to frequent disturbance. Soils around the world develop at rates that are governed by five basic factors that are described in most soil textbooks. In Weil and Brady 2017, the authors describe the factors acting on soil formation. They are parent material, time, climate, topography, and biota. All of these sites are in the same climate in SE Kansas, and transects were selected for similar topography, minimizing the issues associated with aspect. Therefore, in this project we considered the climate and topography factors to be the same at all the sites.

Three factors remain and only two are of major consideration in this project. In locating sampling sites, the assumption was made that the fauna (animal community) would be the largely the same at all the sites, but we cannot say the same for the plant community. All of our reclaimed sites were planted grasslands, while the un-reclaimed sites were all wooded areas.
That is because un-reclaimed sites were left by the mining companies and were later randomly colonized by a great many woody tree and shrub species that over time will shade out the grasses. The plant community is a very important factor in soil development for many reasons. The source and concentration of organic matter is primarily due to the plants and animals that live on and in the soils. Plants in particular, provide lots of vegetative inputs to soils.

All plants have positive effects on soil organic matter (SOM), but there is a difference between the effects of grasses and trees on soil formation. Grasses that senesce annually and add below ground organic matter that contribute to higher SOM concentrations than are typically found in woodland areas (Weil and Brady 2017, page 564). Soil organic matter concentrations could potentially affect soil development, however the A horizons that we found at our sites are so minimal that it will take many more years before they hold great quantities of SOM. Therefore, biota at our sites is not as uniform as climate and topography, and it is possible that differences in the plant community will contribute to differences in rates of soil development. However, there is no evidence that the plant community has had as great an influence as two of the other factors at work at our sites.

The two remaining factors are parent material and time, and their influence is intertwined to an extent that makes it difficult to be sure which characteristics are due to parent material and which are due to differences in development time. These are the most important variables at these sites are of great importance for this project. Parent material refers to the mineral and organic material from which the soil forms over time. The parent material of undisturbed natural soil is rock. Naturally developed soils will display some of the chemical and physical characteristics of its parent material. For example, mineral composition and texture of western Kansas soils tends to be high in calcium and sodium content due to the limestone parent materials from which they developed (Whitney and Lamond, 1993). The parent material at our previously mined sites was not rock, however. In the case of the un-reclaimed sites, the current A-horizons developed from a residue left over after mining that was a heterogeneous jumble of coal fines and shales. This material was often acidic due to the reaction of sulfur bearing shales with precipitation and oxygen (Johnson and Hallberg 2005). We were interested to learn how quickly, if at all, a new A-horizon was developing at these sites. In contrast, the parent material at our reclaimed sites had organic matter (straw) added, along with lime to neutralize acidity.

These materials were uniformly mixed into the site and grasses planted. Our hypothesis that soil would develop faster at the reclaimed sites is based on the idea that the parent material was amended with carbon (straw) to provide energy for biotic weathering.

Time is an important variable for this project because three of the sites are greater than 50 years old and the other three are less than 50 years old. We hypothesized that remediated soils would develop faster because 1) the remediated parent material would weather faster and be more amenable to biotic and chemical weathering processes. In contrast, un-reclaimed soils, though older, will provide parent material less hospitable to biota (low organic matter and acidic pH) and so will be slower to develop.

There are various techniques that can be used to ensure the land remains useful after the mining process has ended. These techniques include rebuilding soil structure, managing soil pH, increasing the fertility of the soil, re-establishing soil microbes specifically the bacteria and mycorrhiza, reestablishing the carbon and nitrogen cycles and the management of the top soil. Revegetation is another very important method and the plants used in the process should be able to survive the harsh soil conditions and stabilize the structure of the soil. Successful soil reclamations can be measured by considering multiple factors (for example, nutrient levels, microbial biomass, etc.), but this project is not tasked to measure reclamation success in those terms. (Bentham et al., 1992) instead we are looking at the development of A-horizon as a measure of how rapidly the soil regenerates. It is safe to say that land reclamation is a very important activity if human beings are to survive and thrive. To better understand the long-term effects that soil reclamation has on soil development rates, we will obtain:

(1) An approximate rate of soil development in reclaimed SE KS soils.

(2) Compare soil development rate, soil depths, and C: N ratios in reclamations of different ages.

Chapter II

Materials and Method

This project sampled six sites in SE Kansas. Three of these sites were reclaimed after strip mining and the other three have not been reclaimed at this time (Figure 1). Prior to the 1960's, mining companies were not required to reclaim mined land before they left the site; so many strip-mined areas were left damaged and sometimes dangerous (Bailey and Hooey, 2017). Since then, a number of sites (e.g. with acid mine drainage or pits that were too close to traveled roads) in our region have been reclaimed by the Surface Mining Division (Frontenac, Kansas). However, there are still many previously mined areas that have not been reclaimed because there is no impending danger associated with the sites.

Previously mined sites of known age were located in SE Kansas. Level collection transects were selected at each site. Equipment used to collect the samples included a LaMotte Soil Core Sampler (1016), device for measuring sample depth, and collection bags. Twenty soil core samples were randomly gathered by throwing a hoop along each transect. From within each hoop, five soil samples of the A-horizon only were collected. Identifying the A-horizon was not difficult because the underlying layers are a heterogeneous mixture of clays, shales and coal fines. The dark, more homogeneous A-horizon stands out in contrast, and also displays a texture difference because it is less clayey that the material below it. The depth of each A- horizon was recorded. The A-horizon cores were then combined in a zip-lock bag to form one composite sample. Each zip-lock bag composed one numbered sample, and twenty composite samples were obtained from each of the six sites.

Due to the cost of analysis, we prepared a subset of samples for carbon and nitrogen analysis (C: N ratios). In the laboratory, I used a 2 mm sieve to prepare five samples from each site. Sieving allows us to provide samples with a uniform texture for analysis. We sent three grams of air-dried soil from each of the sieved samples to the Soil Laboratory at Kansas State University. There, C: N analysis was performed by dry combustion on a LECO CN 2000 (NC Region Publication 221, 1998). Soil development rates were calculated by dividing the A-horizon depth by the age of the site. Soil depths and rates were analyzed using Sigma Plot 2017 for statistical procedures.

Chapter III

Results

The soil depth of the A-horizons at the reclaimed sites ranged from 3.2 cm at Site 3 (32 years), to between 1 and 2 cm at the two younger reclamations (Figure 2). Analysis of Variance (ANOVA) indicates that the two younger sites (8 years and 5 years old) do not have significantly different accumulations of A-horizon soil, with P = 0.558 (Sigma Plot 2017). However, Site 3, the Monahan reclamation at 32 years old, has an A-horizon depth that while not significantly different from Site 2 (P = 0.237), is different from Site 1 (P = 0.002). Descriptive statistics and details from the ANOVA are in Appendix I.

None of the A-horizon depths at the un-reclaimed sites were significantly different from each other (Appendix I). Both Site un-reclaimed RR and the Reserve Site were different from all of the younger and reclaimed sites. However, the un-reclaimed Pavilion Site was not different from reclaimed Site 3 (P = 0.269).

Figure 3 displays accumulation rates of A-horizon soil at three reclaimed sites at 5, 8, and 32 years since remediation. Also shown are rates of development at three associated sites with un-reclaimed soils (N = 20 samples, and error bars are standard deviation). The three sites that were reclaimed following strip-mining show horizon development rates that decline from about 0.25 cm each year at a reclamation of five years of age, to a rate of approximately 0.1 cm per year at over

32 years since reclamation occurred. Analysis of Variance (ANOVA) performed on the raw data (Sigma Plot 2017) indicated that the sites of five and eight years since reclamation were not significantly different from each other in rate of development, P = 0.991 (Appendix 2). The five-year-old reclamation also shows a development rate for the A-horizon that is significantly different from the 32-year-old site (P=.008).

The eight-year-old reclamation at Site 2 is statistically the same as the 32-year-old Site 32 with a P-value of 0.053, though very close to being different. While the two means appear not to overlap on the graph, the deviation around the mean is such that the two values cannot be determined by Sigma Plot to be different. With the P-value of 0.053, the limitations of the graphics are not representing the difference between 0.05 (different) and 0.053 (not different).

All three of the un-reclaimed soils display a rate of A-horizon development of about 0.05 cm per year over the 78 years since major disturbance occurred. None of these sites were significantly different from the others, and all were significantly different from the five and eight-year-old sites (P=0.001). However, Site 3, a reclaimed site, and Site 4 un-reclaimed, were determined to be not different (P = 0.227).

Figure 4 provides the mean C: N ratios of all six sites, n = five values from each site. The mean ratios at the reclaimed sites ranged from a low of 15.2 at Site 2 (8 years) to 22.5 at the other two. At the un-reclaimed sites, values ranged from a low of 15.7 at the Reserve, to 32.6 at the RR Site (all 78 years). The Pavilion site ratio was 24.7, and was the most variable of all the sites, with standard deviation of 6.0. One-way ANOVA performed on this data set was inconclusive, with five of the comparisons being significant and ten not significant.

Figure 5 is a presentation of the C: N data based on only two treatments: Reclaimed and un-reclaimed, n = 15. The consolidated C: N data provides a mean C: N ratio at the reclaimed sites of 16.713. The un-reclaimed mean ratio is 24.3. ANOVA run on these two treatments shows that they are significantly different, p = 0.005.

Chapter IV

Conclusions and Discussion

While soil scientists tend to think about soil development for the rate at which the entire profile develops in any one area, often the question is, “How long does it take for an inch/centimeter of soil to develop.” There is no simple answer, because the rate of development depends on all of the five factors discussed earlier in this paper. However, one of the studies consulted in this project cited a rate of formation of an A horizon in central Iowa at eight centimeters per century. While the climate and biota might be similar, none of the five factors (climate, parent material, biota, time, and topography) can be considered the same as the soils in this project. However, with that number in mind, our rates of development in the reclaimed sites of 0.1 - 0.24 cm of soil accumulated annually, or 10 – 24 cm accumulated in 100 years, would be faster than those Iowa soils (Simpson 1959 OR Buol et. al. 1997). This is not really surprising in view of the fact that the reclaimed soil is prepared for maximum weathering because it consists of small, uniform particles with a great deal of surface area for chemical reactions to take place, as well as having additions of organic matter that provide energy for microorganisms that facilitate decomposition processes.

In contrast, the un-reclaimed sites, at development rates of 0.05 – 0.06 cm annually, would only produce about 5-6 cm of A-horizon soil in 100 years. Our un-reclaimed sites, therefore, are accumulating soil slowly in comparison to what we might see elsewhere. The un- reclaimed parent materials provide an unconsolidated material initially and might seem more likely to weather to soil more rapidly than solid rock. However, these mining leftovers are often inhospitable to plants and microorganisms because of their acidic pH and lack of organics that would provide energy for growth. Biotic action is critical to soil formation because organisms process and breakdown existing OM, and add to SOM as plant and animal debris collect. Therefore, this could be one of the important reasons we see such low rates of A-horizon development at the un-reclaimed sites.

One of our concerns about soil depths at Site 1, the youngest site at 5 years since reclamation, had to do with a slightly greater slope than the other sites. Indeed, the depth of soil at that site was only 1.2 cm, which could be due to greater erosion or just because the site is our youngest. Overall, however, this site was not significantly different in A-horizon depth from Site 2 (8 years old), so concern about slope was not important to our findings.

The fact that organic matter (OM) is usually introduced to a reclaimed area may be one of the most important steps in the reclamation protocols. Naturally- occurring OM is composed of complex molecules (Weil and Brady, 2016, page 528) that are so highly variable that they can be hard to categorize. Complex OM provides rapidly available energy (labile components), and several types of more slowly available components that can take years to decompose. The slowly decomposing OM traps and binds up chemicals, as well as aids in water and nutrient retention. Straw is a common type of OM added into reclaimed soils. The added straw is composed of about the same proportions of complex and simple carbohydrates across the landscape, and therefore does not provide as much heterogeneity of OM as would occur naturally. Moreover, it has a much higher percentage of labile, short-lived carbohydrates than, than for example, woody debris would provide (Weil and Brady, 2016, page 531). However, it does provide a uniform distribution of OM, and subsequently energy, across the landscape.

Soil microbes and invertebrates of all kinds graze on the OM in the belowground environment. The carbon in OM provides them with energy, and the nitrogen contained in the OM provides them with the building blocks for their cellular components. While other elements are certainly important to microbial growth, without nitrogen for proteins, they cannot grow. Soil microbes require a ratio of about 8:1 to build their cellular components, but 24:1 to provide enough energy for both building and loss of CO_2 during respiration. The change in C: N ratios at our sites suggests some ways that the soil environment is developing in our previously mined areas.

The energy in the OM provided in a reclamation creates an initial environment that is much more hospitable to soil microbes and invertebrates than is found in un-reclaimed sites. However, our data indicated that the C: N ratios at the reclamations are declining over time, from a ratio of 22.5 at the 5-year site, to 15.2 and 12.4 at the 8 years and 32 year sites, respectively. This could be a result of the loss of the labile parts of the straw decomposing rapidly at the beginning of the reclamation, and slowing as the site ages. These sites, with faster than expected accumulation of A-horizon depth, seem to display a declining environment for microbial growth.

In contrast, we saw C: N ratios at the un-reclaimed sites of at least 78 years that are close to the 24:1 ratio needed by soil microbes. However, their A-horizon depths show much slower accumulation than at the reclaimed sites. When the mining stopped, any OM in the soil would have been depleted as the soil materials were churned and exposed to air and precipitation. At that early time, there would have been little if any biotic action occurring in the soil-materials. Our results suggest that there may be point in the development of these un-reclaimed materials where physical weathering is surpassed, or at least equaled by the biotic action of soil micro- biota.

While it might be true that the combined differences in parent material and time (factors of soil development) can explain why the older, un-reclaimed soils have significantly higher C: N ratios, there could be another factor at work. As mentioned earlier, grasses and trees have different SOM accumulation rates. With other factors equal, grasslands accumulate more SOM over time, and the quality of the organic matter has an overall lower C: N ratio (Weil and Brady 2016, Chapter 12). In contrast, woody debris consistently contains a large proportion of carbon. Organic matter that contains a great deal of woody debris could be expected to produce high C: N ratios in the SOM. While we did not at first think that vegetation (biota) would have as great an influence as parent material and time at our sites, it actually could be an important factor to consider.

To find out if this is happening would require periodic observation of the C: N ratios, perhaps every ten years. Additional tests that would be of interest would include microbial biomass comparisons over time. At this time, this project suggests that the reclamations may be lacking in sufficient OM, and consequently, sufficient energy immediately following the initial project. Furthermore, after at least 78 years, the un-reclaimed areas, with severely inhibited soil accumulation rates, appear to have energy and nitrogen levels sufficient to allow for belowground biotic activity.

Ideally, an investigation of this topic would include sites that are newly abandoned following strip mining. If such sites were available, it would be possible to watch the progression of A-horizon development at un-reclaimed sites from the beginning. Fortunately, mining companies are no longer allowed to abandon mined sites without initial reclamation. While not ideal for our study, it is better for the environment that such sites are no longer being created in SE Kansas

Figure 1: Sites Map

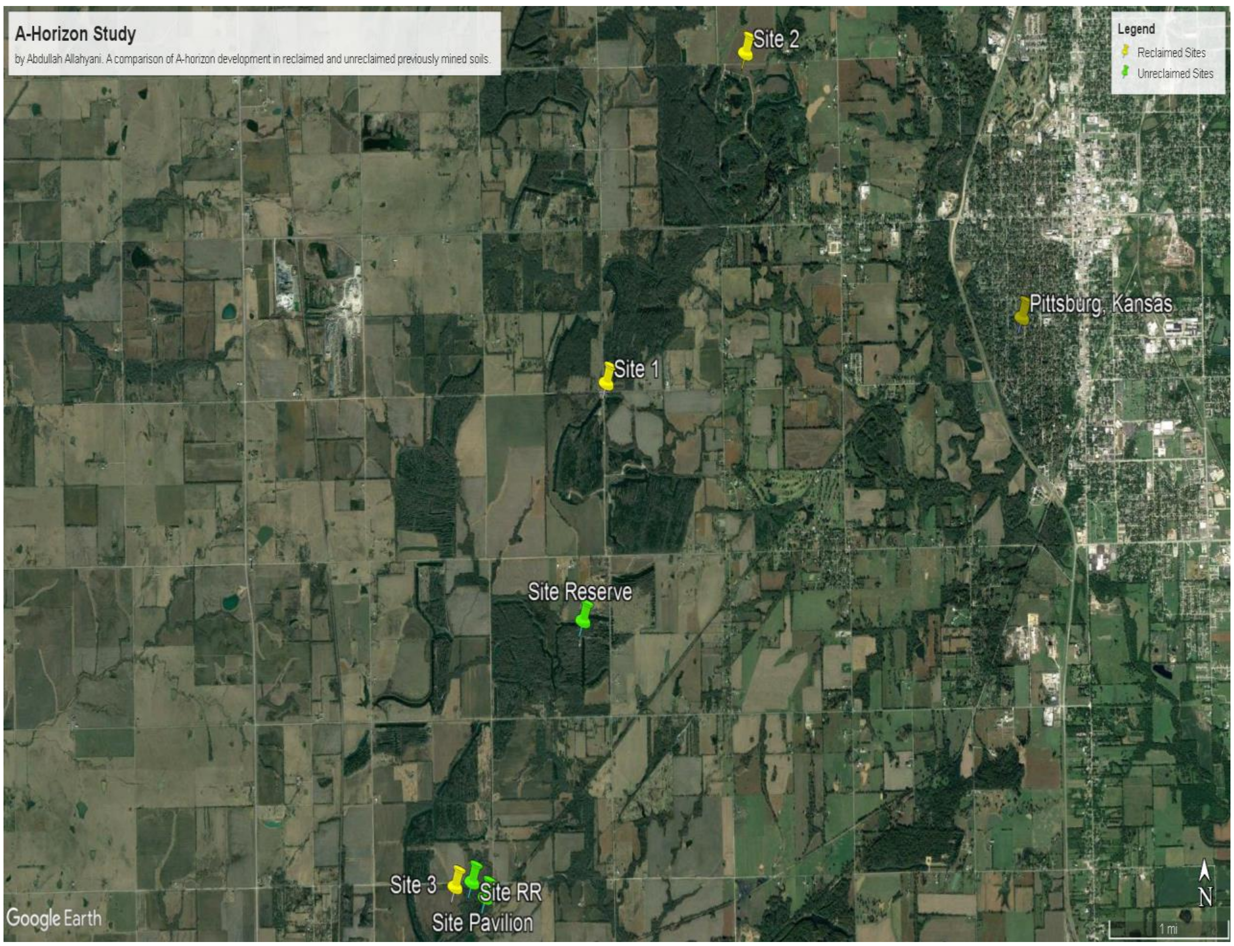


Figure 2: Depth of Soil A-Horizons at Reclaimed at Reclaimed and Un- reclaimed Sites (n = 20)

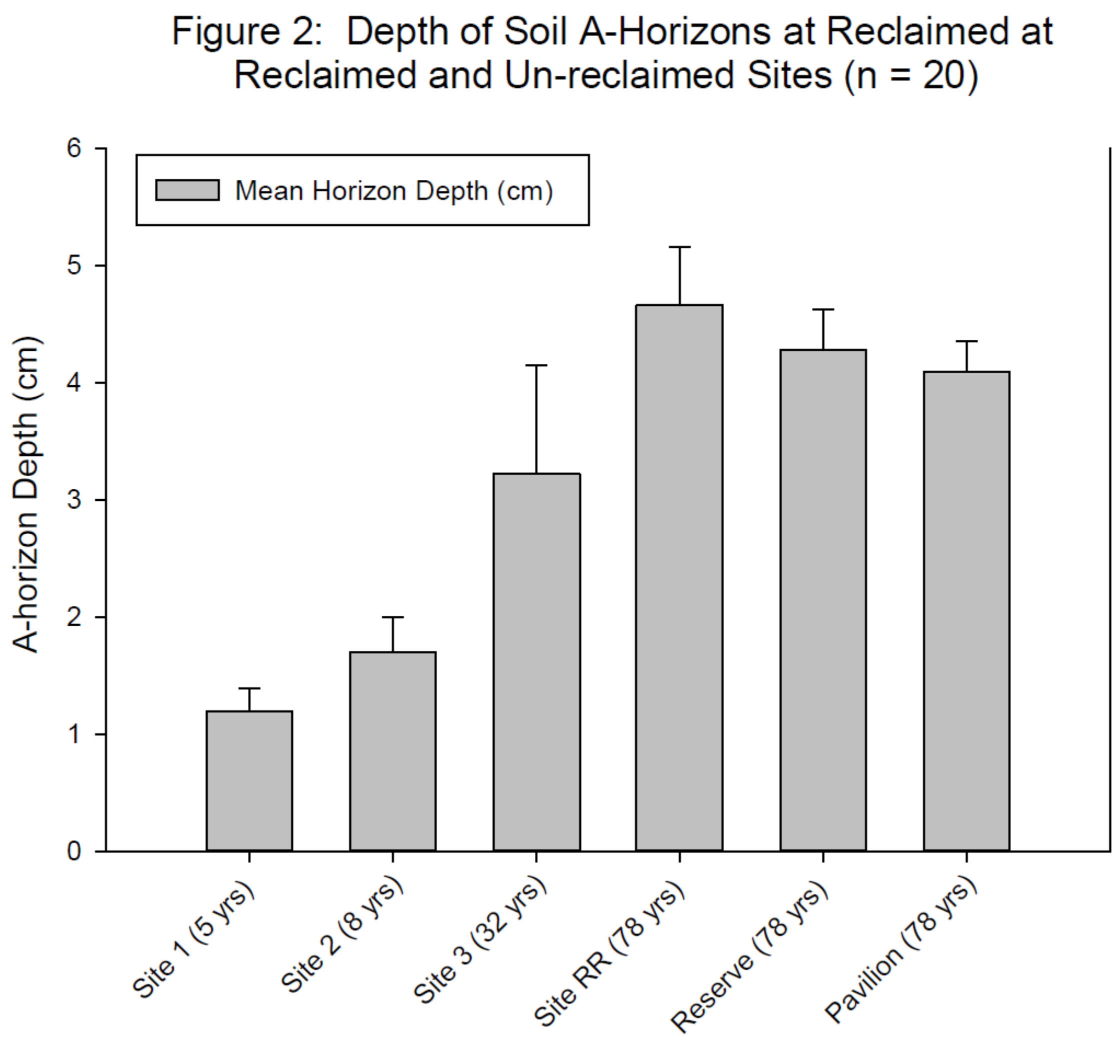


Figure 3: A-Horizon Development Rates at Reclaimed and Un-reclaimed Sites

Figure 3: A-Horizon Development Rates
at Reclaimed and Unreclaimed Sites

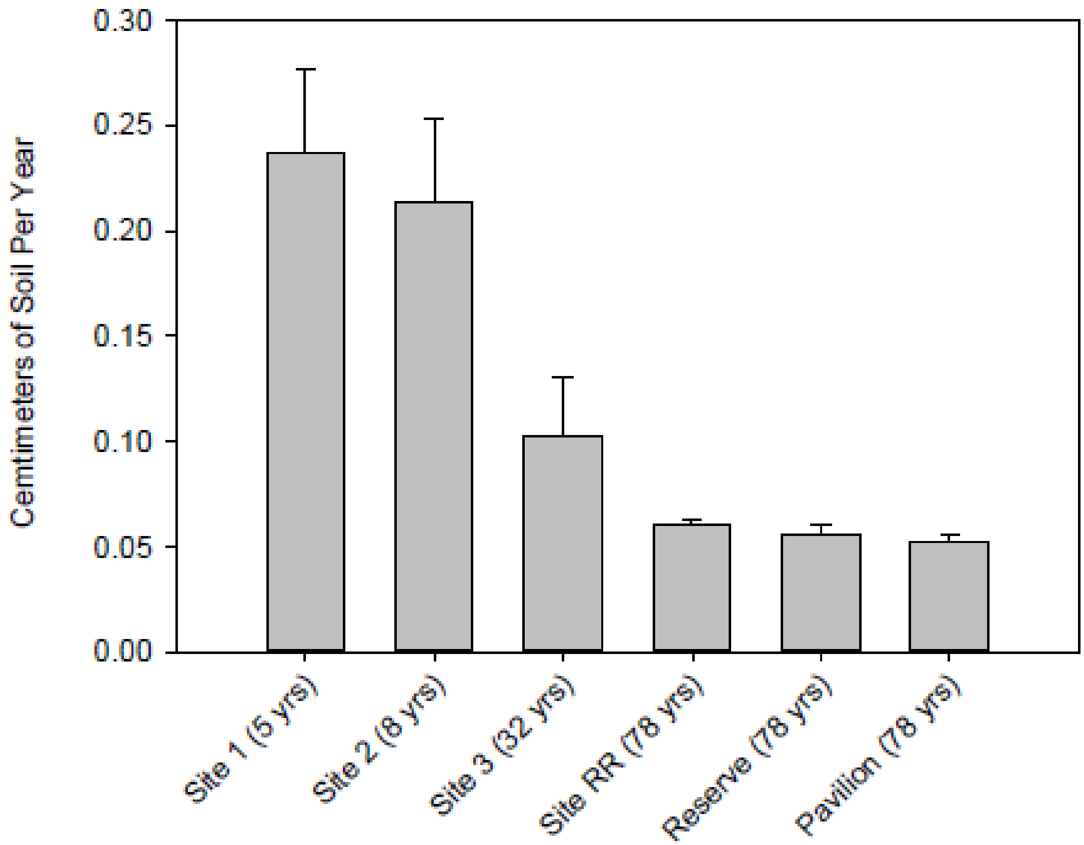


Figure 4: A-Horizon Carbon to Nitrogen Ratios at Reclaimed and Un- reclaimed Sites

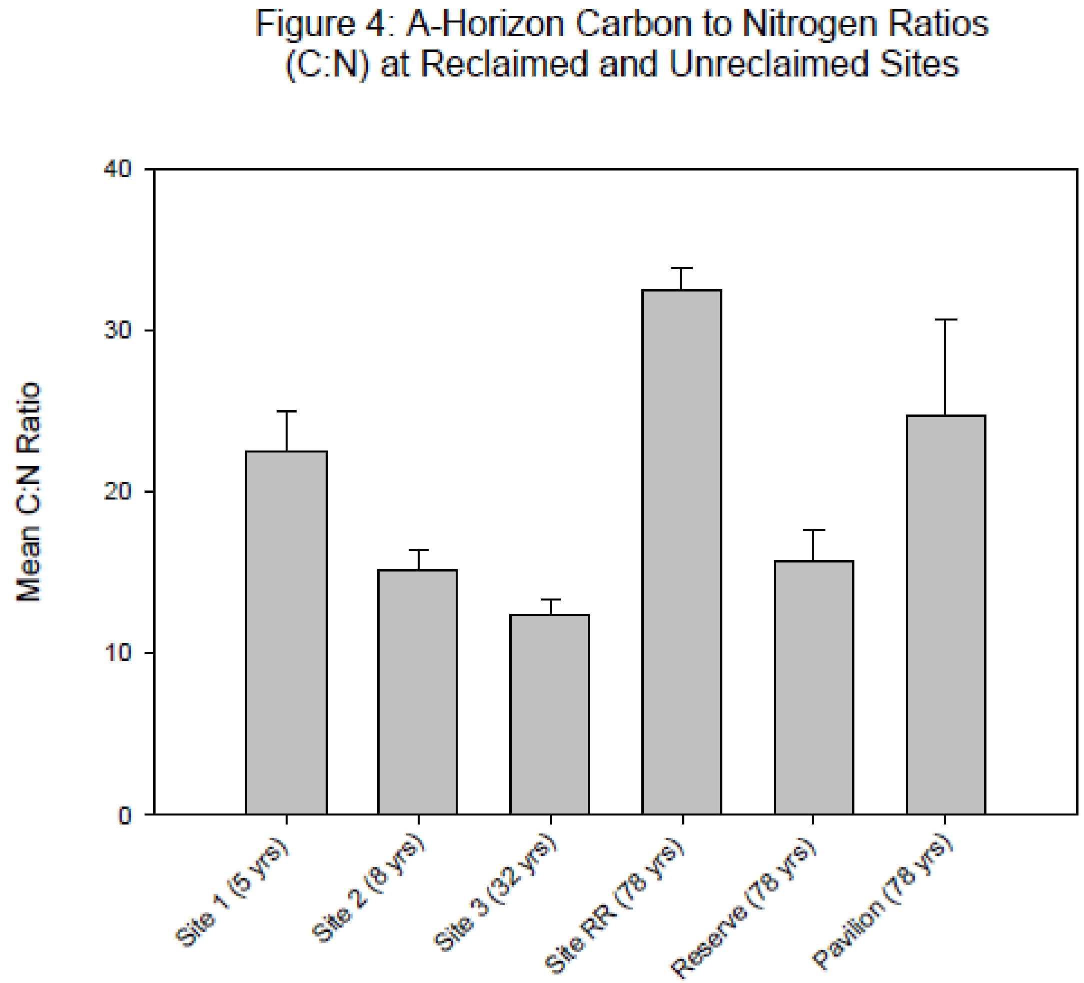
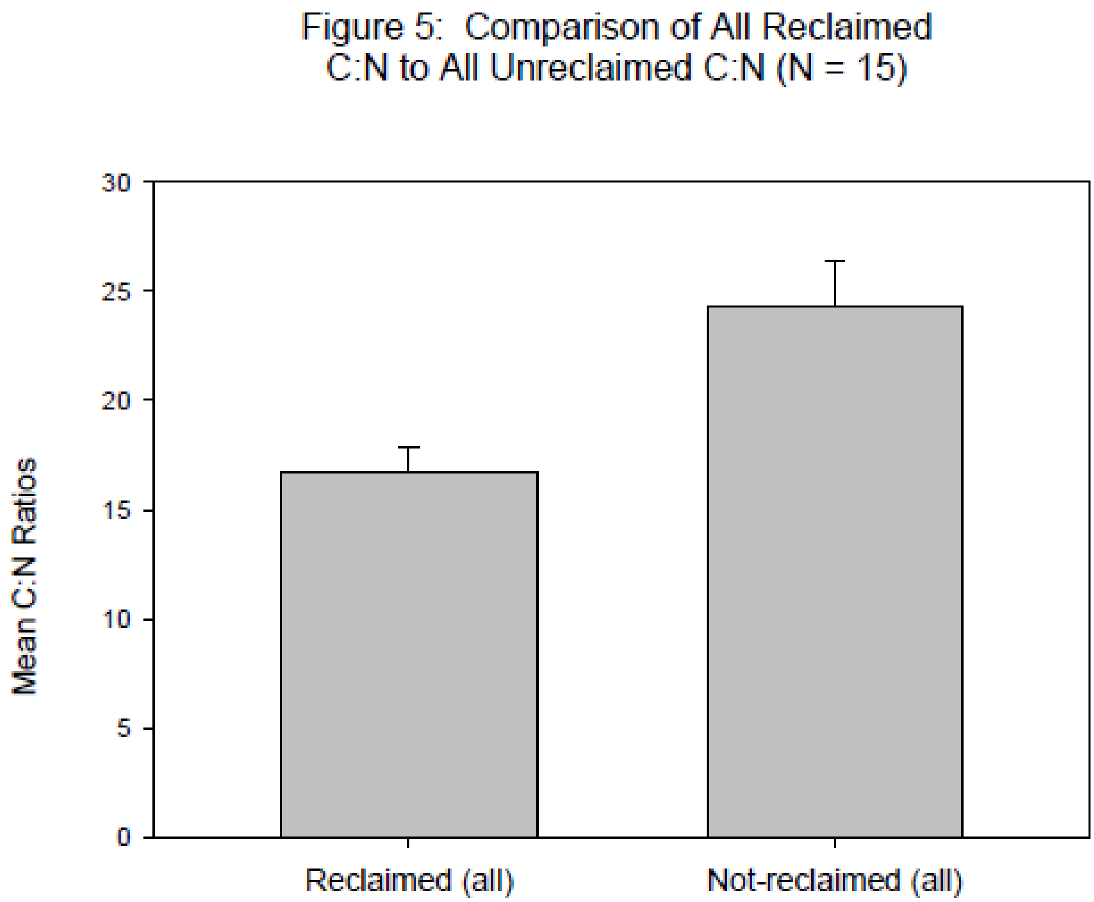


Figure 5: Comparison of All Reclaimed C: N to All
Un-reclaimed C: N (N = 15)



REFERENCES

Bailey, Timothy; Hooey, Catherine.(2017) From Wasteland to Wonderland": New Uses for Mined Land in Rural Southeast Kansas "The Midwest Quarterly"**:** Vol. 58, Iss. 3, : 252- 263,248.

Bentham, H., Harris, J. A., Birch, P., and Short, K. C. (1992). "Habitat classification and soil restoration assessment using analysis of soil microbiological and physico-chemical characteristics." *The Journal of Applied Ecology* 29.3: 711-718.

Bormann, B., Spaltenstein, H., McClellan, M., Ugolini, F., Cromack, K., & Nay, S. (1995). Rapid Soil Development After Windthrow Disturbance in Pristine Forests. *Journal of Ecology,83*(5), 747-757. doi:10.2307/2261411

Buol, S.W., F.D. Hole, R. J. McCracken and R.J. Southard. (1997). Chapter 5: Time as a Factor of Soil Formation in Soil Genesis and Classification, 4th edition. Iowa State University Press, Ames, Iowa.

Caravaca, F., Alguacil, M. M., Figueroa, D., Barea, J. M., and Roldan, A. (2003). "Re-establishment of *Retama sphaerocarpa* as a target species of reclamation of soil physical and biological properties in a semi-arid mediterranean land." *Forest Ecology and Management* 182.1: 49-58.

Crow, S., Lajtha, K., Filley, T., Swanston, C., Bowden, R. and CALDWELL, B. (2009). Sources of plant-derived carbon and stability of organic matter in soil: implications for global change. *Global Change Biology*, 15(8), pp.2003-2019.

Emily S. Bernhardt, Brian D. Lutz, Ryan S. King, John P. Fay, Catherine E. Carter, Ashley M. Helton, David Campagna, and John Amos. (2012). *Environmental Science & Technology 46* (15), 8115-8122. DOI: 10.1021/es301144q

Johnson, D. and Hallberg, K. (2005). Acid mine drainage remediation options: a review. *Science of The Total Environment*, 338(1-2), pp.3-14.

Jones, M.L.M., Sowerby, A., Williams, D.L. (2008) Plant Soil 307:219. https://doi.org/10.1007/s11104-008-9601-9.

NC Region Publication 221. (1998). Recommended Chemical Test Procedures for the North Central Region Publication 221 (Revised). University Agriculture Experiment Station, Columbia, MO.

Pittstate. (2018). *Monahan Outdoor Education Center - Biology*. [Online] Available at: https://www.pittstate.edu/biology/monahan-outdoor-education-center.html [Accessed 3 Jul. 2018].

Pond, G., Passmore, M., Pointon, N., Felbinger, J., Walker, C., Krock, K., Fulton, J. and Nash, W. (2014). Long-Term Impacts on Macroinvertebrates Downstream of Reclaimed Mountaintop Mining Vally Fills in Central Appalachia. *Environmental Management,* 54(4), pp.919-933.

Sheoran, V.; Sheoran, A. S.; and Poonia, P. (2010) "Soil Reclamation of Abandoned Mine Land by Revegetation: A Review," International Journal of Soil, Sediment and Water: Vol. 3 : Iss. 2 , Article 13.

Sigma Plot (2017). Systat Software, San Jose, CA.

Walker, L., Wardle, D., Bardgett, R. and Clarkson, B. (2010). The use of chronosequences in studies of ecological succession and soil development. *Journal of Ecology*, 98(4), pp.725- 736.

Weil RR and Brady NC, (2016). “The Nature and Properties of Soils”, 15th Edition. Pearson. ISBN- 13:978-13-325448-8

Whitney, D. A. and Lamond, R. E. (1993). *Liming Acid Soils*, Kansas State University, March.

APPENDICES

APPENDIX 1A: Basic statistics for A-horizon Depths

Descriptive Statistics: Tuesday, June 12, 2018, 1:31:07 PM

Data source: Data 1 in ANOVA of soil depths.JNB

Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
Area 5 cm Depth	20	0	1.694	0.305	0.0682	0.143
Monahan 32 yr cm depth	20	0	3.220	0.932	0.208	0.436
Area 7 cm depth	20	0	1.196	0.197	0.0441	0.0924
Railroad Monahan cm depth	20	0	4.660	0.495	0.111	0.232
Research R cm depth	20	0	4.278	0.349	0.0780	0.163
Mon Pavilion cm depth	20	0	4.092	0.266	0.0594	0.124

Column	Range	Max	Min	Median	25%	75%
Area 5 cm Depth	1.380	2.600	1.220	1.700	1.450	1.855
Monahan 32 yr cm depth	4.050	5.500	1.450	3.305	2.600	3.700
Area 7 cm depth	0.600	1.600	1.000	1.100	1.045	1.335
Railroad Monahan cm depth	1.760	5.500	3.740	4.610	4.265	5.075
Research R cm depth	1.160	4.820	3.660	4.350	3.935	4.580
Mon Pavilion cm depth	1.100	4.800	3.700	4.100	3.915	4.230

Column	Skewness	Kurtosis	K-S Dist.	K-S Prob.	SWilk W	SWilk Prob
Area 5 cm Depth	1.228	2.941	0.171	0.127	0.908	0.058
Monahan 32 yr cm depth	0.164	1.082	0.122	0.551	0.952	0.404
Area 7 cm depth	0.955	-0.459	0.250	0.002	0.838	0.003
Railroad Monahan cm depth	-0.197	-0.896	0.154	0.241	0.969	0.731
Research R cm depth	-0.176	-1.271	0.149	0.279	0.937	0.206
Mon Pavilion cm depth	0.591	1.446	0.152	0.254	0.929	0.145

Column	Sum	Sum of Squares
Area 5 cm Depth	33.880	59.162
Monahan 32 yr cm depth	64.392	223.804
Area 7 cm depth	23.920	29.349
Railroad Monahan cm depth	93.200	438.977
Research R cm depth	85.560	368.337
Mon Pavilion cm depth	81.840	336.232

APPENDIX 1B: Analysis of Variance of A-horizon Depths

One Way Analysis of Variance Tuesday, June 12, 2018, 3:56:29 PM

Data source: Raw Depths in ANOVA of soil depths.JNB

Normality Test (Shapiro-Wilk): Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Tuesday, June 12, 2018, 3:56:29 PM

Data source: Raw Depths in ANOVA of soil depths.JNB

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Area 5 cm Depth	20	0	1.700	1.450	1.855
Monahan 32 yr cm depth	20	0	3.305	2.600	3.700
Area 7 cm depth	20	0	1.100	1.045	1.335
Railroad Monahan cm depth	20	0	4.610	4.265	5.075
Research R cm depth	20	0	4.350	3.935	4.580
Mon Pavilion cm depth	20	0	4.100	3.915	4.230

H = 96.653 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple

comparison procedure. All Pairwise Multiple Comparison Procedures

(Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P**	**P<0.050**
Railroad Mona vs Area 7 cm dep	1764.000	11.339	<0.001	Yes
Railroad Mona vs Area 5 cm Dep	1398.500	8.990	<0.001	Yes
Railroad Mona vs Monahan 32 yr	914.000	5.875	<0.001	Yes
Railroad Mona vs Mon Pavilion	444.000	2.854	0.332	No

Railroad Mona vs Research R cm	279.500	1.797	0.802	Do Not Test
Research R cm vs Area 7 cm dep	1484.500	9.543	<0.001	Yes
Research R cm vs Area 5 cm Dep	1119.000	7.193	<0.001	Yes
Research R cm vs Monahan 32 yr	634.500	4.079	0.045	Yes
Research R cm vs Mon Pavilion	164.500	1.057	0.976	Do Not Test
Mon Pavilion vs Area 7 cm dep	1320.000	8.485	<0.001	Yes
Mon Pavilion vs Area 5 cm Dep	954.500	6.136	<0.001	Yes
Mon Pavilion vs Monahan 32 yr	470.000	3.021	0.269	No
Monahan 32 yr vs Area 7 cm dep	850.000	5.464	0.002	Yes
Monahan 32 yr vs Area 5 cm Dep	484.500	3.114	0.237	No
Area 5 cm Dep vs Area 7 cm dep	365.500	2.350	0.558	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.
A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4
vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

APPENDIX 2A: Descriptive Statistics for A-Horizon Development Rates

Tuesday, June 12, 2018, 11:52:42 AM

Data source: Data 1 in Anova of rates.JNB

Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
Monahan (32)	20	0	0.102	0.0292	0.00652	0.0137
Area 5 (8)	20	0	0.214	0.0394	0.00880	0.0184
Area 7 (5)	20	0	0.237	0.0393	0.00879	0.0184
Monahan RR (78)	20	0	0.0600	0.00725	0.00162	0.00340
R_Reserve (78)	20	0	0.0555	0.00510	0.00114	0.00239
Pavilion (78)	20	0	0.0520	0.00410	0.000918	0.00192

Column	Range	Max	Min	Median	25%	75%
Monahan (32)	0.120	0.170	0.0500	0.105	0.0800	0.120
Area 5 (8)	0.180	0.330	0.150	0.215	0.183	0.230
Area 7 (5)	0.120	0.320	0.200	0.220	0.210	0.268
Monahan RR (78)	0.0200	0.0700	0.0500	0.0600	0.0525	0.0675
R_Reserve (78)	0.01000	0.0600	0.0500	0.0600	0.0500	0.0600
Pavilion (78)	0.01000	0.0600	0.0500	0.0500	0.0500	0.0500

Column	Skewness	Kurtosis	K-S Dist.	K-S Prob.	SWilk W	SWilk Prob
Monahan (32)	0.121	0.363	0.126	0.514	0.951	0.376
Area 5 (8)	1.193	2.915	0.150	0.267	0.909	0.062
Area 7 (5)	0.958	-0.383	0.272	<0.001	0.844	0.004
Monahan RR (78)	3.324E-015	-0.931	0.250	0.002	0.815	0.001
R_Reserve (78)	-0.218	-2.183	0.361	<0.001	0.637	<0.001
Pavilion (78)	1.624	0.699	0.487	<0.001	0.495	<0.001

Column	Sum	Sum of Squares
Monahan (32)	2.050	0.226
Area 5 (8)	4.270	0.941
Area 7 (5)	4.750	1.158
Monahan RR (78)	1.200	0.0730
R_Reserve (78)	1.110	0.0621
Pavilion (78)	1.040	0.0544

APPENDIX 2B: Analysis of Variance for A-Horizon Development Rates

Monday, June 11, 2018, 3:46:31 PM
Data source: SigmaPlot Version 14.0. Data 1 in Notebook "ANOVA of rates.JNB"

Normality Test (Shapiro-Wilk): Failed ($P < 0.050$)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Monday, June 11, 2018, 3:46:31 PM

Data source: SigmaPlot Version 14.0. Data 1 in Notebook "ANOVA of rates.JNB"

Group	N	Missing	Median	25%	75%
Monahan (32)	20	0	0.105	0.0800	0.120
Area 5 (8)	20	0	0.215	0.183	0.230
Area 7 (5)	20	0	0.220	0.210	0.268
Monahan RR (78)	20	0	0.0600	0.0525	0.0675
R_Reserve (78)	20	0	0.0600	0.0500	0.0600
Pavilion (78)	20	0	0.0500	0.0500	0.0500

H = 99.901 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure. All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P	P<0.050
Area 7 (5) vs Pavilion (78)	1630.500	10.481	<0.001	Yes
Area 7 (5) vs R_Reserve (78)	1431.000	9.199	<0.001	Yes
Area 7 (5) vs Monahan RR (78)	1242.000	7.984	<0.001	Yes
Area 7 (5) vs Monahan (32)	753.000	4.840	0.008	Yes
Area 7 (5) vs Area 5 (8)	130.500	0.839	0.991	No
Area 5 (8) vs Pavilion (78)	1500.000	9.642	<0.001	Yes
Area 5 (8) vs R_Reserve (78)	1300.500	8.360	<0.001	Yes
Area 5 (8) vs Monahan RR (78)	1111.500	7.145	<0.001	Yes
Area 5 (8) vs Monahan (32)	622.500	4.002	0.053	No
Monahan (32) vs Pavilion (78)	877.500	5.641	0.001	Yes
Monahan (32) vs R_Reserve (78	678.000	4.358	0.025	Yes
Monahan (32) vs Monahan RR	489.000	3.143	0.227	No

(7				
Monahan RR (7 vs Pavilion (78)	388.500	2.497	0.488	No
Monahan RR (7 vs R_Reserve (78	189.000	1.215	0.956	Do Not Test
R_Reserve (78 vs Pavilion (78)	199.500	1.282	0.945	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.
A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4
vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

APPENDIX 3A: Descriptive Statistics for C: N Ratios

Data source: Raw Data in C to N Data.JNB

Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
Site 1 (5 years)	5	0	22.520	2.531	1.132	3.143
Site 2 (8 years)	5	0	15.220	1.148	0.513	1.425
Site 1 (5 years)	5	0	22.520	2.531	1.132	3.143
Site 2 (8 years)	5	0	15.220	1.148	0.513	1.425
Site 3 (32 years)	5	0	12.400	0.894	0.400	1.111
Site RR (78 years)	5	0	32.560	1.320	0.590	1.639
Reserve (78 years)	5	0	15.740	1.963	0.878	2.437
Pavilion (78 years)	5	0	24.740	5.966	2.668	7.407

Column	Range	Max	Min	Median	25%	75%
Site 1 (5 years)	5.700	26.000	20.300	21.200	20.500	25.200
Site 2 (8 years)	3.000	17.000	14.000	15.100	14.250	16.250
Site 1 (5 years)	5.700	26.000	20.300	21.200	20.500	25.200
Site 2 (8 years)	3.000	17.000	14.000	15.100	14.250	16.250
Site 3 (32 years)	2.000	13.000	11.000	13.000	11.500	13.000
Site RR (78 years)	3.700	34.600	30.900	32.400	31.650	33.550
Reserve (78 years)	5.100	19.000	13.900	15.200	14.300	17.450
Pavilion (78 years)	16.100	33.900	17.800	22.800	20.300	30.150

Column	Skewness	Kurtosis	K-S Dist.	K-S Prob.	SWilk W	SWilk Prob
Site 1 (5 years)	0.758	-1.987	0.299	0.152	0.855	0.211
Site 2 (8 years)	0.957	1.029	0.204	0.581	0.948	0.726
Site 1 (5 years)	0.758	-1.987	0.299	0.152	0.855	0.211
Site 2 (8 years)	0.957	1.029	0.204	0.581	0.948	0.726
Site 3 (32 years)	-1.258	0.313	0.349	0.046	0.771	0.046
Site RR (78 years)	0.707	2.251	0.318	0.101	0.885	0.330
Reserve (78 years)	1.495	2.581	0.268	0.269	0.878	0.302
Pavilion (78 years)	0.833	1.273	0.227	0.463	0.940	0.668

Column	Sum	Sum of Squares
Site 1 (5 years)	112.600	2561.380
Site 2 (8 years)	76.100	1163.510
Site 1 (5 years)	112.600	2561.380
Site 2 (8 years)	76.100	1163.510
Site 3 (32 years)	62.000	772.000
Site RR (78 years)	162.800	5307.740
Reserve (78 years)	78.700	1254.150
Pavilion (78 years)	123.700	3202.690

APPENDIX 3B: One Way Analysis of Variance for C:N Ratios of A-horizons

Wednesday, June 27, 2018, 3:58:31 PM

Data source: Raw Data in C to N Data.JNB

Normality Test (Shapiro-Wilk): Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Wednesday, June 27, 2018, 3:58:31 PM

Data source: Raw Data in C to N Data.JNB

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Site 1 (5 years)	5	0	21.200	20.500	25.200
Site 2 (8 years)	5	0	15.100	14.250	16.250
Site 3 (32 years)	5	0	13.000	11.500	13.000
Site RR (78 years)	5	0	32.400	31.650	33.550
Reserve (78 years)	5	0	15.200	14.300	17.450
Pavilion (78 years)	5	0	22.800	20.300	30.150

H = 25.819 with 5 degrees of freedom. (P = <0.001)
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P**	**P<0.050**
Site RR (78 y vs Site 3 (32 ye	121.000	6.147	<0.001	Yes
Site RR (78 y vs Site 2 (8 yea	85.000	4.318	0.028	Yes
Site RR (78 y vs Reserve (78 y	81.000	4.115	0.042	Yes
Site RR (78 y vs Site 1 (5 yea	37.000	1.880	0.769	No
Site RR (78 y vs Pavilion (78	27.000	1.372	0.927	Do Not Test
Pavilion (78 vs Site 3 (32 ye	94.000	4.775	0.010	Yes
Pavilion (78 vs Site 2 (8 yea	58.000	2.946	0.296	No
Pavilion (78 vs Reserve (78 y	54.000	2.743	0.378	Do Not Test
Pavilion (78 vs Site 1 (5 yea	10.000	0.508	0.999	Do Not Test
Site 1 (5 yea vs Site 3 (32 ye	84.000	4.26	0.031	Yes

		7		
Site 1 (5 yea vs Site 2 (8 yea	48.000	2.438	0.516	Do Not Test
Site 1 (5 yea vs Reserve (78 y	44.000	2.235	0.612	Do Not Test
Reserve (78 y vs Site 3 (32 ye	40.000	2.032	0.705	No
Reserve (78 y vs Site 2 (8 yea	4.000	0.203	1.000	Do Not Test
Site 2 (8 yea vs Site 3 (32 ye	36.000	1.829	0.789	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

APPENDIX 3C: Descriptive Statistics FOR C:N Ratios at Reclaimed and Un-reclaimed Sites (Only two Treatments)

Monday, July 02, 2018, 4:16:59 PM

Data source: Raw Data in C to N Data.JNB

Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
Reclaimed Sites (all ages)	15	0	16.713	4.682	1.209	2.593
Col 9	15	0	24.347	7.897	2.039	4.373

Column	Range	Max	Min	Median	25%	75%
Reclaimed Sites (all ages)	15.000	26.000	11.000	15.100	13.000	20.700
Col 9	20.700	34.600	13.900	22.800	15.900	32.400

Column	Skewness	Kurtosis	K-S Dist.	K-S Prob.	SWilk W	SWilk Prob
Reclaimed Sites (all ages)	0.782	-0.574	0.202	0.100	0.899	0.093
Col 9	-0.00333	-1.809	0.197	0.120	0.873	0.037

Column	Sum	Sum of Squares
Reclaimed Sites (all ages)	250.700	4496.890
Col 9	365.200	9764.580

APPENDIX 3D: Second One Way Analysis of Variance (ANOVA) on C:N Ratios At Reclaimed and Un-reclaimed Sites (Only Two Treatments)

Thursday, June 28, 2018, 1:57:43 PM

Data source: Raw Data in C to N Data.JNB

Normality Test (Shapiro-Wilk): Passed (P = 0.081)

Equal Variance Test (Brown-Forsythe): Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Thursday, June 28, 2018, 1:57:43 PM

Data source: Raw Data in C to N Data.JNB

Group	N	Missing	Median	25%	75%
All reclaimed Sites	15	0	15.100	13.000	20.700
All Un-reclaimed sites	15	0	22.800	15.900	32.400

H = 7.849 with 1 degrees of freedom. (P = 0.005)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.005)

To isolate the group or groups that differ from the others use a multiple

comparison procedure. All Pairwise Multiple Comparison Procedures

Comparison	Diff of Ranks	q	P
All Un-reclai vs All reclaimed	135.000	3.959	0.005

(Tukey Test):

Note: The multiple comparisons on ranks do not include an adjustment for ties.