Using Principle Component Analysis (PCA) to Discriminate Taxonomically Distinct Soil Orders Based on their Characteristics

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Abstract

Soils represent a complex and difficult barrier for the environment. A barrier between soil taxonomy and environmental soil processes is difficult to decipher, and it would be beneficial to the environmental quality to use soil taxonomy to predict the characteristics and processes. This study was conducted to see how three different soil orders, Alfisols, Mollisols, and Ultisols, are discriminated based upon their characteristics and properties. The soils were mapped using the Web Soil Survey website and 10 soils sampled from each soil order using traditional soil sampling methods. Principle Component Analysis (PCA) was used to cluster and model soil order characterization data to further determine which characteristics influenced each soil order. The project research can be used as a building block for further research to help enhance environmental quality by using soil taxonomy to predict characteristics and processes. Fate and transport of water and contaminants, biodegradation, soil available water, and fertility are a few examples of processes that can be correlated into this research in the future for predictions of each soil biogeochemical process to help predict soil processes based on their taxonomy. The ultimate goal is to continue experiments of sorption, incubation, and degradation to add to this dataset to further use taxonomy to help predict soil processes and chemical reactions for enhanced soil, water, and environmental quality.

Introduction

The purpose of soil taxonomy is to classify soils into categories that help provide distinguished and non-arbitrary information about the soil based on a hierarchy. Soil taxonomy includes detailed information within the name of the soil that allows us to determine the geographic location, temperature regime, and their natural development (Young and Hammer, 1996). There are twelve different soil orders; however, this study is only focused on the three soil orders Alfisols, Mollisols, and Ultisols. The soil orders chosen were based on their geographic location, abundance of each soil order around the United States, and their characteristic differences. Within each soil order, there is a scheme of classification from the broadest to the most specific soil type. The broadest begins with Order, Sub Order, Sub Group, Great Group, and Series; which is the most specific taxonomic classification of a soil. Each part of the taxonomy describes different information about the soil; for instance, the Great Group describes the temperature region of the soil and gives an idea of location ("Soil Genesis and Development, Lesson 5 - Soil Classification and Geography."). There is a soil map of the soil orders used to locate certain soil orders of interest in the U.S. for the research. Originally, soil taxonomy was created for the soil survey purpose to provide exact locations of soil series within the U.S. and the United States Department of Agriculture (USDA) was responsible for the soil taxonomy and soil survey (Young and Hammer, 1996).

The Web Soil Survey website, which includes the U.S. system called the National Resources Conservation System (NRCS), was used to map out the soil series and locations of soil orders. Diverse soil series within the same soil order were collected to determine the characteristics of each soil within each soil order. Soil taxonomic systems, like the U.S. NRCS system, are based primarily on descriptions of the soil profile and morphology (*Web Soil*

Survey). Also, it describes the chemical, physical, biological, geographical, and climatic information related to the soil through geological time. The soil taxonomic description can help describe the chemical and physical properties of the soil and help soil scientists understand the strengths and weaknesses of the soil for a variety of reasons such as agriculture, military, plant and animal life, and marine and terrestrial ecosystems. With information systems like this, it is possible to map each soil across different dimensions of characteristics such as fertility, aridity, and moisture (McGowen et al. 2000). Soils are an important part to the quality of the environment, and understanding different aspects regarding the taxonomy and details about the soil will help advance knowledge and use of soils for a better environment.

The three soil orders chosen for this research are the Alfisols, Mollisols, and Ultisols. Each soil order is different chemically, physically, geographically, biologically, and climatically. All of the different properties of the soil controls how all of the soil reactions occur. Since each soil order contains different features, structures, and properties; then, each reaction within the soil occurs differently (Young and Hammer, 1996). The Alfisols are located mostly in between the Midwest and east coast of the U.S. however, they are found across the entire U.S. They are mainly a forest soil located in highly vegetated areas with a lot of trees, organic matter, and leaf litter, and Alfisols are a dark grayish soil and contain a more silty clay texture. Their location may also contain a slope, or be on flat ground. Mollisols are located around the Midwest from north to south of the U.S. and contain a very thick organic horizon that is usually about 20-30 cm in depth. The organic horizon is the subsurface of Mollisols and is very dark black. And throughout the pedon, the color will be very dark black. They are mostly located in a cultivated filed with usually no slope. The majority of the Ultisols soil order is located along the eastern part of the U.S. and they are a mostly sandy soil that is a brownish color. Ultisols don’t contain a

thick organic horizon, and usually doesn't have much organic matter at the surface, and are located in different regions and climates. Since they are more of a sandy material soil, water drains easily throughout the soils profile (Young and Hammer, 1996). The soils order map on page 7 provides the descriptions of where each soil order is located. Each soil order is pictured on page 8 to show the physical distinction between each soil order.

Soils play an important role in the environment, and in order to sustain soil quality it is vital to continue further research. In this study, researching three different soil taxonomic orders and how their properties differentiate among each order, will potentially help to understand the influence these characteristics have on the quality of soil across different soil orders (Hundal, 1997). The quality of soil is important for human and animals in regards to their water and food, and since ground water is a major source for drinking water, fate and transport of contaminants can cause illness and health problems. Complex soil processes like fate and transport need to be further researched for the sake of human, animal, and plant health. Soil quality is directly related to environmental quality and sustaining the health of all living things (Kuo, 1996). Therefore, using taxonomy for further predicting soil processes can be substantial to improving the environment. As additional experiments are conducted and data is added to this research, predictions of soil processes based on taxonomy will potentially become achieved.

Soil is a major deposit for contamination of heavy metal that can be released into the environment by anthropogenic activity. Even though some heavy metals are naturally within the earth and soil may contain low concentrations of them, anthropogenic activity has caused contaminant levels to increase for some ecosystems. The higher concentrations of these contaminants, the more toxic the heavy metal is to soil in the environment (Mathangwane, et. al. 2008). The level of toxicity depends on the regulatory concentration of the element set by laws

associated with the human and environmental health impact of a specific element. Geochemical analysis on soil samples can be tested for the background of each specific element and metal. As done in this research, extractions of soil samples with a mehlich-3 solution for ICP measurements of specific elements can reveal the natural background levels. Human and environmental health can be impaired if the soils are contaminated at toxic levels (Steevens, et al. 2011). Therefore, it is important to know if the soil contains a background of an element of concern beforehand. As the total elemental concentration is added to the dataset from the extraction for each element analyzed, it can be determined which element seems to influence a soil order. For further sorption research in the future, these properties will be important. Also, plants and crops that are grown in soil with high contamination concentrations can produce foods for animals and humans that cause health problems and issues (Chung, et al. 2014). We can potentially help to reduce contamination to water and food by using this research as a baseline. Predictions of how an element reacts with these chosen soil orders can become a further step for an overall better understanding of the relationship between soil properties and the sorption fate within different soil orders.

Principle Component Analysis (PCA) is a multivariate statistical technique used to analyze relationships between a large number of variables and smaller number of objects. In this study, the objects are the soil samples and the variables are the soil characterization components (i.e. pH, EC, Fe, TOC C%, et al). The interrelationship among the two are explained through variables called principle components (PC) (Esbensen, 2010). The soil variable data is obtained from the characterizations was transformed, auto scaled, and evaluated using the PCA to geochemically distinguish soils. Relationships among samples was demonstrated by data points

in the score plots, and important variables loaded on the samples were demonstrated by complementary PC subspace distributions in the loading plot. Highly clustered samples in the score plot allows for the down-selection of statistically distinguished samples to avoid redundancies in the future experiments.

The statistical relationship between soil taxonomy and soil physical and chemical characteristics is obtained from the reconstructed exploratory analysis. Using the PCA, I was able to cluster the chosen soil orders and suborders selected from the NRCS database (Esbensen, 2010). The easily searchable soil taxonomy information from the soil database was studied utilizing exploratory data analysis (EDA) techniques to articulate latent structure that could connect soil physical and chemical properties to soil taxonomy and morphological criteria. The PCA was used to distinguish samples by their properties and perform an orthogonal decomposition of multiple soil variables into a reduced set of PC's. The PC's contain a linear combination of co-varying soil variables. Graphical correlations between the variable loadings and scores plots indicate the similarities and differences between each taxonomic soil order (Esbensen, 2010).

The focus of this study was to investigate characterization data across three different soil orders, and utilize soil taxonomy as a way to predict soil processes for further research and modeling. Soils were characterized morphologically using standard field survey methods, physically and chemically using standard soil analytical methods including total organic carbon, pH, EC, particle size distribution, and ion chromatography for background elements (Chappell, 2015). The hypothesis is that soil taxonomy can be used to predict soil chemical and physical properties, and this study will determine, with the help of PCA, how these different soil orders influence biogeochemical characteristics.

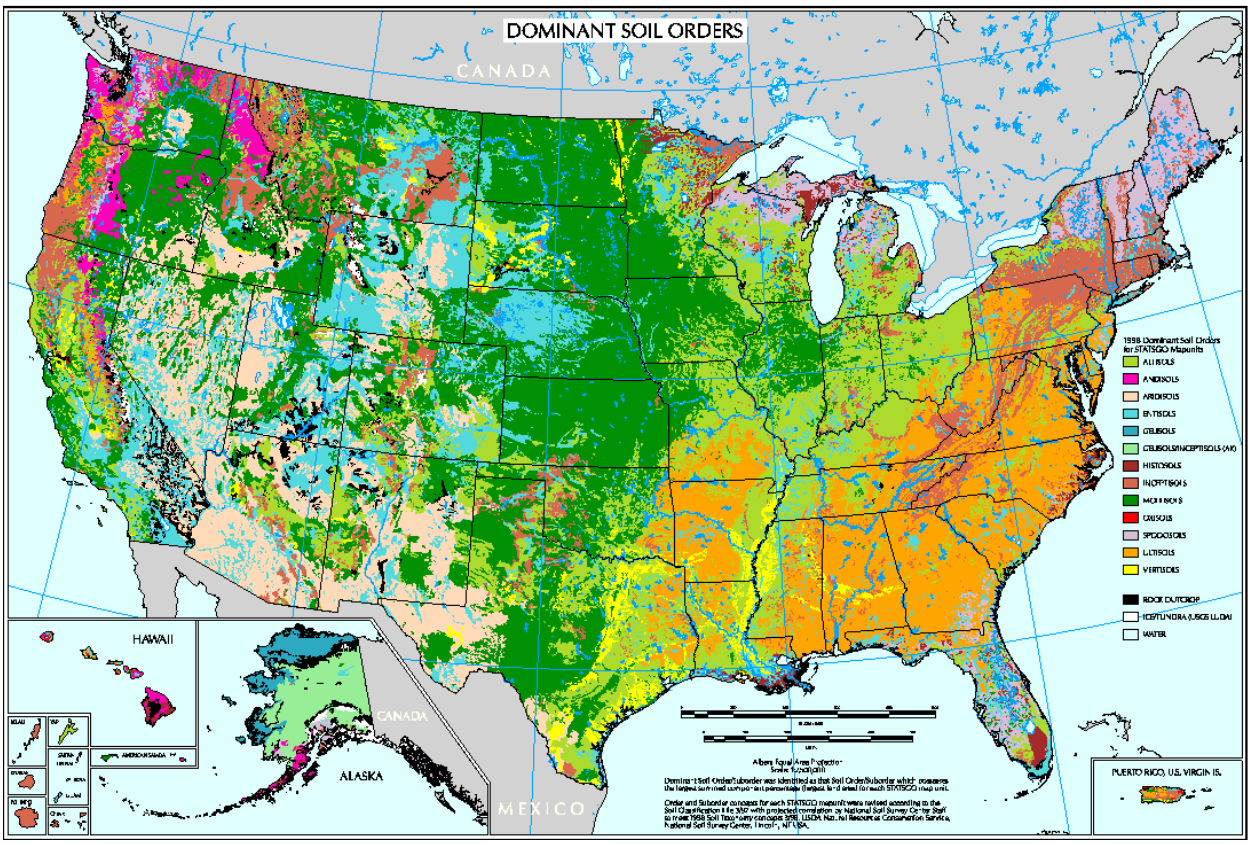

Figure 1. *Soils Orders Map within The United States of America.* Alfisols are light green, Mollisols are dark green, and Ultisols are orange (Nrcs.usda.gov.*Maps, 2017).*

Figure 2. Ultisol

Figure 3. Alfisol

Figure 4.Mollisol

Materials and Methods

1. Soil Sampling

Traditional field sampling was completed on soils mapped using the web soil survey to locate 10 soils from each of the three soil orders. Permission to collect these soils was proposed and granted around surrounding state parks and national parks. All samples in the parks were undisturbed and in their natural form. Samples were collected using a two-stage sample design, with location as the primary unit and soil taxonomic profiles as the secondary unit. In the field, the standard proper equipment was used and the traditional pedology techniques completed (Burt, 2004). Equipment such as: soil probe, spade, tape measure, Munsell color book, recordings, etc. were used to perform the soil sampling, and all data recorded in field books as well as GPS coordinates of soil sample locations. A picture of an example of the web soil survey mapping and the soil sampling tools is on page 19.

2. Soil Processing

All soils collected were processed the same way for consistency and accuracy. The soil samples were air dried, sieved with a standard 2 mm sieve, and acoustically mixed for assurance of a completely homogenized soil sample. If some soils were contained rocks, they were ground until they fit through the 2 mm sieved to ensure all samples were consistent for analysis. The acoustic mixer was used once the soils were sieved and ready to be homogenized, and they were placed in bottles on the acoustic mixer for a mixing time of 1 minute (Van Es, 2002). Once the soils were completed processed, they were labeled according to the state park or national park and given a number based on the site in the park of collection.

3. Lab Analysis

A series of characterization methods was completed in the lab for each soil. All analysis were done in triplicates in order to obtain the average and standard deviation, and all instruments, scales, pipettes, and other equipment were calibrated and standardized. The lab analysis were completed using traditional soil lab analysis methods (de Gruijter, 2002).

3.1 pH

The pH was measured on each triplicated soil sample using a pH probe and meter, and the probe was calibrated using pH standards of 4, 7, and 10, and the scale was calibrated with its automatic internal calibration. Each soil sample was weighed out in triplicate into a labeled tube with the soil sample name and reps listed as A, B, C. 5.0 g of soil was weighed out into each tube and 5.0 mL of deionized water was added to the tube for a 1:1 ratio of soil:solution. Each sample was placed on a shaker on low speed for 10 minutes, and removed for 1 hour until complete separation of solid and liquid was confirmed. The pH probe was placed in the liquid portion of the tube for reading, then the pH measurement was recorded (Amacher, 1996. pp 487-488).The average was calculated from all three reps for each soil.

3.2 The Conductivity (EC)

The electrical conductivity (EC) was measured the same way as the pH, using a calibrated EC probe and instrument. Two standards were used to calibrate the EC instrument, 1413 uS/cm and 74 uS/cm. Once the instrument was calibrated and the data recorded, the EC probe was placed into the liquid portion of the 1:1 soil: solution (deionized water) for reading. The EC was

recorded for each soil sample (Amacher, 1996. pp 420). The average was calculated from all three reps for each soil.

3.3 Mehlich- 3 Extraction

A soil extraction was performed using a Mehlich-3 solution. The extraction was completed with a 1:10 ratio of 2.0 g +/-.005 g of soil: 20 mL of Mehlich-3 solution. The solution was made with specific reagents, and were dissolved as instructed with procedure; then, the pH of solution was tested and was 1.99.

1. NH_4F-EDTA solution: Dissolve 138.9 g of NH_4F and 73.5 g of EDTA in deionized water and dilute to 1 L.

2. 1 M HNO_3: Dilute 62.5 mL of select grade concentrated HNO_3 to 1 L with deionized water.

3. Mehlich III extracting solution: Dissolve 80 g of NH_4NNO_3 in 3 L of deionized water. Add 16 mL of the NH_4F-EDTA solution (that you made), 46 mL of acetic acid, and 13 mL of 1 M HNO_3. Dilute to 4 L with deionized water. The final pH should be 2.0 +/- 0.1.

All weights were collected and recorded. The soil samples were weighed into polycarbonate centrifuge tubes, capped, and placed on the shaker at low speed for 5 minutes. Once they completed shaking, they were placed into a thermo RC 6+ for centrifuging at 5,000 RPM for 5 minutes. Samples were then filtered into sampling tubes for analysis (Amacher, 1996. pp 739-768). The samples were sent to the Environmental Chemistry Branch (ECB) in Vicksburg, MS for analysis and ran on an ICP instrument with detection limits of 0.0200 mg/L, and a reporting limit of 0.100 mg/L. The instrument was calibrated and used a SW 846/6010 method for a sweep of certain metals by EPA 6000/7000 series method. The analytes tested for were Aluminum

(Al), Arsenic (As), Barium (Ba), Calcium (Ca), Iron (Fe), Magnesium (Mg), Manganese (Mn), Phosphorous (P), Potassium (K), Sodium (Na), Sulfur (S), and Zinc (Zn). All elements were measured and recorded in ppm (mg/L). The calculations were completed to obtain each analytes in mg/kg for all soil samples in triplicates. Then, the average of all three triplicates was calculated and that value was recorded into the data table.

mg/kg = ((mg/L of element x total solution V (L)) / kg of soil)

For example:

Ba mg/L data from ECB for Alfisols order sample Ohiopyle 4 A = 1.07 mg/L, Ohiopyle 4 B = 1.10 mg/L, and Ohiopyle 4 C = 1.07 mg/L.

Average mg/L Ba for Ohiopyle 4 = 1.08 mg/L

20 mL = 0.02L 2.0g = 0.002 kg

mg/kg Ba = (1.08 mg/L x 0.02L) / 0.002 kg = 10.88 mg/kg Ba

3.4 Cation Exchange Capacity

The cation exchange capacity (CEC cmolc/kg) was calculated with a formula that used the averages of mg/kg of certain analytes from the Mehlich-3 extraction.

Analytes used: Ba, Ca, Mg, K, and Na

For Example:

For Alfisol order soil sample Ohiopyle 4, average mg/kg for Ba = 10.88 mg/kg, Ca = 28.66 mg/kg, Mg = 15.79 mg/kg, K = 71.48 mg/kg, and Na = 30.00 mg/kg

CEC = ((Ba avg mg/kg x atom charge/atomic mass) + (Ca avg mg/kg x atom charge/atomic mass) + (Mg avg mg/kg x atom charge/atomic mass) + (K avg mg/kg x atom charge/atomic mass) + (Na avg mg/kg x atom charge/atomic mass))

CEC = ((10.88 x 2 /137) + (28.66 x 2/40.08) + (15.79 x 2 /24.3) + (71.48/39.1) + (30.00/23)

CEC for Ohiopyle 4 = 6.02 cmolc/kg

Reference: (Soil Chemical Analysis: Advanced Course by M.L. Jackson).

3.5 Particle Size Distribution

The particle size distribution method was used in triplicate for texture analysis of each soil for %Silt, %Sand, %Clay. Each percentage of particles were averaged for all triplicate reps for each soil. The pipette method was used to perform the particle size distribution procedure for all soil samples. The reagent used was 3% $NaPO_3$ (sodium hexametaphosphate) solution. 15 g of soil was added to 45 mL of 0.5% $NaPO_3$ solution to a 250 mL Nalgene bottle. The bottle was placed on a reciprocating shaker for 2 hours. After dispersion from that step, the slurry was sieved through a 0.053 mm (no. 270) mesh sieve. The particles that passed through the 0.053 mm sieve were collected in a plastic bucket, and transferred to a 1 L beaker and kept for later steps. The particles that remained on the 0.053 mm sieve were collected as the sand particles. The sand collected on the 0.053 mm sieve was dried at 55C until dried, or the weight of the sample was constant, and the weight of the sand was recorded. A large magnetic stir bar was used and magnetic stir plate to stir the clay + silt suspension thoroughly to achieve a uniform suspension of particles. The suspension sat in the beaker, undisturbed at room temperature (18-24C) with a vertical orientation for at least 90 minutes, but less than 6 hours to allow the silt particles to settle. After the sedimentation period, the silt particles settled down to the bottom of the beaker

and were visible while clay particles were still being suspended in solution. The liquid solution (containing clay particles) was decanted and discarded. Carefully decanting the clay suspension liquid, to not lose any silt particles. The magnetic stir bar was removed and the remaining silt particles were dried in the beaker from previous steps at 105C until the weight of the sample was constant. The dry weight of the silt particles was recorded (Glendon, 2002; pp 255-294). Calculations were completed with the following equations to obtain each particle percentage for all replicates. The average of all replicates was calculated for each soil sample and added into the data table.

Total sample mass = (oven dry silt mass + oven dry clay mass)

% Sand = (oven dry sand mass / original sample mass) x 100%

% Silt = (oven dry silt mass / original sample mass) x 100%

% Clay = 100 - (% Sand + % Silt)

3.6 Total Organic Carbon

The total organic carbon was calculated with the LECO instrument. The instrument was calibrated with EDTA standard and blanks. Two methods were performed on each soil replicate called the TC method (Total Carbon) and IC method (Inorganic Carbon). Each sample was weighed out and prepped for each method. For the TC method, each soil sample was weighed out at 0.25 g into the Leco foil cup and ran on the instrument for TC Carbon%. Then for the IC method, each sample was weighed out at 0.25 g into a ceramic crucible. About 4-5 drops of 1:1 hydrochloric acid (HCl^-): deionized water was added to each sample, or until each sample was covered with the acid solution. The solution was made with 50 mL of hydrochloric acid solution

and 50 mL of deionized water. All samples were heated in an oven until soils were completely dried. The samples were inserted into Leco foil cups and ran on the instrument for TOC Carbon% analysis. As the samples were ran, the data was collected from the instrument for all three replicates per soil (*CN 628 Carbon/Nitrogen Determinator Instruction Manual*.2014). The average of all replicates for each soil was taken for the TOC % Carbon and recorded into the data table.

3.7 KCl Extraction- Ammonia

A soil extraction was completed on all soil sample reps with a 1M KCl^- solution. The extraction was completed with a 1:10 ratio of 2.5 g +/-.005 g of soil: 25 mL of 1M KCl^- solution. The solution was made with a KCl^-specific reagents, and dissolved in DI H_2O

1M KCl^- Solution:

KCl^-= 74.55 g/mol

Wanted 4L of 1M KCl^- Solution, M = moles of solute

74.55 g/mol x 1M x 4L

74.55 g/mol x 1 mol x 4 L = 74.55 g x 4 L

74.55 g x 4L = 298.2 g of KCl^-solid in 4 L of DI H_2O

All weights were collected and recorded. The soil samples were weighed into polycarbonate centrifuge tubes and were placed into a thermo RC 6+ for centrifuging at 5,000 RPM for 10 minutes. Once they completed their centrifuge cycle, the samples were filtered into sampling tubes for analysis (Amacher, 1996. pp 490-510). The samples were sent to the Environmental

Chemistry Branch (ECB) in Vicksburg, MS for analysis and ran on an instrument with detection limits of 0.00200 mg/L, and a reporting limit of 0.0100 mg/L. The instrument was calibrated and used EPA 350.1 method for the nutrient by EPA 6000/7000 series method. The nutrient tested for was NH_4-N (ammonia as N). All measurements were recorded in ppm (mg/L). The calculations were completed to obtain the component in mg/kg for all soil samples in triplicates. Then, the average of all three triplicates was calculated and that value was recorded into the data table.

mg/kg = ((mg/L of element x total solution V (L)) / kg of soil)

For example:

NH_4-N mg/L data from ECB for Alfisols order sample Ohiopyle 4 A = 1.29 mg/L, Ohiopyle 4 B = 1.26 mg/L, and Ohiopyle 4 C = 1.20 mg/L.

Average mg/L NH_4-N for Ohiopyle 4 = 1.25 mg/L

25 mL = 0.025L 2.5g = 0.0025 kg

mg/kg NH_4-N = (1.25 mg/L x 0.025L) / 0.0025 kg = 12.5 mg/kg NH_4-N

3.8 Ion Chromatography- from Water Extraction

A soil extraction was completed on all soil sample reps using deionized H_2O The extraction was performed using a 1:10 ratio of 2.5 g +/-.005 g of soil: 25 mL of DI H_2O. The soil samples were weighed into polycarbonate centrifuge tubes and were placed into a thermo RC 6+ for centrifuging at 5,000 RPM for 10 minutes. Once completed, samples were filtered into sampling tubes for analysis (Amacher, 1996. pp 510-520). The samples were sent to the

Environmental Chemistry Branch (ECB) in Vicksburg, MS for analysis and ran on an IC instrument with detection limits of 0.0200 mg/L, and a reporting limit of 0.0600 mg/L. The instrument was calibrated and used the EPA 300 method for the IC analytes by EPA 6000/7000 series method. The analytes tested were Bromide (Br^-), Chloride (Cl^-), Nitrate (NO_3), Nitrite (NO_2), Orthophosphate (Ortho-PO_4-2), and Sulfate (SO_4^{-2}). All measurements were recorded in ppm (mg/L). The calculations were completed to obtain the component in mg/kg for all soil samples in triplicates. Then, the average of all three triplicates was calculated and that value was recorded into the data table.

mg/kg = ((mg/L of element x total solution V (L)) / kg of soil)

For example:

Cl^-mg/L data from ECB for Alfisols order sample Ohiopyle 4 A =0.673 mg/L, Ohiopyle 4 B =0.553 mg/L, and Ohiopyle 4 C =0.679 mg/L.

Average mg/L NH_4-N for Ohiopyle 4 = 0.635 mg/L

25 mL = 0.025L 2.5g = 0.0025 kg

mg/kg NH_4-N = (0.635 mg/L x 0.025 L) / 0.0025 kg = 6.35 mg/kg NH_4-N

3.9 PCA Analysis using UnscramblerX program by CAMO Software

The UnscramblerX program was used to perform PCA models, scores plots, and loadings plots of each soil order and of all soil orders together. The data was created in a tables in excel and then uploaded into the program to begin the statistical modeling. Data was then transposed into rowsets and columnsets to create the scores and loadings plots. All zeroes, negatives (if

any), or no detections (ND), are to be left as blank cells as the UnscramblerX program does not recognize negatives. Graphs and plots were designed with color coordination, leverages, and groupings.

Reference: Esbensen, K. H. (2010). "Multivariate Data Analysis - In Practice," CAMO Software AS, Norway.

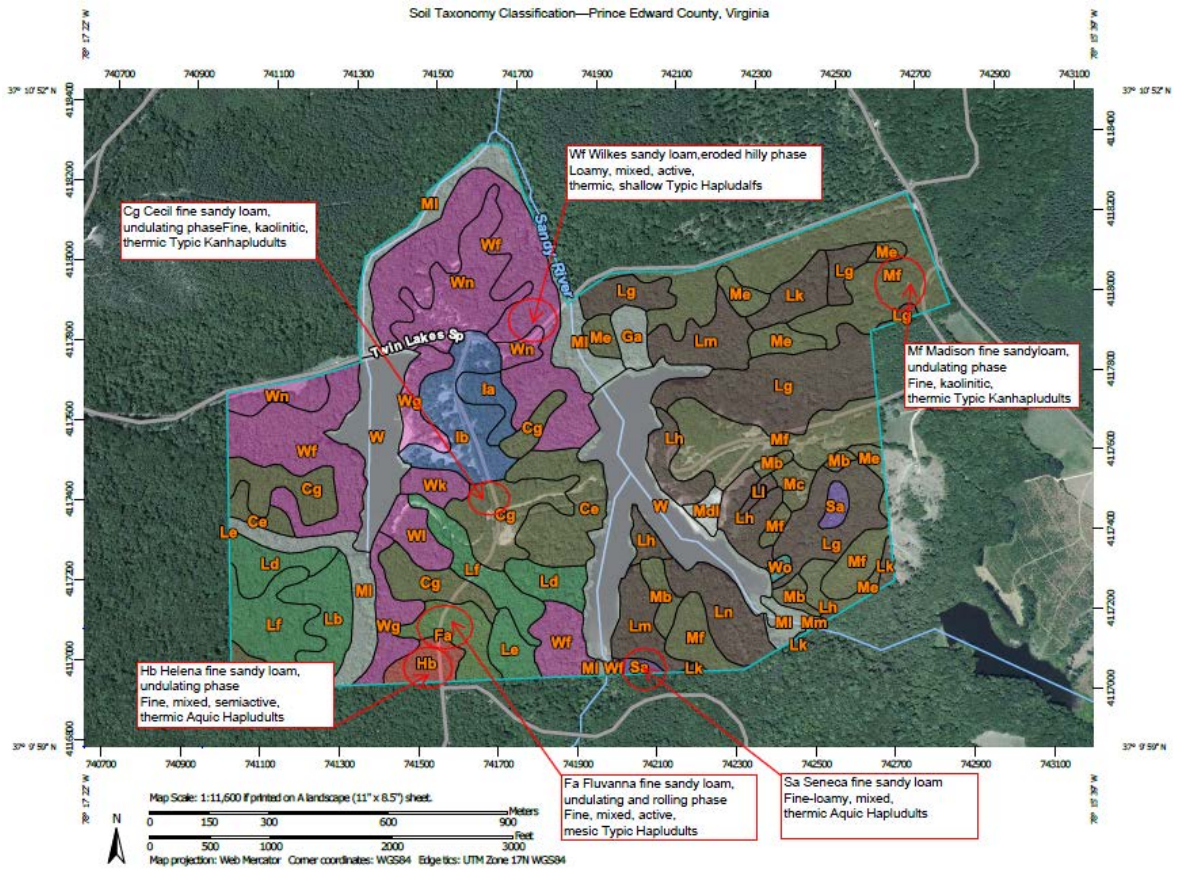

Figure 5. Example of using Web Soil Survey for locating specific soils of interests in parks.

Figure 6. Picture of field equipment used for soil sampling.

Results

1.1 Characterization and Lab Data for the Alfisols Order soil samples. 10 Alfisol selected and analyzed for this research in the Sample ID. The characterization data are the averages of 3 reps.

Order: Alfisols			
	Taxonomic Information		
Sample ID	**Sub Order**	**Sub Group**	**Great Group**
Chappell 1	Paleudalfs	Typic	Thermic
Chickasaw 1	Endoaqualfs	Typic	Thermic
Fort Polk 1	Hapludalfs	Chromic Vertic	Thermic
Itasca 1	Hapludalfs	Typic	Frigid
Luster 4	Hapludalfs	Typic	Mesic
Morrow 6	Hapludalfs	Ultic	Thermic
Ohiopyle 4	Hapludalfs	Ultic	Mesic
Tyler 2	Paleudalfs	Grossarenic	Thermic
Twin 4	Hapludalfs	Shallow Typic	Thermic
Zippel 1	Glossudalfs	Oxyaquic	Frigid

Table 1. Alfisols Order soil samples with taxonomy information.

Characterization Data							
Sample ID	CEC (cmolc/kg)	pH (H2O)	EC (uS/cm)	Al (mg/kg)	Ba (mg/kg)	Ca (mg/kg)	Fe (mg/kg)
Chappell 1	70 +/-0.6	5 +/-0.06	119 +/-5.0	885 +/-1.0	62 +/-1.0	1020 +/-2.0	126 +/-2.0
Chickasaw 1	17 +/-0.2	4 +/-0.1	44 +/-1.0	484 +/-2.0	23 +/-0.8	110 +/-2.0	129 +/-0.5
Fort Polk 1	8 +/-0.1	5 +/-0.08	34 +/-2.0	341 +/-1.0	14 +/-0.6	62 +/-2.0	63 +/-3.0
Itasca 1	139 +/-1.0	6 +/-0.04	221 +/-1.0	385 +/-1.0	31 +/-0.1	2098 +/-2.0	205 +/-0.8
Luster 4	171 +/-0.6	6 +/-0.1	146 +/-1.0	489 +/-2.0	65 +/-0.3	2494 +/-1.0	166 +/-0.02
Morrow 6	8 +/-0.1	4 +/-0.01	101 +/-3.0	604 +/-1.0	9 +/-0.08	38 +/-0.2	375 +/-1.0
Ohiopyle 4	6 +/-0.3	3 +/-0.02	66 +/-2.0	906 +/-2.0	10 +/-0.1	28 +/-2.0	130 +/-2.0
Tyler 2	21 +/-0.6	6 +/-0.1	48 +/-6.0	188 +/-3.0	27 +/-0.8	279 +/-3.0	56 +/-2.0
Twin 4	67 +/-3.0	4 +/-0.02	94 +/-2.0	627 +/-2.0	22 +/-2.0	637 +/-1.0	205 +/-2.0
Zippel 1	65 +/-1.0	6 +/-0.02	116 +/-2.0	267 +/-1.0	15 +/-0.5	931 +/-2.0	155 +/-3.0

Table 2. Alfisol Characterization Data. All values are averages of three replicates.

Characterization Data											
Sample ID	Mg (mg/kg)	Mn (mg/kg)	P (mg/kg)	K (mg/kg)	Na (mg/kg)	S (mg/kg)	Zn (mg/kg)	% Silt	% Sand	% Clay	TOC Carbon%
Chappell 1	190 +/-1.0	31 +/-2.0	73 +/-1.0	127 +/-3.0	94 +/-1.0		5 +/-0.7	74 +/-1.0	7 +/-0.2	18 +/-2.0	1 +/-0.02
Chickasaw 1	76 +/-1.0	74 +/-0.8	2 +/-0.1	56 +/-1.0	95 +/-1.0	3 +/-0.1	7 +/-0.3	43 +/-1.0	41 +/-0.1	15 +/-0.9	1 +/-0.03
Fort Polk 1	15 +/-0.5	76 +/-1.0	2 +/-0.1	32 +/-0.7	66 +/-1.0	4 +/-0.1	3 +/-0.2	13 +/-1.0	73 +/-0.5	18 +/-1.0	1 +/-0.2
Itasca 1	30 +/-1.0	17 +/-0.9	51 +/-1.0	230 +/-2.0	78 +/-0.4	25 +/-2.0	6 +/-0.2	58 +/-0.9	22 +/-0.5	20 +/-1.0	3 +/-0.1
Luster 4	486 +/-0.4	445 +/-3.0	10 +/-0.1	111 +/-0.4	77 +/-0.2	28 +/-4.0	5 +/-0.3	80 +/-0.5	6 +/-0.8	14 +/-1.0	3 +/-0.1
Morrow 6	52 +/-0.6	5 +/-0.1	4 +/-0.4	28 +/-0.1	35 +/-0.8	17 +/-0.4	1 +/-0.1	77 +/-0.4	9 +/-0.1	14+/-0.4	1 +/-0.09
Ohiopyle 4	15 +/-0.8	34 +/-1.0	3 +/-2.0	71 +/-1.0	30 +/-1.0	31 +/-1.0	1 +/-0.2	55 +/-0.1	19 +/-0.1	25 +/-0.2	2 +/-0.08
Tyler 2	33 +/-0.5	71 +/-0.3	10 +/-0.1	54 +/-1.0	65 +/-1.0	3 +/-0.3	4 +/-0.1	14 +/-0.3	81 +/-1.0	4 +/-1.0	1 +/-0.05
Twin 4	395 +/-3.0	97 +/-0.8	4 +/-0.3	52 +/-0.3	33 +/-1.0	6 +/-0.8	1 +/-0.1	38 +/-0.6	45 +/-0.6	16 +/-0.1	1.5 +/-0.05
Zippel 1	159 +/-4.0	109 +/-0.3	48 +/-1.0	86 +/-0.5	76 +/-0.8	20 +/-0.7	1 +/-0.1	32 +/-1.0	47 +/-1.0	20 +/-0.3	1 +/-0.1

Table 3. Alfisol Characterization Data continued. All values are averages of three replicates.

Characterization Data					
Sample ID	NH4-N (mg/kg)	Cl- (mg/kg)	NO3 (mg/kg)	Ortho-PO4-2 (mg/kg)	SO4-2 (mg/kg)
Chappell 1	8 +/-1.0	23 +/-0.5	48 +/-0.3	1 +/-0.1	8 +/-0.2
Chickasaw 1	8 +/-1.0	22 +/-0.4	21 +/-0.3		5 +/-0.2
Fort Polk 1	3 +/-0.1	17 +/-0.2	5 +/-0.2	3 +/-0.1	6 +/-0.1
Itasca 1	17 +/-0.3	25 +/-0.2	2 +/-0.1	1 +/-0.2	6 +/-0.6
Luster 4	17 +/-0.6	15 +/-0.2	5 +/-0.3		5 +/-0.1
Morrow 6	12 +/-0.3	8 +/-0.6	1 +/-0.04		12 +/-0.4
Ohiopyle 4	13 +/-0.4	6 +/-0.7	1 +/-0.1		13 +/-0.1
Tyler 2	3 +/-0.3	18 +/-0.3			4 +/-0.5
Twin 4	13 +/-0.1	5 +/-0.6			4 +/-0.4
Zippel 1	17 +/-0.7	18 +/-0.1	1 +/-0.1	2 +/-0.7	3 +/-0.1

Table 4. Alfisol Characterization Data Continued. All values are averages of three replicates.

1.2 Characterization and Lab Data for the Mollisols. 10 Mollisol soils selected and analyzed for this research in the Sample ID. The characterization data are the averages 3reps.

Order: Mollisols			
	Taxonomic Information		
Sample ID	**Sub Order**	**Sub Group**	**Great Group**
Buffalo 1	Endoaquolls	Typic	Frigid
Buffalo 3	Calciaquolls	Aeric	Frigid
Buffalo 4	Calciaquolls	Aeric	Frigid
Buffalo 5	Hapludolls	Oxyaquic	Frigid
Buffalo 7	Endoaquolls	Cumulic	Frigid
Dodge 4	Hapludolls	Typic	Mesic
Huntsville 3	Epiaquolls	Cumulic	Thermic
Glacial 1	Hapludolls	Typic	Frigid
Green 8	Hapludolls	Fluventic	Mesic
Zippel 5	Endoaquolls	Typic	Frigid

Table 5. Mollisols Orders soil samples with taxonomy information.

Characterization Data								
Sample ID	CEC (cmolc/kg)	pH (H2O)	EC (uS/cm)	Al (mg/kg)	Ba (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)
Buffalo 1	769 +/-0.1	8 +/-0.1	462 +/-0.2	35 +/-0.9	20 +/-0.5	12976 +/-0.2	63 +/-0.1	1372 +/-0.3
Buffalo 3	400 +/-0.2	7 +/-0.1	1226 +/-0.2	131 +/-0.3	5 +/-0.2	6006 +/-0.1	94 +/-0.1	1059 +/-0.1
Buffalo 4	237 +/-0.1	8 +/-0.1	191 +/-0.1	336 +/-0.4	19 +/-0.5	3790 +/-0.1	76 +/-0.2	516 +/-0.2
Buffalo 5	150 +/-0.3	7 +/-0.2	63 +/-0.1	387 +/-0.3	18 +/-03	2308 +/-0.1	89 +/-0.4	347 +/-0.1
Buffalo 7	341 +/-0.2	7 +/-0.1	299 +/-0.3	139 +/-0.2	18 +/-0.4	5758 +/-0.1	408 +/-0.1	571 +/-0.1
Dodge 4	192 +/-0.2	7 +/-0.2	257 +/-0.2	371 +/-0.5	29 +/-0.4	3206 +/-0.2	116 +/-0.1	291 +/-0.2
Huntsville 3	269 +/-0.2	8 +/-0.1	230 +/-0.7	42 +/-0.4	18 +/-0.1	5075 +/-0.2	154 +/-0.3	97 +/-0.1
Glacial 1	159 +/-0.3	6 +/-0.1	94 +/-0.1	402 +/-0.2	22 +/-0.4	2464 +/-0.2	99 +/-0.2	369 +/-0.4
Green 8	164 +/-0.1	7 +/-0.08	346 +/-0.2	692 +/-0.4	39 +/-0.6	2582 +/-0.2	400 +/-0.1	320 +/-0.2
Zippel 5	259 +/-0.1	7 +/-0.04	197 +/-0.2	592 +/-0.2	932 +/-0.1	3303 +/-0.3	306 +/-0.1	896 +/-0.4

Table 6. Mollisol Characterization Data. All values are averages of three replicates.

Characterization Data										
Sample ID	Mn (mg/kg)	P (mg/kg)	K (mg/kg)	Na (mg/kg)	S (mg/kg)	Zn (mg/kg)	% Silt	% Sand	% Clay	TOC Carbon %
Buffalo 1	77 +/-0.2	8 +/-0.2	152 +/-0.3	109 +/-0.1	96 +/-0.2	1 +/-0.05	32 +/-0.1	38 +/-0.1	29.5 +/-0.7	4 +/-0.1
Buffalo 3	193 +/-0.1	9 +/-0.08	95 +/-0.2	237 +/-0.4	304 +/-0.3	1 +/-0.09	23 +/-0.8	54 +/-0.3	22 +/-0.5	4 +/-0.05
Buffalo 4	140 +/-0.1	12 +/-0.2	81 +/-0.3	79 +/-0.9	28 +/-0.1	1 +/-0.03	17 +/-0.2	60 +/-0.2	23 +/-0.3	2 +/-0.03
Buffalo 5	139 +/-0.1	24 +/-0.2	88 +/-0.1	77 +/-0.5	29 +/-0.1	2 +/-0.05	13 +/-0.1	67 +/-0.1	20 +/-0.2	2 +/-0.03
Buffalo 7	17 +/-0.2	7 +/-0.1	75 +/-0.1	92 +/-0.1	70 +/-0.1	3 +/-0.06	42 +/-0.5	45 +/-0.1	13 +/-1.0	4 +/-0.1
Dodge 4	145 +/-0.1	20 +/-0.8	169 +/-0.3	76 +/-0.7	32 +/-0.2	13 +/-0.1	34 +/-0.2	47 +/-1.0	19 +/-1.0	3 +/-0.1
Huntsville 3	97 +/-0.2	5 +/-0.5	98 +/-0.8	106 +/-0.5	5 +/-0.9	10 +/-0.1	20 +/-0.7	58 +/-0.8	21 +/-0.8	3 +/-0.06
Glacial 1	143 +/-0.3	40 +/-0.1	110 +/-0.2	77 +/-0.2	30 +/-0.1	3 +/-0.1	20 +/-0.3	60 +/-0.2	20 +/-0.2	2 +/-0.1
Green 8	192 +/-0.1	37 +/-0.4	159 +/-0.1	103 +/-0.1	16 +/-0.7	14 +/-0.2	61 +/-0.2	15 +/-0.08	25 +/-0.8	2 +/-0.06
Zippel 5	27 +/-0.4	24 +/-0.4	126+/-0.2	93 +/-0.9	34 +/-2.0	2 +/-0.9	30 +/-3.0	44 +/-1.0	26 +/-1.0	1 +/-0.08

Table 7. Mollisol Characterization Data continued. All values are averages of three replicates.

Characterization Data						
Sample ID	NH4-N (mg/kg)	Cl- (mg/kg)	NO3 (mg/kg)	No2 (mg/kg)	Ortho-PO4-2 (mg/kg)	SO4-2 (mg/kg)
Buffalo 1	19 +/-0.5	13 +/-0.1	5 +/-0.6			86 +/-0.2
Buffalo 3	18 +/-0.2	18 +/-0.2	8 +/-0.1			540 +/-0.2
Buffalo 4	17 +/-0.2	18 +/-0.5	7 +/-0.5			6 +/-0.5
Buffalo 5	16 +/-0.1	17 +/-0.3	2 +/-0.2			5 +/-0.2
Buffalo 7	19 +/-0.4	13 +/-0.2	5 +/-0.1			55 +/-0.1
Dodge 4	17 +/-0.7	19 +/-0.6	20 +/-0.3		1 +/-0.1	8 +/-0.1
Huntsville 3	3 +/-0.6	23 +/-1.0				6 +/-0.6
Glacial 1	17 +/-0.2	18 +/-1.0	4 +/-0.4	1 +/-0.1	1 +/-0.1	5 +/-0.2
Green 8	6 +/-0.3	24 +/-0.3	44 +/-1.0		1 +/-0.1	68 +/-0.2
Zippel 5	18 +/-0.5	23 +/-0.8	4 +/-1.0			19 +/-0.2

Table 8. Mollisol Characterization Data Continued. All values are averages of three replicates.

1.3 Characterization and Lab Data for the Ultisols.10 Ultisol soils selected and analyzed for this research in the Sample ID. The characterization data are the averages of 3 reps.

Order: Ultisols			
	Taxonomic Information		
Sample ID	**Sub Order**	**Sub Group**	**Great Group**
Dismal 1	Endoaquults	Typic	Thermic
Dismal 5	Paleaquults	Typic	Thermic
Holmes 3	Hapludults	Typic	Thermic
Laurel Hill 3	Endoaquults	Typic	Mesic
Laurel Hill 4	Endoaquults	Aeric	Mesic
Morrow 1	Hapludults	Aquic	Thermic
Morrow 3	Kanhapludults	Typic	Thermic
Suseque 3	Hapludults	Typic	Mesic
Woodlake 1	Hapludults	Aquic	Thermic
Woodlake 2	Kanhapludults	Arenic	Thermic

Table 9. Ultisol Orders soil samples with taxonomy information.

Characterization Data								
Sample ID	CEC (cmolc/kg)	pH (H2O)	EC (uS/cm)	Al (mg/kg)	Ba (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)
Dismal 1	8 +/-0.6	3 +/-0.02	129 +/-3.0	1268 +/-1.0	11 +/-0.2	58 +/-3.0	255 +/-2.0	22.5 +/-0.4
Dismal 5	16 +/-0.2	4 +/-0.05	127 +/-2.0	932 +/-1.0	17 +/-0.2	174 +/-2.0	268 +/-3.0	44 +/-1.0
Holmes 3	18 +/-0.3	5 +/-0.05	43 +/-0.3	358 +/-1.0	21 +/-0.4	129 +/-2.0	66 +/-1.0	84 +/-2.0
Laurel Hill 3	9 +/-0.4	3.5 +/-0.02	79 +/-1.0	1915 +/-3.0	17 +/-0.3	56 +/-2.0	343 +/-3.0	24 +/-1.0
Laurel Hill 4	32 +/-0.7	4 +/-0.05	74 +/-2.0	1135 +/-1.0	17 +/-0.4	497 +/-1.0	247 +/-2.0	43 +/-1.0
Morrow 1	47 +/-0.8	4 +/-0.03	120 +/-2.0	689 +/-1.0	18 +/-0.3	588 +/-1.0	244 +/-0.7	170 +/-3.0
Morrow 3	26 +/-0.5	4 +/-0.01	111 +/-3.0	1017 +/-2.0	11 +/-0.1	307 +/-3.0	94 +/-2.0	79 +/-1.0
Suseque 3	26 +/-0.5	5 +/-0.07	94 +/-0.5	883 +/-1.0	17 +/-0.4	350 +/-1.0	185 +/-1.0	71 +/-1.0
Woodlake 1	7 +/-0.4	5 +/-0.05	81 +/-2.0	758 +/-1.0	3 +/-0.1	88 +/-2.0	91 +/-0.9	11 +/-0.8
Woodlake 2	3 +/-0.2	4 +/-0.02	132 +/-2.0	611 +/-1.0	1 +/-0.08	20 +/-2.0	150 +/-3.0	8 +/-0.6

Table 10. Ultisols Characterization Data. All values are averages of three replicates.

Characterization Data										
Sample ID	Mn (mg/kg)	P (mg/kg)	K (mg/kg)	Na (mg/kg)	S (mg/kg)	Zn (mg/kg)	% Silt	% Sand	% Clay	TOC Carbon %
Dismal 1		10 +/-0.6	41 +/-0.1	43 +/-0.1	23 +/-0.7	1 +/-0.1	40 +/-0.6	39 +/-0.08	20 +/-0.5	3 +/-0.3
Dismal 5		15 +/-0.4	35 +/-0.5	52 +/-0.6	19 +/-0.3	1 +/-0.1	21 +/-0.9	56 +/-0.1	23 +/-0.09	2 +/-0.08
Holmes 3	33 +/-0.1	4 +/-0.06	40 +/-0.1	65 +/-1.0	8 +/-0.2	4 +/-0.3	18 +/-2.0	72 +/-0.2	10 +/-2.0	
Laurel Hill 3	26 +/-0.9	7 +/-0.2	101 +/-3.0	39 +/-1.0	39 +/-1.0	3 +/-0.2	54 +/-1.0	5 +/-0.05	41 +/-1.0	4 +/-0.01
Laurel Hill 4	73 +/-0.3	8 +/-0.4	77 +/-0.2	37.5 +/-0.1	24 +/-0.1	5 +/-0.3	57 +/-0.2	10 +/-0.3	33 +/-1.0	2 +/-0.2
Morrow 1	161 +/-0.2	5 +/-0.09	52 +/-0.2	39 +/-0.1	14 +/-0.1	2 +/-0.02	68 +/-1.0	14 +/-0.1	19 +/-1.0	2 +/-0.2
Morrow 3	65 +/-2.0	4 +/-0.2	86 +/-1.0	31 +/-0.7	49 +/-0.9	1 +/-0.06	51 +/-1.0	5 +/-0.1	44 +/-0.8	1 +/-0.05
Suseque 3	51 +/-0.4	89 +/-1.0	33 +/-0.6	32 +/-0.2	11 +/-0.8	2 +/-0.1	33 +/-1.0	52 +/-0.2	16 +/-0.9	1 +/-0.01
Woodlake 1	21 +/-0.7	7 +/-0.2	19 +/-1.0	27 +/-0.3	10 +/-0.6	1 +/-0.07	30 +/-1.0	49 +/-0.2	21 +/-0.2	1 +/-0.03
Woodlake 2	1 +/-0.1	6 +/-0.4	21 +/-0.2	28 +/-0.2	16 +/-0.3	1 +/-0.1	19 +/-1.0	48 +/-0.1	33 +/-0.2	2 +/-0.4

Table 11. Ultisols Characterization Data Continued. All values are averages of three replicates.

Characterization Data				
Sample ID	NH4-N (mg/kg)	Cl- (mg/kg)	NO3 (mg/kg)	SO4-2 (mg/kg)
Dismal 1	10 +/-0.7	10 +/-1.0	4 +/-0.2	9 +/-1.0
Dismal 5	13 +/-0.7	9 +/-1.0	7 +/-0.1	14 +/-0.01
Holmes 3	3 +/-0.1	16 +/-0.1	1 +/-0.2	10 +/-2.0
Laurel Hill 3	18 +/-1.0	9 +/-0.1		16 +/-2.0
Laurel Hill 4	17 +/-1.0	6 +/-0.4	3 +/-0.1	10 +/-0.7
Morrow 1	11 +/-1.0	5 +/-0.3		10 +/-0.6
Morrow 3	11 +/-0.7	8 +/-1.0		28 +/-0.4
Suseque 3	9 +/-0.2	4 +/-0.1	15 +/-0.2	2 +/-0.05
Woodlake 1	8 +/-0.9	7 +/-1.0	2 +/-0.2	4 +/-0.9
Woodlake 2	9 +/-0.8	8 +/-1.0		11 +/-0.5

Table 12. Ultisols Characterization Data Continued. All values are averages of three replicates.

2.1 PCA scores and loadings plots for all three soil orders.

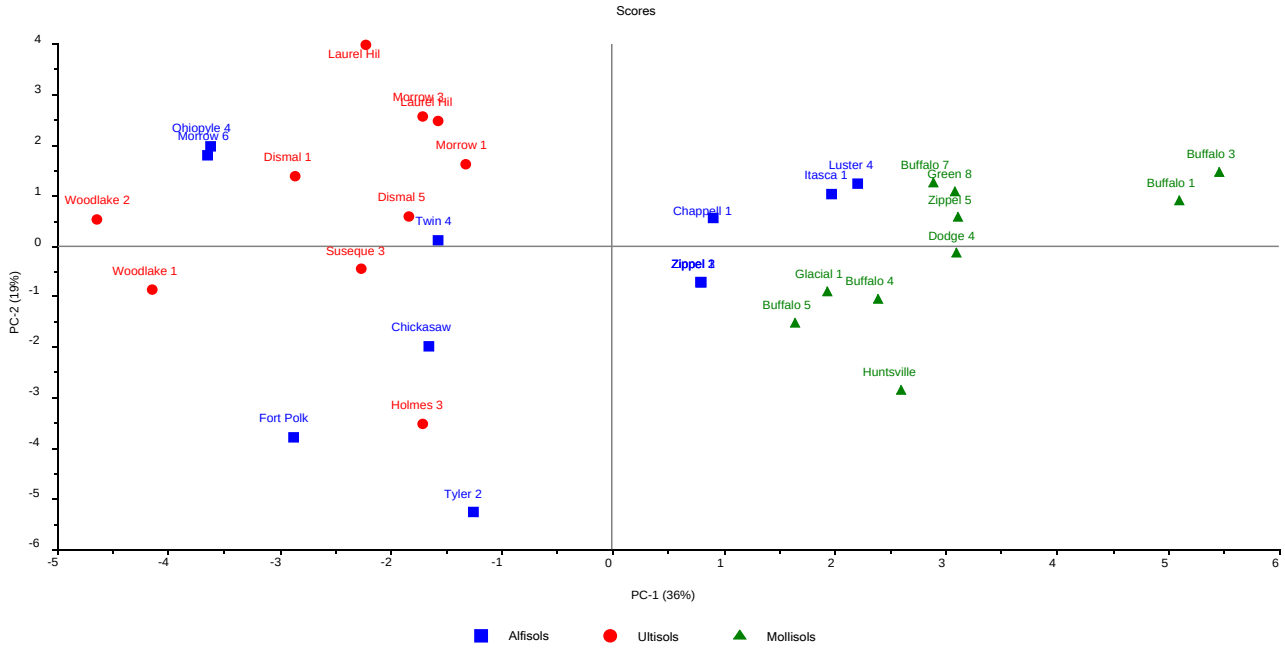

Figure 7. Scores plot from PCA describing the 10 soil samples from each soil order which are color coordinated. Alfisols are in blue, Mollisols are in green, and Ultisols are in red. Notice that the Mollisols and Ultisols are grouped together on opposites sides of the plot just as they are located on opposite sides of the United States geographically.

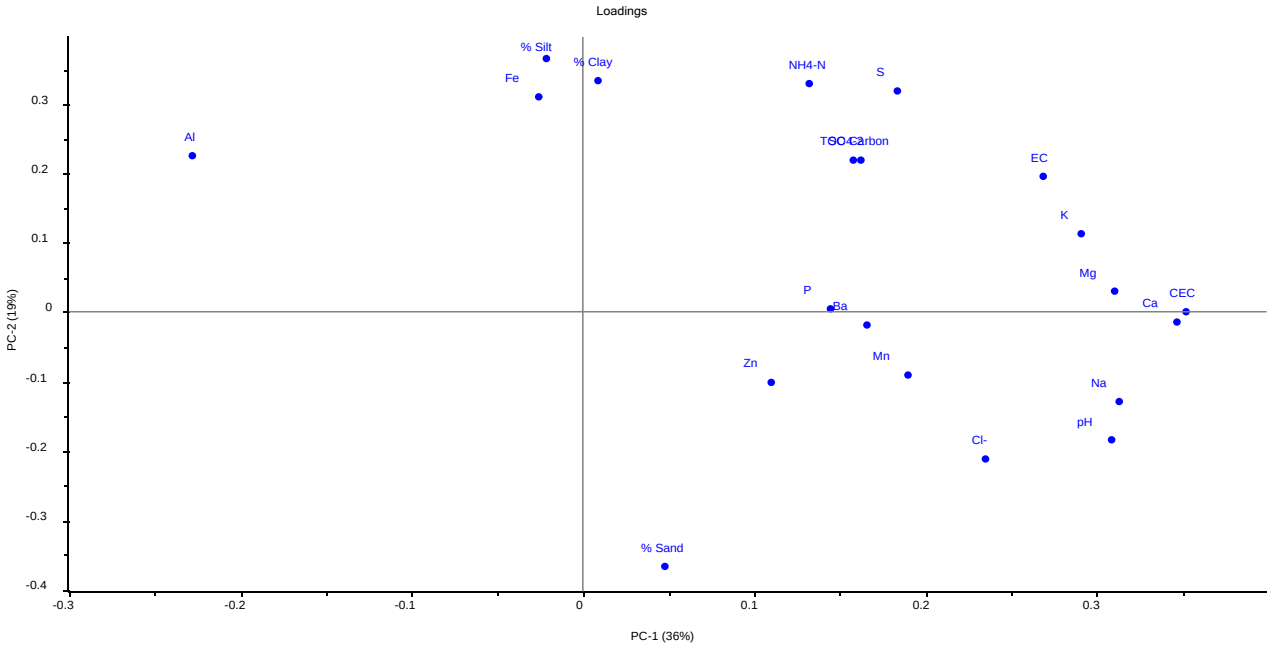

Figure 8. Loadings plot from PCA describing the soil properties from the characterization data averages that influence each soil order. If you were to lay this plot on top of the scores plot above, you see that most of the properties influence the Mollisols and separate them out from the other soil orders.

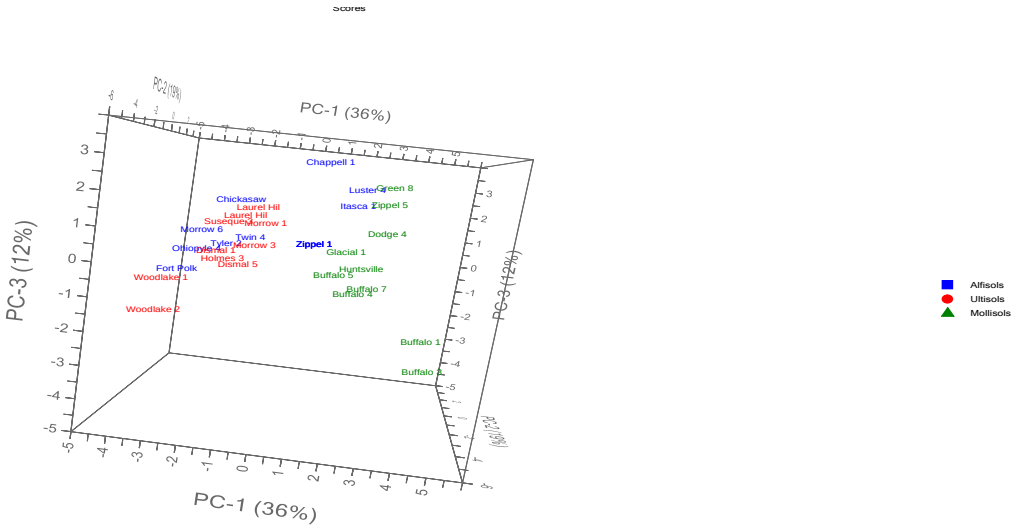

Figure 9. A 3-D scatter plot of the scores plot in Figure 7 showing PC-1, PC-2, and PC-3. The 3-D plot describes the complete separation more precisely between the Mollisols and Ultisols which are opposite completely in several physical and chemical properties.

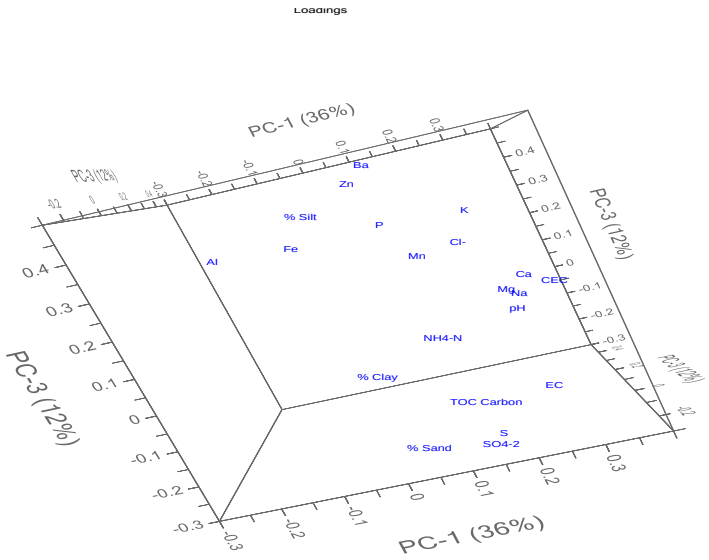

Figure 10. A 3-D scatter plot of the loadings plot from Figure 8 showing the soil properties that influence which soil order the most.

2.2 Partial Lease Square (PLS) scores and loadings plots for all three soil orders describing the separation of each soil and which soil properties influence that separation between the soil orders.

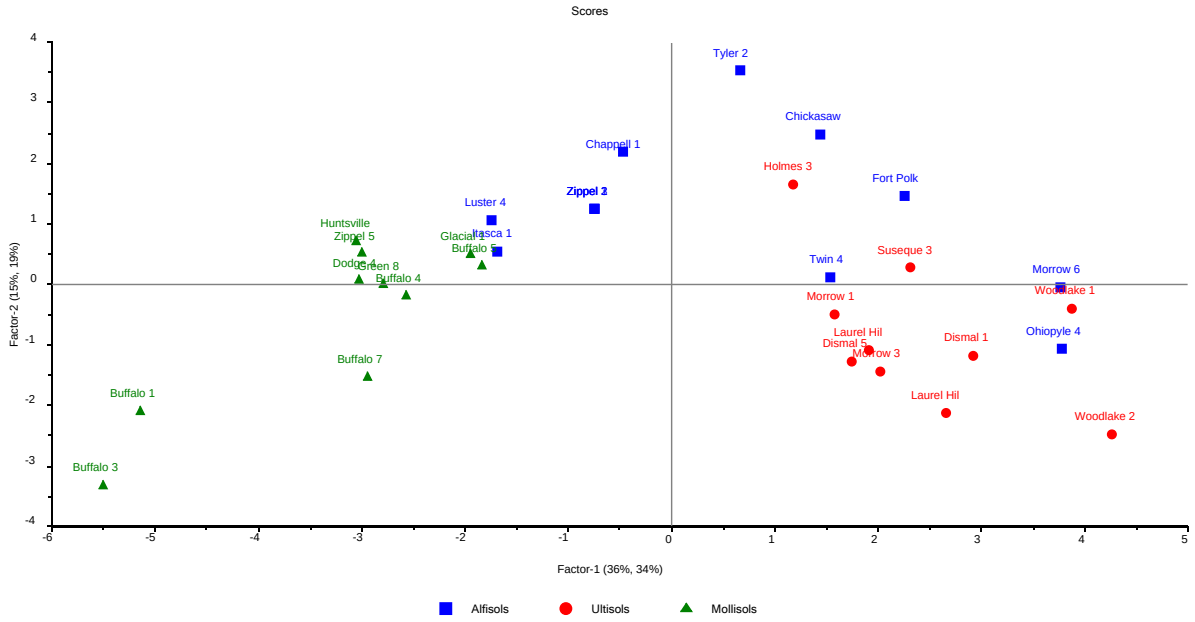

Figure 11. The scores plot from the PLS showing the three soil orders separation.

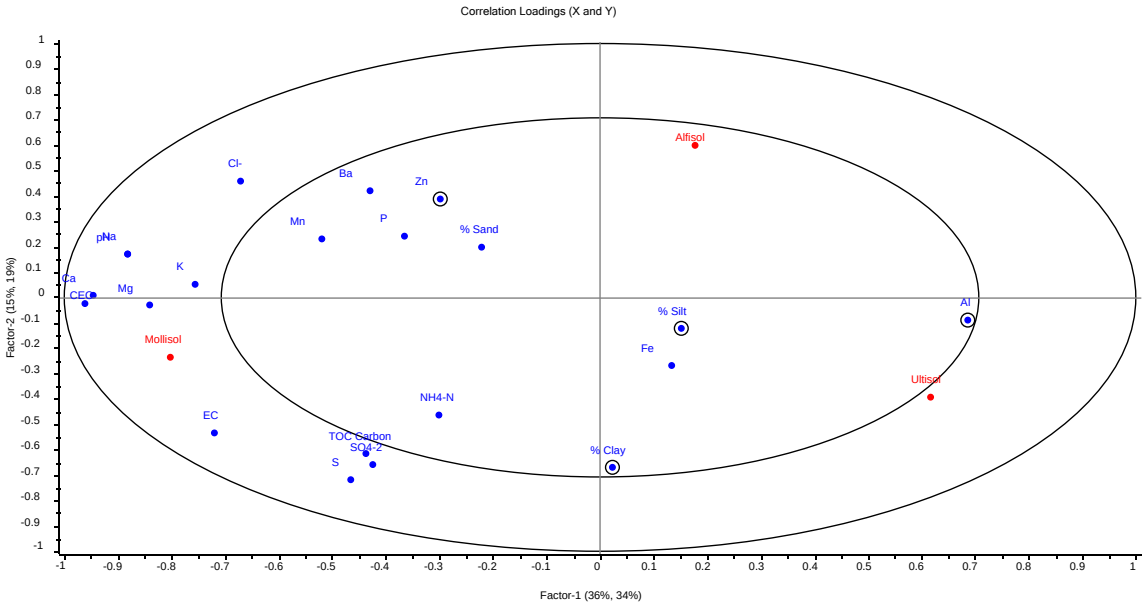

Figure 12. The correlation loadings plot from the PLS matching the scores plot in Figure 11 with the location of the soil order. Again notice the separation between the three soil orders matches their geographical location with the NCRS system in the United States. The soil properties that were characterized with this dataset dominantly surround and influence the Mollisols.

Discussion

The significance of the findings in this research is that we have shown that soil taxonomy can be linked to its chemical and physical properties to help determine soil processes. Using the PCA models, we proved that each soil order is clustered on different parts of the plot and the variables influence the groupings of the plots. Within the final models, we are able to geochemically distinguish soils through the latent structure based on taxonomically distinct orders. In Figure 7, we see that the Ultisols and the Mollisols were completely opposite of each other on the plots. Thinking solely about the physical difference between the two like soil structure and color, proved this separation to be correct. Mollisols are a more thick dark organic soil, as seen in the picture in figure 4, rich in C, and Ultisols are a light soil with less organic

matter. The PCA data also shows that the Alfisols are between the Ultisols and the Mollisols; which makes sense based on the geographical location and the properties of the Alfisol order. Alfisols are similar to both Mollisols and Ultisols in properties, yet not as extremely different as the other two are from each other. The PLS scores plot in Figure 11 shows accurate separation between the soil orders as well, and how the Mollisols and Ultisols differ from each other more so than the Alfisols. A correlation loadings plot of the PLS in Figure 12 shows the soil properties that influence each soil order and displays the Y values (soil orders) in red describing which properties from the dataset effect which soil order the most.

The scores and loadings plots for all of the soil orders combined reveal the chemical and physical soil properties on the loadings plots that influence each order on the scores plots. This data reveals that taxonomy can be used to distinguish what chemical and physical properties influence a soil order, and which soil orders are opposite from each other in properties. There is overlapping of some Alfisols with Mollisols and Ultisols on the scores plots which suggests that that those particular Alfisol samples are similar to the soil properties of other orders it overlaps with. Not all soil properties were analyzed due to time and expense, so these models provide a general basis and beginning of this type of research. However, the properties that were tested show that this method and research concept can work and may be suitable for future intensive research. Only a few physical and chemical properties of soils were analyzed, and no biological soil properties were tested. This implies that unless all of the soil properties are tested and used for these models, sufficient claims about which soil properties influence which order cannot be obtained. However, the separations between the orders show evidence of a successful building block for this research. The Alfisols are a problem with overlapping because if you recall the soil map they are geographically overlapping other soil orders within the United States. Finally, the

models of all three soil orders together shows that there is a significant difference in the orders as each soil order groups together based on their soil properties.

Conclusions

Soil taxonomy can be used to discriminate soils from each other based on their properties. Although this research is a basis for future research, the few soil properties experimented with for three different soil orders showed great separation and influence to each soil order. The Mollisols were influenced mostly by CEC, Ca, K, Mg, TOC Carbon%, and other chemical elements from the characterization dataset according to the PCA data. Evidence of this result is logical because Mollisols are a soil that contain the most organic matter and are the best soil for crop growth (Young and Hammer, 1996).

Figure 1 of the United States soil orders map corresponds with the scores plots from the PCA data in regards to the Mollisols being on opposite sides of the Ultisols, and the Alfisols in between them and overlapping periodically. The Ultisols did not seem to have many soil properties analyzed in this experiment that influenced their structure on the score plots. Aluminum (Al) on the loadings plots in Figures 8, 10, and 12 seemed to be a major property that influenced some Ultisols. Also, the scores plots for the Ultisols and the Alfisols revealed that the samples ranged from top to bottom of the graphs. A reasonable explanation for this would be the climate region in the U.S. from which these samples were collected. The Great Groups in the taxonomy data tables provides an idea of the location regarding the temperature. Frigid soils are soils from a colder region from up north, and mesic and thermic Great Groups are soils from a humid warmer region. The Ultisols were collected in different ranges alongside the east coast from North Carolina to Pennsylvania, and the Alfisols were collected from scattered locations

from Texas to Pennsylvania to Minnesota. This possibly describes the range in the separation of these soil orders on the scores plots.

The experimental design, research, and statistical analysis completed in this project supports the conclusion that soil taxonomy can be used to make predictions about soil properties and environmental responses. Future studies and experiments can be added to this research project to further investigate soil taxonomy and discriminate soil properties and reactions. The ultimate goal is to be able to use PCA and other statistical analyses to discriminate soil taxonomy based on the chemical, physical, and biological properties, and to further make predictions about a specific taxonomically distinct soil's environmental responses. Predictions about a soil's fate and transport of water and contaminates, degradation, sorption properties, fertility, field capacity and other responses will be able to be made. The use of this would be beneficial for people within the army and military, farmers, animals, plants, marine life, and the environment. This research proves that with a small dataset of soil properties that soil taxonomy can be discriminated and results can be accurately perceived, and a base for further research has been established.

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