To the Graduate Council:

I am submitting herewith a thesis written by Ryan Hudson Blair entitled "Classification and Fertility of Soils in the Big South Fork National River and Recreation Area Based on Landscape Position and Geology." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental and Soil Science.

John T. Ammons, Major Professor

We have read this thesis
and recommend its acceptance:

Michael Essington____

Amy Johnson________

Robert Freeland______

Accepted for the Council:

Carolyn R. Hodges_____________________
Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Classification and Fertility of Soils in the Big South Fork National River and Recreation Area Based on Landscape Position and Geology

A Thesis

Presented for the

Masters of Science

Degree

The University of Tennessee, Knoxville

Ryan H. Blair

May 2010

Acknowledgments

The author would like to thank the College of Agriculture and Natural Resources and the Department of Biosystems Engineering and Soil Science for their support in providing the opportunity to pursue graduate studies at The University of Tennessee in Knoxville.

A special thanks is extended to Dr. John T. Ammons for serving as the major professor and for providing direction and moral support to the author throughout the research process.

Thanks is offered to the members of the author's graduate committee, Dr. Michael Essington, Dr. Amy Johnson, and Dr. Robert Freeland for their help and words of encouragement.

The author would also like to thank Brian Lester, Cassi Jones, and Stephen Holland for their help in the field and in the laboratory.

Appreciation is extended to Steve Bakaletz of the National Park Service for assisting in site location.

Finally, a special word of thanks is offered to the author's parents, Ron and Nancy, brother, Reece, and fiancée Shannon Walker, for their unending love and support over the years.

Abstract

The Big South Fork National River and Recreation Area encompasses more than 50,585 hectares (125,000 acres) of the Cumberland Plateau along the border of Tennessee and Kentucky. Highly dissected and steep terrain have made accessibility to much of the park limited, thus little work has been done to investigate the formation of these soils. Seven native soil profiles were selected for chemical and physical analysis representing Pennsylvanian-aged acidic sandstone and shale geology and landforms. The objectives of this study included the characterization of selected native profiles by physical and chemical analysis, as well as classification using US Soil Taxonomy, to determine baseline soil fertility through chemical analysis, to provide fertilizer recommendations for Bicolor Lespedeza (*Lespedeza bicolor*) to be grown as wildlife food plots. The parent materials and site- specific geology, including the Pennington Formation, were compared to the profiles in order to establish any relationships that might exist. The methods of chemical analysis included: total carbon analysis, cation exchange capacity, percent base saturation, pH, particle size analysis, KCl total acidity, total elemental analysis and Mehlich I extraction. From the data, soils examined from an upland summit have the lowest Mehlich I extractable phosphorus (M1P) ranging from 0.8-3.14 mg kg^{-1}, and this soil was classified as a Typic Hapludult. Soils examined on backslopes and sideslopes had M1P values ranging from 0.3-11.53 mg kg^{-1} and these soils were classified as either Lithic Dystrudepts or Typic Dystrudepts. The footslope soils examined have M1P values ranging from 1.95-19.79 mg kg^{-1} and were classified as Typic Hapludults. Floodplain soils had M1P values from 7.69-56.85 mg kg^{-1} and were classified as Fluventic Dystrudepts. Landscape position and parent material play major roles in the formation of soils, and their degree of weathering controls

the amount of plant available nutrients. Using geologic and topographic maps for comparison, it was concluded that the development of these soils was directly related to the underlying geology and the surrounding topography throughout various landscapes. This information can be used as a guide to aid in predicting the chemical and physical properties of native soils on the Cumberland Plateau.

TABLE OF CONTENTS

List of Tables

List of Figures

Introduction

Overview of Native Soil Formation and Fertility in the Big South Fork National River and Recreation Area

Introduction

The Big South Fork National River and Recreational Area (BSFNRRA) makes up more than 50,585 hectares (125,000 acres) of the Upper Cumberland Plateau. The park is located in Scott, Pickett, and Fentress Counties of northern Tennessee and in McCreary County of southern Kentucky. In 1974, congress established this area as a National Park to ensure that this area would be preserved and managed in a way that would allow visitors to come and enjoy the beauty of nature at its best. The BSFNRRA has a long history and significance to the surrounding communities. Native American Indians once used this area to hunt game and used the many natural rock shelters for overnight stays and dry storage. This area was also home to the English Community of Rugby. This community determined that the land was not fertile enough to grow the crops needed for their sustenance. During the time of the Industrial Revolution, what is now the BSFNRRA was dotted with coal mining camps along the Big South Fork River as steam engines fueled by coal became the popular energy source for the growing country. Now this area of the Cumberland Plateau is a public oasis for families and friends to visit having recreational options of back-county camping, horseback riding, canoeing, hiking, hunting, fishing, and many other outdoor activities.

The soils forming in the Upper Cumberland Plateau and in the BSFNRRA form mainly from alluvium, residuum, or colluvium derived from Pennsylvanian Sandstone with interbedded layers of siltstone and shale. Landforms and the position on these landforms dictate the nature of development among each soil. Depending on the soil's location along the landscape, (upland summit, backslope, sideslope, footslope, or floodplain), the five soil forming factors have different degrees of influence based on parent material, slope steepness, etc. More stale landscapes such as summits and footslopes allow soils to develop argillic horizons because the soil is in place longer and has sufficient time to weather and allow for clays to migrate and accumulate. Due to the steepness of the sideslopes and backslopes of this area, it is typical to find shallow Inceptisols forming from residuum derived from sandstone. These soils are subject to erosion and surface creep that is constantly translocating the soil material down slope, depositing more soil on the footslope or being washed away when it meets one of the many creeks or rivers. Because the soils in these positions are frequently being moved, there is no accumulation of clay; therefore, cambic horizons form in these morphologically young soils. Floodplains of the Big South Fork River (BSF) and throughout the Upper Cumberland Plateau are active with periods of high and fast waters. The reasons for this are shallow depth to bedrock, the steepness of the valley walls, and the narrow valley floors and river channels. Because of the activity of the floodplains, sediment is eroded away and re-deposited with heavy rain events. These narrow floodplains form Fluventic Dystrudepts with stratified horizons containing varying percentages of sand, silt, and clay and have an irregular melanization curve where organic carbon does not decrease consistently throughout the profile with increase in depth.

Seven profiles of native soils that represent the various landforms and landscape positions mentioned above were sampled and analyzed for their chemical and physical features. From the data collected, it is now possible to predict what soil type will be forming on the different landscape positions. Because of the stratigraphy of the Cumberland Plateau and the BSFNRRA, soils forming on the same landscape at different elevations will show similar morphology patterns in their profiles. For example, argillic horizons are to be expected on stable landforms such as summits and footslopes, but the chemical properties will differ to some degree. Soils forming on or below a siltstone or shale formation have finer particle sizes with higher Cation Exchange Capacity (CEC) values and base activity; as where soils forming on cemented sandstone have higher sand content with fewer base cations and lower pH's. The Pennington Formation containing interbedded limestone, dolomite, argillaceous sandstone, dusky-red and grayish-olive mudstone, and minor shaly coal is present in the BSFNRRA. This formation provides higher levels of base cations which effect the classification of certain soils. The soils forming in a footslope just below the Pennington Formation were found to be high base status Ultisols, where as most all of the other soils with argillic horizons throughout this area are low base content Ultisols. Chapter 1 creates a model showing that Ultisols form on stable summits and footslopes, Inceptisols form on the steeper backslopes and sideslopes, and Inceptisols also form on the floodplains. This material can be used by resource planners and park employees to develop maps using topography and geology maps to further understand what soils are present and how to better manage the land on a site-specific basis.

Soil fertility across the Upper Cumberland Plateau in the area of the BSFNRRA is very low. This is evidenced by the lack of row crops and rugged timber growing here. Some vegetables, such as green beans, successfully grow here because of the cool evenings and length of growing season; however, production requires extensive management including lime and fertilizer additions. The reason for this is that the parent material simply does not have the amounts of essential elements needed for most crop production. Slope steepness and shallow soils in many areas also limits crop production.

One of the uses that come with being a National River and Recreational Area is that this land is open to the public during most hunting seasons. Hunters here are able to pursue white tail deer, black bear, feral hogs, turkey, and squirrel, along with many other game species. While the hunting here is good due to the remoteness of this land, wildlife managers within the Park Service could improve hunting by growing healthy wildlife food plots such as Bicolor Lespedeza (*Lespedeza Bicolor*). These plots would both provide nutrient-rich food and cover for the wild game and provide centralized feeding and bedding areas for hunters to use to their advantage when going after game.

For the implementation of healthy food plots, it is necessary to evaluate the chemical properties of the soils to determine what elements are limited and the amount of needed elements to be applied. Data showing the levels of plant available elements that were present at each site was collected using a double acid extraction termed the Mehlich I procedure. Total elemental analysis was performed using a modified hydrofluoric acid microwave digestion technique. These data were used to determine how much reserve or potentially available elements were present. With this and other data collected from the seven native soils discussed above, fertilizer and lime requirements can be calculated to maximize yield of Bicolor Lespedeza and improve wildlife management.

Because Bicolor Lespedeza is a legume, nitrogen fertilizer does not have to be applied. The most limiting nutrients for growing this crop are phosphorus and potassium. In Chapter 2, phosphate and potash recommendations along with lime recommendations based on laboratory data were made for these seven sites, representing the various landscape positions found in the BSFNRRA. Bicolor Lespedeza is used as an example for recommendations because wildlife food plot implementation is important in wildlife conservation.

Chapter 1

Chemical and Physical Characterization and Classification of Selected Native Soil Profiles in the Big South Fork National River and Recreation Area

Chapter 1

Chemical and Physical Characterization and Classification of Selected Native Soil Profiles in the Big South Fork National River and Recreation Area

Introduction

Located on the Cumberland Plateau about 160 km northwest of Knoxville, Tennessee, the Big South Fork National River and Recreation Area (BSFNRRA) encompasses more than 50,585 hectares along the border of Tennessee and into Kentucky. Big South Fork is a geological and historical area filled with river gorges carved by eons of erosion, historic homesteads reserving the determined spirit of the settlers of the area, and inspiring rock shelters and sandstone arches.

Formed by the confluence of the New River and the Clear Fork, the Big South Fork of the Cumberland River (called Big South Fork River for short) is a major tributary of the Cumberland River, which is itself a tributary of the Ohio River. The Cumberland River watershed is a 46,620 km^2 region that stretches from the western slope of the Appalachian Mountains to the mouth of the Ohio River. Because the Big South Fork gathers runoff from an extensive area lying more than 304 m in elevation, it has a steep gradient and plenty of flow. Long stretches of the river are sufficiently constricted, steep, and rapid-filled (Finegan, 2008).

Human occupancy in this area can be traced back to around 12,000 years BP when groups of nomadic Native Americans would travel through the Cumberland Plateau as hunters and gatherers. The Big South Fork area provided many species of wild game and grew plants that the natives found beneficial. Around 1,000 years BP, these natives moved out of the area due to the invention of farming techniques. Without modern fertilizing practices, the soils of the

Plateau are not suitable for farming and the natives moved to the more fertile river valleys where crops could be grown. Although the natives moved away, they still frequented the area to hunt game. History does not provide us with the name of these nomadic natives, but by the late 1700's Cherokee people were known to live in this area (National Park Services Staff, 2008).

By 1810, pioneer settlers came to the Upper Cumberland Plateau in the area of the Big South Fork and the Cumberland River. These pioneers are credited with developing the first communities as they worked the numerous saltpeter mines (dating around 1813-1860) found throughout the area. Post Civil War, timber and coal harvesting took over and then oil and gas resources began development (National Park Service Staff, 2008).

The reason Congress establishing the Big South Fork NRRA in 1974 was to preserve the evidence and remains of these past cultures and people while at the same time providing visitors with numerous outdoor activities (Finegan, 2008).

The Big South Fork NRRA is located in a humid climatic region, typified by mild winters and moist warm to hot summers. Storm systems typically bring heavy rains from December through March, which may cause flooding. Summer thunderstorms are common. Winter snowfall occurs intermittently in the area and averages 43.18 cm per year.

Seven soil profiles were selected in the Big South Fork NRRA for study and characterization of their native properties. The sites were located in Scott, Fentress, and Pickett counties of Northeastern Tennessee, and McCreary County of southern Kentucky, Figure 1. The objectives of this study were first to characterize selected soil profiles with physical and chemical analysis and classify these soils using the US Soil Taxonomy, and secondly to develop any comparison between these soil profiles with parent materials and local geology, Figure 2.

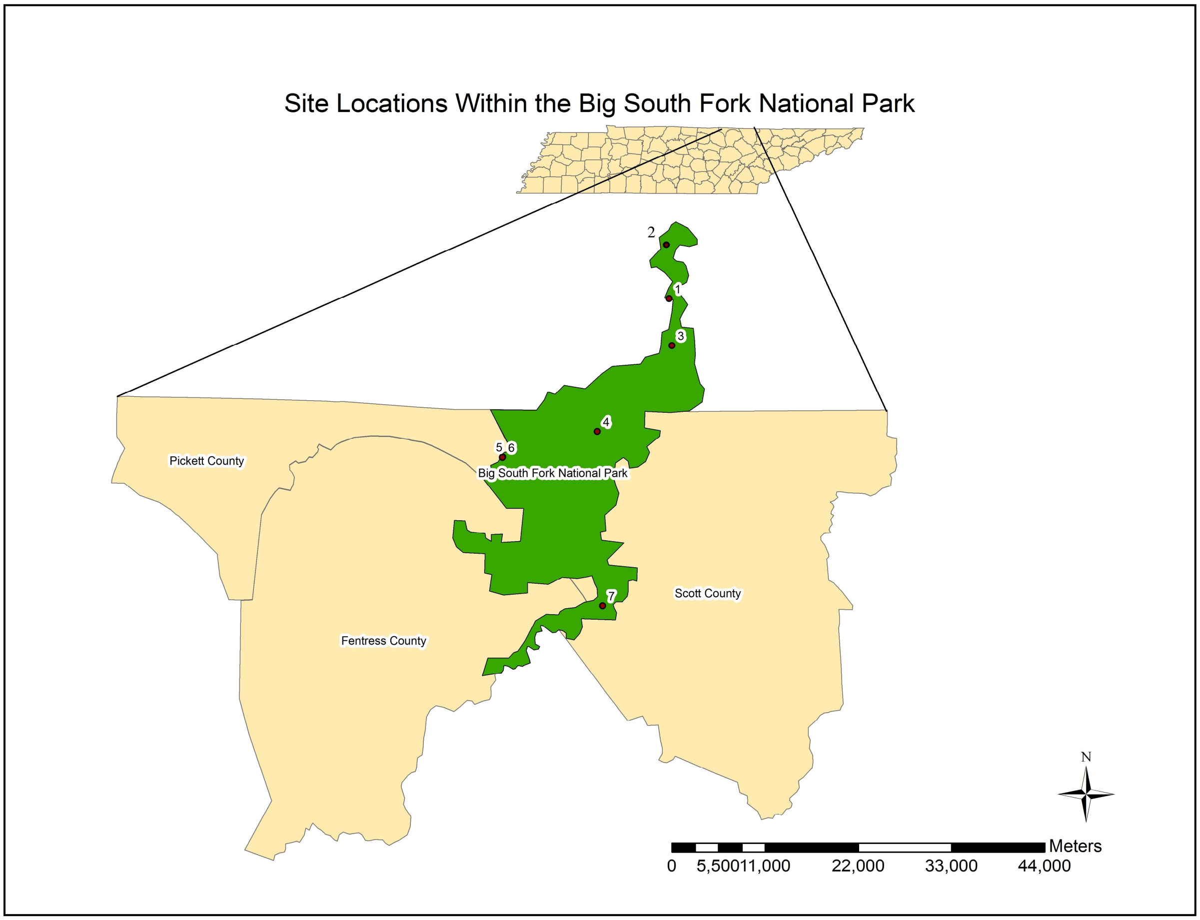


Figure 1. Location of soil pedons sampled from the Big South Fork National River and Recreational Area

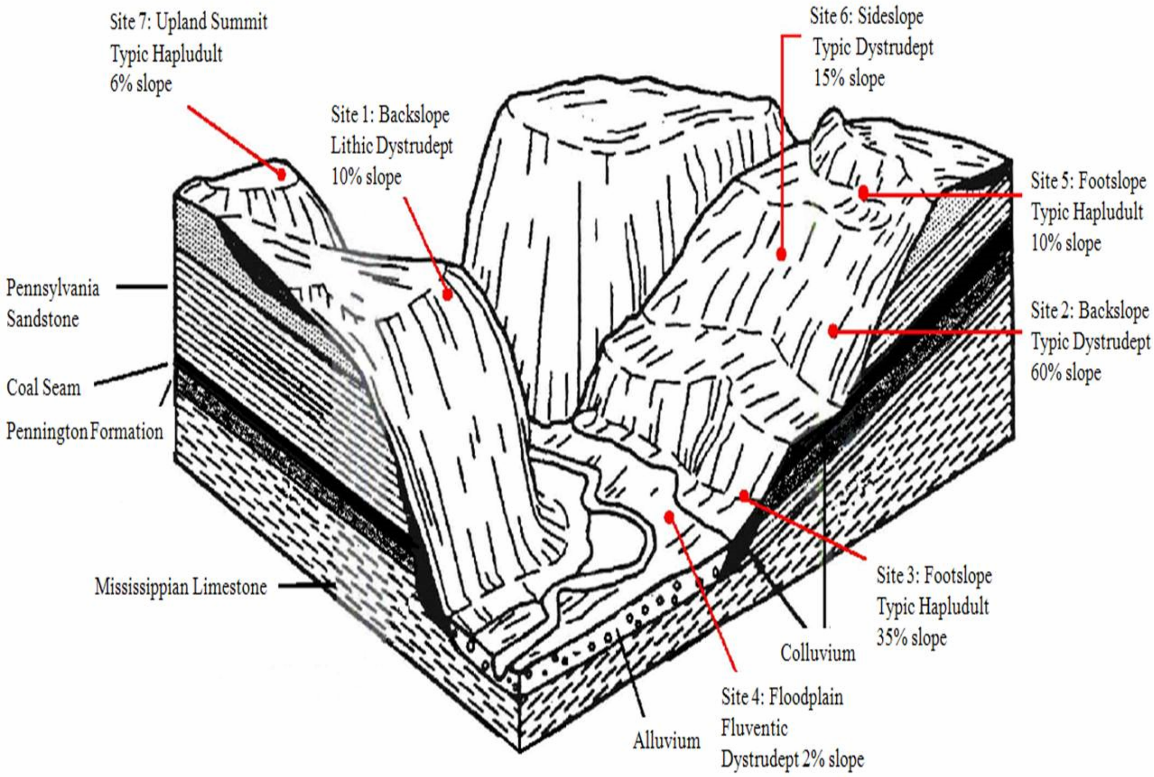


Figure 2. Site position on landscape

Literature Review

Soil Genesis

Dokuchaev considered the soil as a natural body having its own genesis and its own history of development, a body with complex and multiform processes taking place within it (Krasil'nikov, 1958). Soil is considered as differing from bedrock. The latter becomes soil under the influence of a series of soil forming factors. According to Dokuchaev, soil should be called the daily or outward horizons of rocks regardless of the type; it is changed naturally by the common effect of water, air and various kinds of living and dead organisms (Krasil'nikov, 1958). Variations in development depend on the five soil forming factors: climate, time, parent material, topography, and biotic factors (Jenny, 1941). These five factors work simultaneously and to differing degrees to influence the intensity of soil development.

Climate comprises the meteorological conditions which surround the soil system (temperature, rainfall, humidity, etc.), and is consistent with the concept of regional climate. The real soil climate (pedoclimate) depends both on regional climate and unique features of the soil, such as depth, color, texture, and its position on the landscape (Certini, 2007).

Time is based on the amount of time that has passed since the parent material first began to be influenced by the soil forming factors. Time-zero usually occurs directly after a major event such as a landslide, earthquake, volcano, flood, or some other catastrophic event (Brady, 1984; Batjes, 1995). Upland soils may have been developing for thousands of years, while soils along a floodplain may be of recent deposition (Springer and Elder, 1980). Soils also form and evolve as a weathering profile lowers into and disrupts underlying bedrock (Frazier and Graham, 2000).

Parent material is the material from which soil forms, namely hard rock, unconsolidated sediment, or organic remnants. For a soil that is reforming after severe disturbances or major climate change, the parent material is the soil that was present at the beginning of the new state factor assemblage (Certini, 2007). The mineral composition of the parent material determines its resistance to weathering. Texture and the type of clay present in the soil are determined by the parent material. Texture influences the movement of water through the soil and the erodibility of the soil (Birkeland, 1984).

Topography involves the size, shape, and position of the land surface as well as relief and aspect. These attributes mediate how the regional climate, such as solar radiation, precipitation, and wind affect soil formation. From a pedologic perspective, topography is important because it exerts a strong influence on the disposition of energy and matter experienced by soils on the landscape (Certini, 2007). Local landform has a major impact on soils by controlling water and sediment movement (McKenzie and Ryan, 1999).

Geologic mapping of 7.5-min quadrangles in Kentucky since 1960 and a slope stability reconnaissance study throughout the Appalachian Plateau since 1974 have provided abundant new data on the structure, stratigraphy, and geomorphology of the entire NRRA. These studies show that bedrock units vary in lithology and thickness through the region and that the topography varies directly with the stratigraphy. The terrain can be divided into geomorphic units that reflect bedrock control of geomorphic processes (Newell, 1978). During landslide studies of the region, it was found that landforms are controlled by bedrock lithology and are modified by landsliding. Streams function mainly too carry away the debris from landslides (Outerbridge, 1987). The type and abundance of landslides and the slope on which they lie are controlled by bedrock (Outerbridge, 1980).

The biotic potential was defined by Jenny (1941) as the independent factor represented by the biota of the system, namely the microbial, plant, and animal gene flux that enters the system from the surroundings. Soil biota has a major effect on development by mixing the soil, recycling nutrients, increasing organic matter, and increasing structural stability (Springer and Elder, 1980). Vegetative cover influences soil development as well due to the elements contained in the leaves and stems. Most soils developed in forested environments are acidic, where as, grassland soils have a higher cation exchange capacity than forest soils. Vegetation is also an erosion buffer that affects soil depth and the level of exposed soil to the forming factors (Brady, 1984).

Soil development proceeds much more rapidly in deep, loose clastic deposits than when it must follow downward weathering into solid bedrock. In any case, existing biogeochemical and other reactions, known as the soil-forming processes, act together to produce soils that are characteristic of the environmental conditions that collectively produce those processes. In each kind of soil, processes of soil formation occur in unique proportion, intensities, and sequences (Buol et al., 2003).

Horizon differentiation is ascribed to additions, removals, transfers, and transformations within the soil system. Examples of important changes that contribute to development of horizons are additions of organic matter, removals of soluble salts and carbonates, transfers of humus and sesquioxides, and transformations of primary minerals into secondary minerals. It is postulated that these kinds of changes, as well as others, proceed simultaneously in all soils (Simonson, 1959).

Development of soil morphology proceeds through time, beginning with organic matter accumulation in the surface layer and proceeding through clay accumulation and structure development (Hall et al., 1982). The extent of clay accumulation in the subsoil horizons is a primary morphologic indicator of degree of soil development and is an easily observable feature of the soil profile (Hall et al., 1982). Color also tends to be a significant morphologic indicator of genetic processes. Changes in color occur as oxidation/reduction and weathering proceed in young geologic materials (Scully and Arnold, 1979). The formation of oxidized iron compounds as it accumulates in the subsoil is a major contributor to soil color. Braunification or "turning brown" of soil materials occurs as iron is weathered from primary minerals in relatively young soils (Blume, 1988). This color change is also influenced by the process known as lessivage, or transport of soil particles vertically downward in the profile (Blume, 1988)

The fact that soils are organized natural bodies (Simonson, 1959) covering the Earth's surface makes it possible to describe the various properties of individual soil layers in either quantitative or semi-quantitative terms. The morphology of the soil reveals to an investigator a great deal about the genesis and degree of development of a soil profile. Distinctness and degree of expression of properties among horizons in a profile as compared with its presumed parent material is a mechanism of evaluating the relative pedologic age of a soil (Bilzi and Ciolkosz, 1977; Bossuyt and Hermy, 1999).

Classification

Soil classification in Russia and the former Soviet Union influenced classification efforts in other countries and continued the general approach first outlined by Dokuchaev and Sibirtsev (Gerasimov and Ivanova, 1959). This included a strong emphasis on evaluating soil properties according to pedogenic processes. The action of soil-forming factors in producing soil properties in profiles called "soil types" or genetic soil types was strongly emphasized. Soil types in the Russian sense are defined by Prasolov as having "unity of origin, substance transformation, migration, and accumulation; that is, they are generalizations of many actual soils that have a common origin and similar pedogenic processes" (Prasolov, 1931; Rozov and Ivanova 1968).

A soil classification system completely new in design and nomenclature was created and continues to evolve in the United States (Soil Survey Staff 1960, 1964, 1975, 1994, 1999). The system was developed to serve the National Cooperative Soil Survey of the United States (Soil Survey Staff, 1975). Those who were most active in the development of the system based their decisions on experience developed in over 50 years of soil survey within the United States. They also envisioned the continuing need for a system that would include all soils in the world and would accommodate new knowledge (Buol, 2003).

Differentiating characteristics selected are properties of the soils themselves and include dynamic seasonal status of soil temperature and moisture. Pedogenic theory is not employed to determine classification criteria, but is used as a guide to relevance and weighing of soil properties (Smith, 1968). By necessity, methods of analysis must be specified to avoid conflicting data resulting from alternative analytical methods. Definitions are precise and quantitative rather than comparative and are written in terms that are compatible with soil survey operations (Smith, 1968).

Nomenclature has always been confusing among soil types due to various names given to the soil. The sources of names were often folk terms in different languages as well as coined terms, many of which carried no connotation of soil properties. Since there is no way of updating published names, despite the need to incorporate new data, new names were required. Thus, a new nomenclature was devised, using mainly classical Greek and Latin sources (Heller, 1963).

The system contains six categories. From highest to lowest levels of generalization these are order, suborder, great group, subgroup, family, and series, see Table 1 (Buol, 2003). There are many possible combinations of properties that affect the classification of soils at taxonomic levels below the soil order. These include particle size, mineralogy, soil temperature regime, moisture regime, fragment content and organic matter content, among numerous others (Soil Survey Staff, 1999). For the sake of brevity these many features and their taxonomic limits will not be discussed here.

Table 1: Categories of Soil Taxonomy (Buol, 2003)

Category	Number of Taxa	Nature of Differentiating Characteristics
Order	12	Presence or absence of major diagnostic horizons, mineralogical properties and extremes of soil temperature and moisture regimes
Suborder	61	Soil moisture regimes and diagnostic horizons
Great group	316	Degree of diagnostic horizon expression within each suborder taxon
Subgroup	2484	Properties that intergrade to taxa in other order, suborders, and great groups or that extragrade to nonsoil material
Family		Soil temperature regimes, particle size, and mineralogy of the pedon control section
Series	18,000 (approximate number in US)	Any consistently identifiable soil property not specifically identified as a criterion in a higher category

For this research project, the soils examined were located in residuum, colluvium, and alluvium parent materials derived from the local sandstone. The following paragraphs briefly describe the soil orders that are thought to apply to this research project, and some of their diagnostic properties. Classification criteria below the order level are not discussed for the sake of brevity of presentation.

Inceptisols are genetically younger soils that do not possess a degree of profile development that suggests intense weathering. They typically have brownish colors throughout, with relatively little development of soil structure and little vertical translocation of materials from upper horizons into the subsoil. The major diagnostic feature of most Inceptisols is that some horizons in the subsoil show some degree of alteration when compared to the soil's presumed parent material. That is, they are obviously unlike the parent material and this dissimilarity has occurred because of the action of soil forming factors. This subsoil zone of alteration is called a cambic horizon (Soil Survey Staff, 1999).

The central concept of Ultisols is that of soils that have a horizon that contains an appreciable amount of translocated silicate clay (an argillic or kandic horizon) and few bases (base saturation less than 35 %). Base saturation in most Ultisols decreases with depth (USDA, NRCS, 1999). Ultisols are strongly leached, acid soils with relatively low native fertility. They are found primarily in humid temperate and tropical areas of the world, typically on older, stable landscapes. Intense weathering of primary minerals has occurred, and much Ca, Mg, and K has been leached from these soils. Ultisols have a subsurface horizon in which clays have accumulated, often with strong yellowish or reddish colors resulting from the presence of Fe oxides (USDA, NRCS, 1999).

Alfisols form in semiarid to humid areas, typically under a hardwood forest cover. They have a clay-enriched subsoil and relatively high native fertility. Alfisols have undergone only moderate leaching. By definition, they have at least 35% base saturation, meaning that Ca, Mg, and K are relatively abundant. Although Alfisols are not common in this area, they can be found where parent materials, like those of the Pennington Formation, are higher in base cations.

Entisols are soils that "have little or no evidence of the development of pedogenic horizons" (Soil Survey Staff, 1999). Where such horizons are lacking but plant growth goes on, the plant growth is evidence enough that the unconsolidated parent materials are functioning as soils. Entisols are formed from such inert materials such as quartz sand, or are of recent exposure to pedogenic processes where diagnostic horizons are typically absent, although ochric epipedons and/or albic horizons may be present. Entisols include both (1) simple soils with one or more of the horizons mentioned and (2) pedogenically featureless, life-supporting natural materials, intermediate between “not-soil” (hard rock, playa salts, deep bodies of water, glaciers) and horizonated soil. Featureless soil bodies created by human mixing of soil materials are assigned to this order (Buol, 2003).

Geology

The Cumberland Plateau is an area of low local relief, generally about 50-250 m, with rounded hills and wide, low-gradient, flat-floored valleys with meandering streams. Tributaries of the meandering rivers have dendritic patterns. The Cumberland Plateau is developed principally on almost flat lying orthoquartzitic sandstone of the Lower Pennsylvanian Lee Formation of Kentucky and it equivalents in Tennessee. Few landslides occur on the flat to gently sloping surfaces of the Cumberland Plateau (Outerbridge, 1987). This area is characterized by rugged terrain, a moderate climate, and abundant rainfall. Although the soils are typically thin and infertile, the area was once covered by a dense hardwood forest equal to that of the Appalachians less than 96.5 km to the east (National Park Service Staff, 2008). As a landform, the Allegheny Plateau reaches from north-central Alabama through Tennessee, Kentucky and Pennsylvania to the western New York border. Geographers commonly call this landform the Appalachian Plateau, although it is known by various names throughout the different regions. In Tennessee and Kentucky, it is called the Cumberland Plateau (National Park Service Staff, 2008).

The rocks that now form the cap of the Cumberland Plateau were laid down in an ancient shallow sea over 350 million years ago, during the Mississippian (360-320 million years ago) and the Pennsylvanian (320-284 million years ago) periods of geologic time (USGS, 2002). These eras are combined and called simply the Carboniferous Period, because of the large coal deposits found in rocks of this age throughout the world. These sediments were deposited in horizontal layers thousands of feet thick. The resulting pressure hardened these sediments into layers of limestone, shale, coal, and sandstone. Beginning about 285 million years ago, the entire area was slowly lifted over 609 m above sea level and erosion immediately began to shape the landscape (National Park Service Staff, 2008).

Alternating layers of Pennsylvanian-age sandstones and shales dominate the surface geology. These rocks have very low permeability, so rainfall penetration into the subsurface is limited, especially in areas of steep topography. Consequently stream flow responds rapidly to storm events (Murdock, 2008).

Most of the sediment carried by streams and rivers through the Cumberland Plateau is brought to them by creep, debris flows, slumps, and debris avalanches (Sharpe, 1938). The process helps maintain the steepness of the outsides of the entrenched meanders (Newell, 1978) or, more generally, of any slope with a stream at its base. Any stream flowing along the side of a valley receives steady contributions of debris due to creep and episodic contributions due to slumps in colluvium and bedrock. Debris flows and debris avalanches are more common in the spring and summer as direct and immediate results to torrential thunderstorms. The response time of small streams to heavy rain is very short, and flash floods carry much of the new alluvium away immediately. Larger streams have alluvial fan deposits where higher gradient tributaries enter them. Most river bottoms have a thin sediment cover of less than 1-m thick.

Stratigraphy

Orthoquartzitic sandstone of the Lee Formation is distributed in discontinuous, extensive bodies that decrease in age westward at and within the base of the Breathitt Formation and within the top of the Pennington Formation. These sandstone bodies, about 150-km long, 50-km wide, and as much as 100-m thick, have been considered to be sandbars (Horne et al., 1971) and channel-fill deposits (Rice et al., 1979). Conglomeratic sandstone is abundant in the lower parts of channel fills. The sandstone is at least 90 % quartz and has been mined for glass sand near Paintsville, Ky., and at the northeast end of Pine Mountain on the Kentucky-Virginia border (Outerbridge, 1987). The sandstone is generally resistant to erosion and forms prominent cliffs, although locally it is leached and friable. Orthoquartzitic bodies of the Lee Formation are interbedded with dark gray shale, siltstone, and even-bedded subgraywacke sandstone of the lagoonal facies of the Breathitt Formation.

The Breathitt Formation and the Pocahontas and New River Formations of West Virginia are a westward-thinning wedge of subgraywacke sandstone, siltstone, shale, and coal that can be divided into three facies; lagoonal, lower delta plain, and upper delta plain (Horne et al., 1971). The oldest rocks, on the eastern side of the wedge, were deposited in a narrow basin. Younger beds were deposited in successively wider zones to the west. The beds most distant from the sediment sources were dark gray shale containing rare marine fossils interbedded with thin siltstone and sandstone beds. The dark gray shale generally lies on and is interbedded with orthoquartzitic sandstone of the Lee Formation and is included in the lagoonal facies, Figure 3.

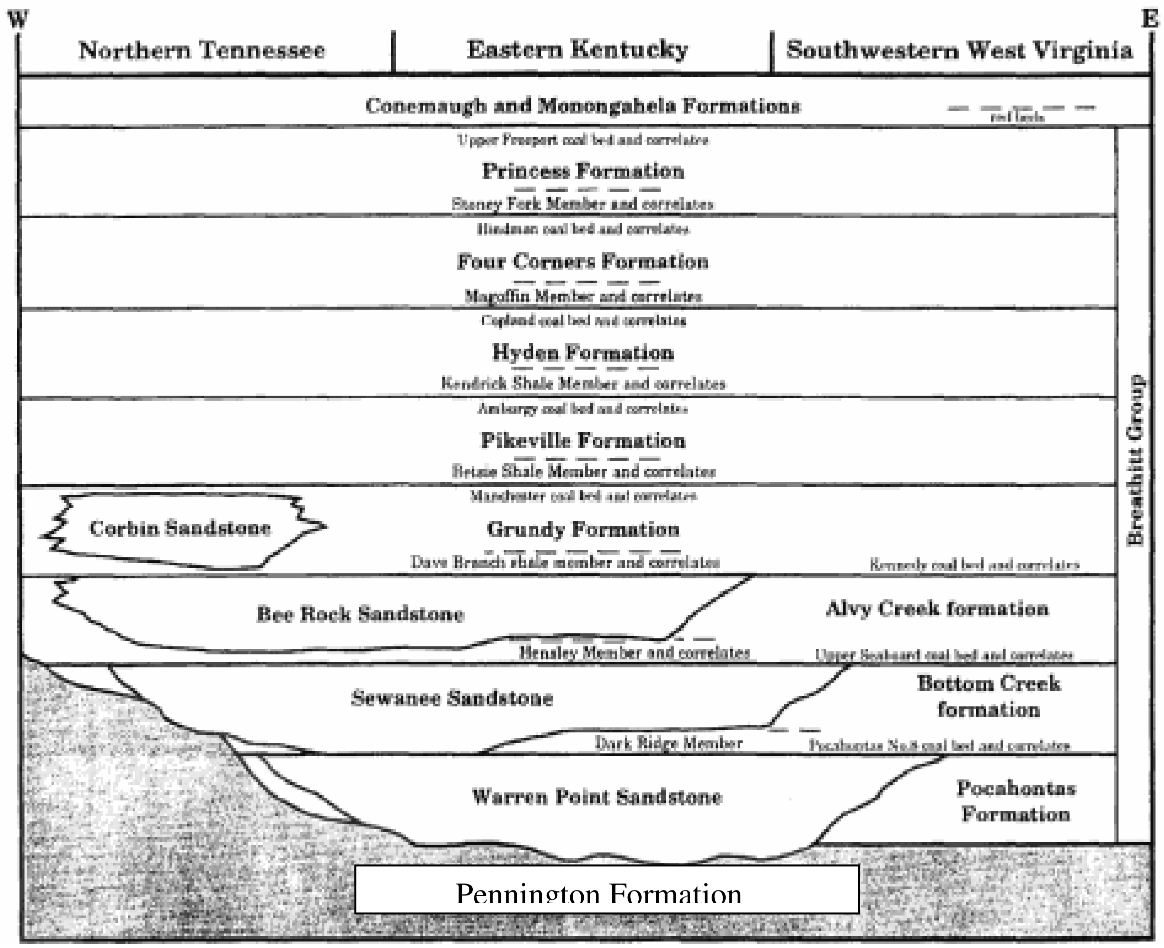


Figure 3. Geologic Framework for the Coal-Bearing rocks of the Central Appalachian Basin (Chesnut, 1996)

Materials and Methods

Field Methods

Soil morphology was completed according to National Cooperative Soil Survey Standards (USDA, NRCS, Soil Survey Manual, 1993). Field notes included: horizon designation, depth, boundary distinctness, texture, color, consistence, and structure (Schoeneberger, 2002).

The presence of clay skins, rock particles, roots and pores, and other observations were noted. Elevation, aspect, vegetation, slope, and other site characteristics were also recorded.

Laboratory Methods

Sample Preparation

Each sample was air dried and sieved through a 2-mm screen. The coarse fragments were separated and kept for further analysis. The soil that passed through the screen was mixed thoroughly and a portion was ground to pass through a 60-mesh screen for total elemental analysis (Soil Survey, 1996). Great care was taken to eliminate possibility of contamination.

Qualitative fizz test were first conducted to determine the presence of free carbonates with 10% hydrochloric acid (HCl) solution and the presence of excess carbon in organic matter using 30% hydrogen peroxide (H_2O_2). Effervescence was noted, and those samples were treated to remove unwanted materials (Soil Survey, 1996).

Chemical Characterization

Soil pH was determined using two techniques including the 1:1 (soil: solution) paste or slurry and the 2:1 (solution: soil) suspension in 0.01 M $CaCl_2$ solution (Olsen and Ellis, 1982). After electrode calibration, the pH was read on an Expandable IonAnalyzer EA940.

Cation exchange capacity was measured using the "Ammonium Acetate at pH 7 Procedure" (Basta and Tabatabai, 1992; Hussain et al., 1999). The method involves saturating the exchange complex of a soil sample with ammonium ions by repeated washings with ammonium acetate (NH_4OAc) followed by centrifugation and decantation of the supernatant. The NH_4OAc supernatant is saved for determination of exchangeable bases (Ca, Mg, Na, K) by inductively coupled argon plasma spectrophotometer (ICP) analysis. The sample was then washed with 95% ethanol to remove excess NH_4^+. Once the sample has been washed free of NH_4^+ the adsorbed ammonium was replaced by additions of a slightly acidic 10% sodium chloride (NaCl) solution. The supernatant solution from these washings was saved and the NH_4^+ present was determined by first distilling the solution using a Lab Conco distillation unit and then titrating using a boric acid indicator solution and 0.01 N HCl to determine cmol (+) kg^{-1} for cation exchange capacity (Chapman, 1965).

Potassium chloride exchangeable Al^{3+} was determined by ICP using a 1M KCl solution (Lin and Coleman, 1960).

Effective cation exchange capacity (ECEC) was computed from the sum of NH_4OAc extractable bases and the KCl extractable Al. The KCl extractable Al represents a major constituent in strongly acid soils (pH <5). The KCl extractant is an unbuffered salt and usually changes the soil pH by one unit or less. Therefore, extraction is performed at or near soil pH. The ECEC is not reported for soils containing soluble salts. ECEC was calculated by the following equation (Soil Survey, 1996):

$$ECEC = NH_4OAc \text{ extractable bases} + KCl \text{ extractable Al}$$

Use of a microwave oven digestion technique for total elemental analysis was performed. This technique calls for a digestion using reagent grade hydrofluoric acid (48%) and aqua-regia (reagent grade hydrochloric acid (37%) and reagent grade nitric acid (70%) in distilled, deionized water; 3:1:1). The solution was processed using the ICP (Ammons et al., 1995). Elements measured included: Al, Ba, Ca, Dd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, S, Se, Si, Sr, Ti, Zn, and Zr.

Dilute double acid nutrient extraction (Mehlich I) was analyzed using ICP-spectroscopy (Mehlich, 1953). The plant nutrients measured included Ca, Cu, Fe K, Mg, Mn, Na, P and Zn.

Free iron was determined by a reductive dissolution with sodium dithionite ($Na_2S_2O_4$) (Kilmer, 1960). Sodium dithionite decomposes to hydrogen sulfite, resulting in an acid solution (pH 2.6-3.5) and the possible precipitation of FeS and elemental S. To prevent this precipitation reaction, Mehra and Jackson (1960) used citrate to chelate dissolved Fe^{2+}. Holmgren (1967) concluded that either $CaHCO_3$ or citrate in adequate quantities will result in sufficient pH buffering to prevent reagent decomposition and precipitation of reaction products and that bicarbonate is not necessary if the citrate/dithionite ratio is greater than 20:1. The amounts of pedogenically formed iron oxides extracted using dithionite procedures have been shown to correlate well with the amounts of iron oxides determined by x-ray diffraction (Loeppert and Inskeep, 1996).

Manganese oxides in soils are found to be readily dissolved by an acidified hydroxylamine hydrochloride (NH_2OH * HCl) solution, leaving the major part of iron oxides in the residue. This procedure is based on the method of Chao (1972). The solubility of manganese minerals of soils in the NH_2OH * HCl solution is related to several parameters of the mineral species, which may vary as a result of duration of weathering. Among these are mineralogical forms, degree of crystallinity, and particle size or surface area. Since the major functions of the acidified NH_2OH * HCl solution are both reduction and dissolution, the more readily soluble fraction would represent the more reactive secondary manganese oxides which also presumably possess a stronger scavenging action on heavy metal ions (Chao, 1972). After dissolution, these samples were analyzed with air-acetylene atomic absorption spectroscopy.

Soil organic carbon (SOC) estimation at the landscape level is critical for assessing impacts of management practices on C sequestration and soil quality (Terra et al., 2004). SOC was determined using the Walkley-Black method (Jackson, 1958).

Physical Characterization

Particle size distribution is a basic physical property of mineral soils that affects many important soil attributes (Skaggs et al., 2001). The pipette method was used to determine percent sand, silt, and clay for particle size analysis (Kilmar and Alaexander, 1949). By knowing the percentages of particle sizes, textures can be determined with the aid of a soil textural triangle (Soil Survey Staff, 1993). The sands were fractionated into very coarse sand (vcs), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs) (Gee and Bauder, 1986). These fractioned sands are examined using a microscope and used to determine the mineralogy class at the family level (Shepherd and Walsh, 2002).

Results and Discussion

Site description and classification:

Site 1

Site 1 is located in major land resource area (MLRA) 125; Cumberland Plateau and

Mountains, on a backslope of a ridgetop in Scott State Forest, 300 m northwest of the intersection of Bandy Creek Road and Tennessee Highway 297 (Leatherwood Road), about 1,609 m by road northwest of the South Fork of the Cumberland River; USGS Honey Creek Quadrangle, 36˚33'18.10''N, 84˚46'10.80''W (Table 30).

This area is covered in a mixed forest consisting of American holly, Virginia pine, hickory, huckleberry, mountain laurel, oak, and woodfern. These stable ridges form soils with loamy residuum or colluvium weathered from sandstone or quartzite parent materials. Depending on their location along the hill slope, those lower on the hill have a thicker covering of colluvial parent material as surface creep occurs down hill covering the residual material. At Site 1, the hard bedrock is at a depth of 41 cm and is indurated sandstone. This fairly young soil in genetic age sits on a 10% slope at an elevation of 463 m above mean sea level.

Soil textures range from silty clay for the surface horizon to sandy loam and channery loam just above lithic contact with the sandstone bedrock (Tables 2 and 3). Coarse fragments increase with depth from 3% flat subangular indurated 2 to 150 mm sandstone fragments in the A horizon to 15% in the Bw2, just above the R. This is typically seen in soils with residual parent material as the weathering processes are stronger near the surface, breaking down coarse fragments faster at shallower depths. Below the ochric epipedon, surface horizon (A), is a zone of elluviation forming an E horizon 5-cm thick. This horizon has been stripped of clays which can be seen from particle size analysis in Table 3. A cambic diagnostic subsurface horizon has formed in the loamy textured subsoil where little weathering has occurred, but enough movement of water and enough fine material is present to begin forming some weak medium subangular blocky structure.

Table 2. Soil morphology data for Site 1.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-5	10YR 3/2	SiC	1,F,GR	CS	VFR
E	5-10	10YR 4/3	SL	1,F,SBK	CS	VFR
Bw1	10-25	10YR 5/4	L	1,M,SBK	GS	VFR
Bw2	25-41	10YR 5/6	L	1,F,SBK	AS	VFR
R	41-45	-	-	-	-	-

SiC-Silty Clay, SL-Sandy Loam, L-Loam, 1-weak, F-Fine, M-Medium, GR-Granular, SBK-Subangular Blocky, C-Clear, G-Gradual, A-Abrupt, S-Smooth, VFR-Very Friable

Table 3. Particle size distribution for Site 1.

		Particle Diameter (microns)			
Horizon	Depth	sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	------------------percent---------------			
A	0-5	11.91	39.66	48.43	Silty Clay
E	5-10	54.74	36.62	8.64	Sandy Loam
Bw1	10-25	52.33	37.45	10.22	Loam
Bw2	25-41	51.79	34.10	14.11	Loam
R	41+	NA	NA	NA	NA

Free iron decreases from the surface horizon to the subsoil where it levels off and little variation exists throughout the E horizon and 2 Bw horizons Table 4. Throughout, the free iron is equal to total iron indicating that iron bearing primary minerals in this profile have been weathered of iron. Although iron has significantly weathered from the minerals in the E, the underlying Bw1 did not show a large accumulation of free iron. Presence of iron oxides was high enough to maintain strong pigmentation in the E horizon.

The CEC dropped by nearly 60% from the A horizon to the Bw2 Table 5. The higher clay content and organic matter generate higher CEC values in the A horizon. Base saturation is fairly uniform throughout this profile with the largest change occurring between the E and the Bw1. This decrease was over 70% lower in the Bw1 compared to the E. The Bw1 has the lowest base saturation and the lowest pH values of the profile Table 5.

The profile at Site 1 was classified as a loamy, siliceous, subactive, mesic Lithic Dystrudept (USDA-NRCS, 1998).

Table 4. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 1.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}-------	
A	0-5	0.27	45,975	6.3
E	5-10	1.97	19,050	390.0
Bw1	10-25	0.88	19,600	259.8
Bw2	25-41	0.36	20,050	66.8
R	41+	NA	NA	NA

Table 5. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 1.

Horizon	Lower Depth	CEC (NH_4OAc)	Ca	Mg	Na	K	Al	ECEC	Base Saturation (NH_4OAc) pH 7	pH 1:1	pH 2:1	Total Clay
			Exchangeable Bases									
	(cm)	-----------------------------cmol (+) / kg---------------------------------							%			%
A	5	12.20	1.60	0.51	0.07	0.13	6.77	9.08	18.96	3.9	3.4	48.43
E	10	10.72	1.68	0.40	0.06	0.27	3.26	5.67	22.56	3.7	3.25	8.64
Bw1	25	6.27	0.25	0.10	0.04	0.09	3.02	3.50	7.67	3.6	3.6	10.22
Bw2	41	4.48	0.15	0.37	0.06	0.08	2.23	2.88	14.70	3.7	3.4	14.11
R	41+	NA	NA	NA	NA	NA	NA	NA	NA	3.65	3.2	NA

Site 2

Site 2 is located in MLRA-125; Cumberland Plateau and Mountains, on a backslope of a side slope on a mountain slope in McCreary County, Kentucky. Site 2 is on the west side of Big South Fork River, 1.75 miles south of Yamacraw Bridge, about 46 m up from road, 36˚43'1.00''N, 84˚32'42.00''W (Table 30). The primary vegetation is hardwood trees, mainly mixed oak and hickory. Colluvium derived from sedimentary rock has gathered on this backslope position where the upslope shape is concave and the cross-section shape of this landform is convex where the slope begins to drop back down the hill side. The slope where this soil is forming is between 40 and 60% and at an elevation of 253 m above sea level.

Soil textures range from a loam in the surface, A horizon, to silt-loams throughout a transitional BA horizon, into a series of Bw horizons and into a transitional BC horizon Tables 6 and 7. The BA horizon has similar textures and structure as the overlying A horizon but a mixing has occurred and can be seen by the color becoming redder with depth into the transitional horizon. An ochric epipedon is present as determined by color and depth criteria. Below the surface, diagnostic cambic subsurface horizonation occurs with horizons denoted by a series of Bw horizons. The cambic horizons forming here are due to an absence of clay accumulation because of the degree of weathering of primary minerals into clays. Presence of weathering can be seen in the development of structure in the subsurface horizons. Coarse fragments are present throughout the profile beginning with 5% flat subangular sand stone channers between 2 and 76 mm. The BA contains 2% siltstone fragments and 3% sandstone fragments. The Bw1 has 5% siltstone fragments and 3% sandstone fragments. With increasing depth, presence of rock fragments also increases. Both the Bw2 and Bw3, along with the BC

Table 6. Soil morphology data for Site 2.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-10	10YR 3/3	L	1,F,SBK	CS	FR
BA	10-25	7.5YR 5/6	SiL	1,F,SBK	CS	FR
Bw1	25-45	7.5YR 5/6	SiL	1,M,SBK	CS	FI
Bw2	45-71	7.5YR 5/6	SiL	2,M,SBK	CS	FI
Bw3	71-121	10YR 5/6	SiL	2,M,SBK	CW	VFI
BC	121-152	10YR 5/6	SiL	2,M,SBK	-	VFI

L-Loam, SiL-Silt Loam, 1-weak, 2-moderate, F-Fine, M-Medium, SBK-Subangular Blocky, C-Clear, S-Smooth, W-Wavy, FR-Friable, FI-Firm, VFI-Very Firm

Table 7. Particle size distribution for Site 2.

		Particle Diameter (microns)			
Horizon	Depth	sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	------------------percent---------------			
A	0-10	29.60	49.66	20.73	Loam
BA	10-25	15.66	61.56	22.78	Silt Loam
Bw1	25-45	19.94	55.99	24.06	Silt Loam
Bw2	45-71	18.90	58.15	22.95	Silt Loam
Bw3	71-121	18.69	56.10	25.21	Silt Loam
BC	121-152	21.80	51.12	27.08	Silt Loam

horizons contain 12% flat siltstone channers and 3% flat sandstone channers between 2 and 76 mm. At a depth of 121 cm is a transitional BC horizon that has similarities of both the overlying B and underlying unweathered bedrock. Like the Bw3, the BC has the same matrix color, texture and structure. The difference is that the BC horizon has some stratified soft rock remnants remaining from the siltstone parent material. Below this BC horizon at a depth of 152 cm, this colluvial parent material makes paralithic contact where the cambic subsurface horizons meets silt stone soft rock. Evidence that this soil is forming in colluvium can be seen by the mixing of silt stone and sand stone fragments throughout the profile. These fragments and the soil itself have accumulated by gravitational forces and erosional forces from upslope.

Table 8 shows that percent organic carbon decreases with depth until the BC horizon where organic carbon increases slightly. This is due to the BC being a transitional horizon at the contact between the colluvial parent material and bedrock. Siltstone fragments increase near the bottom of this profile showing evidence of weathering in place of bedrock.

Table 9 shows base saturation begins to increase at the Bw2 and increase furthermore in the BC. This is due to residual development and leaching of bases from the overlying horizons and migration and deposition into these subsoil horizons.

The profile at Site 2 was classified as a fine-loamy, siliceous, semi-active, mesic Typic Dystrudept (USDA, NRCS, 1998).

<u>Site 3</u>

Site 3 is located in MLRA-125; Cumberland Plateau and Mountains, on a footslope of a side slope on a mountain slope in McCreary County, Kentucky, 36˚40’10.40’’N, 84˚32’33.90’’W (Table 30). The site is on a hillside about 100 m south of the snack bar at the

Table 8. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 2.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}----------	
A	0-10	2.17	33,450	1,287.5
BA	10-25	0.45	21,200	615.0
Bw1	25-45	0.41	24,200	580.0
Bw2	45-71	0.35	22,850	597.5
Bw3	71-121	0.30	32,400	552.5
BC	121-152	0.37	32,200	437.5

Table 9. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 2.

			Exchangable Bases									
Horizon	Lower Depth	CEC (NH_4OAc)	Ca	Mg	Na	K	Al	ECEC	Base Saturation (NH_4OAc) pH 7	pH 1:1	pH 2:1	Total Clay
	(cm)	-----------------------------------	------------	------------	cmol (+) / kg	------------	------------	-----------------------------------	%			%
A	10	16.92	5.51	1.91	0.09	0.60	1.37	9.48	47.93	4	4.32	20.73
BA	25	7.89	0.72	0.44	0.09	0.10	3.46	4.81	17.17	3.9	3.74	22.78
Bw1	45	7.74	0.95	0.57	0.07	0.11	3.18	4.88	21.94	4	3.81	24.06
Bw2	71	6.55	1.09	0.80	0.06	0.13	2.55	4.63	31.76	3.9	3.93	22.95
Bw3	121	6.91	0.79	0.98	0.07	0.12	2.93	4.90	28.42	4.13	3.85	25.21
BC	152	7.59	0.70	1.55	0.07	0.16	2.90	5.37	32.63	4.19	3.85	27.08

Blue Heron mining community visitor center. This site has a concave upslope shape and a linear cross slope shape at 35% slope. Primary vegetation consists of hardwood trees. Because of its location on a footslope, soil is being deposited here and the parent material in this landscape is colluvium derived from sedimentary rock.

Textures for this profile range from silty clay loams in the top four horizons to a depth of 101 cm and silty clays beginning at 101 cm to a depth of 182 cm (Tables 10 and 11). This profile has an ochric epipedon from 0 to 10 cm and a diagnostic argillic subsurface designation from 10 to 142 cm. As can be seen in Table 11, clay is accumulating in the subsoil as a result of weathering. Clay films where noticed beginning in the Bt1 horizon with 5% patchy distinct films on all faces of peds and increased to 20% discontinuous distinct clay films on all faces of peds in the Bt2 and Bt3. Sandstone and siltstone channers were found throughout the profile where sandstone fragments stayed consistently at 3% flat subangular 2 to 76 mm and siltstone fragments increased with depth beginning with 5% flat subangular 2 to 76 mm in the Bt1 to 12% flat subangular 2 to 76 mm in the C horizon. This well drained soil has 20% distinct light brownish gray (10YR 6/2) mottles and 20% prominent yellowish red (5YR 5/6) mottles in the Bt3 horizon and 40 % distinct light brownish gray (10YR 6/2) mottles in the C horizon. The mottles are not due to redoximorphic processes, but merely relict coloration from when the siltstones were deposited. An increase in this gray color in the unweathered C horizon provides proof of this.

Argillic horizons are not unusual for soils developing in footslope positions on the landscape throughout this area of the Cumberland Plateau. However, this soil and its argillic horizon have certain properties that do make it unusual for this area. This site is developing in

Table 10. Soil morphology data for Site 3.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-10	10YR 3/4	SiCL	1,F,SBK	AS	FR
Bt1	10-40	10YR 4/6	SiL	1,M,SBK	CS	FR
Bt2	40-76	10YR 5/6	SiCL	2,M,SBK	CS	FI
Bt3	76-101	10YR 4/6	SiCL	2,M,SBK	CW	FI
Bt4	101-142	10YR 6/4	SiC	2,M,SBK	CW	VFI
Bt5	142-182	10YR 5/6	SiC	2,M,SBK	-	VFI

SiCL-Silty Clay Loam, SiL-Silt Loam, SiC-Silty Clay, 1-weak, 2-moderate, F-Fine, M-Medium, SBK-Subangular Blocky, A-Abrupt, C-Clear, S-Smooth, W-Wavy, FR-Friable, FI-Firm, VFI-Very Firm

Table 11. Particle size distribution for Site 3.

		Particle Diameter (microns)			
Horizon	Depth	sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	-----------------	percent	--------------	
A	0-10	14.91	47.38	37.72	Silty Clay Loam
Bt1	10-40	11.37	52.40	36.22	Silty Clay Loam
Bt2	40-76	15.24	47.31	37.45	Silty Clay Loam
Bt3	76-101	13.94	50.40	35.66	Silty Clay Loam
Bt4	101-142	8.36	42.90	48.74	Silty Clay
C	142-182	9.96	40.61	49.43	Silty Clay

colluvium originating in the Pennington Formation characterized by multicolored clay shale, and contains siltstone and locally gray, fine-grained sandstone. Although this soil looks very similar to most soils forming in the same landscapes throughout this area of the Cumberland Plateau, what make it unusual are the high base saturation levels seen in Table 13. Because Pennsylvanian sandstone makes up the majority of parent material in this area, exchangeable bases are typically low, as is the base saturation. This outcrop of the Pennington Formation which is higher in silt and clay allows for soils to form with NH_4OAc buffered at pH 7 base saturation levels between approximately 60 and 100. In taxonomy, base saturation by sum of cations has to be greater than 35% at critical depth to be classified as an Alfisol. This soil has less than 35% base saturation (sum of bases plus acidity) 125 cm below the upper boundary of the argillic horizon. When comparing this soil to the other six profiles examined, total and exchangeable calcium and magnesium are higher throughout, as is CEC (Table 13). Site 3 also has the highest pH values of the seven profiles sampled, ranging from 5.4 to 5.72 (Table 13).

Organic carbon follows a typical melanization curve where percent organic carbon decreases with depth (Table 12). This indicates a weathering sequence that has not been disrupted by irregular additions of parent materials.

The profile at Site 3 was classified as a fine-silty, mixed, active, mesic Typic Hapludult (USDA-NRCS, 1998).

<u>Site 4</u>

Site 4 is located in MLRA 125, Cumberland Plateau and Mountains of Scott Co. Tennessee, 36°34’48.90’’N, 84°38’37.80’’W (Table 30). Follow Highway 297 west from

Table 12. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 3.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}----------	
A	0-10	1.51	27,850	590.0
Bt1	10-40	0.33	33,800	244.5
Bt2	40-76	0.23	27,850	266.8
Bt3	76-101	0.18	27,850	397.5
Bt4	101-142	0.11	19,050	367.5
C	142-182	0.13	28,100	405.0

Table 13. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 3.

			Exchangeable Bases						Base Saturation				
Horizon	Lower Depth	CEC (NH_4OAc)	Ca	Mg	Na	K	Al	ECEC	(NH_4OAc) pH 7	Sum of Cations	pH 1:1	pH 2:1	Total Clay
		---------------------------------cmol (+) / kg--------------------------											
	(cm)	-----							-----------%---------				%
A	10	15.48	10.96	4.34	0.29	0.67	0.03	16.29	105.05	28.76	5.72	5.1	37.72
Bt1	40	12.90	4.27	2.87	0.10	0.41	1.69	9.34	59.35	20.95	5.4	4.3	36.22
Bt2	76	13.77	6.37	4.61	0.28	0.44	0.30	12.00	84.96	22.40	5.9	4.7	37.45
Bt3	101	13.45	4.44	5.14	0.11	0.40	0.79	10.89	75.11	21.60	5.49	4.5	35.66
Bt4	142	15.12	4.22	6.00	0.13	0.47	1.36	12.18	71.56	24.52	5.45	4.4	48.74
C	182	13.73	4.32	6.28	0.13	0.48	0.78	11.99	81.68	23.31	5.49	4.5	49.43

Oneida, TN approximately 16,093 m into the Big South Fork NRRA. Follow signs to Station Camp. Upon crossing the park boundary, travel 3,218 m and turn right onto Big Island Road. Travel 3,218 m to gate then follow the road to the Big Island Loop Trail where this profile is approximately 6 m west of trail. Site 4 is situated on a floodplain with a 2% slope and parent material consisting of alluvium derived from Pennsylvanian aged acid sandstone, siltstone, and shale. The majority of this floodplain is dominated with young hardwood forest of oak and hickory.

Site 4 has an ochric epipedon and a diagnostic cambic subsurface horizonation. Textures at Site 4 range from a loamy sand on the surface or A horizon, sands in the Bw1 and Bw2, loamy sands in the Bw3, Bw4, and Bw5 and a sandy loam at a depth of 152 cm to make up the Bw6 horizon (Tables 14 and 15). Starting with the A and continuing down through the Bw6, distinct mottles are seen. In the A horizon there is 1 % fine faint spherical very dark grayish brown (10YR 3/2) mottles found. Ten percent fine distinct spherical light yellowish brown (2.5Y 6/4) and 10% medium distinct spherical yellowish brown (10YR 5/4) mottles are common throughout the Bw horizons. Structure for this profile consist of weak medium granular in the A horizon then alternating horizons of weak; medium, fine, coarse, medium, medium, coarse; subangular blocky structure through the Bw horizons to a depth of 188 cm. This alternating layering of different sized particles, along with distinct stratification within horizons clearly demonstrates different flood events with varying levels of intensity of stream flow and deposition.

Table 16 shows the organic carbon levels do not produce a typical melanization curve. This is due to the poor development of this soil due to its relative age. This site floods regularly and deposits sediment with varying amounts of organic carbon. The A horizon has the highest

Table 14. Soil morphology data for Site 4.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-8	10YR 4/3	LS	1,M,GR	CS	VFR
Bw1	8-31	10YR 4/4	S	1,M,SBK	CS	FR
Bw2	31-58	10YR 4/6	S	1,F,SBK	CS	VFR
Bw3	58-94	10YR 4/4	LS	1,C,SBK	GW	VFR
Bw4	94-135	10YR 3/4	LS	1,M,SBK	GW	FR
Bw5	135-152	10YR 4/4	LS	1,M,SBK	GW	FR
Bw6	152-188	10YR 5/6	SL	1,C,SBK	-	FR

LS-Loamy Sand, S-Sand, SL-Sandy Loam, 1-weak, M-Medium, F-Fine, C-Course, GR-Granular, SBK-Subangular Blocky, C-Clear, G-Gradual, S-Smooth, W-Wavy, VFR-Very Friable, FR-Friable

Table 15. Particle size distribution for Site 4.

		Particle Diameter (microns)			
Horizon	Depth	sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	------------------percent----------------			
A	0-8	82.01	12.92	5.07	Loamy Sand
Bw1	8-31	89.49	7.85	2.66	Sand
Bw2	31-58	92.34	4.47	3.19	Sand
Bw3	58-94	74.93	16.31	8.76	Loamy Sand
Bw4	94-135	72.20	17.87	9.93	Loamy Sand
Bw5	135-152	76.66	14.49	8.85	Loamy Sand
Bw6	152-188	57.22	26.63	16.15	Sandy Loam

levels of organic carbon, due to surface vegetation. At a depth of 94 cm, the Bw4 has about 50% lower levels of organic carbon than the surface, but has about 42% higher organic carbon levels from the overlying Bw3. This Bw4 could have higher amounts of organic carbon because it was the surface horizon for some time and built up levels with vegetation or could be due to a deposition of higher organic carbon sediment. This irregular melanization curve is typical in Inceptisols.

Cation exchange capacity increased with depth, as did total clay percent (Table 17). Both CEC and total clay percentages are low, but increased in CEC with increasing clay content shows that the majority of exchange sites are located on the clay particles. Because of the sandy nature of this soil and pH values between 4.93 and 4.24, exchangeable bases are low (Table 17).

The profile at Site 4 was classified as a coarse-loamy, siliceous, active, mesic Fluventic Dystrudept (USDA-NRCS, 1998).

Table 16. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 4.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}	----------
A	0-8	0.47	13,100	146.5
Bw1	8-31	0.17	19,950	74.5
Bw2	31-58	0.18	15,000	78.8
Bw3	58-94	0.16	15,850	83.8
Bw4	94-135	0.22	9,750	78.0
Bw5	135-152	0.17	13,950	46.5
Bw6	152-188	0.11	21,200	90.0

Table 17. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 4.

Horizon	Lower Depth	CEC (NH_4OAc)	Exchangeable Bases Ca	Mg	Na	K	Al	ECEC	Base Saturation (NH_4OAc) pH 7	pH 1:1	pH 2:1	Total Clay
	(cm)	cmol (+) / kg							%			%
A	8	3.78	1.90	0.44	0.07	0.21	0.16	2.78	69.41	4.45	4.5	5.07
Bw1	31	3.34	0.88	0.19	0.06	0.15	0.16	1.44	38.39	4.93	4.45	2.66
Bw2	58	3.32	0.67	0.19	0.07	0.14	0.19	1.25	31.88	4.81	4.31	3.19
Bw3	94	5.48	0.65	0.24	0.06	0.19	1.20	2.34	20.70	4.46	3.97	8.76
Bw4	135	5.92	0.55	0.20	0.07	0.18	1.68	2.68	16.79	4.28	3.9	9.93
Bw5	152	3.70	0.28	0.15	0.06	0.14	1.20	1.83	16.99	4.37	3.9	8.85
Bw6	188	6.72	0.36	0.33	0.07	0.19	2.34	3.28	14.09	4.24	3.84	16.15

Site 5

Site 5 is located in MLRA region 125; Cumberland Mountains and Plateau in Morgan County, Tennessee, 36˚4'22.60''N, 84˚23'13.30''W (Table 30). In Morgan County, take Highway 62 West approximately 402 m, turn right onto Big Mountain Valley Road. Travel approximately 3,218 m; site is 9 m north of road. Site 5 is situated within a concave section of the footslope of a base slope of a mountain slope. Vegetative cover throughout this area is mixed hardwoods, mostly oaks. This soil is forming in skeletal loamy colluvium derived from sedimentary rock washed from upslope.

Like most soils formed on footslopes throughout the BSFNRRA, Site 5 has an ochric epipedon and diagnostic argillic subsurface horizonation. This Ultisol has a good mixture of sand, silt, and clay throughout with enough clay increase between depths of 15cm and 101cm to form an argillic horizon (Tables 18 and 19). Clay films can be seen on the faces of all peds within the Bt horizons. Textures throughout this profile are loams with structure ranging from weak, fine granular in the A horizon to weak to moderate, fine subangular blocky through the argillic Bt horizons (Table 18). At a depth of 101cm, a BC horizon is found illustrated by a drop in clay and a pick up in sand from the underlying parent material consisting of sandstone bedrock. The BC has moderate, fine subangular blocky structure. Below the BC, is a CB horizon that is more like the underlying sandstone parent material, but shows some development, seen by the weak, coarse subangular blocky structure. Evidence of colluvial material can be seen throughout the profile with increasing percentages of non-flat, subrounded, very strongly cemented 75-250 mm sandstone fragments. The percent of sandstone fragments increases with depth. These subrounded fragments are not orientated in any specific plane, proving this

Table 18. Soil morphology data for Site 5.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-5	10YR 3/2	L	1,F,GR	CS	VFR
BE	5-15	10YR 5/6	L	1,F,SBK	CS	VFR
Bt1	15-40	7.5YR 5/6	L	2,F,SBK	AS	FR
Bt2	40-101	7.5YR 4/6	L	2,F,SBK	GS	FR
BC	101-162	5YR 4/6	L	2,F,SBK	GW	FI
CB	162-203	7.5YR 4/6	L	1,C,SBK	-	FI

L-Loam, 1-weak, 2-moderate, F-Fine, C-Coarse, GR-Granular, SBK-Subangular Blocky, C-Clear, A-Abrupt, G-Gradual, S-Smooth, W-Wavy, VFR-Very Friable, FR-Friable, FI-Firm

Table 19. Particle size distribution for Site 5.

		Particle Diameter (microns)			
Horizon	Depth	sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	------------------percent---------------			
A	0-5	30.79	50.02	19.19	Loam
BE	5-15	32.74	46.01	21.26	Loam
Bt1	15-40	33.61	42.57	23.82	Loam
Bt2	40-101	32.01	35.43	32.56	Loam
BC	101-162	47.70	34.38	17.91	Loam
CB	162-203	39.83	36.08	24.08	Loam

material has been deposited in this footslope, washing downhill with runoff and through surface creep.

Organic carbon decreases throughout the profile from 2.48% in the surface horizon to 0.12% in the CB horizon (Table 20). This melanization curve shows that this soil has been stable for an extended period of time and weathering throughout the profile has been consistent. When dealing with soils which contain argillic horizons, it is important to take note of the base saturation levels at the critical depth to differentiate between Ultisols and Alfisols. As can be seen in Table 21, % base saturation levels range from 5.89 in the Bt1 to 11.62 in the Bt2. The % base saturation at the critical depth is 11.62 which according to Soil Taxonomy (USDA-NRCS, 1998), makes this soil an Ultisol. A %base saturation summation level of 35 or above at the critical depth would constitute an Alfisol. Because of the low pH values, ranging from 4.04 at its lowest to 4.35 at its highest, % base saturation and CEC levels are both low. High levels of acidity will leach out exchangeable bases as rain water infiltrates through the profile (Table 21).

The profile at Site 5 is classified as a fine-loamy, siliceous, active, mesic Typic Hapludult, (USDA-NRCS, 1998).

Table 20. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 5.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}----------	
A	0-5	2.48	28,250	485.0
BE	5-15	0.64	24,600	220.8
Bt1	15-40	0.30	27,800	126.8
Bt2	40-101	0.27	34,950	217.3
BC	101-162	0.15	36,700	124.0
CB	162-203	0.12	41,500	415.0

Table 21. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 5.

			Exchangeable Bases									
Horizon	Lower Depth	CEC (NH_4OAc)	Ca	Mg	Na	K	Al	ECEC	Base Saturation (NH_4OAc) pH 7	pH 1:1	pH 2:1	Total Clay
	(cm)	-----------------------------cmol (+) / kg						-------------------------------	%			%
A	5	21.84	3.67	1.08	0.11	0.27	3.52	8.66	23.51	4.14	4.04	19.19
BE	15	10.32	0.51	0.19	0.32	0.13	3.06	4.21	11.20	4.07	3.9	21.255
Bt1	40	9.62	0.25	0.10	0.15	0.07	3.84	4.41	5.89	4.04	3.78	23.82
Bt2	101	9.66	0.48	0.48	0.08	0.08	3.61	4.74	11.62	4.33	3.83	32.56
BC	162	8.48	0.18	0.60	0.05	0.06	3.61	4.50	10.49	4.31	3.77	17.91
CB	203	8.06	0.30	0.70	0.07	0.07	2.86	4.00	14.24	4.35	3.87	24.08

Site 6

Site 6 is located in MLRA region 125; Cumberland Plateau and Mountains in Fentress County, Tennessee, 36˚33'19.90''N, 84˚46'10.10''W (Table 30). To get to Site 6, follow TN Highway 297 west, then right to Hwy. 154 north, then right onto Divide Rd, travel 5,472 m on right of road approximately 45 m down slope. This site is situated on a convex slope on the backslope of a side slope with a slope of 15%. The primary vegetation in this area is mixed hardwoods with young saplings covering the forest floor. Forming on a backslope, the parent material is fine-loamy residuum weathered from sandstone. Lithic contact with hard sandstone bedrock is reached at a depth of 69 cm. A dark brown, 10YR 3/3, 9-cm thick surface horizon constitutes an ochric epipedon because it is not dark enough to be mollic or umbric (Table 22). With this soil forming from the weathering of sandstone bedrock, the clay percentages are all under 25%. In Table 23, the data shows that there is no clay accumulation to form an argillic horizon, therefore, this soil has a diagnostic cambic subsurface horizon. Textures at Site 6 range from sandy loams in the surface through the Bw1 to a depth of 64 cm, followed by a Bw2 with a sandy clay loam texture just over lithic contact at 73 cm. Because of the sandy nature of this soil, most of the clay has been leached out of the upper horizons and deposited in the Bw2. Structure for this soil consist of weak, medium granular in the A horizon followed by moderate, medium subangular blocky in the E, BE, Bw1, and Bw2 horizons.

Table 24 shows the elluvial E horizon and transitional BE horizon where aluminum is being striped and deposited in the Bw horizons. This shows that Al is dominating the exchange sites making the CEC higher in the Bw horizons and lower in the E/BE horizons (Table 25).

Organic carbon percentages throughout a profile are a good indicator of stability within the soil. This well drained soil shows stability with a melanization curve that follows a trend of decreasing organic matter with increase depth (Table 24). The A horizon has the highest percent of organic matter due to vegetation, and % organic matter decreases consistently through the Bw2. Percent base saturation decreases with depth with the highest percentage being at the surface (near 40%) and the lowest almost ten fold lower just above lithic contact (Table 25). The higher level of Ca and Mg in the surface is thought to be due to dust coming off the limestone gravel road that runs next to this site (Table 25). This is a good indicator that this is a residual soil, forming in situ.

The profile at Site 6 is classified as a coarse-loamy, siliceous, active, mesic Typic Dystrudept (USDA-NRCS, 1998).

Table 22. Soil morphology data for Site 6.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-9	10YR 4/1	SL	2,F,GR	CS	VFR
E	9-25	10YR 5/6	SL	2,M,SBK	GS	VFR
BE	25-41	10YR 5/8	SL	2,M,SBK	GS	VFR
Bw1	41-64	7.5YR 5/6	SL	2,M,SBK	GS	FR
Bw2	64-73	10YR 6/6	SL	2,M,SBK	AS	FR
R	73+	-	-	-	-	-

SL-Sandy Loam, 2-moderate, F-Fine, M-Medium, GR-Granular, SBK-Subangular Blocky, C-Clear, G-Gradual, A-Abrupt, S-Smooth, VFR-Very Friable, FR-Friable

Table 23. Particle size distribution for Site 6.

Horizon	Depth	Particle Diameter (microns) sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	------------------percent---------------			
A	0-9	68.77	20.15	11.08	Sandy Loam
E	9-25	74.61	15.57	9.82	Sandy Loam
BE	25-41	75.09	15.15	9.76	Sandy Loam
Bw1	41-64	62.95	28.49	8.56	Sandy Loam
Bw2	64-73	60.55	13.70	25.75	Sandy Clay Loam
R	73+	NA	NA	NA	NA

Table 24. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 6.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}	----------
A	0-9	1.41	4,100	33.3
E	9-25	0.22	4,800	31.0
BE	25-41	0.17	4,000	19.3
Bw1	41-64	0.15	13,400	22.5
Bw2	64-73	0.14	14,700	15.0
R	73+	NA	NA	NA

Table 25. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 6.

Horizon	Lower Depth	CEC (NH_4OAc)	Exchangeable Bases Ca	Mg	Na	K	Al	ECEC	Base Saturation (NH_4OAc) pH 7	pH 1:1	pH 2:1	Total Clay
	Cm	----------------------------------			cmol (+) / kg			--------------------------------	%			%
A	9	11.10	2.85	1.21	0.07	0.10	0.85	5.09	38.17	4.06	3.33	11.08
E	25	2.92	0.21	0.11	0.12	0.10	0.60	1.14	18.56	4.56	4.04	9.82
BE	41	2.06	0.09	0.02	0.09	0.03	2.59	2.83	11.47	4.63	4.04	9.76
Bw1	64	6.50	0.20	0.06	0.08	0.03	3.68	4.05	5.62	4.41	3.7	8.56
Bw2	73	6.96	0.14	0.04	0.08	0.08	4.77	5.11	4.85	4.28	3.59	25.75
R	73+	NA	NA	NA	NA	NA	NA	NA	NA	4.59	3.87	NA

Site 7

Site 7 is located in MLRA region 125; Cumberland Plateau and Mountains in Fentress County, Tennessee, 36˚23'41.20''N, 84˚38'33.30''W (Table 30). To visit this site, travel on Highway 27 from Elgin, TN, turn west onto Highway 52, travel 6,115 m, turn west onto Honey Creek Loop Rd., travel 2,896 m, approximately 152 m on right of road on north facing shoulder. This site is situated on a 6 % convex slope on an upland shoulder of the summit. The primary vegetation in this area is hardwood tree cover. Timber was harvested in this area in the past and as a result, erosion has been influenced by human activity. Forming in place, this soil is derived from fine-loamy residuum weathered from interbedded shale, siltstone, and sandstone.

Tables 26 and 27 show textures at Site 7 are silt loams in the A and E horizon to a depth of 36 cm followed by a horizon with a loam texture from 36 to 55 cm forming a Bt1 horizon, then a clay loam from depths 55 to 78 cm forming a Bt2 horizon. Paralithic contact is made with indurated shale at a depth of 78 cm. An ochric epipedon is present at the surface to a depth of 11 cm. The elluviation and accumulation of clay in this profile forms a diagnostic argillic subsurface horizon between depths of 18 to 68 cm where clay films where observed on all faces of peds. Because the base saturation is below 35% at the critical point (Table 29), this soil is classified as an Ultisol. This well drained soil has common fine and medium roots and also less than 10% sandstone and siltstone fragments ranging from 2 to 150 mm between the surface and the Bt3 horizon.

Table 29 shows an accumulation of calcium and magnesium just above contact with soft rock. This is due to leaching of bases with infiltrating water and depositing them when the water slows as it reaches paralithic contact. Table 28 shows a translocation of Al which affects CEC values as can be seen where the CEC is highest just above paralithic contact. In soils with pH values ranging from 4.4 to 4.6 (Table 29), it is common for Fe and Al oxides to dominate.

Organic carbon percentages show a typical melanization curve where levels decrease with depth (Table 28). This melanization curve is expected because of the 6% slope and landscape position being on a shoulder. With this slope and position, irregular additions of soil are unlikely and weathering should continue through this profile undisturbed.

The profile at Site 7 is classified as a fine-loamy, siliceous, semi-active, mesic Typic Hapludult (USDA-NRCS, 1998).

Table 30 gives the location of each site as latitude and longitude, classification according to U.S. Soil Taxonomy, and the geomorphic setting according to landscape position.

Table 26. Soil morphology data for Site 7.

Horizon	Depth (cm)	Color	Texture	Structure	Boundary	Moist Consistency
A	0-17	10YR 5/3	SiL	2,M,GR	CS	VFR
E	17-36	10YR 5/4	SiL	2,M,SBK	GW	FR
Bt1	36-55	10YR 5/6	L	2,M,SBK	GW	FR
Bt2	55-78	7.5YR 5/6	CL	2,M,SBK	GW	FR
Cr	78+	2.5YR 4/8 2.5Y 6/4	-	-	-	-

Si-Silt Loam, L-Loam, CL-Clay Loam, 2-moderate, M-Medium, GR-Granular, SBK-Subangular Blocky, C-Clear, G-Gradual, S-Smooth, W-Wavy, VFR-Very Friable, FR-Friable

Table 27. Particle size distribution for Site 7.

Horizon	Depth	Particle Diameter (microns) sand 2000-50	silt 50-2	clay <2	USDA Texture
	(cm)	------------------percent---------------			
A	0-17	36.49	54.10	9.41	Silt Loam
E	17-36	32.08	52.06	15.86	Silt Loam
Bt1	36-55	31.17	45.69	23.14	Loam
Bt2	55-78	20.83	46.53	32.64	Clay Loam
Cr	78+	NA	NA	NA	NA

Table 28. Chemical properties including organic carbon, free iron, and easily reducible manganese for Site 7.

Horizon	Depth	Organic Carbon	Free Iron	Mn
	(cm)	%	---------mg kg^{-1}----------	
A	0-17	0.74	5,100	118.8
E	17-36	0.20	5,900	28.5
Bt1	36-55	0.11	13,550	13.0
Bt2	55-78	0.06	22,800	5.0
Cr	78+	NA	NA	NA

Table 29. Chemical properties including cation exchange capacity (CEC), exchangeable bases (assuming Al is trivalent), effective cation exchange capacity (ECEC), base saturation, pH, and total clay of native Site 7.

			Exchangeable Bases									
Horizon	Lower Depth	CEC (NH_4OAc)	Ca	Mg	Na	K	Al	ECEC	Base Saturation (NH_4OAc) pH 7	pH 1:1	pH 2:1	Total Clay
	(cm)	----------------------------------cmol (+) / kg--------------------------------							%			%
A	17	5.50	0.05	0.00	0.12	0.00	1.92	2.09	3.11	4.48	3.85	9.41
E	36	5.70	0.16	0.06	0.18	0.10	2.81	3.31	8.77	4.47	3.73	15.86
Bt1	55	6.62	0.10	0.05	0.11	0.09	3.67	4.02	5.26	4.65	3.74	23.14
Bt2	78	9.82	0.36	0.29	0.12	0.07	6.26	7.10	8.51	4.65	3.74	32.64
Cr	78+	NA	NA	NA	NA	NA	NA	NA	NA	4.66	3.68	NA

Table 30: Classification of Sites

Site #	Location	Classification	Geomorphic Setting
1	36˚33’18.10’’N 84˚46’10.80’’W	loamy, siliceous, subactive, mesic Lithic Dystrudept	backslope of side slope of dissected plateau on ridge
2	36˚43’1.00’’N 84˚32’42.00’’W	fine-loamy, siliceous, semi-active, mesic Typic Dystrudept	backslope of side slope of mountain slope on mountains
3	36˚40’10.40’’N 84˚32’33.90’’W	fine-silty, mixed, active, mesic Typic Hapludult	footslope of side slope of mountain slope on mountains
4	36˚34’48.90’’N 84˚38’37.80’’W	coarse-loamy, siliceous, active, mesic Fluventic Dystrudept	floodplain
5	36˚4’22.60’’N 84˚23’13.30’’W	fine-loamy, siliceous, active, mesic Typic Hapludult	footslope of base slope of mountain slope on mountains
6	36˚33’19.90’’N 84˚46’10.10’’W	coarse-loamy, siliceous, active, mesic Typic Dystrudept	upland sideslope
7	36˚23’41.20’’N 84˚38’33.30’’W	fine-loamy, siliceous, semi-active, mesic Typic Hapludult	upland summit

Conclusions

The soils examined in the Big South Fork National River and Recreational Area showed a strong association with landscape position and parent material. Various soil properties, both observed and measured, reflected the interaction of the geologic materials with the forces of erosion, deposition, and soil formation active upon the parent materials. Hill slope processes across the landscape, as well as human activity, in the case of limestone gravel roads, were shown to have a bearing on the properties of some of the soils, and to some extent affect the classification of the soils. The following will show major relationships among the soils, landscape, and geology for the study area.

Soils investigated covered a range from weakly developed soils to well developed soils in a morphological sense. These soils were representative of the different landscapes found throughout the BSFNRRA and into the Cumberland Plateau ranging from an upland summit soil to a floodplain soil and all between along the landscape.

It was found that the soils forming on the upland summit with slopes less than 10% and in footslopes formed argillic horizons and were classified as Ultisols. The summit soil (Site 7) is forming from residuum parent material where the slope is not great enough for erosion to wash away the substrate. In the case of Site 7, paralithic contact is made. This is typical with soils forming on softer slopes to have soft rock because erosion does not break off shear faces in soft rock and form cliffs like it does with hard rock. It is due to the stability of this site and the length of time this soil has had to form that these areas formed argillic horizons. Footslope landscapes have a concave shape where colluvium accumulates as it creeps down the slope due to gravity and erosion. As the soil is deposited here (Sites 3 and 5), it becomes more stable in place and begins weathering processes. As weathering proceeds, clays have time to accumulate and form argillic horizons. Most soils with argillic horizons found throughout this area are going to be classified as Ultisols due to the Pennsylvanian age sandstone parent material from which these soils form. Soils developing below the Pennington Formation will have considerably higher base status than soils not influenced by this formation. Even with high base saturation, by the summation of bases; Ca, Na, K, and Mg, and acidity, these soils will not make Alfisols in most cases.

Where steep slopes are encountered, like on the backslopes and sideslopes of the mountains, it was determined that Inceptisols are to be expected to be developing. Sites 1, 2, and 6 formed on such landscapes. While Site 2 has colluvial parent material, Site 1 and 6 are formed in residuum. These soils are forming on more unstable slopes where erosion and gravitational creep are occurring. The instability of these soils makes them younger morphologically. These soils form diagnostic cambic subsurface horizons where soil structure is developing, but there is no clay accumulation. There has not been enough time for the primary minerals to weather and form clays before the primary minerals were translocated down slope. Because these soils are forming from Pennsylvanian sandstone, the primary minerals do not contain high levels of bases, and because of this CEC's and base saturations are low.

Floodplains are common throughout this area of the Cumberland Plateau and the BSFNRRA because of the highly dissected nature of this area. Steep slopes form with creeks and rivers at their base which contain narrow floodplains where alluvium is deposited with flood events. These floodplains form Inceptisols with stratified horizonation with organic carbon varying erratically with depth. This is not only typical of floodplains in this area, but with floodplains in general. One difference is that these floodplains are narrower and extreme flood events commonly remove sediment from these landscapes and redeposit them downstream.

On the sloping and steep landscape components, relief was the dominant soil forming factor. Erosion of the landscape had obliterated deeper profiles that existed previously on several of the geologic units, as described above. Soils on these landscapes were forming in the remains of the older deep soils profiles. Parent material and time seem to have had an overriding influence on the formation of soils on the more stable parts of the landscape, namely Site 7. By clearing the uplands when settling the area, and accelerating erosion on the landscape, humans have changed the nature of the plant cover. High base parent materials higher on the slope have apparently been significant contributors of bases in soils below the Pennington Formation.

This research has shown the variety of soils that may be produced by the interactions of soil forming factors and landscapes acting upon different geologic materials. A close interaction of the various landforms is evident when the soil properties are studied across a series of varying geologic units and slope gradients. Relief has influenced, to a large degree, the effects of other soil forming factors on several of these landscape units, but the mineralogy and various physical and chemical properties of these soils are still closely related to the parent materials and stages of development of the soils studied.

Literature Cited

Ammons, J.T., M.E. Essington, R.J. Lewis, A.O. Gallagher, and G.M. Lessman. 1995. An application of a modified microwave total dissolution technique for soils. Commun. Soil Sci. Plant Anal. 26:5-6

Basta, N.T.,and M.A. Tabatabai, 1992. Effect of cropping systems on adsorption of metals by soils: I single-metal adsorption. Soil Science 153:2.

Batjes, N.H. 1995. Development of a world data set of soil water retention properties using pedotransfer rules. Geoderma 71:31-52.

Bilzi, A. F. and E. J. Ciolkosz. 1977. A field morphology rating scale for evaluating pedological development. Soil Sci. 124:45-48.

Birkeland, P. W. 1984. Soil sand geomorphology. Oxford Univ. Press. NY.

Blume, H. P. 1988. The fate of iron during soil formation in humid-temperate environments. *In* J. W. Stucki, et. al. (eds). Iron in soils and clay minerals. D. Reidel Publ. Co.

Bossuyt, B, J. Deckers, and M. Hermy. 1999. A field methodology for assessing man-made disturbance in forest soils developed in loess. Soil Use and Management. 15:14-20.

Brady, N. C. 1984. The nature and properties of soils. Macmillan Publishing Co., N. Y.

Buol, S.W., F.D. Hole, R.J. McCracken and J.A. Thorp. 2003. Soil genesis and classification. 5th ed. Iowa State Univ. Press, Ames, IA.

Certini, Giacomo and Riccardo Scalenghe. 2007. “Soil forming factors.” In: Encyclopedia of Earth. Eds. Cutler J. Cleveland Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. July 6, 2007; retrieved August 20, 2008.

Chao, T.T. 1972. Selective dissolution of manganese oxides from soils and sediments. Soil Sci. Soc. Am. Proc. 36:764-768.

Chapman, H. D. 1965. Cation exchange capacity. *In* C.A. Black (ed.). Methods of soil analysis, Part 2. 1st ed. Agronomy 9:891-901.

Finegan, Chance. 2008. National Parks Traveler webzine; Park History: Big South Fork National River and Recreation Area. September 16th, 2008.

Frazier, C. S., and R. C. Graham. 2000. Pedogenic transformation of fractured granitic bedrock, southern California. Soil Sci. Soc. Am. J. 64:2057-2069.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. p. 383-412. *In* A.Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy Monogr. 9. ASA and SSSA. Madison, WI.

Gerasimov, I.P., and E.N. Ivanova. 1959. Comparison of three scientific trends in resolving general questions of soil classification. Soviet Soil Sci., Transl. 1960 from Pochvovedenie 11:1-18

Hall, G. F., R. B. Daniels and J. E. Foss. 1982. Rate of soil formation and renewal in the U.S.A. *In* Determinates of soil loss and tolerance. ASA, CSSA, Madison, WI.

Heller, J. L. 1963. The nomenclature of soils, or what's in a name? Soil Sci. Soc. Am. Proc. 27:216-220.

Holmgren, B.B.S. 1967. A rapid citrate-dithionite extractable iron procedure. Soil Sci. Soc. Am. Proc. 31:210-211.

Horne, J.C., Swinchatt, J.P., and Ferm, J.C., 1971. Lee-Newman barrier shoreline model, in Ferm, J.C., Horne, J.C., Swinchatt. J.P., and Whaley, P.W., Carboniferous deposition environments in northeastern Kentucky, Guidebook for Geological Society of Kentucky 1971 field excursion: Lexington, Kentucky Geological Survey, p. 5-9.

Hussain, I., K.R. Olson, and S.A. Ebelhar. 1999. Long term tillage effects on soil chemical properties and organic matter fractions. Soil Science Society of America Journal 63:1335-1341.

Jackson, M. L. 1958. Soil Chemical Analysis. 214-221.

Jenny, H. 1941. Factors of soil formation. A system of Quantitative Pedology. McGraw Hill Book Company, New York, NY, USA. 281 pp.

Kilmer, F.J. 1960. The estimation of free iron oxides in soils. Soil Sci. Soc. Am. Proc. 24:420-421.

Kilmer, F.J. and L. T. Alexander. 1949. Methods of making mechanical analysis of soils. Soil Sci. 68:15-24.

Krasil'nikov, N. A. 1958. Soil Microorganisms and Higher Plants. Academy of Sciences of the USSR, Moscow. Institute of Microbiology

Lin, Clara, and N.T. Coleman. The Measurement of Exchangeable Aluminum in Soils and Clays. Soil Sci Soc Am J 24:444-446.

Loeppert, R.H., and W.P. Inskeep. 1996. SSSA and ASA, Methods of Soil Analysis. Part 3. Chemical Methods—SSSA Book series no. 5. Madison, WI

McKenzie, Neil J. and Ryan, P.J. 1999. Spatial prediction of soil properties using environmental correlation. Geoderma 89:67-94.

Mehlich, A. 1953. Determination of P, Ca, Mg, K, Na, and NH_4. North Carolina Soil Test Division Mimeo.

Mehra, O.P and M.L. Jackson. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. In Clays and clay minerals. Proc. 7th Natl. Congr. Pergamon, London.

Murdock, Nora. Emmott, R. Hughes, J. 2008. Cumberland Plateau River Prairies: Understanding hydrologic links between "river prairies" and other threatened riparian resources of the Cumberland Plateau. National Park Service. U.S. Dept. of the Interior.

National Park Service Staff, 2008. Geology and History of the Cumberland Plateau. U.S. Dept. of the Interior. Big South Fork National River and Recreational Area. Oneida, TN.

Newll, W.L. 1978. Understanding natural systems-A perspective for land-use planning in Appalachian Kentucky: U.S. Geological Survey Bulletin 1438, 50p.

Olsen, R.V. and R. Ellis. 1982. Iron. p. 301-312. ***In*** A. L. Page (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy Monogr. 9. ASA and SSSA, Madison, WI.

Outerbridge, W.F. 1980. Lithologic control of landslides in part of the southern Appalachian Plateau [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 2, p. 76.

----------1987. The Logan Plateau, a young physiographic region in West Virginia, Kentucky, Virginia, and Tennessee. U.S. Geological Survey Bulletin 1620.

Prasolov, L.I. 1931. A Unified Nomenclature and the Fundamentals of Genetical Soil Classification. (O edinoi nomenclature i osnovakh genetischkoi klassifikatsii pochva.) Pochvovedenie, 1931, no. 8.

Rice, C.L., Sable, E.G., Dever, G.R., Jr., and Kehn, T.M., 1979. The Mississippian and Pennsylvanian Systems in the United States, Kentucky: U.S. Geological Survey Professional Paper 1110-F, p. F1-F32.

Rozov, N. N., and E. N. Ivanova. 1968. Soil classification and nomenclature used in Soviet pedology, agriculture, and forestry. In World Soil Resour. Rep. 32. FAO, Rome, Italy. pp. 53-77.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. (eds.), 2002. Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Scully, R. W. and R. W. Arnold. 1979. Soil-geomorphic relationships in postglacial alluvium in New York. Soil Sci. Soc. Am. J. 43: 1014-1019.

Sharp, C.F.S., 1938. Landslides and related phenomena; a study of mass movements of soil and rock: New York, Columbia University Press, 136 p. (reprinted 1960, Pageant Books, Paterson, N.J.)

Shepherd, Keith D. and M.G. Walsh. 2002. Development of reflectance spectral libraries for characterization of soil properties. Soil Science Society of America Journal 66:988-998.

Simonson, R.W. 1959. Ouline of a generalized theory of soil genesis. Soil Sci. Soc. Am. Proc. 23:152-156. Madison, WI. USA.

Skaggs T.H., L.M. Arya, P.J.Shouse, and B.P. Mohanty. 2001. Estimation particle size distribution from limited soil texture data. Soil Science Society of America Journal 65:1038-1044.

Smith, B. R., and S. W. Buol. 1968. Genesis and relative weathering intensity studies in three semiarid soils. Soil Sci. Soc. Am. Proc. 32:261-265.

Soil Survey Staff. 1960. Soil Classification, a Comprehensive System-7th Approximation. USDA. U.S. Govt. Printing Office, Washington, DC.

----------1964. Supplement to Soil Classification, a Comprehensive System-7th Approximation. USDA. U.S. Govt. Printing Office, Washington, DC.

----------1975. Soil Taxonomy, USDA Handb. 436. U.S. Govt. Printing Office, Washington, DC.

----------1994. Keys to Soil Taxonomy USDA Soil Conservation Service, 6th ed. Washington, DC.

----------1996. Soil Survey Laboratory Methods Manual: the Soil Survey Analytical Continuum. Soil Survey Investigations Report No. 42. Version 3.0. January 1996.

----------1999. Soil Taxonomy- A Basic System of Soil Classificatio for Making and Interpreting Soil Surveys. 2nd ed. Agric. Handb. No. 436. USDA-NRCS, p. 869.

Springer, M. E. and J. A. Elder. 1980. Soils of Tennessee. University of Tennessee Agri. Exper. Stat. Bull. 596. Knoxville, TN.

Terra J.A., J.N. Shaw, D.W. Reeves, R.L. Raper, E. van Santon, and P.L. Mask. 2004. Soil carbon relationships with terrain attributes, electrical conductivity, and a soil survey in a coastal plain landscape. Soil Science 169:819-831.

United States Department of Agriculture, Natural Resources Conservation Service. 1993. Soil Survey Manual. Soil Surv. Staff. U.S. Dep. Agric. Handb. 18.

----------1998. Keys to soil taxonomy. 8th ed. Soil Surv. Staff.

----------1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd ed. Soil Surv. Staff. U.S. Dep. Agric. Handb. 436.

United States Geological Survey (USGS). 2002. A tapestry of time and terrain: Mississippian and Pennsylvanian Rocks. U.S. Dept. of the Interior, U.S. Geological Survey.

Chapter 2

Soil Fertility in the Big South Fork National River and Recreation Area Based on Geology and Landscape Position

Chapter 2

Soil Fertility in the Big South Fork National River and Recreation Area based on Geology and Landscape Position

Introduction

Rising over 304.8 m above the region around it, the Cumberland Plateau is a large, flat-topped tableland consisting of an uplifted block of intricately dissected, horizontally bedded, Pennsylvanian and Mississippian age bedrock that is bound on the west by the back wasting Pottsville or Cumberland Escarpment and to the east by the Cumberland Mountains (Fenneman, 1938; Newell, 1986). This area is characterized by rugged terrain on steep slopes with accumulations of talus and weathered colluvium that is frequently transported by mass wasting (Newell, 1986). Within the plateau, wooded, knife-edged ridge tops of Pennsylvanian sandstone bound by vertical cliffs extend in all directions with deep, narrow, sinuous valleys between ridges. Although the soils are typically thin and infertile, the area was once covered by a dense hardwood forest equal to that of the Appalachians less than 96.56 km to the east (National Park Service Staff, 2008). As a landform, the Allegheny Plateau reaches from north-central Alabama through Tennessee and Kentucky and Pennsylvania to the western New York border. Geographers commonly call this landform the Appalachian Plateau, although it is known by various names throughout the different regions. In Tennessee and Kentucky, it is called the Cumberland Plateau (National Park Service Staff, 2008).

The rocks that now form the cap of the Cumberland Plateau were laid down in an ancient shallow sea over 350 million years BP, during the Mississippian (360-320 million years BP) and the Pennsylvanian (320-284 million years BP) periods of geologic time (USGS, 2002). These eras are combined and called the Carboniferous Period, because of the large coal deposits found in rocks of this age throughout the world. These sediments were deposited in horizontal layers thousands of meters thick. The resulting pressure hardened these sediments into layers of limestone, shale, coal, and sandstone. Beginning about 285 million years BP, the entire area was slowly lifted over 609.6 m above sea level and erosion immediately began to shape the landscape (National Park Service Staff, 2008).

Alternating layers of Pennsylvanian-age sandstones and shales dominate the surface geology. These rocks have very low permeability, so rainfall penetration into the subsurface is limited, especially in areas of steep topography. Consequently stream flow responds rapidly to storm events (Murdock, 2008).

Within the Cumberland Plateau, it is necessary for various land resource planners, farmers and Park Service personnel to have accurate background fertility data in order to properly implement management decisions in the region. About 160.93 km northwest of Knoxville, Tennessee, the Big South Fork National River and Recreation Area (BSFNRRA) encompasses more than 50,585.70 hectares along the border of Tennessee and into Kentucky. The BSFNRRA lies within the greater Cumberland River watershed, a 46,620 km^2 region that stretches from the western slope of the Appalachian Mountains to the mouth of the Ohio River, and covers a substantial area of the Cumberland Plateau. The South Fork Cumberland River Watershed, designated 05130104 by the USGS, is approximately 3,535 square km (2,527 km^2 in Tennessee) and drains to the Cumberland River.

Access to various landforms and surface geology is available within the Big South Fork that are representative of the Upper Cumberland Plateau. It has been previously shown that soil properties are highly related to landscape position. Further study is therefore needed to ascertain the general nutrient availability, and how landscape position is related to soil fertility in this area. Objectives for this study were: first to determine baseline fertility status for the seven sites selected based on total elemental analysis and Mehlich I analysis, and secondly to give fertilizer and lime recommendations for Bicolor Lespedeza (*Lespedeza bicolor*) to be grown as wildlife food plots.

Literature Review

The productivity of a given area is largely determined by the chemical and physical attributes of the underlying soil. According to Carter et al. (1997), the quality of any soil is dependent on the soil's inherent composition which is a function of climate, parent material, time, topography, and organisms. Soil chemical attributes of specific interest are base saturation, pH, Mehlich I, total elemental analysis, and organic C, as these will determine nutrient abundance for aid in fertilizer additions. Parent materials and landscape position are also of considerable importance as these will influence the spatial distribution of soil types and thus the distribution of the chemical properties (Windingstad et al., 2007). Numerous researchers have studied the relationship and distribution of soils across hillslopes identifying a certain degree of predictability between specific soil characteristics and slope position (Birkeland, 1999; Carter and Ciolkosz, 1991; Conachera and Dalrymple, 1977; Finney et al., 1962; Gerrard, 1981; Kleiss, 1970; Losche et al., 1970; Milne, 1935 and Ruhe and Walker, 1968). This relationship is the result of specific geomorphic processes inherent to individual slope elements which are characterized by steepness and the predomination of erosional or depositional processes. Subsurface B horizon variables such as base saturation and texture are considered to be less dynamic and change over longer time spans (thousands of years) while surface horizons attributes such as organic carbon content, available phosphorus, and pH can fluctuate over several years to less than a month and can easily be influenced by humans. Therefore, the soil in its entirety must be described and analyzed in order to draw legitimate conclusions regarding soil fertility.

Research by Furley (1971), Carter and Ciolkosz (1991), and Norten et al. (2003), plot soil properties versus slope position or slope gradient on an XY axis and calculate linear regression equations that predict soil properties within a catena (lateral variability of soils on a slope due to slope position and slope gradient). The basis of these models is that soluble minerals and exchangeable ions are expected to move down slope and be deposited at the footslope while non-soluble materials such as organic carbon are expected to be highest at the summit and toe (Gerrard, 1981). On stabilized slopes these distributions are reflected in a negative or positive parabolic trend with the axis of the curve representing the maximum zone of erosion or accumulation (Norten et al., 2003). Strong parabolic correlations are expected only on stable slopes that have reached some form of steady state. Slopes that have experienced recent mass wasting are expected to show less variation in pedogenic properties between slope position resulting in more linear trends or shifts in the location of the axis of the parabolic curve. Baseline soil fertility was determined for this study area, and is essentially the generalized soil nutrient composition of the different soils associated with the different geologic landscape formations. Different parent materials will have corresponding differing abilities to supply plant nutrient. This is due to the fact that different parent materials have different initial concentrations of specific elements. Weathering of parent material controls the release of the nutrients from the original minerals along with the stability of the original minerals. A baseline soil fertility status can be obtained based on the spatial variability of the geologic formations in the same climatic regions. Further, this baseline fertility data can be used to estimate the soil fertility of geologic areas with similar land uses. Figure 4 illustrates the land use distribution of the BSF watershed.

Chemical weathering is a major factor affecting the nutrient status of soils. Calcium, Mg, K, Fe, and P are the major elements in both pedology and plant nutrition that were evaluated in this study. The trace elements that become available from chemical weathering that were evaluated in this study are Cu, Mn, and Zn. Phosphorus availability is largely dependent on pedogenesis because it is derived almost entirely from primary minerals (Anderson, 1988).

The following list gives a brief explanation of the role of each element measured according to the Soil Fertility Manual (2003) using Mehlich I technique:

- Calcium stimulates root and leaf development, a component of cell walls, aids in the reduction of nitrate in the plant, aids in the activation of some plant enzyme systems, and aids in balancing organic acids in the plant.
- Copper is essential for the formation of chlorophyll in plants and acts as a catalyst for other plant reactions.
- Iron acts as a catalyst to chlorophyll formation, an oxygen carrier in the nodules of legumes, and aids in the formation of certain respiratory enzyme systems.
- Manganese primarily functions as a part of plant enzyme systems, activates several metabolic reactions, aids in chlorophyll synthesis.

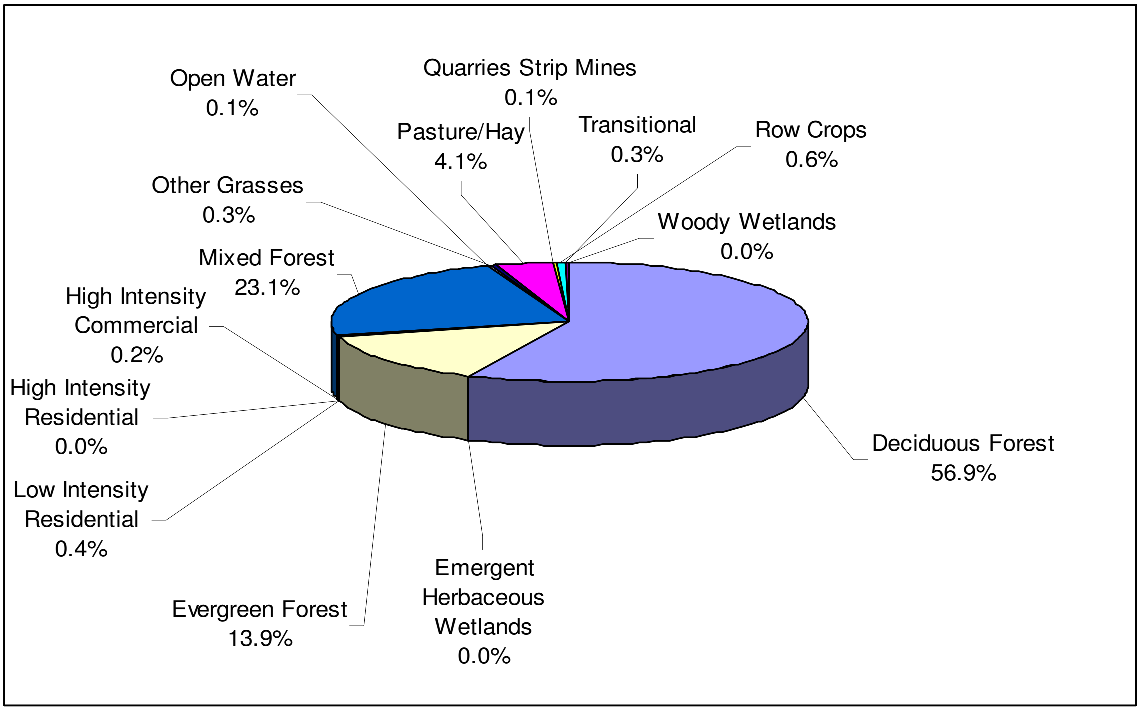


Figure 4. Land Use Distribution in the Tennessee Portion of the South Fork Cumberland River Watershed.

- Magnesium is actively involved in photosynthesis and is a constituent in chlorophyll. Additionally, Mg is involved in phosphate metabolism, plant respiration, and aids in the activation of many enzyme systems.
- Potassium plays a crucial role in photosynthesis, is essential for protein synthesis, is involved in the breakdown of carbohydrates, aids in ionic balance, aids in overcoming plant disease, improves winter hardiness, activates more than 80 enzyme systems involved in the regulation of the major plant growth reactions, and provides turgor.
- Phosphorus plays a role in plant fertility because it is a component of photosynthesis, respiration, energy transfer and storage, cellular processes. Additionally, phosphorus is involved in early root growth and formation.
- Zinc aids in the synthesis of plant growth substances and enzyme systems, and zinc is essential in the promotion of certain metabolic reactions. Additionally, Zn is necessary for the production of chlorophyll and carbohydrates.

Methods

Sample sites were selected on a slope/landscape position basis to represent the majority landforms found in the study area (Figure 5). These sites represent the different positions along the hill slope including summit, backslope, sideslope, footslope, and floodplain.

Soil samples were air dried and passed through a 2-mm sieve. Subsamples of the <2-mm fraction were ground to pass through a 60-mesh sieve for use in the determination of total organic C using the Walkley-Black method, and total elemental concentration by a HF microwave digestion technique followed by inductively coupled plasma spectroscopy (ICP) analysis (Ammons et al., 1995). Particle size was performed using the pipette method as

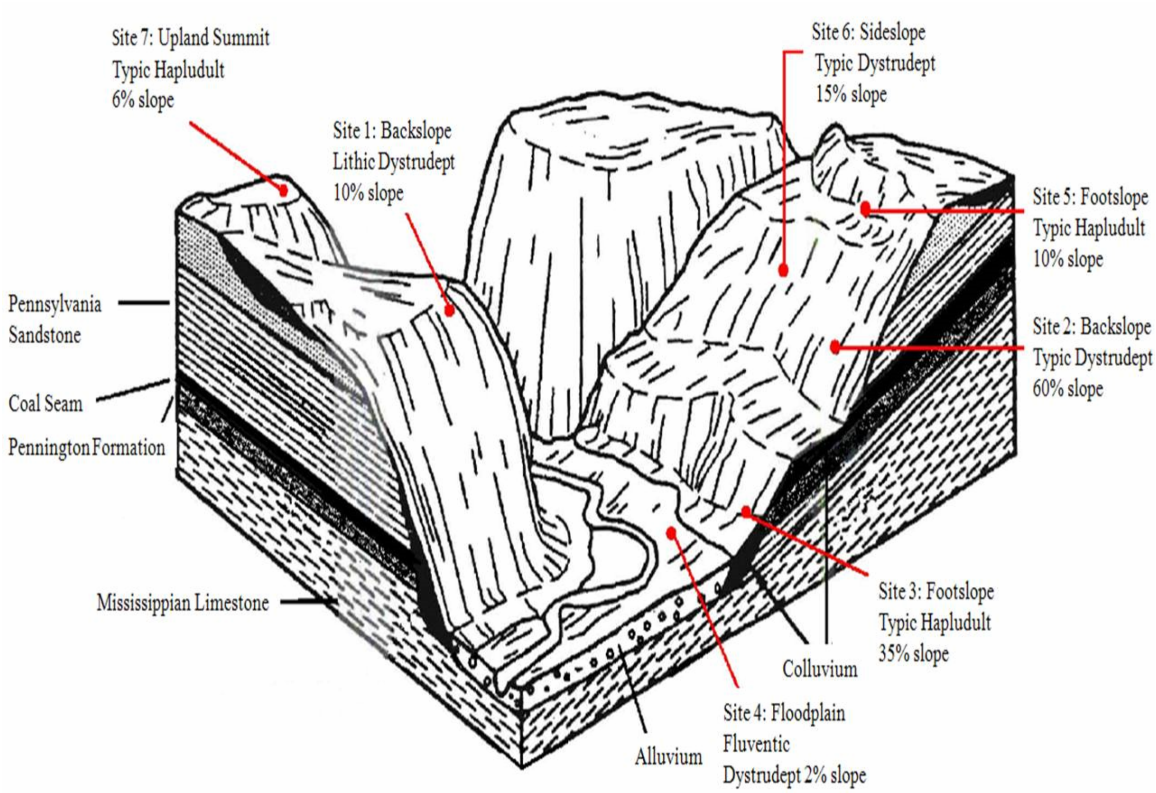


Figure 5. Site position on landscape

described by Kilmer and Alexander (1949). The following methods refer to the Soil Survey Staff (2004) unless otherwise noted. Exchangeable bases (Ca, Mg, Na, K) were extracted using NH_4OAc buffered at pH 7 (Method 4B) and determined through ICP analysis. Exchangeable aluminum and extractable acidity were determined by 1 M KCl extraction (Method 4B3). Extractable acidity was determined through NaOH titration. Base saturation was determined mathematically by dividing the sum of the bases in cmol/kg soil by the CEC. Extractable (or free) Fe was determined using dithionite-citrate extraction and quantified using atomic absorption spectrophotometry (AAS) (Holmgren, 1967). All procedures were carried out including duplicates on all samples to ensure accuracy and repeatability.

Statistical modeling was done using hierarchical clustering implemented by the Gene Cluster version 3.0 software with the following parameters: similarity matrix; correlating uncentered, clustering method; complete linkage data log transformed, centered and normalized before clustering (Eisen, 1998). Tree View software was used to visualize the results of the clustering. Before the statistical analyses, the content of each element in each horizon was normalized to the minimum value of the content across all locations in the horizon. The $\log^{-2}$ values of the normalized contents were then used for the analysis.

The color scheme used in the figures represents the log-ratio of the element content to the minimum (Page, 1996). The black color means minimum value, which is equal to 0. The increase in the value content is showed by red color intensity. Data used for this analysis came from samples of the A horizon and samples from the last horizon within the control section of each profile. The control section sample was used to represent the parent material for each site.

Results and Discussion

The distribution of soils sampled and analyzed reflects the lithologic control over slope steepness in the upland bench and slope topography in this portion of the Upper Cumberland Plateau (Figure 5). The soils of the summit have moderately shallow Ultisols with loam to clay loam argillic horizons and silt loam surface horizons. Shoulder positions were predominately comprised of rock outcrops or extremely shallow soils. The back slope and side slope positions contained Inceptisols with loamy textures over sandstone and shale residuum. The soils of the footslope are Ultisols, one forming from colluvium derived from the Pennington Formation with silt clay loams and silty clay textures and one Ultisol with loam textures. Floodplain soils away from the channel consisted of weakly developed sand to loamy sand to sandy loam Inceptisols. For sake of comparison, the seven profiles examined were divided in to four sub-categories based on position along the landscape (Table 31).

Table 31. Classification and landscape position of soil groups

Soil Group	Classification	Slope Range	Landscape Position
1	Hapludult	<10	Upland Summit
2	Dystrudepts	10-60	Back/Side slope
3	Hapludults	10-20	Footslope
4	Dystrudept	0-2	Floodplain

Soil Group 1: Upland Summit

The pedon from Site 7 makes up soil Group 1. The soil morphology of the summit positions indicates relative stability with respect to erosional processes. Clay accumulation along with leaching of some basic cations and the presence of E horizons indicate long periods of stability. The pedon at Site 7 is extremely weathered with intensive clay accumulation in the Bt horizons, moderate subangular blocky structure, and a well developed elluvial (E) horizon. This pedon has developed in the Breathitt Group which includes the Corbin, Bee Rock, Sewanee, and Warren Point Sandstone members. As was expected, this soil at this stage of development has low CEC and base saturation due to long periods of weathering and leaching processes making it relatively infertile.

Soil Group 2: Sideslope/Backslope

Pedons from Sites 1, 2, and 6 represent soil Group 2. The soils in group 2 are found on slopes with gradients between 10 and 60% and represent zones of moderate to extensive erosion. These soils are forming in residuum weathered from sandstone. Base saturation within B horizons at Sites 1 and 5 are low compared to other sampling locations on the summit, footslope, and floodplain positions. This reflects the erosional nature of the steep backslope position and the low clay contents of the subsurface horizons. The low base saturation within the Bw horizons are likely a result of the lateral flow of water downslope, removing soluble cations. Base saturation at these sites is below 20% and pH levels are less than 4 indicating a predominance of Al on the exchange sites.

Soil Group 3: Footslope

Pedons from Sites 3 and 5 represent soil Group 3. The lower slope gradients in the footslope and toeslope positions have resulted in relative stability facilitating soil development. These colluvial soils are classified as Hapludults with textures ranging from loams to silt clay loams. Base saturation increases from Groups 1 and 2 as does pH in Site 3. Organic carbon (OC) at Site 3 decreases for the surface horizon when compared to Groups 1 and 2 while OC increases in the surface at Site 5. The decrease in slope gradient may be influencing the mixing of fresh organic matter and promoting in situ decomposition. Norten et al. (2003) identified lower organic C levels on lower gradient slope positions in the Colorado Plateau and related it to a lower influx of organic matter resulting in an immobilizing (conversion of inorganic nitrogen and phosphorus into organic forms) microbial environment in which nutrients are being taken out of the soil by microbes to facilitate decomposition. Many traditional hillslope studies identify increasing organic C levels with distance from the summit (Finney et al., 1962, Honeycutt, 1990, and Kleiss,1970). Available P in the surface horizons for Group 3 is higher than Group 1 and 2 with the exception of Site 2 in Group 2. Subsurface available P is comparable to all other subsurface soils in that P is low.

Soil Group 4: Floodplain

The pedon from Site 4 represents Soil Group 4. Variation in Group 4 soils is largely a function of distance from the modern river channel. Sand content increases closer to the channel while silt content decreases. This reflects floodplain deposition processes during peak flow events in which coarser textures drop out close to the channel creating a natural levee and finer grained sediments accumulate in the slower moving floodwaters away from the channel (Ritter et al., 2002). The absence of argillic horizons in these soils also indicates that the alluvium is fairly young. This correlates well with other studies in the southeastern US which have identified Late

Holocene terraces/floodplains having cambic horizons with little clay accumulation (Leigh, 1996; Mills, 2005). The pedon at Site 4 does not have buried horizons but does have an irregular distribution of carbon with depth, indicative of flood events.

Elemental Analysis

From the total elemental and Mehlich I extractable nutrient data, it is important to determine how much of each element's total is plant available. This not only shows what is plant available currently, but by comparing the data a potential availability can be derived by knowing the percent of each total that is bound in the minerals that can be released through weathering processes. The presence or absence of potentially available nutrients will allow for fertilizer and lime requirements to be more accurate and site specific. The elements of focus are phosphorus (P) and potassium (K) because of their importance in plant growth and because these elements are extremely low throughout the research area.

Phosphorus and Potassium

Group 1 soils are located in the highest landscape position of all sites sampled. The total K (TK) concentrations in the profile are lowest in the surface horizon (1,455 mg TK kg^{-1} soil), and the TK concentration is approximately double of that in the Cr horizon (3,085 mg TK kg^{-1} soil) Table 33, Figure 6. The total P (TP) concentrations also followed that of TK with the lowest TP concentration (107 mg TP kg^{-1} soil) occurring in the A horizon. The Cr also had a TP concentration approximately double (201 mg TP kg^{-1} soil) of the A horizon. Mehlich I extractable K (M1K) for the surface horizon was ranked as low according to the Tennessee soil test recommendations for annual lespedeza, Table 32. Mehlich 1 extractable P (M1P) for the surface horizon also ranked as low.

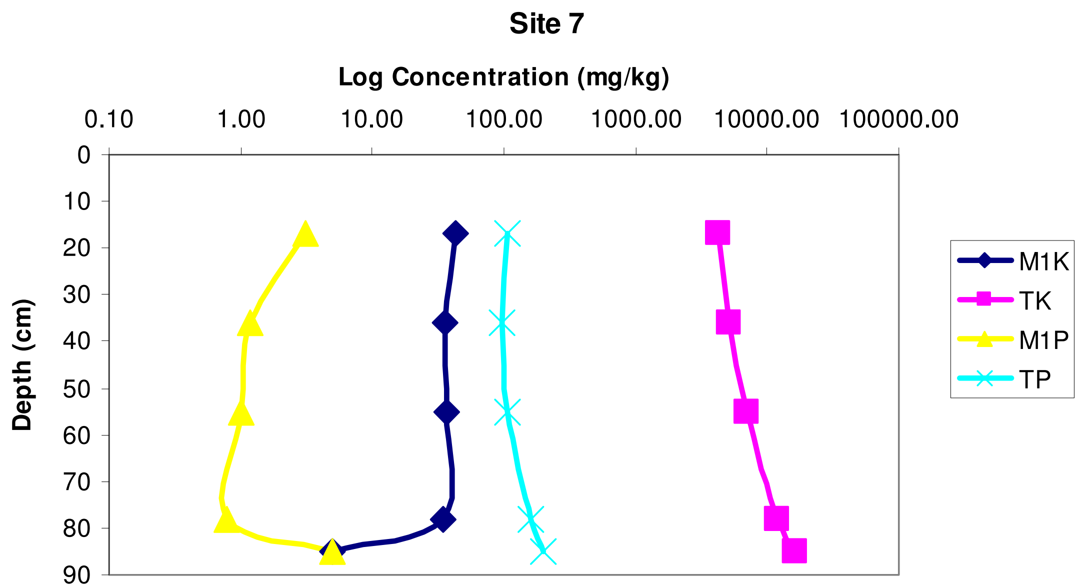


Figure 6. Site 7 M1K, TK, M1P, TP Concentrations vs. Depth

Table 32. Site 7 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	mg kg^{-1}								
7	A	0-17	26.56	0.42	267.80	42.47	7.49	55.10	64.55	3.14	1.83
7	E	17-36	16.27	0.36	47.32	36.14	6.20	6.04	63.35	1.19	0.87
7	Bt1	36-55	69.30	0.82	23.19	36.76	34.07	1.07	136.75	1.01	1.50
7	Bt2	55-78	76.85	0.27	19.48	34.92	74.55	NA	97.95	0.80	0.70
7	Cr	78+	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 33. Site 7 Elemental Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	mg kg^{-1}								
7	A	0-17	1,024.3	35.1	14,545.0	4,190.0	1,015.5	249.8	3,115.0	106.7	39.4
7	E	17-36	791.3	30.0	19,175.0	5,055.0	1,503.8	113.4	2,840.0	97.8	46.4
7	Bt1	36-55	1,028.3	41.0	27,925.0	6,932.5	1,817.3	67.3	2,937.5	107.1	50.5
7	Bt2	55-78	510.0	33.6	38,250.0	11,912.5	2,505.3	30.8	3,065.0	160.1	68.5
7	Cr	78+	439.3	32.2	30,850.0	16,572.5	2,436.8	25.6	2,987.5	200.6	39.9

Group 2 soils are located on the sideslopes of the landscape. Total K concentrations for the first three horizons of Site 6 (A, E, and BE) did not differ greatly (2,426, 2,400, and 2,113 mg TK kg^{-1} soil) Table 35, Figure 7. Total K concentrations more than doubled in the Bt1 and Bt2 (4,828 and 3,935 mg TK kg^{-1} soil) horizons and drop sharply in the R horizon (1,682 mg TK kg^{-1} soil). The highest TP concentration was in the A horizon (135 mg TP kg^{-1} soil). Both M1K and M1P for the surface horizon at Site 6 were ranked as low according to the Tennessee soil test recommendations Table 34.

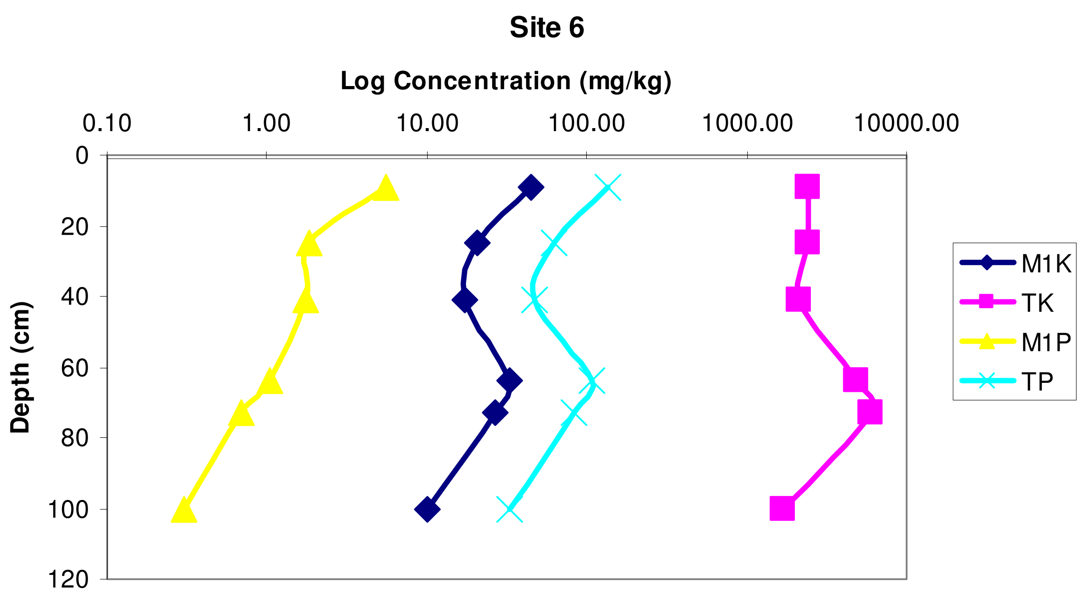


Figure 7. Site 6 M1K, TK, M1P, TP Concentrations vs. Depth

Table 34. Site 6 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	-----------------	-----------------	-----------------	-----------------	mg kg^{-1}	-----------------	-----------------	-----------------	-----------------
6	A	0-9	33.08	0.56	431.50	44.74	11.98	3.04	65.65	5.58	2.20
6	E	9-25	12.54	0.18	147.65	20.60	2.62	2.25	65.60	1.85	1.10
6	BE	25-41	11.07	0.15	86.35	17.35	2.53	1.92	58.20	1.74	0.75
6	Bt1	41-64	29.75	0.55	42.17	33.16	6.24	1.07	118.15	1.03	1.41
6	Bt2	64-73	20.58	0.28	43.57	26.55	3.98	NA	65.75	0.69	0.79
6	R	73+	10.85	0.31	19.94	10.02	1.28	NA	56.15	0.30	0.36

Table 35. Site 6 Elemental Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	-----------------	-----------------	-----------------	-----------------	mg kg^{-1}	-----------------	-----------------	-----------------	-----------------
6	A	0-9	533.0	31.2	12,632.5	2,426.0	584.0	61.9	2,370.8	134.6	22.3
6	E	9-25	378.5	41.7	13,957.5	2,400.0	576.5	64.7	1,695.5	63.3	12.9
6	BE	25-41	418.8	26.9	10,120.0	2,113.0	583.0	35.8	1,854.5	47.7	15.8
6	Bt1	41-64	451.3	33.1	26,175.0	4,827.5	1,396.8	70.8	2,002.3	106.3	29.5
6	Bt2	64-73	337.8	29.9	24,747.5	5,935.0	1,331.5	37.0	2,162.3	84.1	16.4
6	R	73+	680.0	47.2	12,870.0	1,681.8	394.0	55.1	2,455.8	32.9	26.0

Site 1 of Group 2 had within the A and R horizons the greatest concentration of TK throughout the profile (1,523 and 1,275 mg TK kg^{-1} soil) Table 37, Figure 8. The BE horizon had the lowest TK concentration (567 mg TK kg^{-1} soil). The BE horizon had the highest TP concentration in the profile (249 mg TP kg^{-1} soil). Site 1 had M1K rating of medium in the surface horizon and M1P rating of low in the surface Table 36.

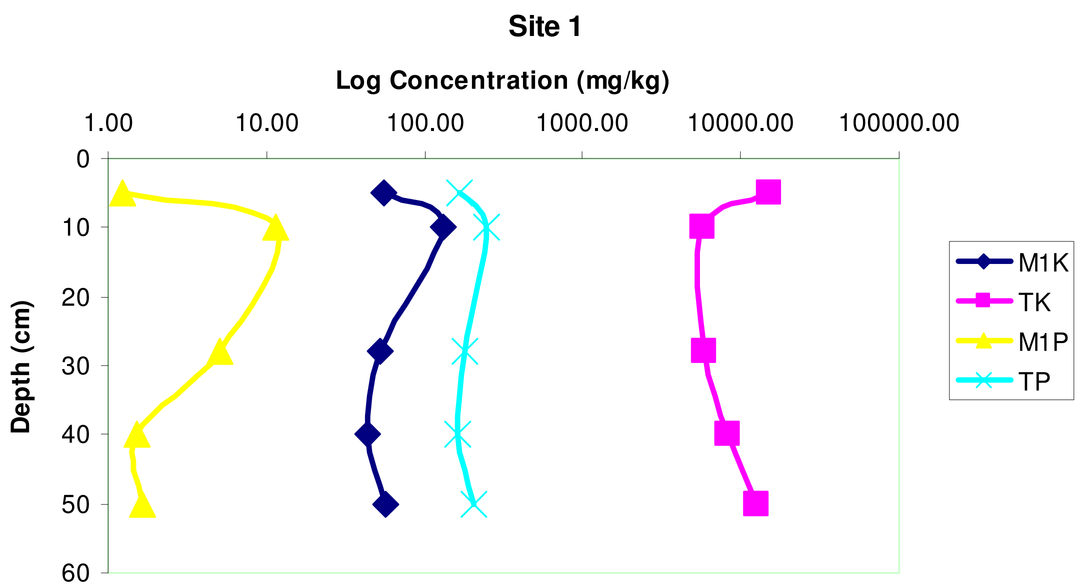


Figure 8. Site 1 M1K, TK, M1P, TP Concentrations vs. Depth

Table 36. Site 1 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
			--mg kg^{-1}---								
		cm					---				
1	A	0-5	228.35	0.94	72.00	55.40	47.94	NA	145.70	1.22	1.43
1	BE	5-10	309.65	1.13	852.00	132.70	47.17	307.80	65.10	11.53	3.73
1	Bw1	10-28	34.73	0.73	903.00	52.94	10.98	140.00	59.25	5.13	1.82
1	Bw2	28-40	30.01	0.50	146.50	43.95	42.26	19.71	84.00	1.52	1.08
1	R	40+	23.92	0.76	173.70	56.60	87.65	21.61	66.90	1.66	1.20

Table 37. Site 1 Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	--mg kg^{-1}---								
1	A	0-5	768.3	24.2	56450.0	15232.5	3220.0	66.7	3152.5	167.9	47.4
1	BE	5-10	831.8	27.0	19575.0	5672.5	1122.3	566.5	2605.0	249.2	28.5
1	Bw1	10-28	576.3	25.7	21552.5	5847.5	1212.5	474.3	2503.5	178.6	31.6
1	Bw2	28-40	376.3	28.1	27725.0	8337.5	1615.8	218.8	2131.8	163.5	26.7
1	R	40+	462.5	28.0	33600.0	12747.5	2670.0	335.5	2635.0	206.4	40.6

Site 2 was located on a landscape position similar to that of Site 1 (backslope). Total K concentration in the A horizon was the lowest for the profile (13,415 mg TK kg^{-1} soil) Table 39, Figure 9. However, the A horizon did have the greatest M1K extracted and was rated as very high according to the Tennessee soil test recommendations. Total K concentrations in the lower horizons of the profile did not vary greatly (17,600-18,242 mg TK kg^{-1} soil). The distribution of M1P was comparable to that of Site 1 except it was higher availability Table 38. There was a substantial difference in the TP concentration from the A horizon and the C horizon, which were 600 and 241 mg kg^{-1}, respectively. This indicates that the majority of P in the surface is recalcitrant. The surface horizon for Site 2 has a M1P rating of medium according to the recommendations for annual lespedeza.

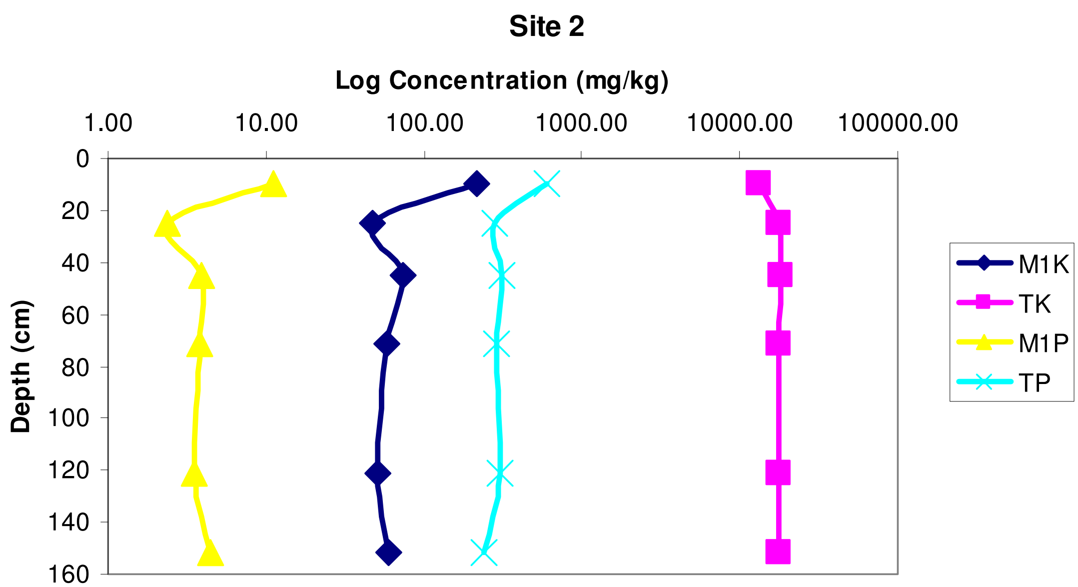


Figure 9. Site 2 M1K, TK, M1P, TP Concentrations vs. Depth

Table 38. Site 2 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	mg kg^{-1}								
2	A	0-10	849.50	1.11	189.90	215.90	183.75	443.75	59.40	11.07	6.19
2	BA	10-25	106.75	1.75	221.70	47.68	45.62	107.05	65.80	2.37	1.49
2	Bt1	25-45	204.70	1.83	250.85	74.40	103.20	142.55	72.15	3.95	1.86
2	Bt2	45-71	169.20	1.25	203.25	57.90	86.75	99.35	92.80	3.86	1.39
2	Bt3	71-121	113.55	1.06	184.00	51.60	100.60	71.65	66.10	3.50	1.35
2	C	121-152	103.60	1.79	177.30	59.90	153.30	80.90	62.20	4.46	1.60

Table 39. Site 2 Elemental Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	mg kg^{-1}								
2	A	0-10	1,351.5	17.1	36,475.0	13,415.0	2,867.5	1,947.3	2,485.8	600.3	69.3
2	BA	10-25	530.8	20.7	29,850.0	17,880.0	3,095.0	1,071.8	2,945.0	282.0	56.6
2	Bt1	25-45	578.5	23.2	32,075.0	18,242.5	3,340.0	1,184.8	2,702.5	310.3	69.4
2	Bt2	45-71	650.3	23.6	34,950.0	17,600.0	3,267.5	1,118.8	3,370.0	284.8	59.6
2	Bt3	71-121	520.0	18.4	36,550.0	17,870.0	3,485.0	1,053.8	2,792.3	305.5	60.7
2	C	121-152	541.5	19.0	34,650.0	17,822.5	3,322.5	904.5	2,880.0	241.2	50.8

Group 3 soils are located further down the landscape and position along the. All horizons below the A were Bt horizons, at Site 3, which could explain the lack of variation of the M1K throughout the argillic, Table 40. The A horizon had the lowest TK concentration (17,363 mg TK kg^{-1} soil) Table 41, Figure 10, but had the highest M1K (222 mg kg^{-1}) and was rated as very high. The lower horizons had TK concentrations ranging from 19,690-21,948 mg TK kg^{-1} soil. The highest TP concentration in this profile occurred in the A horizon (418 mg TP kg^{-1} soil), and the TP concentrations throughout the rest of the profile had similar concentrations ranging from (270 to 320 mg TP kg^{-1} soil. The surface horizon has M1P rating of low.

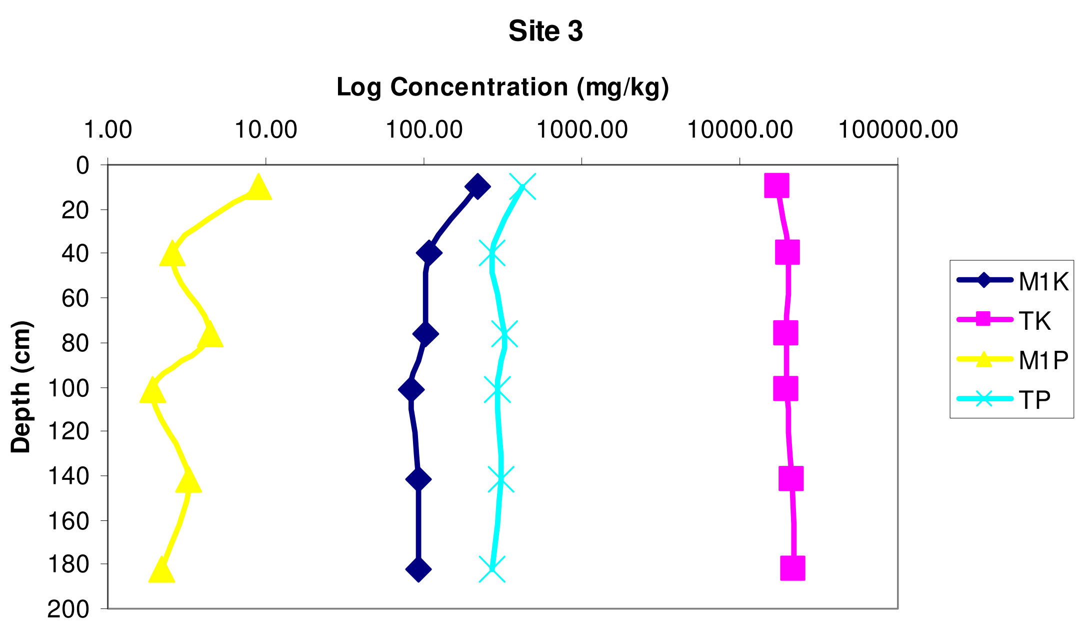


Figure 10. Site 3 M1K, TK, M1P, TP Concentrations vs. Depth

Table 40. Site 3 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm					mg kg^{-1}				
3	A	0-10	1612.00	1.85	332.85	221.95	402.95	315.65	93.80	8.94	3.34
3	Bt1	10-40	624.00	1.55	194.40	108.30	284.60	59.90	72.25	2.58	1.40
3	Bt2	40-76	1131.50	1.52	164.65	101.95	445.40	51.90	75.15	4.43	1.30
3	Bt3	76-101	658.00	1.67	181.50	84.05	531.00	38.41	107.20	1.95	1.74
3	Bt4	101-142	562.50	2.21	241.95	92.90	646.50	47.18	101.05	3.24	2.44
3	C	142-182	584.50	1.75	211.75	92.85	379.70	46.00	81.05	2.18	1.96

Table 41. Site 3 Elemental Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm					mg kg^{-1}				
3	A	0-10	2,060.3	20.3	37,000.0	17,362.5	4,415.0	964.3	2,937.5	417.8	53.5
3	Bt1	10-40	1,048.3	40.9	41,875.0	20,520.0	5,252.5	724.0	3,180.0	269.9	61.8
3	Bt2	40-76	1,334.3	40.7	40,625.0	19,690.0	5,492.5	777.5	3,730.0	320.5	81.4
3	Bt3	76-101	1,124.5	35.1	42,475.0	19,902.5	5,720.0	782.8	3,802.5	289.8	82.3
3	Bt4	101-142	1,082.8	34.6	43,400.0	21,600.0	6,627.5	777.5	3,700.0	311.5	93.6
3	C	142-182	1,148.5	39.9	42,975.0	21,947.5	6,695.0	829.0	3,682.5	270.3	94.4

Site 5 was located on a footslope similar to that of Site 3. Unlike Site 3, Site 5 contained a BE horizon. Site 5 was similar to Site 3 by having Bt horizons comprising most of the profile. Total K concentrations increased throughout the profile with the highest TK concentration occurring in the Bt3 horizon, Figure 11, Table 43. Total K concentrations ranged from 10,073 to 15,255 mg TK kg^{-1} soil. Total P was highest in the surface horizon as was M1P. Below the surface horizon, there was little variation among concentrations of either TP or M1P, Table 42. The surface horizon at Site 5 was rated as high for both M1K and M1P according to the Tennessee soil test recommendations for annual lespedeza.

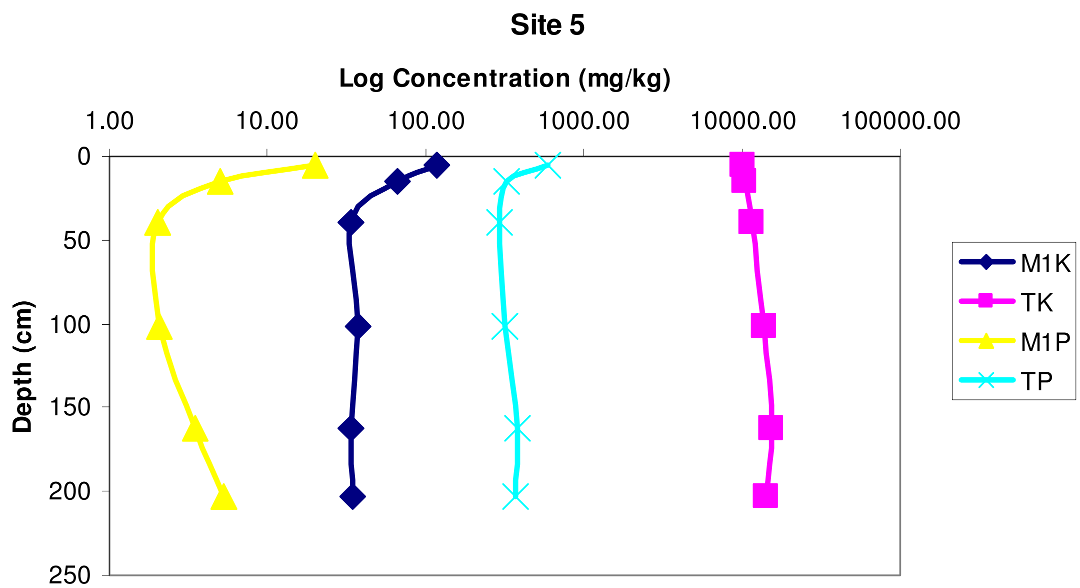


Figure 11. Site 5 M1K, TK, M1P, TP Concentrations vs. Depth

Table 42. Site 5 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	--				mg kg^{-1}				--
5	A	0-5	576.00	3.84	473.10	118.55	117.75	259.25	66.10	19.79	8.94
5	BE	5-15	74.75	1.41	473.25	66.55	25.39	90.35	125.35	5.03	2.41
5	Bt1	15-40	33.01	0.90	231.30	33.42	12.07	43.10	52.60	2.03	1.42
5	Bt2	40-101	70.80	0.87	112.65	36.97	54.25	54.80	87.80	2.10	1.50
5	Bt3	101-162	29.52	1.38	85.85	33.37	67.85	19.13	61.20	3.51	1.45
5	BC	162-203	38.69	1.28	106.80	34.98	80.45	45.92	66.85	5.33	1.60

Table 43. Site 5 Elemental Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	--				mg kg^{-1}				--
5	A	0-5	1,259.0	39.9	33,950.0	10,072.5	2,567.5	816.0	3,787.5	586.5	112.6
5	BE	5-15	617.0	24.8	30,600.0	10,270.0	2,200.5	441.3	3,925.0	324.5	71.5
5	Bt1	15-40	545.0	30.0	39,775.0	11,652.5	2,445.8	289.5	3,725.0	291.3	81.2
5	Bt2	40-101	496.3	32.9	47,925.0	13,832.5	2,775.0	519.5	3,767.5	314.0	83.5
5	Bt3	101-162	616.5	34.0	47,875.0	15,255.0	3,275.0	317.8	4,315.0	380.8	96.8
5	BC	162-203	505.3	30.6	48,850.0	14,290.0	3,017.5	677.3	4,315.0	369.8	83.1

Group 4 soils are located in a floodplain. Site 4 had much lower TP concentrations than that of the next higher landscape position on the footslope of group 3 soils. Total K was highest in the Bw6 horizon with 6,590 mg kg^{-1} and lowest in the Bw2 with 1,470 mg kg^{-1}, Figure 12. Mehlich 1 K was also highest in the Bw6 and lowest in the Bw2, Table 44. The surface horizon had M1K rating of medium. Total P was also highest in the Bw6 and lowest in the Bw2, Table 45. A rating of low was assigned for the M1P of the surface horizon according to Tennessee soil test recommendations.

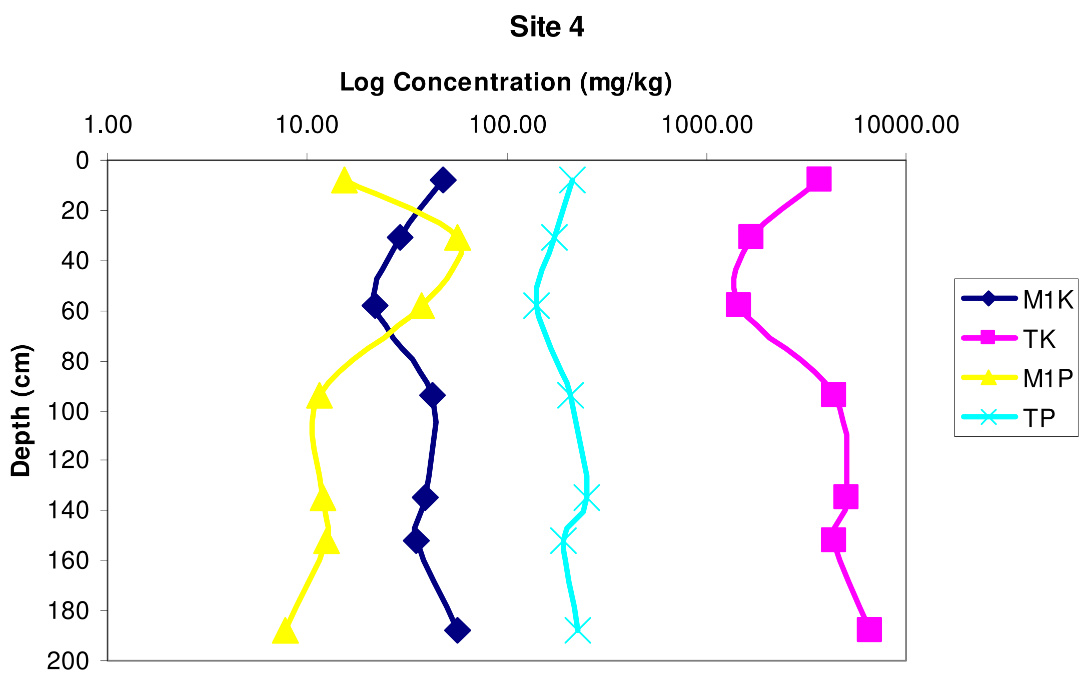


Figure 12. Site 4 M1K, TK, M1P, TP Concentrations vs. Depth

Table 44. Site 4 Mehlich I

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	mg kg^{-1}								
4	A	0-8	330.80	1.04	361.15	47.67	52.55	78.65	59.80	15.25	3.99
4	Bw1	8-31	157.20	1.15	328.35	29.42	24.31	22.85	76.20	56.85	1.63
4	Bw2	31-58	98.90	1.06	284.35	21.75	19.40	16.12	51.19	37.05	1.36
4	Bw3	58-94	115.00	1.53	358.15	42.65	28.64	19.04	123.00	11.55	1.26
4	Bw4	94-135	91.20	1.64	311.90	39.17	22.84	18.93	56.05	11.88	1.31
4	Bw5	135-152	46.24	1.55	244.55	35.52	19.16	15.24	60.75	12.55	1.39
4	Bw6	152-188	57.25	1.23	403.80	56.45	38.46	25.13	62.90	7.69	1.45

Table 45. Site 4 Elemental Totals

Site	Horizon	Depth	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
		cm	mg kg^{-1}								
4	A	0-8	695.8	20.3	17,512.5	3,677.5	863.8	297.8	2,680.0	214.8	30.2
4	Bw1	8-31	484.5	19.4	16,645.0	1,695.0	410.0	164.8	2,408.0	172.4	15.5
4	Bw2	31-58	443.3	22.7	19,730.0	1,470.3	382.0	161.6	2,203.0	141.8	17.2
4	Bw3	58-94	542.5	16.7	15,545.0	4,410.0	1,075.8	324.5	3,230.0	209.0	30.9
4	Bw4	94-135	545.8	19.5	16,780.0	5,025.0	1,192.3	397.0	3,552.5	252.0	36.0
4	Bw5	135-152	422.0	16.4	14,072.5	4,382.5	973.8	295.8	2,972.5	193.7	27.5
4	Bw6	152-188	434.5	18.5	20,332.5	6,590.0	1,554.8	448.8	3,297.5	227.6	40.4

Table 46: Range of total elemental concentrations averaged over all horizons

Element	Range mg kg^{-1}	Expected Range mg kg^{-1}
Ca	338 to 2,060	700 to 500,000
Cu	16 to 47	2 to 250
Fe	10,120 to 56,450	80 to 37,000
K	1,470 to 21,948	2,000 to 550,000
Mg	382 to 6,695	400 to 9,000
Mn	26 to 1,947	20 to 10,000
Na	1,1696 to 4,315	150 to 25,000
P	33 to 600	35 to 5,300
Zn	13 to 113	1 to 900

Background elemental concentrations of selected chemical elements occurring in the soil were determined within this study. The seven soils examined represent MLRA 125 of Tennessee. Ranges for the nine elements analyzed for this fertility study were obtained by averaging all horizons for each pedon Table 46. These values are in agreement with elemental concentrations of soils and geological materials established in other studies, Table 46, (Essington, 2003).

Statistical Analysis

Revealing similarities between site by clustering of element contents in the A horizon and parent material:

To reveal similarity between sites in their chemical and fertility characteristics we analyzed the data produced in this study using hierarchal clustering. Results of the clustering are given in Figures13-15. Figure 13 illustrates clusters sites by the concentration of elements present from Mehlich I and totals in the A horizon. Figure 14 illustrates clustering results of Mehlich I and totals in the parent material. These figures indicate similar clusters of sites for both horizons and both methods. The combination of parameters produces clusters presented in Figure 15. According to this figure, sites 1,2,3,4, and 5 have the most common chemical and fertility characteristics. These sites have greater concentration of most model elements from Mehlich I in the A horizons for including P, Ca, Mg, Mn, and Tn. The natural enrichment of the sites with micro and macro nutrients makes them in general more fertile. Sites 6 and especially 7 have essentially lower concentration of elements and lower fertility compared to other sites. Our field description of the soil morphology (Chapter 1) explains the observed differences and is observed in the fertility and chemical properties of both main clusters. It was determined that sites 1, 2, 3, and 5 have colluvial parent material that leads to accumulation of elements in the soil due to its receiving position. Soils with residual parent material are on Sites 6 and 7. This parent material is poorer in elements because erosion dominates. In conclusion, results of the clustering allow us to predict the potential fertility of the sites in terms of both model and total elements and help us to find similarity between them.

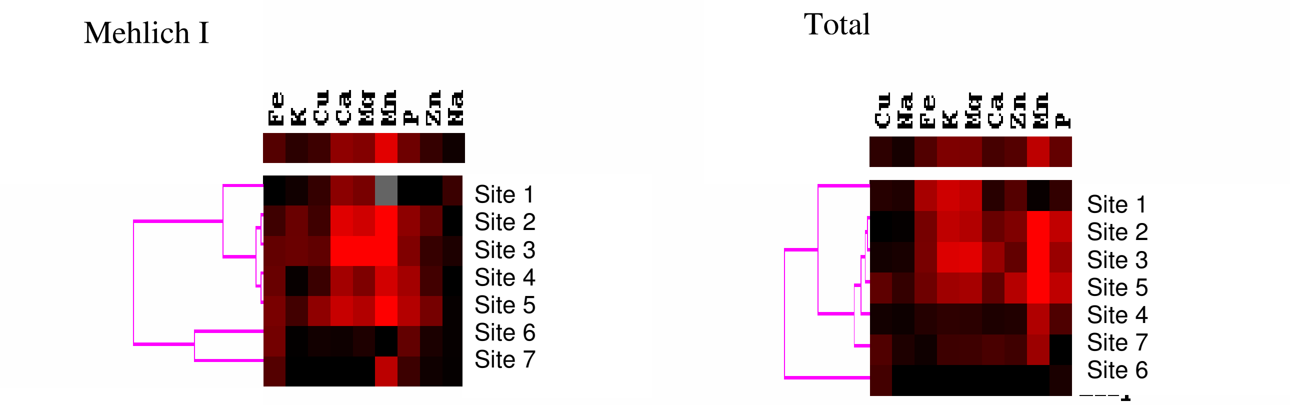


Figure 13: Hierarchical clustering of sites according to Mehlich I and totals of the elements in A horizon. Black color represents minimal concentration of elements across all sites and the intensity of red color represents increased concentrations of the element.

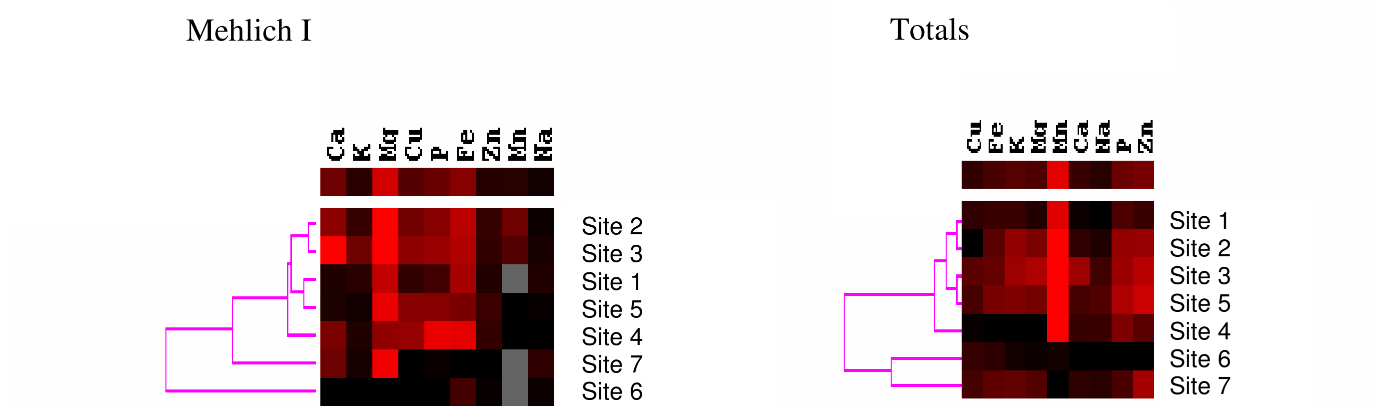


Figure 14: Hierarchical clustering of sites according to Mehlich I and totals of the elements in parent material. Black color represents minimal concentration of elements across all sites and the intensity of red color represents increased concentrations of the element.

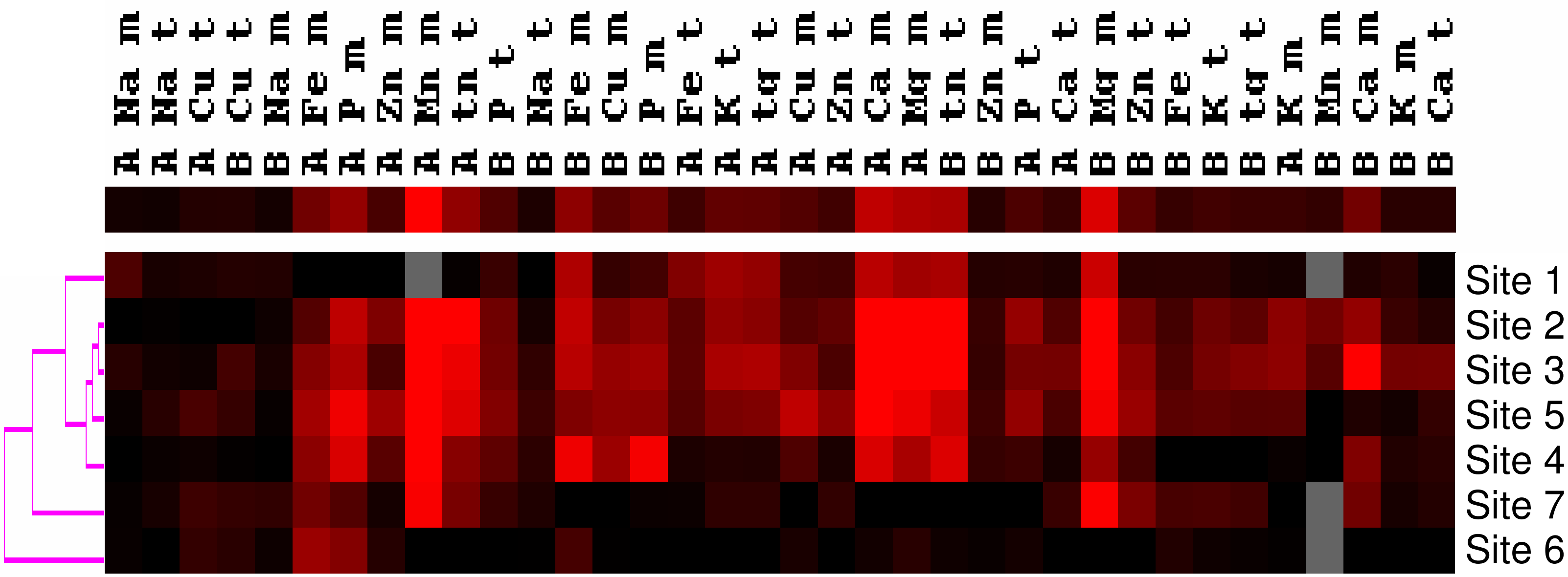


Figure 15: Hierarchical clustering of sites according to Mehlich I and totals of the elements in A horizon and parent materials. Black color represents minimal concentration of elements across all sites and the intensity of red color represents increased concentrations of the element.

Predicting concentration of the element in the parent material from the concentration in the A horizon:

A correlation coefficient was determined between element content in the A horizon and in the parent material across all samples to reveal if we can predict the concentration in the parent material from the concentration in the A horizon. Figure 16 shows that some elements have a high correlation between the A horizon and the parent material among both methods due to an accumulation of certain elements in the A horizon. Total elements that have high correlation are Mn, Ca, and P. Mehlich I elements with high correlation include Mn, Ca, and Mg. Weathering of parent material is one of the factors explaining these correlations. Some elements have a low correlation between content in the A and content in the parent material due to leaching causing a depletion of certain elements in the A horizon. Iron has a low correlation between the A horizon and the parent material in both Mehlich I and total methods, as does Na and Cu. Mehlich I phosphorus also has a low correlation. The results show that for many elements we can predict concentration in the parent material based on the concentration of elements in the A horizon.

Predicting total content of the elements from its model content determined by Mehlich I:

Figure 17 shows the correlation between total element content and content determined by Mehlich I using data from the A horizon and parent material. This figure can be used to determine the content of total elements based on results of Mehlich I or content of Mehlich I based on the results from total analysis. For elements that show a high correlation, like Ca, Mg, and Mn can be used to predict the content if only one method, either totals or Mehlich I, was preformed.

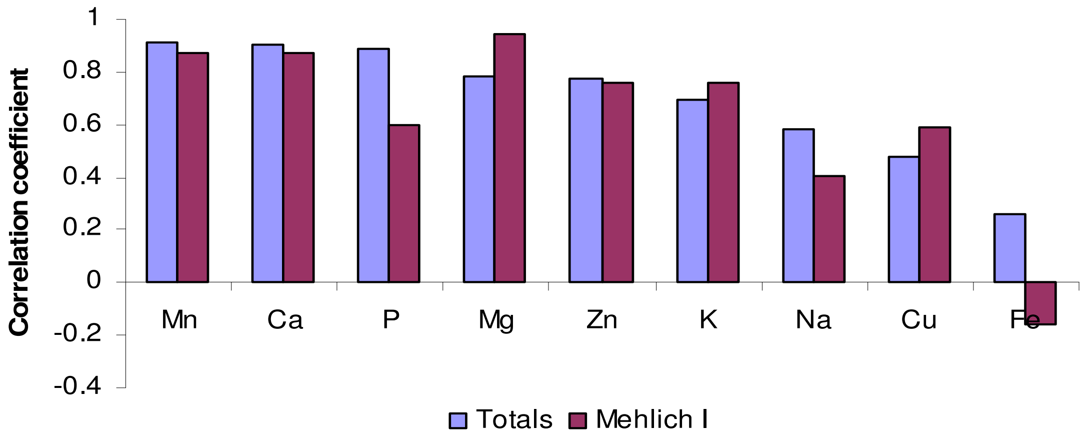


Figure 16: Correlation between element content in the A horizon and in the parent material

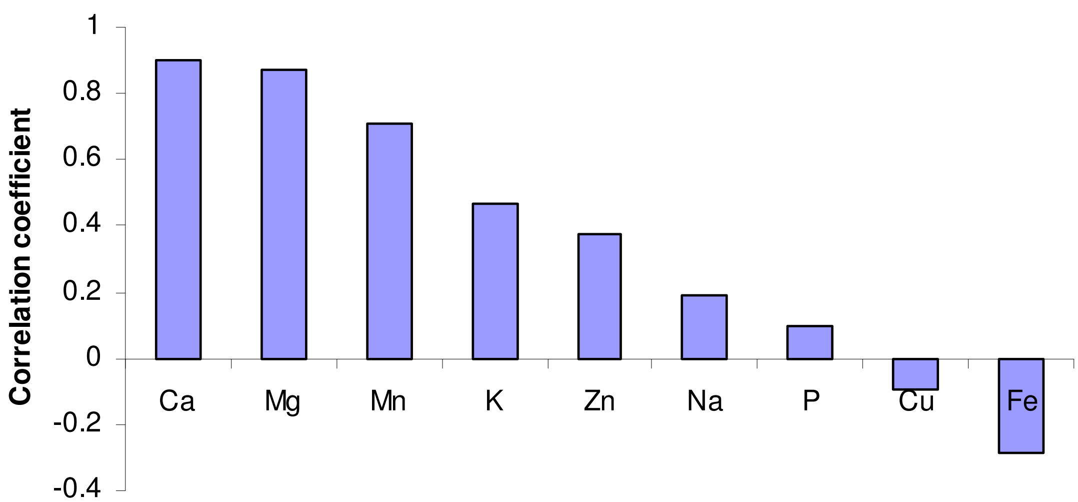


Figure 17: Correlation between the total content of the element and the content determined by Mehlich I within all measurements

Fertilizer and Lime Requirements for Bicolor Lespedeza

Table 48 is a soil test rating for P and K and is ranked as L-Low, M-Medium, H-High, or V-Very High concentrations. The Mehlich I results were evaluated based on the explanation of soil test recommendations for Tennessee, Table 47. Once a rating is established, Table 49 is used for the additions of N, P_2O_5, and K_2O in pounds per acre specific for Bicolor Lespedeza.

Table 47. Available K and P (Pounds Per Acre)

Site	M1K	Rank	M1P	Rank
1	110.8	M	2.44	L
2	431.8	VH	22.14	M
3	443.9	VH	17.87	L
4	95.34	M	30.49	M
5	237.1	H	39.57	H
6	89.48	L	11.16	L
7	84.93	L	6.27	L

Table 48. Soil Test Rating in Pounds Per Acre Phosphorus and Potassium

Rating	Phosphorous (P)	Potassium (K)
Low (L)	0-18	0-90
Medium (M)	19-30	91-160
High (H)	31-120	161-320
Very High (V)	120+	320+

L-Low, M-Medium, H-High, V-Very High

Table 49. Annual Lespedeza Soil test Recommendations for N, P_2O_5 and K_2O (Pounds Per Acre)

	Nitrogen	Phosphate (P_2O_5)				Potash (K_2O)			
	Soil Test Levels								
Practice	(NT)	L	M	H	V	L	M	H	V
1.Established	0	40	20	0	0	40	20	0	0

NT-Not Tested, L-Low, M-Medium, H-High, V-Very High

Soil Test Ratings – Phosphorus and Potassium

Low- Means that in most cases, plants will respond to the application of that nutrient. If the nutrient is not applied, deficiency symptoms may occur and crops usually yield less than 75% of their potential. Medium- Means plants may or may not respond to the application of that nutrient. Deficiency symptoms are not likely and soils can be expected to produce 75% or more of their potential without the application of the nutrient. High- The soil will produce at or near 100% of its potential without the addition of the nutrient. Amounts recommended are primarily to maintain present soil test levels. Very High- Supply of the nutrient in the soil is well in excess of the amount needed to produce 100% of the soil's potential. Application of the nutrient is not recommended since further additions may create nutrient imbalances.

Conclusions

Based on the soil test recommendations for Tennessee and the establishment recommendations for Bicolor Lespedeza, Sites 6 and 7 have low M1K ranking thus requiring 40 pounds per acre K_2O fertilizer. Sites 1 and 4 have medium M1K ranking thus requiring 20 pound per acre K_2O fertilizer, while Site 2, and group 3; Sites 3, and 5 ranked high to very high and do not require any K_2O fertilizer supplement. Sites 1, 3, 6, and 7 have low M1P ranking thus requiring 40 pounds per acre P_2O_5 fertilizer. Sites 2 and 4 have medium M1P ranking thus requiring 20 pounds per acre P_2O_5 fertilizer, while Site 5 has high M1P ranking and does not require any P_2O_5 additions.

Based on the 1:1 pH and the total acidity of the soil, it is assumed that all of the soils examined will be out of the minimum range thus requiring 5 tons of lime per acre according to the lime requirements to target a value of pH 6.5. According to the recommendation for Bicolor

Lespedeza, additions of lime should not exceed 4 tons per acre for any given addition (Savoy and Joines, 2009). After two years, the soils should be retested and lime requirements should be reevaluated.

Site 6 and 7, which sit on a sideslope and an upland summit, respectively, would require the greatest amount of amendments to establish Sericea Lespedeza. Both of these sites are forming on residuum parent material and have the most limiting concentrations of P and K. Site 1, located on a backslope and developing in residuum, requires the second most additions of P and K for adequate plant growth. Site 4, located on the floodplain, requires less additions of P and K fertilizer and ranks third in most amendments needed to satisfy yield. Site 3, situated at the footslope, requires even less additions of P and K fertilizer and ranks fourth in most amendments needed to satisfy yield. Site 2, located on a backslope and forming in colluvium, requires the least amount of P and K fertilizer additions and ranks fifth in most amendments needed. Site 5, which is located on a footslope and forming in colluvium, does not require any P and K fertilizer amendments.

Literature Cited

Ammons, J.T., M.E. Essington, R.J. Lewis, A.O. Gallagher, and G.M. Lessman. 1995. An application of a modified microwave total dissolution technique for soils. Commun. Soil Sci. Plant Anal. 26:5-6

Anderson, D.W. 1988: The effect of parent material and soil development on nutrient cycling in temperate ecosystems. Biogeochemistry 5: 71-79.

Birkeland, P.W., 1999. Soils and Geomorphology (3rd ed.), Oxford University Press, New York (1999).

Carter, M.R., E.G. Gregorich, D.W. Anderson, J.W. Doran, H.H. Janzen and F.J. Pierce, 1997. Concepts of soil quality and their significance. *In*: E.G. Gregorich and M.R. Carter, Editors, Soil Quality for Crop Production and Ecosystem Health, Developments in Soil Science 25, Elsevier, Amsterdam, pp. 1–20.

Carter, B.J. and Ciolkosz, E.J., 1991. Slope gradient and aspect effects on soils developed from sandstone in Pennsylvania. Geoderma 49, pp. 199–213

Chesnut, D.R., 1996. Geologic Framework for the Coal-Bearing Rocks of the Central Appalachian Basin. International Journal of Coal Geology 31. 55-66

Eisen M.B., P.T. Spellman, P.O. Brown, and D. Botstein. 1998. Cluster analysis and display of genome-wide expression patterns. *Proc. Natl. Acad. Sci. USA* , 95:14863-14868.

Essington, M.E., 2003. Soil and Water Chemistry: An Integrative Approach. CRC Press.

Fenneman, N.M. 1938. Physiography of Eastern United States, McGraw-Hill, New York (1938).

Finney, H.R., N. Holowaychuk and M.R. Heddleson, 1962. The influence of microclimate on the morphology of certain soils of the Allegheny Plateau of Ohio, Soil Science Society of America Proceedings 26, pp. 287–292.

Furley, P.A., 1971. Relationships between slope form and soil properties developed over chalk parent materials. *In:* D. Brunsden, Editor, *Slopes, Form and Process* vol. 3, Institute of British Geographers Special Publication, pp. 141–164.

Gerrard, A.J. 1981.Soils and Landforms: an Integration of Geomorphology and Pedology, George Allen & Unwin Ltd., London, UK.

Holmgren, B.B.S. 1967. A rapid citrate-dithionite extractable iron procedure. Soil Sci. Soc. Am. Proc. 31:210-211.

Honeycutt, 1990 C.W. Honeycutt, R.D. Heil and C.V. Cole, Climatic and topographic relations of three Great Plains soils: II. Carbon, nitrogen, and phosphorus, Soil Science Society of America Journal 54: pp. 476–483

Kilmer, F.J. and L. T. Alexander. 1949. Methods of making mechanical analysis of soils. Soil Sci. 68:15-24.

Kleiss, H.J. 1970. Hillslope sedimentation and soil formation in northeastern Iowa, Soil Science Society of America Proceedings 34, pp. 287–290.

Leigh, 1996 D.S. Leigh, Soil chronosequence of Brasstown Creek, Blue Ridge Mountains, USA, Catena 26, pp. 99–114.

Losche, C.K., R.J. McCracken and C.B. Davey, 1970. Soils of steeply sloping landscapes in the southern Appalachian Mountains, Soil Science Society of America Proceedings 34, pp. 473–478.

Mills, 2005. H.H. Mills, Relative-age dating of transported regolith and application to study of landform evolution in the Appalachians, Geomorphology 67, pp. 63–96.

Milne, G. 1935.Composite units for the mapping of complex soil associations, Transactions of the 3rd International Congress. Soil Science 1, pp. 345–347.

Murdock, Nora. Emmott, R. Hughes, J. 2008. Cumberland Plateau River Prairies: Understanding hydrologic links between "river prairies" and other threatened riparian resources of the Cumberland Plateau. National Park Service. U.S. Dept. of the Interior.

National Park Service Staff, 2008. Geology and History of the Cumberland Plateau. U.S. Dept. of the Interior. Big South Fork National River and Recreational Area. Oneida, TN.

Newell, W.L., 1986, Physiography, *In:* McDowell, R.C. (ed.), The Geology of Kentucky – A Text to Accompany the Geologic Map of Kentucky, US Geological Survey Professional Paper 1151-H, pp. H-64-H-68.

Norten, J.B., J.A. Sandor and C.S. White, 2003. Hillslope soils and organic matter dynamics within a Native American agroecosystem on the Colorado Plateau, Soil Sci. Soc. of Am. J. 67, pp. 225–234.

Page RD.TreeView: an application to display phylogenetic trees on personal computers. Comput Appl Biosci. 1996 Aug;12(4):357-8.

Ritter et al., 2002 D.F. Ritter, R.C. Kochel and J.R. Miller, Process Geomorphology, McGraw-Hill, New York.

Ruhe R.V., and P.H. Walker, 1968. Hillslope models and soil formation. I. Open systems. Ninth International Congress on Soil Science, Transactions Vol. 4, pp. 551–560.

Savoy, H. J. and D. Joines. 2009. Lime and Fertilizer Requirements for the Venious Crops of TN. Chapter III. Pasture/Hay/Silage Crops. BESS Information Sheet #100.

Soil Fertility Manual, 2003. Potash & Phosphate Institute (PPI) and the Foundation for Agronomic Research (FAR). Revised October 2003.

Soil Survey Staff, 2004 Soil Survey Staff, Soil Survey Laboratory Manual, Soil Survey Investigations Report No. 42, version 4.0, US Government Printing Office, Washington, DC USDA.

United States Geological Survey (USGS). 2002. A tapestry of time and terrain: Mississippian and Pennsylvanian Rocks. U.S. Dept. of the Interior, U.S. Geological Survey.

Windingstad, J.G., S.C. Sherwood, K.J. Gremillion and N.S. Eash. 2008. Soil fertility and slope processes in the Western Cumberland Escarpment of Kentucky: influences on the development of horticulture in the Eastern Woodlands. Journal of Archaeological Science. 35 (6): 1717-1731

APPENDIX A

EXPLANATION OF ABBREVIATIONS USED IN THE

MORPHOLOGY TABLES

I. Soil texture.

A. Texture classes.

L = loam
SiL = silt loam
SiCL = silty clay loam
Cl = clay loam
SiC = silty clay
C = clay

II. Soil structure

A. Grade of structure

1 = weak
2 = moderate
3 = strong

B. Size of structure

f = fine
m = medium

C. Type of structure

Gr = granular
SBK = subangular blocky
Ma = massive

III. Boundary

A. Distinctness class

A = abrupt
C = clear
G = gradual

B. Topography

S = smooth
W = wavy

III. Moist consitence

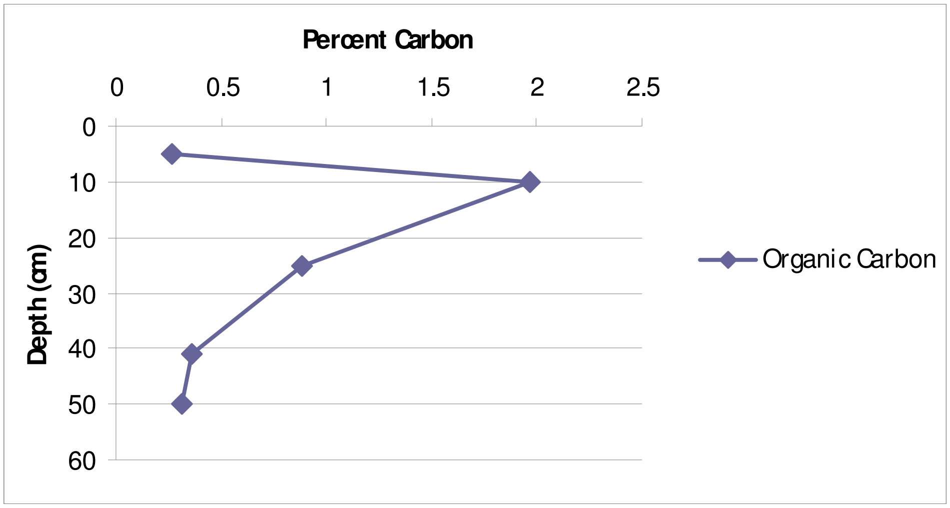
VFR = very friable
FR = friable
FI = firm

APPENDIX B

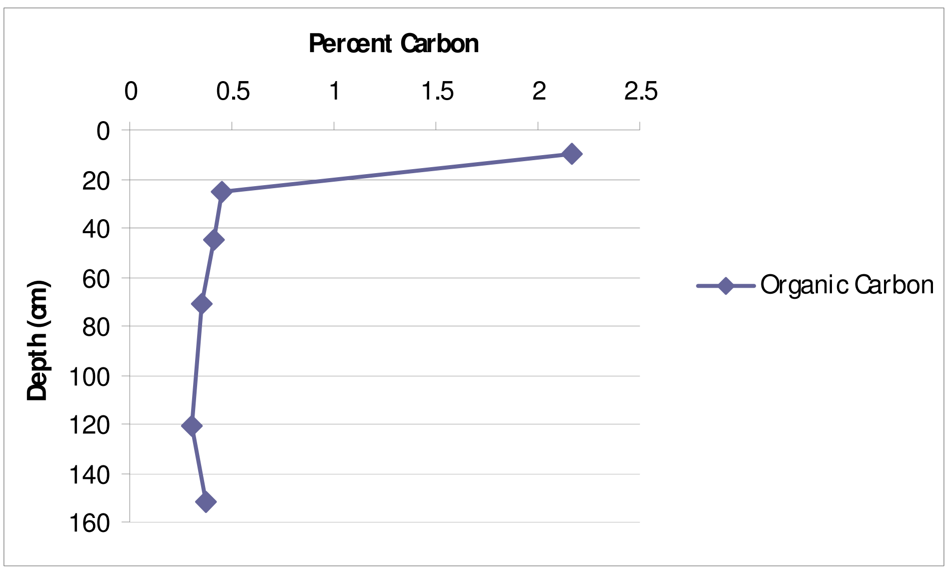
% ORGANIC CARBON BY DEPTH FIGURES

FOR SITES 1-7

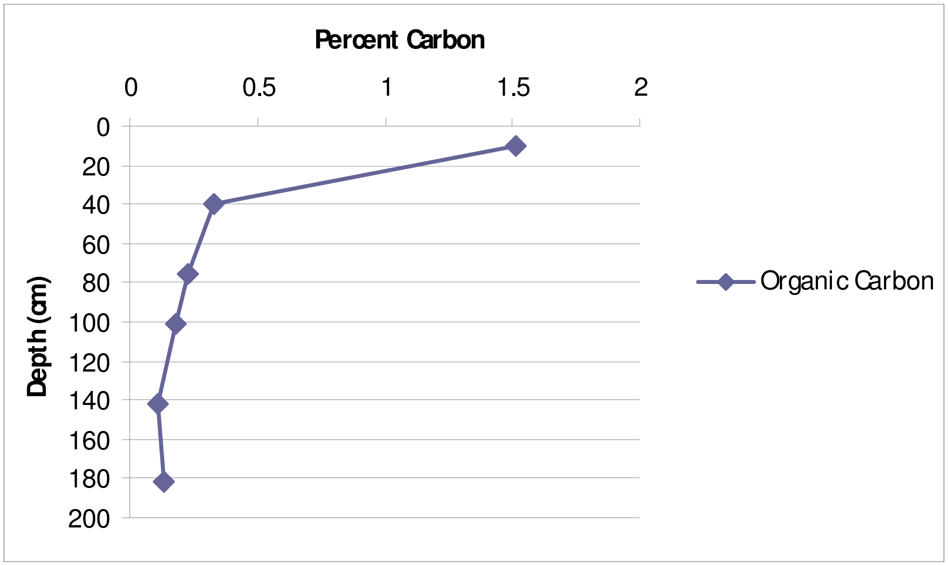
Site 1


Percent Carbon
0
0.5
1
1.5
2
2.5
0
10
20
30
40
50
60
Depth (cm)
Organic Carbon

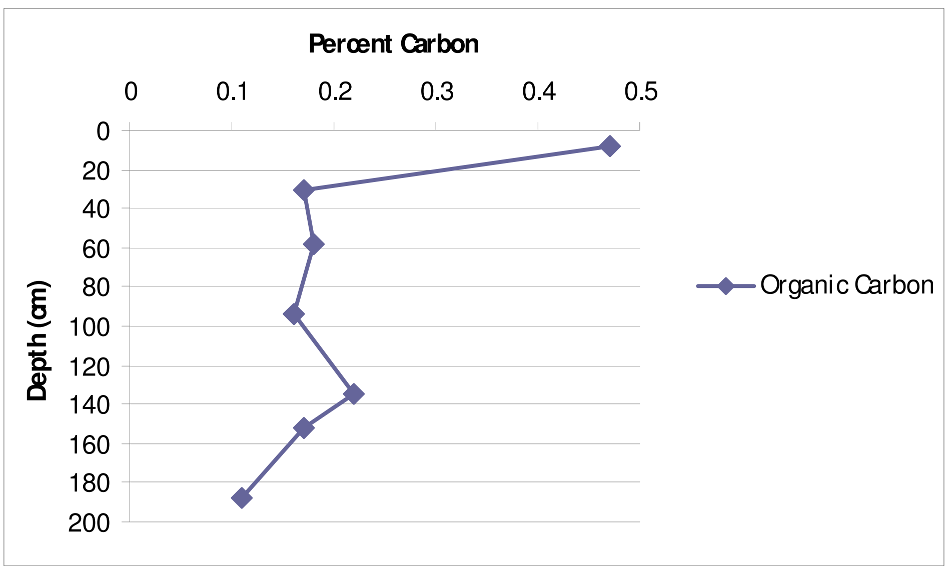
Site 2


Percent Carbon
0
0.5
1
1.5
2
2.5
0
20
40
60
80
100
120
140
160
Depth (cm)
Organic Carbon

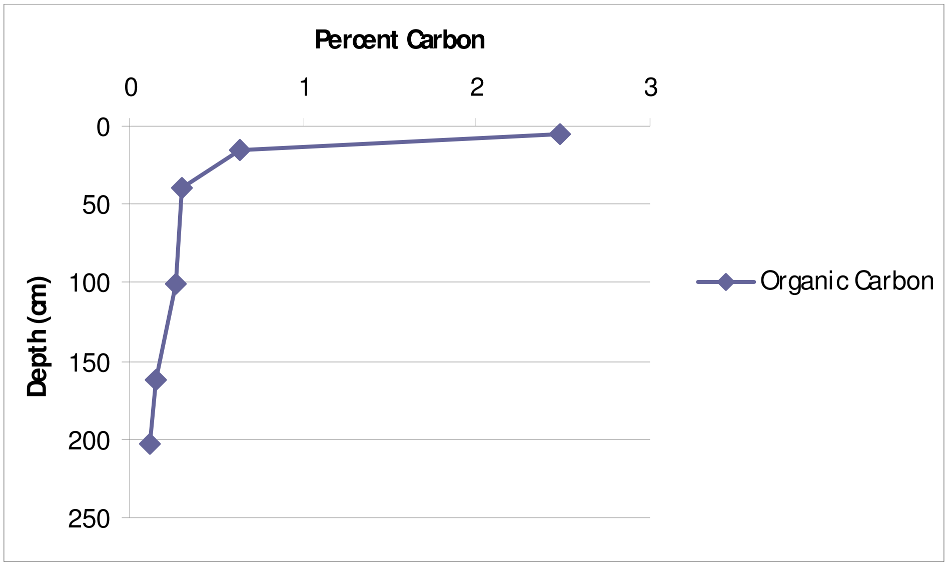
Site 3


Percent Carbon
0
0.5
1
1.5
2
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
Organic Carbon

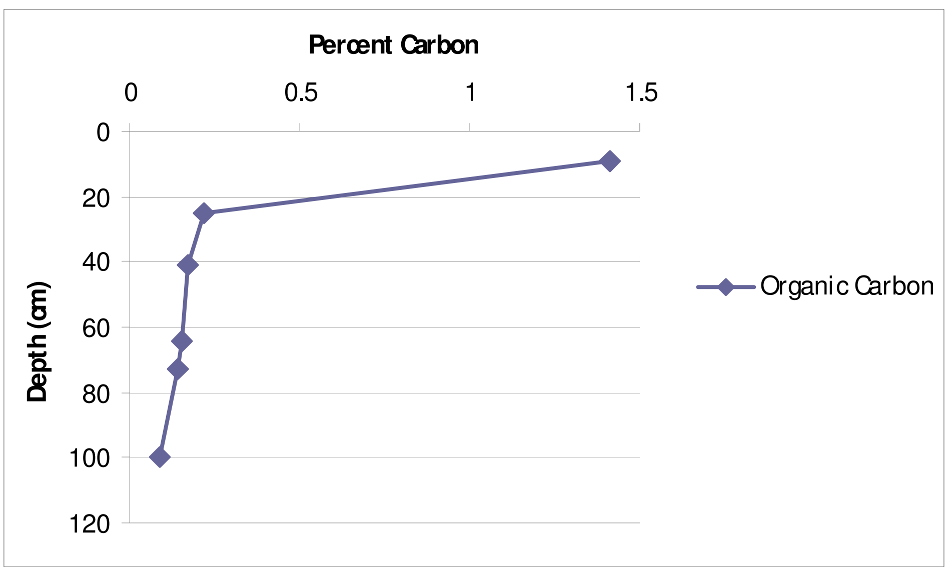
Site 4


Percent Carbon
0
0.1
0.2
0.3
0.4
0.5
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
Organic Carbon

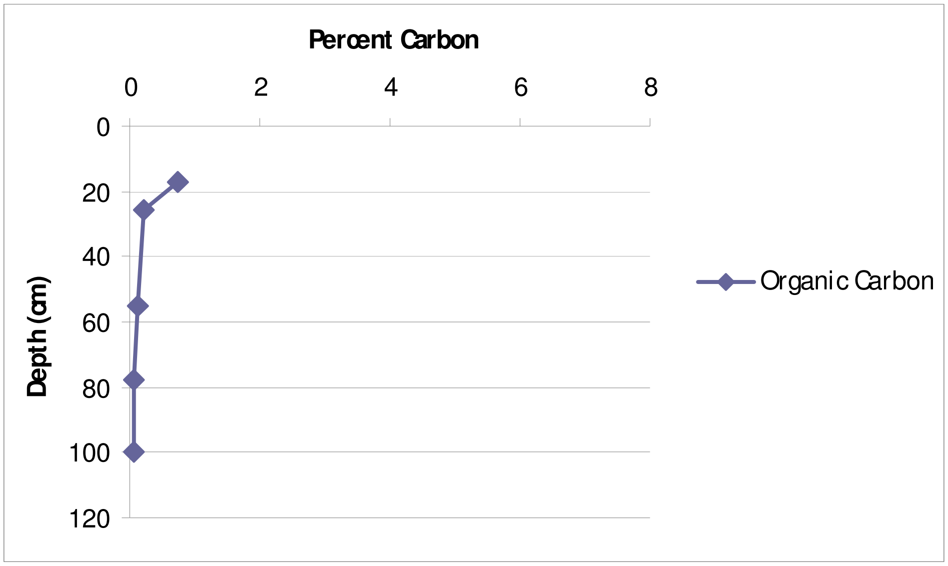
Site 5


Percent Carbon
0
1
2
3
0
50
100
150
200
250
Depth (cm)
Organic Carbon

Site 6


Percent Carbon
0
0.5
1
1.5
0
20
40
60
80
100
120
Depth (cm)
Organic Carbon

Site 7

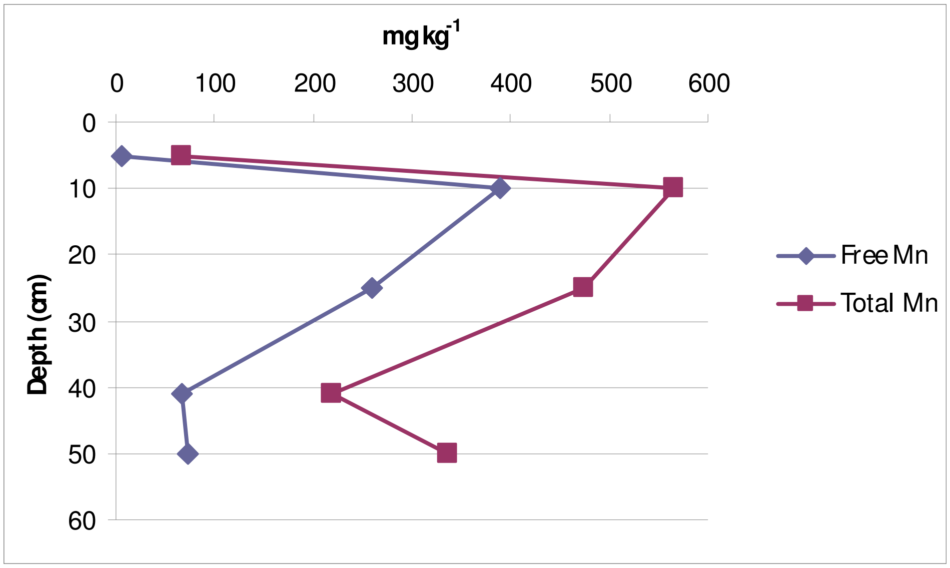

Percent Carbon
0
2
4
6
8
0
20
40
60
80
100
120
Depth (cm)
Organic Carbon

APPENDIX C

FREE MANGANESE AND TOTAL MANGANESE BY DEPTH

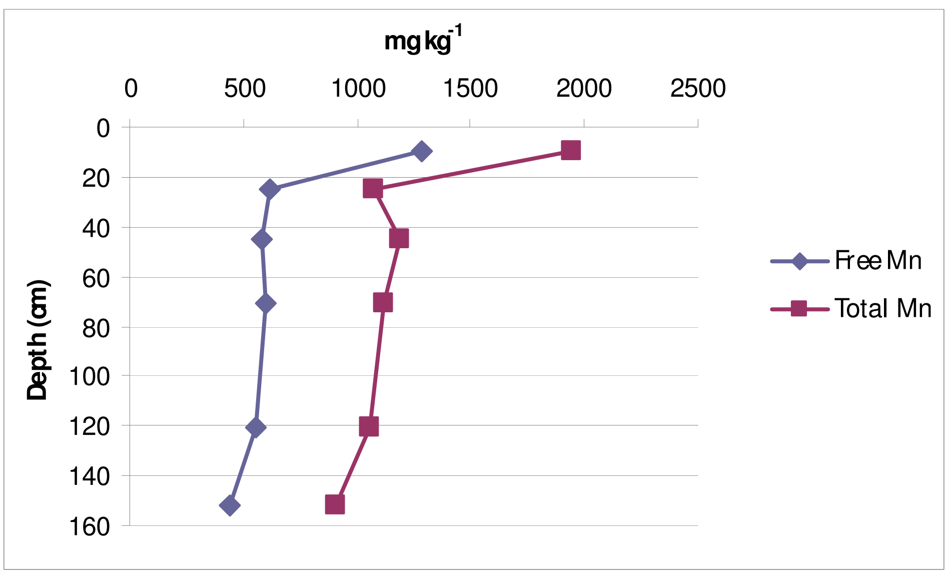
FOR SITES 1-7

Site 1



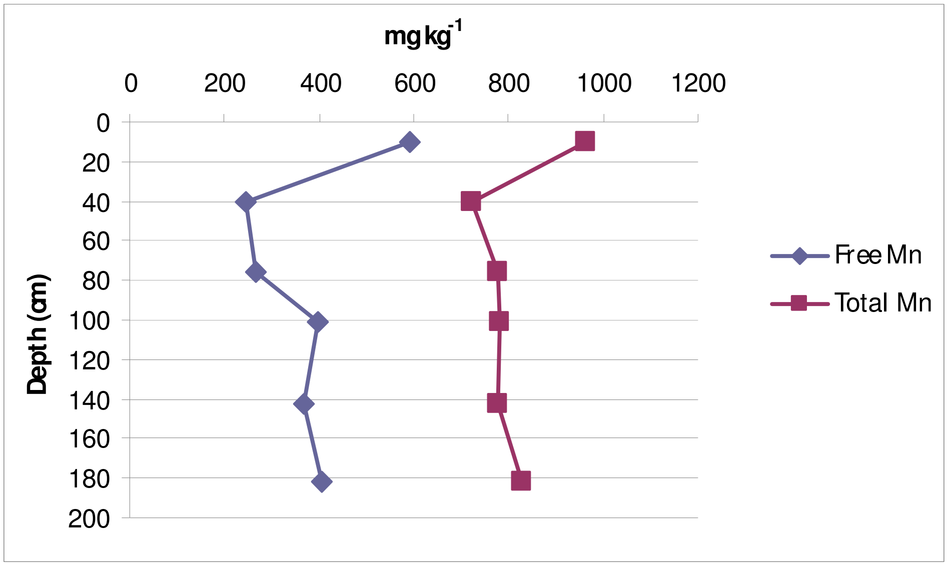
mg kg-1
0
100
200
300
400
500
600
0
10
20
30
40
50
60
Depth (cm)
Free Mn
Total Mn

Site 2

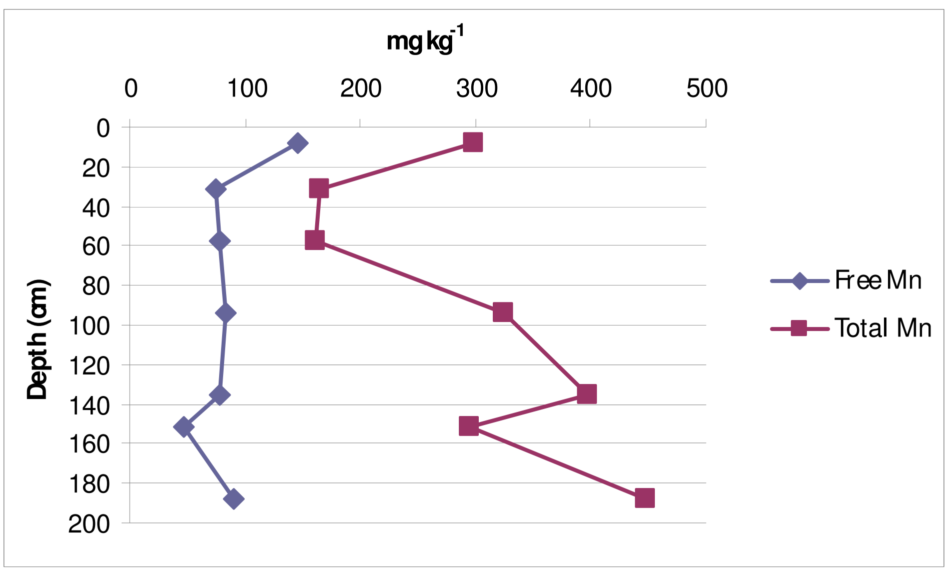


mg kg-1
0
500
1000
1500
2000
2500
0
20
40
60
80
100
120
140
160
Depth (cm)
Free Mn
Total Mn

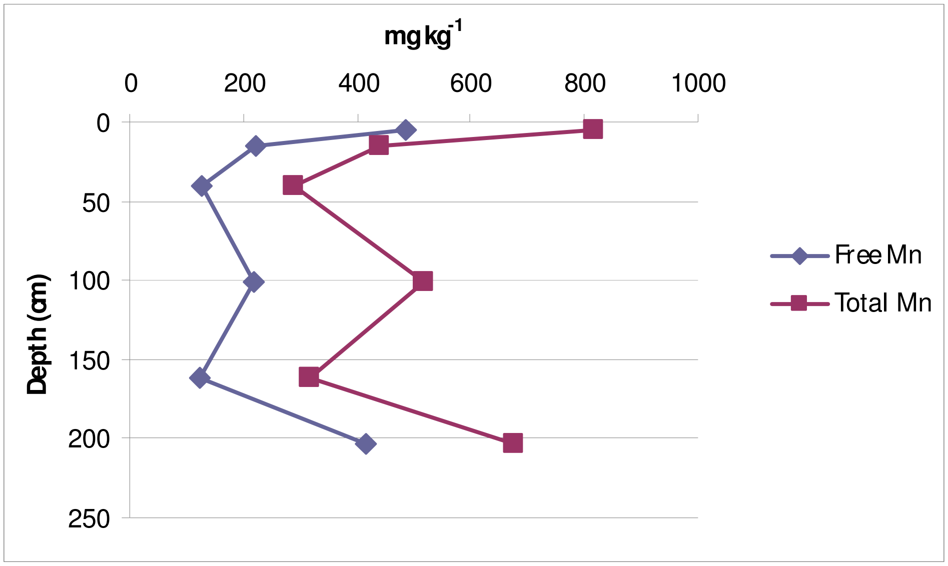
Site 3


mg kg-1
0
200
400
600
800
1000
1200
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
Free Mn
Total Mn

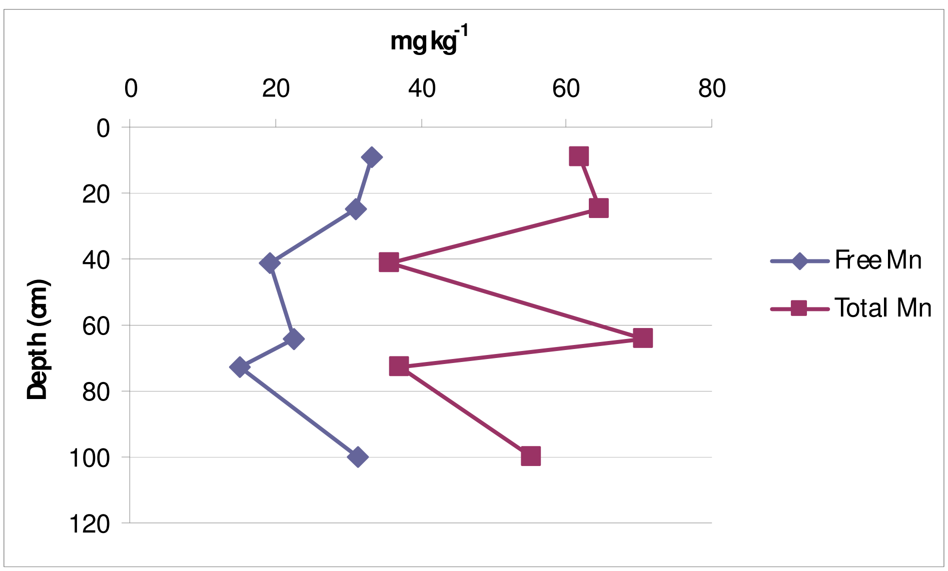
Site 4


mg kg-1
0
100
200
300
400
500
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
Free Mn
Total Mn

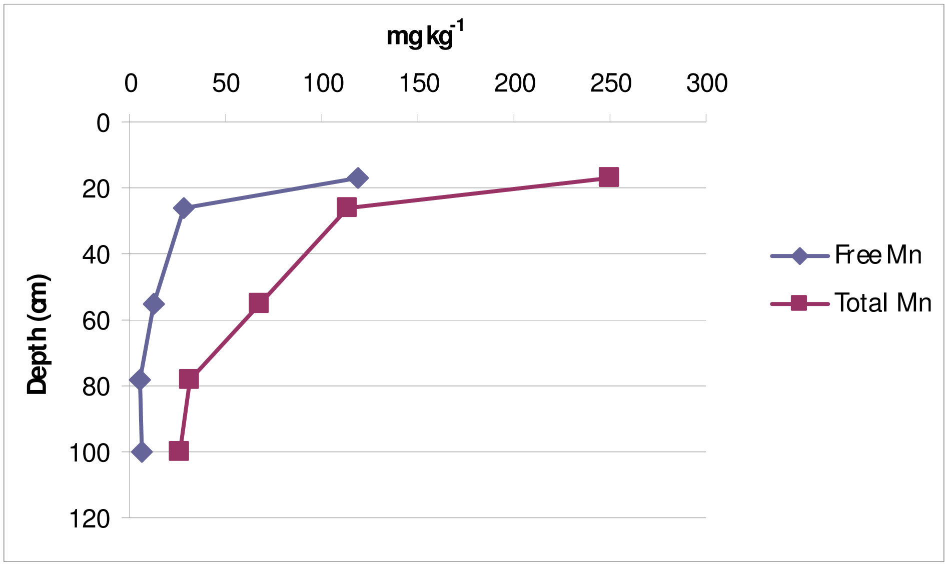
Site 5


mg kg-1
0
200
400
600
800
1000
0
50
100
150
200
250
Depth (cm)
Free Mn
Total Mn

Site 6


mg kg-1
0
20
40
60
80
0
20
40
60
80
100
120
Depth (cm)
Free Mn
Total Mn

Site 7

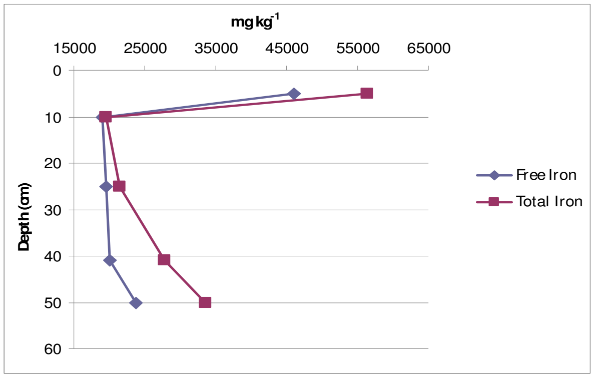

mg kg-1
0
50
100
150
200
250
300
0
20
40
60
80
100
120
Depth (cm)
Free Mn
Total Mn

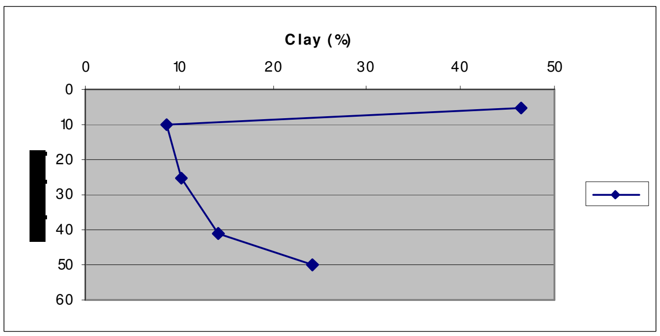
APPENDIX D

FREE IRON, TOTAL IRON AND TOTAL CLAY BY DEPTH

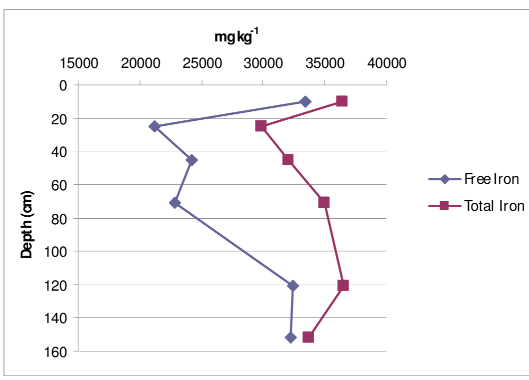
FOR SITES 1-7

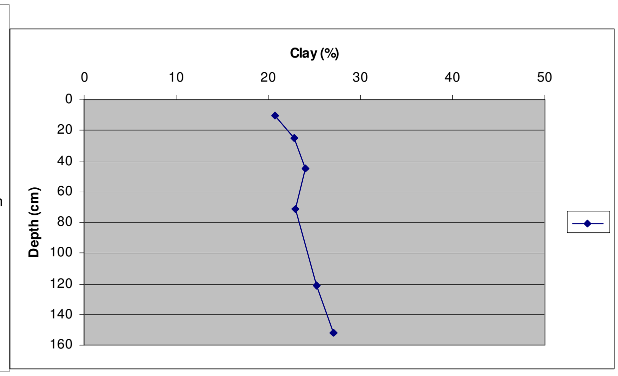
Site 1


mg kg-1
15000
25000
35000
45000
55000
65000
0
10
20
30
40
50
60
Depth (cm)
Free Iron
Total Iron

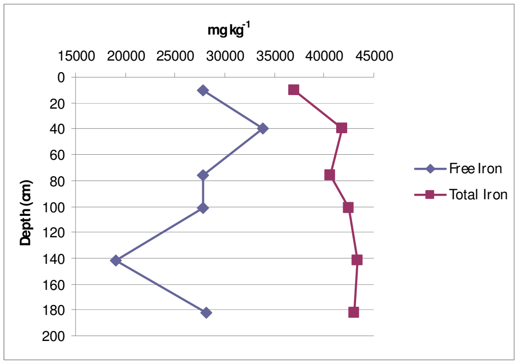

Clay (%)
0
10
20
30
40
50
0
10
20
30
40
50
60

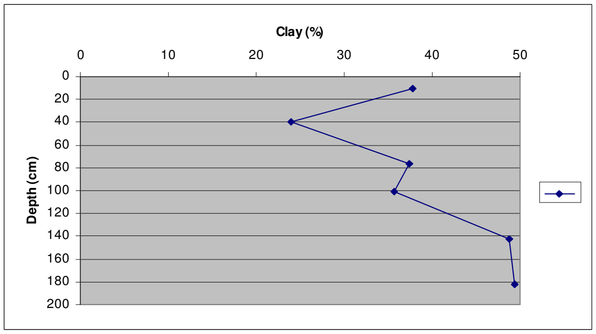
Site 2


mg kg-1
15000
20000
25000
30000
35000
40000
0
20
40
60
80
100
120
140
160
Depth (cm)
Free Iron
Total Iron

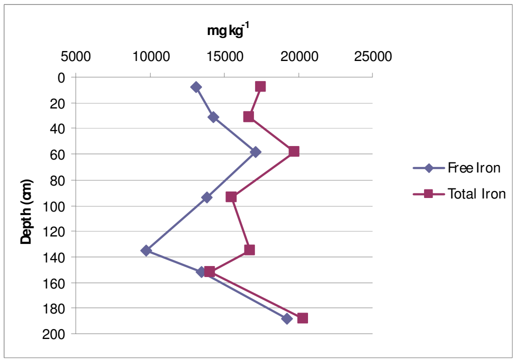

Clay (%)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
Depth (cm)

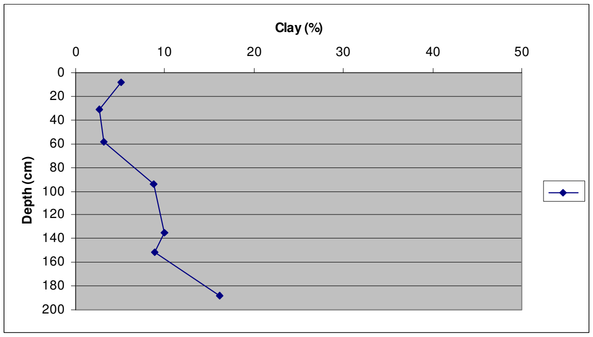
Site 3



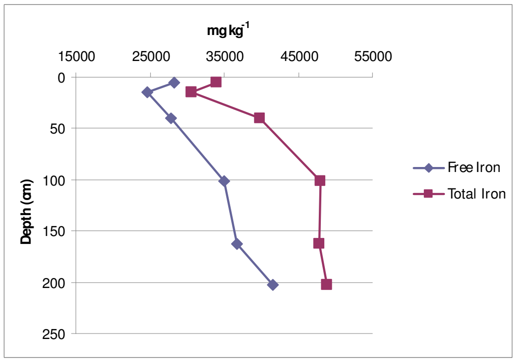


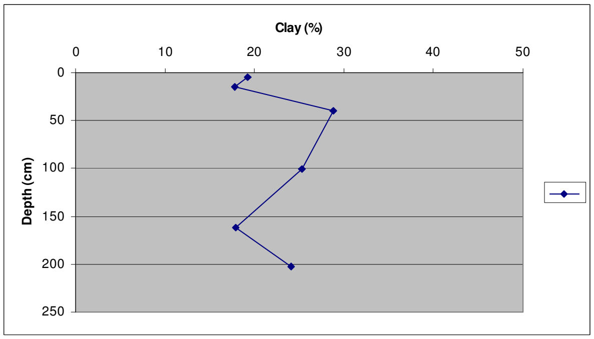
Site 4



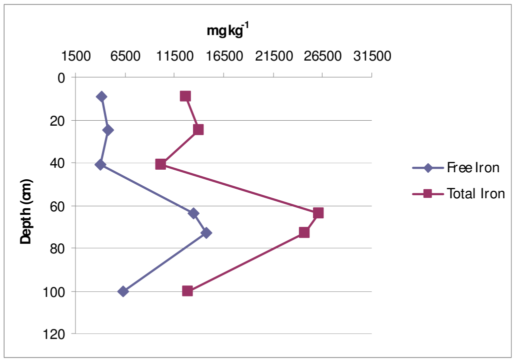


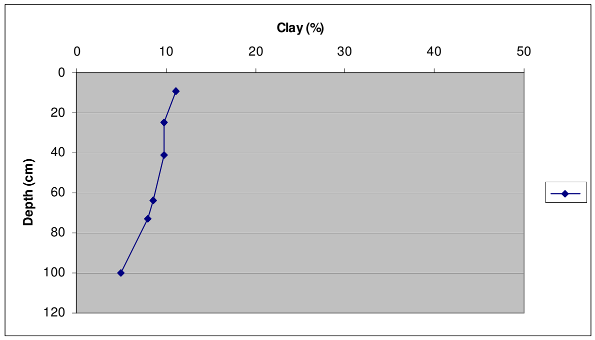
Site 5



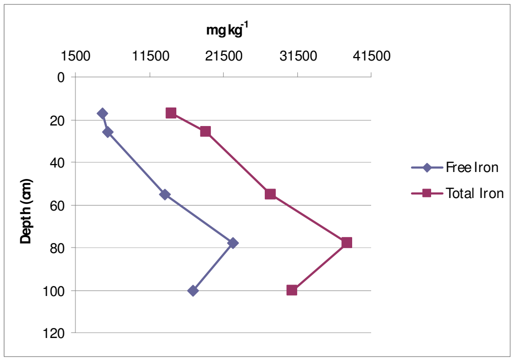


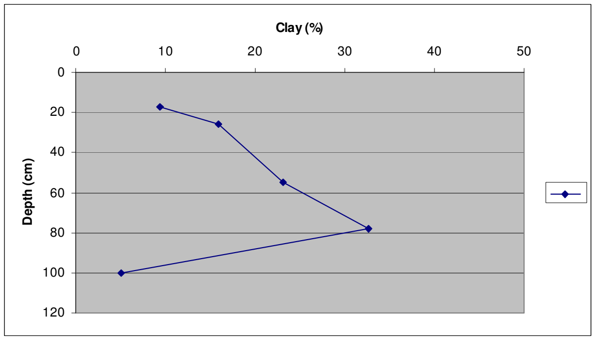
Site 6


mg kg-1
1500 6500 11500 16500 21500 26500 31500
Depth (cm)
0 20 40 60 80 100 120
Free Iron
Total Iron


Clay (%)
0 10 20 30 40 50
Depth (cm)
0 20 40 60 80 100 120

Site 7


mg kg-1
1500 11500 21500 31500 41500
Depth (cm)
0 20 40 60 80 100 120
Free Iron
Total Iron


Clay (%)
0 10 20 30 40 50
Depth (cm)
0 20 40 60 80 100 120

APPENDIX E

ELEMENTAL TOTALS

HEAVY METALS ARE HIGHLIGHTED

FOR SITES 1-7

Site 1: Elemental totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-5	96275.0	349.8	768.3	4.9	6.1	77.0	24.2	56450.0	15232.5	31.2	71.3	3220.0	66.7
BE	5-10	29875.0	182.0	831.8	2.4	14.4	31.5	27.0	19575.0	5672.5	21.3	22.0	1122.3	566.5
Bw1	10-28	32025.0	227.9	576.3	2.3	15.5	34.5	25.7	21552.5	5847.5	18.5	23.9	1212.5	474.3
Bw2	28-40	41250.0	207.0	376.3	2.5	8.1	43.7	28.1	27725.0	8337.5	17.7	31.2	1615.8	218.8
R	40+	-	-	-	-	-	-	-	-	-	-	-	-	-

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
1.9	3152.5	17.9	167.9	289.8	3.9	262300.0	52.8	318.3	47.4	113.3
2.3	2605.0	9.7	249.2	281.8	12.3	280750.0	27.8	159.1	28.5	65.7
1.9	2503.5	17.0	178.6	231.1	12.6	272250.0	26.0	160.8	31.6	61.4
2.4	2131.8	19.6	163.5	179.9	12.8	266800.0	30.8	179.2	26.7	73.1
-	-	-	-	-	-	-	-	-	-	-

Site 2: Elemental totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-10	70800.0	412.0	1351.5	3.6	22.2	59.3	17.1	36475.0	13415.0	31.6	42.4	2867.5	1947.3
BA	10-25	82975.0	407.3	530.8	3.7	17.7	67.2	20.7	29850.0	17880.0	35.6	57.2	3095.0	1071.8
Bw1	25-45	84575.0	413.3	578.5	4.0	17.4	68.3	23.2	32075.0	18242.5	38.9	59.0	3340.0	1184.8
Bw2	45-71	81700.0	396.3	650.3	4.0	18.9	63.6	23.6	34950.0	17600.0	34.8	56.1	3267.5	1118.8
Bw3	71-121	83775.0	398.3	520.0	3.7	20.1	64.3	18.4	36550.0	17870.0	28.2	57.4	3485.0	1053.8
BC	121-152	83675.0	431.0	541.5	3.7	16.5	65.6	20.7	33700.0	17822.5	31.8	56.1	3322.5	904.5

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
1.0	2485.8	35.0	600.3	327.3	44.9	235700.0	55.5	266.0	69.3	105.3
1.0	2945.0	27.0	282.0	218.0	33.2	249025.0	58.8	294.8	56.6	122.1
1.1	2702.5	30.6	310.3	205.9	34.3	201950.0	59.3	276.0	69.4	118.7
1.2	3370.0	36.9	284.8	236.5	28.5	235200.0	58.3	258.8	59.6	106.0
1.4	2792.3	40.1	305.5	217.4	25.7	238225.0	60.8	284.5	60.7	117.3
1.1	2880.0	31.6	241.2	220.7	26.1	241725.0	60.5	304.0	50.8	116.9

Site 3: Totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-10	75675.0	434.3	2060.3	3.8	16.7	55.0	20.3	37000.0	17362.5	33.5	69.3	4415.0	964.3
Bt1	10-40	91250.0	410.8	1048.3	4.5	19.0	72.0	40.9	41875.0	20520.0	39.8	97.0	5252.5	724.0
Bt2	40-76	94900.0	427.8	1334.3	5.5	17.5	82.9	40.7	40625.0	19690.0	56.4	130.2	5492.5	777.5
Bt3	76-101	97175.0	468.0	1124.5	5.5	18.0	85.1	35.1	42475.0	19902.5	57.4	133.6	5720.0	782.8
Bt4	101-142	99750.0	461.0	1082.8	5.6	17.5	89.5	34.6	43400.0	21600.0	55.7	131.3	6627.5	777.5
C	101-182	97900.0	453.0	1148.5	5.8	19.1	89.2	39.9	42975.0	21947.5	52.0	132.6	6695.0	829.0

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
1.2	2937.5	25.8	417.8	242.8	23.1	214775.0	64.8	267.3	53.5	102.0
1.4	3180.0	34.7	269.9	188.3	12.1	205250.0	67.0	6338.0	61.8	112.4
1.5	3730.0	34.6	320.5	180.9	17.7	220425.0	70.0	12850.0	81.4	113.5
1.8	3802.5	34.0	289.8	193.0	10.7	211600.0	69.8	12680.0	82.3	114.4
1.6	3700.0	37.9	311.5	207.4	13.4	222800.0	69.3	12127.5	93.6	112.7
1.9	3682.5	39.5	270.3	222.2	20.6	262750.0	67.0	11650.0	94.4	113.3

Site 4: Totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-8	17562.5	121.0	695.8	2.5	1.0	18.1	20.3	17512.5	3677.5	29.5	13.6	863.8	297.8
Bw1	8-31	9777.5	59.8	484.5	2.0	3.9	12.8	19.4	16645.0	1695.0	27.0	7.0	410.0	164.8
Bw2	31-58	8770.0	48.2	443.3	2.2	3.1	14.1	22.7	19730.0	1470.3	29.3	6.7	382.0	161.6
Bw3	58-94	22400.0	148.5	542.5	2.2	1.7	19.6	16.7	15545.0	4410.0	30.4	16.4	1075.8	324.5
Bw4	94-135	25720.0	157.0	545.8	2.8	1.1	21.9	19.5	16780.0	5025.0	33.5	18.7	1192.3	397.0
Bw5	135-152	21875.0	133.5	422.0	2.3	0.5	18.5	16.4	14072.5	4382.5	29.6	15.4	973.8	295.8
Bw6	152-188	33075.0	194.9	434.5	2.9	3.4	27.7	18.5	20332.5	6590.0	35.2	24.5	1554.8	448.8

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
1.8	2680.0	2.1	214.8	201.7	5.7	284500.0	21.5	3720.0	30.2	70.1
1.4	2408.0	6.0	172.4	155.3	5.6	284000.0	15.5	2200.3	15.5	50.4
1.7	2203.0	5.3	141.8	144.2	7.8	225400.0	13.0	1801.8	17.2	58.0
0.9	3230.0	0.5	209.0	183.3	3.2	222625.0	24.0	3725.0	30.9	66.4
0.8	3552.5	1.5	252.0	197.5	3.3	285975.0	27.0	4505.0	36.0	78.1
1.2	2972.5	2.1	193.7	161.8	1.8	268000.0	24.0	4395.0	27.5	71.3
1.5	3297.5	2.2	227.6	173.3	4.8	225575.0	31.3	5535.0	40.4	85.4

Site 5: Totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-5	52975.0	515.0	1259.0	3.9	12.9	46.4	39.9	33950.0	10072.5	34.4	37.1	2567.5	816.0
BE	5-15	49450.0	408.3	617.0	3.6	12.5	42.9	24.8	30600.0	10270.0	32.1	34.1	2200.5	441.3
Bt1	15-40	56575.0	416.3	545.0	4.0	12.5	50.9	30.0	39775.0	11652.5	35.0	39.9	2445.8	289.5
Bt2	40-101	67000.0	446.5	496.3	4.4	19.4	57.5	32.9	47925.0	13832.5	35.7	48.4	2775.0	519.5
Bt3	101-162	66425.0	475.3	616.5	4.2	13.4	59.8	34.0	47875.0	15255.0	34.6	45.2	3275.0	317.8
BC	163-203	61950.0	446.3	505.3	4.4	21.2	53.6	30.6	48850.0	14290.0	37.7	42.7	3017.5	677.3

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
2.0	3787.5	13.4	586.5	386.5	7.9	208875.0	48.0	6912.5	112.6	85.3
2.0	3925.0	7.6	324.5	263.8	3.1	211400.0	43.3	6820.0	71.5	90.8
1.7	3725.0	11.4	291.3	255.0	2.7	171250.0	45.5	6967.5	81.2	89.0
2.1	3767.5	15.7	314.0	283.0	3.8	190175.0	55.3	7505.0	83.5	92.5
2.0	4315.0	20.2	380.8	246.6	0.7	205175.0	52.3	7247.5	96.8	95.7
2.1	4315.0	16.9	369.8	229.2	3.0	166750.0	50.5	7130.0	83.1	94.8

Site 6: Totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-9	18415.0	91.9	533.0	1.9	2.2	24.5	31.2	12632.5	2426.0	24.6	9.7	584.0	61.9
E	9-25	20775.0	86.4	378.5	1.9	3.1	30.2	41.7	13957.5	2400.0	17.0	8.9	576.5	64.7
BE	25-41	17705.0	71.0	418.8	1.5	1.4	21.2	26.9	10120.0	2113.0	16.1	7.2	583.0	35.8
Bt1	41-64	50675.0	151.3	451.3	3.2	0.5	57.9	33.1	26175.0	4827.5	24.9	19.7	1396.8	70.8
Bt2	64-73	58075.0	127.6	337.8	3.5	1.2	68.2	29.9	24747.5	5935.0	26.6	19.7	1331.5	37.0
R	73+	-	-	-	-	-	-	-	-	-	-	-	-	-

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
2.5	2370.8	0.5	134.6	228.4	6.7	192350.0	18.0	3325.0	22.3	55.1
2.4	1695.5	3.1	63.3	139.0	3.4	250175.0	15.0	3005.0	12.9	51.0
2.2	1854.5	1.2	47.7	168.3	5.2	158675.0	14.3	2707.5	15.8	48.4
3.3	2002.3	7.1	106.3	190.3	0.8	156675.0	24.0	6000.0	29.5	70.6
2.7	2162.3	3.7	84.1	220.5	1.5	214125.0	27.8	7402.5	16.4	91.9
-	-	-	-	-	-	-	-	-	-	-

Site 7: Totals in mg kg^{-1}

Horizon	Depth (cm)	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn
A	0-17	24057.5	191.6	1024.3	2.1	1.2	26.8	35.1	14545.0	4190.0	24.5	16.1	1015.5	249.8
E	17-36													
Bt1	36-55	33150.0	213.7	791.3	2.5	1.7	33.3	30.0	19175.0	5055.0	27.3	20.9	1503.8	113.4
Bt1														
Bt1	36-55	50450.0	257.3	1028.3	3.4	2.1	46.7	41.0	27925.0	6932.5	28.6	26.4	1817.3	67.3
Bt2	55-78													
Bt2	55-78	85025.0	415.5	510.0	4.7	2.4	69.3	33.6	38250.0	11912.5	39.9	37.7	2505.3	30.8
Cr	78+	-	-	-	-	-	-	-	-	-	-	-	-	-

Mo	Na	Ni	P	S	Se	Si	Sr	Ti	Zn	Zr
2.2	3115.0	1.0	106.7	334.0	4.0	168175.0	24.8	7122.5	39.4	79.6
2.5	2840.0	2.8	97.8	262.3	3.8	167800.0	26.5	8660.0	46.4	84.9
2.1	2937.5	5.1	107.1	345.8	4.3	178700.0	32.3	8915.0	50.5	103.1
2.8	3065.0	8.8	160.1	313.5	2.8	175900.0	53.0	10837.5	68.5	121.2

VITA

Ryan Hudson Blair was born in Paris, Tennessee on January 21, 1985. He moved to Lexington, Tennessee in 1988 where he attended elementary and high school. After graduation from Lexington High School in May of 2003, Ryan moved to Knoxville, Tennessee to begin college at The University of Tennessee at Knoxville where he graduated with a Bachelor's in Science in Environmental and Soil Science in December, 2007. In Spring of 2008, he accepted a graduate research assistantship from The University of Tennessee at Knoxville and began study toward a Master's of Science degree in Environmental and Soil Science. He received his M.S. in Environmental and Soil Science in December 2009.

Ryan is a member of Kappa Sigma Fraternity, Gamma Sigma Delta, and the American Society of Agronomy.