12-1986

Soil morphology, soil water, and forest tree growth on three Cumberland Plateau landtypes

Richard D. Hammer

Recommended Citation

Hammer, Richard D., "Soil morphology, soil water, and forest tree growth on three Cumberland Plateau landtypes. " Master's Thesis, University of Tennessee, 1986.
https://trace.tennessee.edu/utk_gradthes/7368

To the Graduate Council:

I am submitting herewith a thesis written by Richard D. Hammer entitled "Soil morphology, soil water, and forest tree growth on three Cumberland Plateau landtypes." 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 Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

W.L. Parks, Major Professor

We have read this thesis and recommend its acceptance:

E.R. Buckner, G.L. Butnley, R.J. Lewis, G.W. Smalley, J.D. Wolt

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Glendon B. Smalley

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Vice Provost
and Dean of The Graduate School

SOIL MORPHOLOGY, SOIL WATER, AND FOREST TREE GROWTH ON THREE CUMBERLAND PLATEAU LANDTYPES

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Richard D. Hammer
December 1986

DEDICATION

This work is dedicated to the memories of Daniel V. Borah and John R. Peacock, formerly my wingmen and my roommates. Both were consumate professionals to whom personal considerations were secondary to considerations of others and to their responsibilities to their chosen profession. They answered every call.

ACKNOWLEDGEMENTS

Major accomplishments in the life of an individual are frequently made possible, directly or indirectly, by the assistance rendered that individual by others. This project was no exception.

I would like to thank the Institute of Agriculture and the Department of Plant and Soil Science (then chaired by Dr. L. F. Seatz) for providing me the opportunity to pursue this research and the degree program while working as a full-time research associate. This project would not have been possible without the financial assistance provided by a grant from the U.S.D.A. Forest Service, Southern Forest Experiment Station, through the Silviculture Laboratory at Sewanee, Tennessee. I am grateful to Dr. C. E. McGee, Project Leader, and Dr. G. W. Smalley, Principal Soil Scientist, for the confidence they showed in me through their sponsorship of the grant.

I am particularly grateful to my committee chairman, Dr. W. L. Parks, and to the remainder of my committee--Dr.'s E. R. Buckner, G. J. Buntley, R. J. Lewis, G. W. Smalley, and J. D. Wolt--for allowing me the freedom to design, implement, and conduct the research according to my personal and professional standards. While my committee allowed me freedom, they also kept me from several blind alleys I would eagerly have entered. To a man, their doors were always open when problems arose, and assistance was always provided when requested. This project could not have been completed without their support, guidance, and friendship.

I also thank Don Bivens, Ken Pierce, and Chuck Grimes, all of the U.S. Forest Service, for their help with the grunt work in the field. Bill Hunt and Stan Williams were invaluable in the laboratory. Thanks also to Martha Cox, who patiently and persistently typed manuscripts and tables, and to Cheryl Broome for helping Martha. Dr. Ron Mitchell provided hours of willing consultation with computer work. Dr. Ralph O'Brien and Dr. John Philpot provided much help with data analysis, and made statistics enjoyable.

My parents instilled in me early in life the desire to excel and to always do my best. Their continued encouragement was integral to this work.

Mostly, however, I owe a great debt to my wife, Jennifer, who spent many evenings and weekends alone during the course of this project. She has provided love and companionship throughout this and previous odysseys.

ABSTRACT

Relationships among soil morphology, soil water, and forest tree growth were investigated on three forested Cumberland Plateau landtypes at two locations, and a forest land classification system was evaluated. Two soil pits on each plot were opened for morphological descriptions, characterization, and moisture cell installation. Moisture cells were read for two years. Thirty-two soil properties from three genetic soil horizons at 132 points located with a 10 meter grid were used in multivariate statistical analyses. Dominant soils were Typic Fragiudults on uplands; Humic Hapludults and Typic Fragiumbrepts on slopes; and Aquic Dystrochrepts and Typic Haplaquepts on first-order bottoms. Parent materials were Pleistocene loess over shale and sandstone residuum. Clay mineralogy of the upper sequum was relatively young. Chlorite was common in A horizons, but only acid upland soils contained hydroxy-interlayered vermiculite. Kaolinite and quartz dominated residual soils. Gibbsite was in the most leached soil horizons and within buried paleosols. Cation exchange capacities averaged 15 $\mathrm{cmol(p+)kg^{-1}}$ on uplands and bottoms and 20 $\mathrm{cmol(p+)kg^{-1}}$ on slopes. Base saturation ranged from less than 10 percent in bottoms to 45 percent in slope A horizons. Base saturation and cation exchange capacity increased as clay and organic matter increased. Soil moisture distribution in soil profiles and landscapes was related to soil morphology and landtypes respectively. Distribution of citrate-dithionite extractable Fe and Mn in profiles and landtypes was related to measured soil moisture distribution. Stem analysis of forest dominants revealed height growth related to the soil moisture gradient across the landscape. Site index of dominants on uplands and slopes increased downslope, and yellow-poplar height on bottoms increased with increasing depth to the winter water table. Maximum likelihood factor analysis reduced 32 soil properties to four factors representing A horizon properties, soil texture, subsurface cations, and soil drainage and thickness. The 25 retained soil variables extracted 71 percent of the variance. Discriminant analysis classified all 132 grid observations into correct landtypes, revealing that measured soil properties were related to landtypes. The forest land classification system appears to be a viable method of grouping soils into units suitable for forest management on the Cumberland Plateau.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

The Problem

America is a land of finite resources upon which a growing population depends for energy, sustenance, and recreation. Certain of these resources, including forest products and agricultural goods, are deemed "renewable." Foresters have been particularly outspoken in proclaiming that "trees are America's renewable resource." Trees and forests are dependent upon a viable, productive gene pool, a favorable climate and a favorable soil base if productivity is to remain high. Soils are natural entities renewable after loss only by processes which occur over time spans too lengthy to meet the needs of one or even several generations of mankind. Like other natural bodies, soils exhibit variability. Not all soils are capable of producing trees, and some trees are very site-specific. Thus soils are a finite resource, and the forests which grow in and upon these soils must also be considered a finite resource whose products can be expanded to certain limits only through care, wisdom, and planning.

American forests are being subjected to pressures for a greater variety of uses than at any time in history. Forests are viewed as an alternate energy source in many areas of the country and are likely to receive increased pressure as a fuel source as declining oil reserves escalate prices. Developers of mineral rights are interested in "developing" vast acreages of federally owned timber land. Further demands come from a mobile population which views forests as sites for both recreation and wildlife habitat. Much of the nation's water supplies are filtered through forested watersheds.

As the population grows the demand for forest products increases. This demand is compounded because the per capita use of forest products has also increased. By the year 2000 demands for all hardwood materials and for quality hardwoods are expected to double and demands for oak pulpwood will likely triple (Quigley, 1971). A demands for forest products have increased, the forest land base has declined due to urbanization.

In summary, American forests will be required to produce more wood products for a growing population while also being subjects to continuing multiple uses as the forest land base diminishes. Foresters will be continually asked to produce more from less.

Reasons for optimism exist. The President's Advisory Panel on Timber and the Environment (1973) estimated that "the forest lands of the nation as a whole are producing probably no more than 25 percent of their biologic potential" and recommended that efforts to increase productivity be concentrated on "those sites, types, and age classes that yield the highest return per dollar expended." Other professional groups have discussed priorities. The Hardwood Research Council (McLintock, 1979) listed establishment of practical site classification methods among the "most urgent" needs in hardwood forest management. To enhance forest productivity it will be necessary "to bring non-stocked and understocked stands to full productivity" because "much of the reduction in productivity now manifest on forest lands originates in low stocking of desirable species . . . and will require research to improve regeneration techniques and to match the various forest sites with the proper tree species" (Megahan et al., 1981).

The need to accurately quantify the forest soil resource and to identify those sites capable of supporting vigorous, valuable trees is obvious. Site-specific stocking cannot be accomplished without an understanding of the relative merits and liabilities of the various sites and soils within a specific forest ecosystem.

In presettlement times Tennessee forests were unique to North America for the variety of valuable hardwood species they contained and in the number of those species which reached their optimum growth (Braun, 1950). Today forests cover over 50 percent of the state (Tennessee Forest Industries Committee, 1964). Much of the land which is now forested was previously cleared for agricultural purposes and reverted to forest after soil erosion, economic factors, and changing agricultural practices made further agricultural use unprofitable. Generations of high-grading, grazing and burning Tennessee forests have reduced the quality of the genetic shock and reduced the frequency of the occurrence of the more desirable species. Much of these forests remain understocked or contain less desirable species (Smith and Linnartz, 1980).

Insufficient data exists to evaluate potential growth of the various tree species indigenous to the Cumberland Plateau in Tennessee, or to predict where optimum tree growth will occur solely on the basis of soil and topographic features. Smalley (1982) has developed a comprehensive forest site classification system for the middle portion of the Cumberland Plateau. On-site study would help to evaluate Smalley's system and is a necessary step in providing information needed to initiate the restocking of these forests. The soils of much of the Cumberland Plateau will be mapped during a soil survey program currently being conducted by the Soil Conservation Service. The program is scheduled for completion by 1990. Applicable soil-site data from this research should be included in these modern survey publications in order to increase their value to users.

Literature Review

Site Index

Measuring site index is the method foresters use to quantify productivity of specific tree species on specific sites. Site index is expressed as the total height of dominant and codominant trees at a base age, usually 50 years for eastern hardwoods. Early site index curves were based on the assumption that individual tree growth patterns within a species were similar across the variety of soil features, ecological settings, and genetic populations within the natural range of the species. Examples of such site index curves include Schnur's (1937) curves for upland oaks, McCarthy's (1933) curves for yellow-poplar (*Liriodendron tulipifera* L.) and McArdle's (1930, 1961) curves for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

These curves were produced by determining ages and heights of dominant and codominant trees from a large number of stands across the ranges of the species. Ages were plotted against heights and a smooth "index" curve was drawn through the points on the age/height plot. This index curve was defined to be the average growth curve for the average site in the species range. Additional curves representing above-average and below-average site classes were then drawn at equal intervals above and below the index curve. These curves were "harmonized" or drawn to the shape of the index curve. This harmonization satisfied the assumption of similar growth rates for all populations on all sites within the species range. This procedure, developed by Bruce (1926), contains weaknesses which have been adequately discussed by Beck and Trousdell (1973) and Carmean (1970a, 1970b, 1975).

Bull (1931) was the first to cast doubt upon the validity of harmonized growth curves. His research on red pine (Pinus resinosa Ait.) plantation growth revealed polymorphic growth across different soils. Polymorphic growth acknowledges that growth rates may be different for different sites, populations, or ages of trees. Bull's work received little attention until Spurr (1952), citing European research, argued the merits of stem analysis techniques in quantifying tree growth. Stem analysis involves felling dominant and codominant trees and sectioning them into lengths from the trunk base to the meristem. Counts of growth rings taken at the ends of each section are paired with the measured lengths (heights) from the base to construct an actual growth curve for the tree. Investigation of the growth patterns of different populations of western white pine (Pinus monticola Dougl.) (Watt, 1953) revealed polymorphic growth patterns among ecotypes, results which were confirmed by Squillace and Bingham (1958). The possible effects of different soil characteristics upon tree growth patterns were introduced by Spurr (1956) and were substantiated by Carmean's (1956) research on Douglas-fir growth on soils in different parent materials in Washington.

A variety of techniques using stem analysis as the framework for site index curves has been presented (Bailey and Clutter, 1974; Curtis, 1964; Curtis et al., 1974; and Strand, 1964). Stage (1959, 1963) worked with grand fir (Abies grandis, (Dougl.) Lindl.), Bishop et al. (1958) and Johnson and Worthington (1963) developed red alder (Alnus rubra Bong.) curves, Curtis and Post (1962) investigated northern hardwoods, and Dahms (1963) published stem analysis-derived curves for lodgepole pine (Pinus contorta Dougl.). Stem analysis has become an accepted procedure. Work has continued to the present and includes results from a variety of ecosystems and species including: white spruce (Picea glauca (Moench) Voss); black spruce (Picea mariana (Mill.) B.S.P.); lodgepole pine and jack pine (Pinus banksiana Lamb.) (Heger, 1968); eastern white pine (Pinus strobus L.) (Beck, 1971); shortleaf pine (Pinus echinata, Mill.) (Graney and Burkhart, 1973); Douglas-fir (Curtis et al., 1974); and loblolly pine (Pinus taeda L.) (Devan and Burkhart, 1982).

Predicting Site Index

The development of site index as a measure of site productivity occurred after much of the nation's forest had been extensively logged. The paucity of suitable, even-aged, relatively undisturbed timber strands prompted researchers to investigate the effects of soil-site factors on tree growth. If positive correlations could be established between site factors and tree growth, it would be possible to predict productivity of sites where existing timber strands were either understocked or did not contain the desired species.

Auten (1945) was among the first researchers to investigate the effects of soil-site factors on tree growth. His work with yellow-poplar will be discussed later. Coile and his students investigated soil-site factors affecting growth of several species indigenous to the Coastal Plain Province of the southeastern United States. Their work was summarized in a comprehensive literature review (Coile, 1952). Steinbrenner (1965) reported the results of his and other soil-site studies important to Douglas-fir growth in the Pacific Northwest. More recently, Brown and Lowenstein (1978) found that certain soil and topographic features accounted for 70 percent of the variation in the growth of several conifer species in the northern Rocky Mountains. Work dealing with oaks and yellow-poplars will be discussed later.

In summary, soil-site factors important to tree growth have been identified for many tree species in a number of biotic provinces. Important factors vary within and among species as climate, soils, competitors, pests and pathogens vary. Some factors which have been found important are physical properties of the subsoil, total soil depth, organic matter content, and thickness of the soil surface horizons. Geomorphic features including slope shape, slope length, aspect and other conditions important to soil moisture movement and retention also affect tree growth. Coile (1952) termed the total of these factors "the quality of the rooting volume."

Several sources of error can result when soil-site factors are used to develop site index prediction equations. The most common error occurs when age-height data from a study are converted to site index and the site index value is used as the dependent variable in a regression analysis equation in which soil-site factors are the independent variables (Carmean, 1970a). The error results when the investigator uses regionally developed site index curves to obtain the site index value. The inadequacies of such curves in accurately quantifying tree growth on a local basis have been discussed.

Another source of error results when tree age is incorporated into the regression equation as an independent variable. Age is so closely correlated to height that it can mask or shadow the effects of site factors (Carmean, 1975).

Beck and Trousdell's (1976) review of methods and procedures in the construction of site index prediction equations discussed another inadequacy--the failure to publish with the equations either a statement of the precision of the results or the limitations of the data gathered for the study. This results in the user's making improper applications of the equations or being unable to work within specified confidence limits.

Both Carmean (1975) and McQuilken (1976) discussed another type of error associated with predictive functions--the failure to test the developed equations against an independent data set. Testing is necessary to ascertain that "meaningless" correlation has not been incorporated into the results and to insure that the predictive function accommodates reality within the confines of the study.

Mixed results have been reported by those who have tested their equations. Broadfoot (1969) investigated the growth of bottomland hardwoods on specific soils within six states of the lower Mississippi Valley and was unable to predict site index on his check plots. Broadfoot attributed his failure to the inherent variability of physical and chemical properties of alluvial soils, while Carmean cited the extensive area of the study as the source of the soil variation. Other researchers including Bowersox and Ward (1972), Graney and Bower (1971), and Graney (1977), working within less extensive study areas, have successfully tested their predictive equations.

The Importance of Soil Series or the Soil Mapping Unit to Site Index

The examination of either the soil series or the soil mapping unit as entities to predict site index was a logical step, for both units are groupings of soil pedons or polypedons into classes with similar chemical and physical properties or with similar management capabilities and limitations.

Among the first to investigate the utility of the soil series for this purpose were Van Eck and Whiteside (1958), who examined site index of red pine on several soil series in Michigan. They reported that soil series "can be valuable tools in the prediction of site quality . . ." Their results contain neither statistical quantification of variability nor reports of site index variability within mapping units.

Other, better substantiated, investigations have not been so positive. Farnsworth and Leaf (1965) studied sugar maple (*Acer saccharum* Marsh.) growth on four soil series in New York and observed so much variation in tree growth within soil series that they recommended that other methods of soil classification should be investigated. Van Lear and Hosner (1967) found "little, if any, usable correlation between soil mapping units and the site index of yellow-poplar in southwestern Virginia." In southeastern Ohio it was revealed that topographic features were more accurate predictors of black oak (*Quercus velutina* Lam.) site index than were soil mapping units (Carmean, 1967). Site index of quaking aspen (*Populus tremuloides* Michx.) in Minnesota was reported to be "poorly related to soil mapping units" (Esu and Grigal, 1979). In Michigan Shetron (1972) found "significant" site index differences within soil mapping units for jack pine, red oak (*Quercus rubra* L.), and bigtooth aspen (*Populus grandidentata* Michx.), but sugar maple showed no significant growth differences within soil mapping units.

Jones (1969) wrote that site index variability within mapping units has been revealed to be so great in so many ecosystems that "soil series alone are too heterogeneous ecologically to serve as a basis for evaluating timber productivity . . ." Jones offered the "more favorable" alternative "landscape mapping" for forest productivity applications. Daniels et al. (1971) and Ruhe (1975) have predicted that future attempts to sort soil units into more usable entities with reduced variability will rely more heavily upon geomorphology than have past efforts.

Two scientists have developed landtype classification systems designed to enhance soil-site classification and timber management techniques. Steinbrenner's (1975) system for the Pacific Northwest has been tested by a number of soil surveys which are in use on Weyerheauser Company Forests (Duncan and Steinbrenner, 1972; Duncan et al., 1973).

Smalley (1984a) presented the central concepts of the landtype classification system he developed for the Cumberland Plateau and the Highland Rim physiographic provinces. Smalley's system utilized landforms as its framework with the justification that in rugged upland terrain, landforms are more important to forest management than individual soil series or soil mapping units. This concept provides a method for forest management which can be utilized by individuals lacking the amount of soils training required by a soils based system. Smalley's system also negates the need for a medium intensity soil survey. However, he relied upon existing soil surveys and site index data to provide information for tree growth, species to be favored, and productivity ratings for the landtypes within his system.

Soil Variability

Soils are naturally occurring, multidimensional bodies possessing chemical and physical properties which vary across time and space. The consequences of soil variability are complicated and important. Voluminous research addresses the issue, but the review of soil variability by Wilding and Drees (1983) is the best on the subject.

Soils may vary greatly within mapping units (McCormack and Wilding, 1969; Powell and Springer, 1965), and in some places variability may be as great within a mapping unit as among mapping units (Wilding et al., 1965). Soils may vary extensively within peds as well as among polypedons. Heil (1964) observed that the cation exchange capacity (CEC) of ped coatings was three to seven times greater than the CEC of the interiors of the same peds.

Variability of physical and chemical properties of soils within forested ecosystems has been documented by several workers. McFee and Stone (1965) investigated the variability of physical and chemical properties of the forest floor and A horizons of some forested soils in New York. They reported that 50 samples were required to reduce the standard error to 10 percent of the mean when measuring forest floor thickness within a 0.04 ha plot. Estimates of chemical components of surface horizons were more dependent upon accurate measurement of surface horizon thickness than actual analysis of the sample. Those soil studies, which use a sample of particular depth (0-10 cm, for instance) rather than a soil horizon, may be incorporating significant sampling error.

In Virginia, the forest floor and soil surface characteristics were compared among plantations of four pine species grown on Tatus soils (Metz et al., 1970). Five of the original 10 study plots were not reported because of "excessive variability," and "great variation" was reported from samples within the remaining plots. In Massachusetts, Mader (1963) determined that within-plot variability was less than between-plot variability for most soil properties investigated in glacial till and outwash soils supporting a red pine plantation. Twenty organic matter samples per plot were required to reduce error to 10 percent of the mean, while the number of samples required for the same level of accuracy for CEC was "prohibitively large." Mollitor et al. (1980) determined that more than 1,000 samples per plot would be necessary to establish potassium concentration levels with error within 10 percent of the sample mean on a northeastern flood plain. Plot size was not specified. In the Virginia Piedmont, Della-Bianca and Wells (1967) found that exchangeable calcium in the A_2 horizon of the Cecil soil series ranged from 2 to 1,090 mg kg^{-1}. They concluded that the soil series concept was inadequate for the evaluation of nutrient levels for forest management purposes.

Wilding and Drees (1983) discussed difficulties in quantifying soil variability, including the analysis of spatial variability, determining if variability is systematic or random, and the selection of proper sampling schemes. The authors cited Campbell's (1977; 1978) use of autocorrelation and semivariance to determine rates of spatial variability and to determine the proper sampling interval across a soil. Wilding and Drees (1983) also discussed the advantages and flexibility of grid sampling and its suitability for statistical and computer plotting techniques, and explained the advantages of a grid sampling system to evaluate geomorphic-pedogenic interpretations. Grid sampling is well-suited to evaluate soil variability within a landtype classification system.

Little effort has been made to investigate and quantify patterns of soil variability on the Cumberland Plateau or to relate soil variability to tree growth. Francis and Loftus (1977) have published chemical properties of common Cumberland Plateau soils, and Franzmeir et al. (1969) and Hutchins et al. (1976) investigated the effects of aspect, topography, and vegetation on certain soil properties. Research is required which will investigate relationships among soil properties related to forest tree growth and to soil management parameters.

White Oak and Yellow-poplar

White oak (*Quercus alba* L.) and yellow-poplar are two of many commercially valuable hardwoods of the eastern deciduous forest. Both species have extensive natural ranges embracing several physiographic provinces, soil parent materials, climatic factors, and associated vegetative species. Because of their value and wide ranges, both species have been the subjects of much research, resulting in a considerable volume of data pertaining to their growth. This literature is not in agreement regarding the soil-site factors important to tree growth and significant differences are found in published site index curves. These differences accentuate the need for species-specific, management oriented research within physiographic provinces.

Yellow-poplar

Yellow-poplar is a particularly site-sensitive species. In a study of 10 tree species common to the southern Appalachians, Doolittle

(1958) found that yellow-poplar had the highest site index on the "best" sites and the lowest site index on the "poorest" sites.

Auten's (1945) studies revealed that depth to a "tight" subsoil was an important tree growth factor. In soils with less than 60 cm to tight subsoil yellow-poplar growth was less than "average." A positive correlation was found between A-horizon thickness and site index. Topographic features affecting available soil moisture were also important because site index increased downslope.

Ike and Huppuch (1968) studied soil and topographic features important to hardwood growth in the southern Blue Ridge Mountains. Factors enhancing yellow-poplar growth were topographic position, higher elevation, higher basal area, thickness and organic matter content of the A horizon, and a clay content less than 30 percent in the B horizon.

In southeastern Ohio, Munn and Vimmerstedt (1980) found statistically significant ($\alpha = 0.05$) correlations between yellow-poplar height and slope position, A-horizon thickness, depth to the B2 horizon, depth to a restrictive layer, aspect, soil pH, soil CEC and soil organic matter. These results have particular significance to the Cumberland Plateau because one of the soils studied was the Muskingum soil series, which has been extensively mapped on the Cumberland Plateau in Tennessee (Hubbard et al., 1950; Moneymaker, 1981).

On the New Jersey Coastal Plain, Phillips (1966) found that depth to mottling, percent clay in the subsoil (positive correlation to 36 percent clay content), depth to a restrictive layer, landscape position, and surface drainage affected yellow-poplar site index. Best height growth occurred on well-drained loamy soils on lower slopes and bottoms.

The importance of A-horizon thickness to yellow-poplar growth is a recurring observation. Tyron et al. (1960) found a positive correlation between height and A-horizon thickness to a maximum of 12 inches. In Michigan, Schomaker and Rudolph (1964) attributed large differences in height and diameter growth within a planted yellow-poplar plantation to supplemental nutrient input from leaf litter from adjacent hardwood stands. Trees were larger in that part of the plantation which received two and a half times the litter input as the poorer growth area. Gilmore et al. (1968) found that increasing levels of organic matter and depth to fragipan increased yellow-poplar growth in southern Illinois.

Yellow-poplar makes its best growth on deep, loamy, well-drained soils which supply adequate moisture throughout the growing season. A-horizon thickness and organic matter content are positively correlated to yellow-poplar growth. These factors may be significant to growth on the Cumberland Plateau, particularly on sites which have been previously disturbed. Loftus (1971) found that yellow-poplar seedling growth was reduced in Hartsells subsoil material. Growth was greater in subsoil material amended with topsoil. Francis (1977) observed a positive growth response when yellow-poplar seedlings growing in Hartsells subsoils were fertilized. Baker and Blackmon (1976) observed that mulching and fertilization improved yellow-poplar growth on eroded Memphis soils.

Russell et al. (1970) measured height growth and survival for planted yellow-poplars over a variety of soil-site conditions on the Cumberland Plateau and Highland Rim. Survival was high on all sites, but growth was best on soils deeper than 24 inches to fragipans or bedrock. Best sites were in coves and upland hollows. On the basis of these findings it was stated that 40 percent of the mid-Cumberland Plateau and Highland Rim were capable of producing average-or-better yellow-poplar growth.

Russell's findings substantiated reports of Smalley (1964, 1969) and Smalley and Pierce (1972), who observed planted yellow-poplar plantations in the southern Cumberland Plateau. Their reports revealed that trees were tallest in moist, well-drained bottoms, and that height growth decreased with position up the slopes. Smalley reported that physical properties of the soils in these plantations were not "consistently related to topographic position" (1964). He concluded that soil moisture availability seemed to be affected by topographic factors.

Site quality of existing yellow-poplar stands can be determined by site index measurement. Existing site index curves include McCarthy's (1933) harmonized curves, which he developed from natural stands across the range of the species. Beck's (1962) two sets of regression analysis curves were derived from natural stands in the Carolina Piedmont and the Blue Ridge Mountains. Schlaegel et al. (1969) produced regression analysis curves from permanent plots in West Virginia.

Beck's research revealed different growth curves between yellow-poplar populations in the Piedmont and Blue Ridge Mountains, so he constructed a set of curves for each population. Differences in site index curves developed by Beck, Schlaegel, and McCarthy indicate that polymorphic growth patterns exist among populations from different physiographic provinces. No stem analysis work has been reported for yellow-poplar and yellow-poplar site index curves are needed for the Cumberland Plateau.

Additional information on yellow-poplar is available from literature reviews (McCarthy, 1933; Olson, 1969) and an extensive, but incomplete, bibliography (Schoeneke, 1980).

White Oak

White oak, which has a wide ecological amplitude, is often associated with yellow-poplar because their site requirements overlap. Ike and Huppuch (1968) reported that the site requirements for white oak appear to be more consistent across its range than are yellow-poplar site requirements. Contradictions do exist in the literature. Some site factors reported to be important to white oak growth include:

1. thickness of the soil solum (Einspahr and McComb, 1951; McClurkin, 1963; Trimble and Weitzman, 1956; Yawney and Trimble, 1968).
2. aspect (Carmean, 1965; Doolittle, 1957; Einspahr and McComb, 1951; Gaiser and Merz, 1951; Graney, 1977; Smalley, 1967; Trimble and Weitzman, 1956; Yawney, 1964; Yawney and Trimble, 1968).
3. stand density (Gaiser and Merz, 1951).

4. position on slope/distance from the ridgetop (Bowersox and Ward, 1972; Carmean, 1965; Della-Bianca and Olson, 1961; Doolittle, 1957; Einspahr and McComb, 1951; Gaiser and Merz, 1951; Graney, 1977; Hannah, 1968; Ike and Huppuch, 1968; McClurkin, 1963; Smalley, 1967; Trimble and Weitzman, 1956).
5. thickness of the A horizon (Carmean, 1965; Doolittle, 1957; Gaiser and Merz, 1951; Hannah, 1968; Ike and Huppuch, 1968).
6. soil texture (Bowersox and Ward, 1972; Graney, 1977; Hannah, 1968; Ike and Huppuch, 1968; McClurkin, 1963; Trimble and Weitzman, 1956).
7. slope steepness (Bowersox and Ward, 1972; Carmean, 1965; Einspahr and McComb, 1951; Graney, 1977; Ike and Huppuch, 1968; Trimble and Weitzman, 1956; Yawney, 1964).
8. slope shape (Graney, 1977; Hannah, 1968).
9. elevation (Ike and Huppuch, 1968).
10. slope length (Smalley, 1967).
11. stoniness of the soil (Carmean, 1965).
12. organic matter content of the A horizon (Della-Bianca and Olson, 1961).

Not all of the above-mentioned factors were positively correlated to height growth. Factors found to be significant in some studies were not reported in others. Consistent findings were concerned with the infiltration and storage of soil moisture.

It appears that lateral moisture movement on sloping landscapes may be important for both white oak and yellow-poplar. This would explain the positive correlation between height growth and distance from the ridgetop for both species. Smalley (1982) considers "irrigation by subsurface flow" to be an important factor in his landtype classification system. Hewlett (1961) investigated soil moisture movement in Appalachian Mountain watersheds and determined that unsaturated downslope water flow continued "for many weeks" without surface water recharge. Hewlett attributed this unsaturated subsurface flow to be the source of water for stream flow in the mountains.

Also in the Appalachians, Helvey et al. (1972) found that lower slope positions displayed limited change in soil moisture content regardless of frequence of occurrence of precipitation or time of year. Helvey cited continual subsurface water flow as the source of recharge for lower slope soils. Research is needed on the Cumberland Plateau to determine if the subsurface flow is an important phenomenon. Research should also investigate whether soil morphology reflects downslope water movement.

One notable difference in the site requirements for white oak and yellow-poplar is that white oak appears to be less sensitive to the presence of a thick A horizon, possible indicating that white oak is less demanding for site fertility.

Yawney (1964) reported that soil parent material is an important factor to white oak growth in the Ridge and Valley Province, with limestone-derived soils producing better height growth than sandstone or shale soils.

Several site index curves are available for the evaluation of growth of white oak and other upland oaks. Schnur's (1937) widely used harmonized curves for upland oaks were developed from natural stands across the range of the species. Olson (1959) developed regression analysis site index curves from natural stands of upland oaks in the Virginia-Carolina Piedmont and the southern Appalachian Mountains. He found that his curves extended beyond the upper limits of growth presented by Schnur. Olson also found that mean site index was higher in the Piedmont than for the same species in the mountains, but that the patterns of growth were the same for both physiographic provinces. Graney and Bower (1971) used stem analysis data collected from natural stands of red and white oaks in the Boston Mountains of Arkansas. They reported no evidence of polymorphic oak growth. Their anamorphic curves were similar to Schnur's curves at younger ages but deviated at older ages and on better sites, where Schnur's curves underestimated tree height.

In the central states, Carmean (1972) used stem analysis data from natural stands of upland oaks to develop site index curves. Carmean reported polymorphic growth patterns within and among oak species. Within-species growth variability was correlated to site factors. Carmean's curves differed from both Schnur's and Olson's curves.

The contradictions among these four sets of curves demonstrate the need for regionally based site index work. Of particular concern to the Cumberland Plateau region, are the contradicting reports of polymorphic growth from Carmean (1972) and Graney and Bower (1971). Carmean worked in the unglaciated portion of southern Ohio while Graney and Bower worked in the Ozark uplands of Arkansas. Both areas contain parent materials and soils similar to those found on the Plateau. Although limited in scope, the stem analysis work in this study will help to reveal white oak growth patterns on the Cumberland Plateau, and may indicate if more extensive site index work is necessary.

Objectives

This study will attempt to evaluate growth of yellow-poplar and white oak, examine soil morphology, and investigate the relationship of soil morphology to soil water and tree growth on selected landtypes on the mid-Cumberland Plateau, with research designed:

1. To assess soil morphological and chemical properties of three major landtypes.
2. To assess soil moisture and temperature flux over time.
3. To use stem analysis to evaluate growth patterns of white oak and yellow-poplar within and among landtypes.
4. To examine relationships of height growth of white oak and yellow-poplar to soil-site factors.
5. To characterize and classify dominant soils on the landtypes.
6. To determine the suitability of the forest land classification system for grouping soils into relatively homogeneous units.

CHAPTER II

GENESIS AND CLASSIFICATION OF SOME MID-CUMBERLAND PLATEAU FOREST SOILS

Abstract

Soil chemical, mineralogical, and physical properties were investigated on three forested landtypes at two locations on the mid-Cumberland Plateau in Tennessee. Soil temperature regimes were mesic for all soils on upland, slope, and first order bottom landtypes. Soils on upland landtypes were dominantly Typic Fragiudults, but included Typic Hapludults. Slope soils consisted of Humic Hapludults, Typic Fragiudults, and Typic Fragiumbrepts. First order bottom soils included Aquic Dystrochrepts, Typic Haplaquepts, and Aquic Hapludults. All investigated soils contained lithologic discontinuities. Parent materials were silty overburden materials which appeared to be Pleistocene loess over residuum from interstratified sandstones and shales. Mineralogy of the clay fraction in the upper sequum was relatively young. Kaolinite and quartz were the most commonly identified minerals in the clay fraction throughout the soils, but were most prevalent in the residual soils. Hydroxy-interlayered vermiculite was found in acid upland soils, and chlorite was a commonly found constituent of A horizons. Gibbsite was found only in the most strongly leached upland soils and within buried paleosols. Soils were moderately deep to deep at all sites, and tree roots had penetrated throughout. The most strongly developed illuvial horizons were found in slope

soils below the currently defined taxonomic control section. Residual soils on slopes were apparently very stable. Cation exchange capacities were low, averaging about 15 cmol(p+)kg^{-1} on uplands and bottoms and about 20 cmol(p+)kg^{-1} on slopes, and base saturation ranged from less than 10 percent in bottom soils to a maximum of 45 percent in A horizons of slopes. Both CEC and base saturation increased with increasing clay and C content, and decreased rapidly from maximum levels in A horizons. Soil pH in mol KCl ranged from 3.3 in buried paleosols to a maximum of 4.7 in A horizons of slope soils, but commonly ranged between 3.5 and 4.0. Generally, C, CEC, and base saturation were highest in slope soils. Uplands were intermediate in CEC and base saturation, and were lowest in A horizon C, and bottoms were lowest in CEC and base saturation and were intermediate in A-horizon C.

Introduction

The Cumberland Plateau in Tennessee encompasses approximately 1.153 x 10^{6} hectares, about half of which are forested. The remaining area is managed for a variety of uses, including pasture, agricultural crops, urban development, and individual homesites. Few modern soil surveys are currently available, and very little research has been reported for Cumberland Plateau soils.

Jared (1973) studied parent materials of upland Cumberland Plateau soils. Francis and Loftus (1977) presented a summary of chemical and physical data for certain Cumberland Plateau forest soils, and Franzmeier et al. (1969) presented findings of investigations of soil properties related to slope aspect and position. Research on Cumberland Plateau soils in Kentucky includes investigations of forest soils by Bailey and Avers (1971) and Hutchins et al. (1976). Smalley (1982) developed a forest land classification system for the Tennessee portion of the Plateau using available soil survey information and forest inventory data. The paucity of published data resulted in his drawing heavily on meager information from adjacent physiographic provinces. Both mesic and thermic Cumberland Plateau soils are currently recognized in published survey reports.

This research was conducted to investigate chemical, physical, and mineralogical properties of soils on extensive Cumberland Plateau landtypes thought to be potentially productive for forestry (Smalley, 1982).

Materials and Methods

Three of Smalley's (1982) landtypes, a broad, undulating sandstone upland, a north-facing sandstone slope, and a first order bottom with good surface drainage, were chosen for study at each of two sites--Catoosa Wildlife Management Area 20 km northeast of Crossville and Fall Creek Falls State Park 40 km southwest of Crossville. The landtypes will hereafter be referred to as uplands, slopes, and bottoms respectively. Upland sites were characterized by forest communities dominated by white oak (Quercus alba L.), and slope and bottom site forests were dominated by yellow-poplar (Liriodendron tulipifera L.). Individual study areas were located on each selected landtype, and a soil pit was dug at both the upslope and downslope extremities of each study area. A total of 12 pits resulted--four on each landtype.

Pits were opened in the summer of 1982, and were dug as deeply as water tables or bedrock permitted. Three of the slope soils and one soil on Fall Creek Falls upland were so deep that excavation was terminated at approximately 2.5 to 3 m. Pits were allowed to dry sufficiently for soils to open along interstitial voids between peds so soil structure and horizons within profiles could be more readily discerned. Horizons were identified and measured on upslope pit faces, then a profile slice was removed from the pit face and laid out on a plastic tarp for detailed descriptions. This procedure allowed more precise determination and description of soil morphological features while retaining the orientation and structural integrity of individual peds. Standards and terminology used for detailed morphological features were developed by Buntley (1963). After profile descriptions and sampling were completed, Soiltest moisture/temperature cells containing a fiberglass sensor (Colman and Hendrix, 1949) were carefully placed at various depths in upslope pit faces. Pits were filled and allowed to settle for three months, then moisture and temperature readings were taken at monthly intervals, or as close thereto as weather permitted, for two years.

Total carbon was determined with a Leco Model CR 12 carbon analyzer. Particle size was determined by pipette (Day, 1965) after removal of sands by wet-sieving. Sand size distribution was determined by sieving the oven-dried sand fraction. Extractable bases and extractable acidity were determined using a mechanical vacuum extractor

(Holmgren et al., 1977) with procedures developed for the National Soil Survey Laboratory (Soil Conservation Service, 1982). Extractable acidity was determined using $BaCl_2$-TEA extractant tiltrated to a pH endpoint with HCl. The procedure was modified somewhat by using 0.08 N HCl rather than 0.14 N HCl, which allowed more precise determination of the pH 4.6 endpoint. Extraction time for base determination was reduced from overnight extraction to 6 hour extraction (Hammer and Lewis, in review). Extractable Ca and Mg were determined by atomic absorption of the lanthanum-buffered extract, and Na and K were determined by flame emission. Cation exchange capacity (CEC) was determined by sum of exchangeable bases and titratable acidity. Extractable phosphorus was determined by dilute double acid extraction (Mehlich, 1953). Soil pH was determined with a combination electrode in 1:1 slurries of soil/H_2O and soil/mol KCl after 30 minute equilibration. Presence of mineral species in the clay fraction of selected soil horizons was determined by X-ray diffraction (Rich and Barnhisel, 1977).

Results

Soil Temperature

Mean annual soil temperatures (MAST) were within the mesic range of 8°C to 15°C (Soil Survey Staff, 1975), and soils were mesic on all three landtypes at both locations. Temperatures used for soil classification are 50 cm (Soil Survey Staff, 1975), but MAST and temperature ranges for various depths on the three investigated landtypes are presented (Table 1). North-facing slope soils were coolest and bottom

Table 1. Mean annual soil temperature (MAST) and annual temperature ranges for Cumberland Plateau soils.

Cell Depth (cm)	MAST (°C)	Range (°C)	Cell Depth (cm)	MAST (°C)	Range (°C)
Catoosa			Fall Creek Falls		
---------Upland---------------			----------Upland------------		
8	12.6	23.3	3	13.0	21.9
50	11.8	15.5	50	12.8	17.0
95	12.5	10.8	91	12.6	13.9
---------Slope---------------			----------Slope------------		
12	11.8	23.3	8	12.4	21.4
50	11.9	18.6	50	11.8	17.0
150	11.8	13.3	104	11.9	13.9
235	11.8	9.4	134	12.3	12.2
			261	11.6	9.5
---------Bottom---------------			----------Bottom------------		
5	12.4	22.2	4	13.6	22.2
50	12.4	14.7	50	12.6	15.9
117	12.3	16.7	126	12.1	12.4
			158	12.4	10.8
			262	13.5	8.8

soils were warmest. The uplands contained well developed understory vegetation. Slopes were approximately 10 percent with north aspect at both sites, so the forest floors on the bottoms probably received more solar radiation than the forest floors of the uplands. Soil temperatures were slightly warmer at Fall Creek Falls than at Catoosa. Hutchins et al. (1976) recorded soil temperatures on north aspect and south aspect slopes under forest vegetation for one year. Their data were not presented as MAST, but they observed differences averaging 1.7° to 2.8°C between aspects (north slopes were cooler), and reported that both aspects were mesic. Such a temperature difference between north and south slopes at Fall Creek Falls sites would result in MAST on south-facing slopes very close to the thermic soil temperature regime. Temperature regimes of soils on south-facing slopes under cultivation or pasture on the southern portion of the mid-Cumberland Plateau should probably be investigated.

Although MAST were relatively constant at all depths in the observed soils, soil temperature ranges declined with depth in all soils except at Catoosa bottom. The soil temperature distribution with depth indicates that soils remain sufficiently warm into the winter months to allow metabolic activity and tree root growth. Teskey (1975), using a phytotron, observed white oak root growth in Missouri soils at similar soil temperature during January and February. His observations indicated that adapted forest species are capable of utilizing the soil resource during times of the year when agricultural crops are not grown. Cumberland Plateau soils are moist throughout the winter months (Hammer et al., 1985), so conditions are favorable to tree root growth during much of the winter.

Examination of stem analysis curves of dominant and codominant trees at both sites (Hammer et al., 1985) revealed no indication that fragipans restricted tree growth. White oak growth was nearly linear throughout the lives of the indexed trees, and curve shapes were very similar to those reported in southeastern Ohio (Carmean, 1967). Indications are that the fragipans in these soils are not developed sufficiently to restrict tree growth, or the native species are adapted to site conditions and are able to generate sufficient root growth during moist soil conditions in winter months to overcome potential site limitations imposed by fragipans. Monthly soil temperature readings and temperature cell placements within individual soils are presented in Appendixes A and E.

Soil Morphological Features

Lithologic discontinuities were observed in all soils. At Fall Creek Falls, two soils contained two discontinuities, the lowermost marking the surface of a strong brown, clayey paleosol. For purposes of clarity the oldest of the three soil materials will be referred to as "the paleosol," the overlying soil will be referred to as "the residual soil" or "the residuum," and the youngest, uppermost material will be referred to as either "the overburden" material of "the silt cap." Profile descriptions for all soils are in Appendix B.

Upland and slope soils at both sites were well drained or moderately well drained, but bottom soils were poorly drained at Fall Creek

Falls and were very poorly drained at Catoosa. Soil colors in upland soils commonly were yellowish brown (10YR 5/4 through 5/8) and dark yellowish brown (10YR 4/6). Slope soils were commonly dark yellowish brown and yellowish brown above lithologic discontinuities, but became yellowish red (5YR 4/6) in the residuum, except were fragipans had developed. Slope soils containing fragipan horizons were commonly yellowish brown (10YR 5/6) or yellowish red (5YR 5/8). Bottom soil colors were more variable between sites due to differences in soil textures, soil structure, and duration and height of the water tables. Catoosa bottom soils were more uniformly colored than soils in Fall Creek Falls bottoms, and ranged from yellowish brown (10YR 5/4) through light brownish gray (2.5Y 6/2). Matrix colors of Fall Creek Falls bottom soils ranged from pale brown (10YR 6/3) through light brown (10YR 7/2), and these soils were mottled on ped surfaces and in ped interiors. Mottles ranged from strong brown (7.5YR 5/8) in ped interiors to very pale brown (10YR 7/3) through light gray (2.5Y 7/2) on ped surfaces.

The downslope portions of the Fall Creek Falls upland and slope sites contained well-expressed fragipans, which caused seasonal perched water tables in late winter and in early spring before leaf-out. The BE horizon in the upland soil was light yellowish brown (2.5Y 6/5) and the BE horizon in the Fall Creek Falls slope soil was dark yellowish brown (10YR 4/4) with brownish yellow (10YR 6/6) mottles.

Soils were moderately deep to deep. Upland soils ranged in depth from 86 cm at the Fall Creek Falls profile at the upslope extremity, to over 270 cm in the downslope profile. The Catoosa upland soils ranged in depth from 95 cm to 120 cm. Slope soil depths ranged from 142 cm to over 240 cm at Catoosa, and from 195 cm to over 280 cm at Fall Creek Falls. The two shallower slope soils were found on "benches" and were underlain by either thin layers of sandstone interbedded with shale (the Fall Creek Falls site), or by shale strata more highly resistant to weathering than adjacent strata (the Catoosa site). Soil depth was not determined at Catoosa bottom because the summer water table prohibited deeper investigation. Depth to this water table ranged from 99 to 104 cm in August 1982. Fall Creek Falls bottom soils were very deep. Pits were excavated to 140 and 160 cm, and the soils were augured to total depths of approximately 250 cm.

Three of the four upland soils contained fragipans in various stages of development. Fragipans were most strongly expressed in the downslope extremities of both upland sites. The Fall Creek Falls fragipan contained the classic bleached "streaks" between polygons, a feature commonly observed in fragipans formed in loess in West Tennessee. Buntley et al. (1977) considered these diagnostic streaks (Soil Survey Staff, 1975) to be indicative of fragipan deterioration. Tree roots had penetrated all of the upland site fragipans through interstitial voids between the polygons. Fragipans were also found in one slope soil at each site. The Catoosa slope fragipan soil was in the upslope extremity of the study site. This soil somewhat resembled the soils found on the downslope extremities at the upland sites. This fragipan lacked the diagnostic vertical bleached streaks on polygon sides, but contained prismatic primary structure. Tree roots had penetrated the pan through interstitial voids between prisms. The Fall Creek Falls slope fragipan was massive and extremely firm and brittle. Tree roots had only infrequently penetrated it. The presence of a BE horizon above this fragipan indicated that a perched water table existed during part of the year, but since this soil was on a 35 percent slope, this water table was of brief duration. The slope soils containing fragipans were the two previously mentioned "shallow" soils on benches. All of the observed fragipan horizons at both sites were extremely resistant to penetration by a soil probe during the dry summer months, but were easily probed during winter after they had become moist. All of the observed fragipans appeared to have formed at lithological discontinuities between residual soils and silty overburden materials. Mixing appeared to have occurred in varying amounts and to varying depths at all discontinuities, but the sharpest boundaries between the two materials appeared to be in upland soils closest to the interfluve summits.

The most strongly expressed soil structural units were observed in slopes at both sites, and were contained within 2Bt and 2BtC horizons. These structural units were horizontal blocky peds with very thick to thick clay skins on horizontal ped faces, and were oriented paralled to pathways of water movement within the profiles and landscape (Hammer et al., 1985). Thicknesses and orientations of the clay skins on these peds indicated that the portions of the profiles containing these horizons had been stable for some time. Strong ped structure was also found in the 2Bt horizons above the bedrock in the Catoosa upland profile at the upslope extremity of the study area. These peds also were coated with very thick clay skins, and were oriented parallel to pathways of lateral water movement.

The primary soil structural units found in most of the investigated soils were prisms which usually were characterized by very thick to thick clay skins on vertical ped faces. The prisms were found in portions of the profiles where downward water movement occurred seasonally (Hammer et al., 1985). If profile slices had not been removed from the pits for detailed investigation, it is very likely that the prismatic structure would have been overlooked, because most prisms parted readily into blocky secondary structure upon removal from the soil matrix.

Well-developed clay skins were commonly found in upland and slope soils, both above and below observed lithologic discontinuities, and as previously discussed, the thickest clay skins were commonly associated with pathways of seasonal water movement. Clay skins developed in the younger parent materials continued across the lithological discontinuities and enhanced relict clay skins on ped surfaces within the older residuum. This would partially explain the development of the thickest clay skins below the lithologic discontinuities. The longer time of soil development to which the residual materials had been exposed would also have permitted thicker clay skin formation. Development of morphological features in the overburden materials similar to soil features in the residuum indicated that the current soil weathering environment is similar to the environment in which the residual soils formed.

The most strongly developed argillic horizons above the lithologic discontinuities occurred in the upland soils, probably because less disturbance and mixing had affected these soils, and because more pronounced wetting and drying cycles had occurred. The combination of these two conditions favored translocation and accumulation of secondary clay minerals. Increases in clay content within argillic horizons in the overburden materials were not so pronounced as might have been expected on the basis of clay skin thicknesses alone. Past disturbance may have interrupted lessivage and remixed the soil profile. All of the study sites except the Fall Creek Falls slope site appeared to have been previously cleared for agriculture and/or timber harvest. Dominant and codominant trees ranged in age from about 80 years on the Catoosa slope site to about 39 on the Catoosa bottom. Dominant yellow-poplar trees on Fall Creek Falls slope contained about 130 tree rings outside the heart rot developing in stem centers. These old yellow-poplar trees were the only early successional trees in the canopy of this site, but the other sites contained a variety of younger early successional species (Appendix C).

Textural distribution within profiles (Tables 2 through 7) revealed that upland and slope soils at both sites had more silt above the lithologic discontinuities than below, and the majority of the silt component was the fine silt fraction. Jared (1973) observed similar textural relationships during his investigations, and found a course

Table 2. Soil textures and pH values for Catoosa upland soil profiles.

Soil Horizon	Horizon Depth	Sand Fraction Very Coarse	Sand Fraction Coarse	Sand Fraction Medium	Sand Fraction Fine	Sand Fraction Very Fine	Silt Coarse	Silt Fine	Clay	Total Sand	Total Silt	Texture	pH H₂O	pH KCl
	(cm)	(%)											(1:1)	
PROFILE 1														
A	0-5	0.8	0.3	0.7	16.2	23.0	19.7	28.4	10.9	41.0	48.1	l	4.7	4.2
BA	5-33	0.7	0.4	0.7	10.9	27.6	16.0	30.6	13.1	40.3	46.6	l	4.7	4.2
Bt	33-48	0.7	0.4	0.6	11.2	25.3	14.2	29.9	17.7	38.2	41.1	l	4.5	4.0
2BtX1	48-60	0.8	0.4	0.6	9.5	27.8	13.3	24.0	23.6	39.1	37.3	l	4.4	3.8
2BtX2	60-73	0.2	0.3	0.4	7.4	27.7	14.2	20.7	29.1	36.0	34.9	cl	4.4	3.7
2Bt1	73-85	0.3	0.1	0.3	6.4	25.4	16.4	13.5	37.6	32.5	29.9	cl	4.5	3.6
2Bt2	85-95	0.6	0.3	0.4	5.8	21.7	13.1	13.8	44.3	20.9	34.8	c	4.5	3.6
PROFILE 2														
A	0-7.5	1.1	0.6	0.8	12.9	25.1	16.3	29.0	13.6	41.1	45.3	l	4.4	4.0
E	7.5-20	0.3	0.3	0.7	10.6	26.5	13.3	32.4	15.9	38.4	45.7	l	4.4	4.0
Bt1	20-30	0.1	0.2	0.5	9.3	24.9	12.8	30.4	21.8	35.0	43.2	l	4.5	3.9
Bt2	30-55	0.1	0.2	0.5	10.3	27.4	12.5	29.9	19.1	38.5	42.4	l	4.5	3.9
2BX1	55-70	0.2	0.2	0.4	10.8	32.0	15.4	27.6	13.4	29.8	42.6	l	4.4	3.8
2BX2	70-90	0.4	0.4	0.9	11.2	34.6	4.6	33.7	14.2	47.5	38.3	l	4.4	3.8
2B/C	90-120	0.5	0.5	0.8	12.8	34.1	14.5	23.1	13.7	48.7	37.6	l	4.4	3.8

Table 3. Soil textures and pH values for Catoosa slope soil profiles.

Soil Horizon	Horizon Depth	Sand Fraction Very Coarse	Sand Fraction Coarse	Sand Fraction Medium	Sand Fraction Fine	Sand Fraction Very Fine	Silt Coarse	Silt Fine	Clay	Total Sand	Total Silt	Texture	pH H₂O	pH KCl
	(cm)	-----------	-----------	-----------	-----------	-----------	(%)	-----------	-----------	-----------	-----------		--(1:1)--	
PROFILE 1														
A1	0-7	0.9	1.0	0.9	2.7	8.6	29.1	34.8	22.0	14.1	63.9	sil	6.0	4.9
A2	7-15	3.0	2.8	1.3	2.9	6.5	20.5	38.2	24.8	16.5	58.7	sil	5.5	4.4
AB	15-26	3.3	2.7	2.0	3.7	8.1	18.4	41.7	20.1	19.8	60.1	sil	5.3	4.0
Bt1	26-47	5.5	2.7	1.3	3.6	7.9	17.5	36.8	24.7	21.0	54.3	sil	5.2	3.8
Bt2	47-71	4.9	3.3	1.6	3.3	7.4	17.6	37.6	26.1	20.5	53.4	sil	5.1	3.8
2Bt3	71-80	2.4	1.8	0.8	1.1	3.3	16.1	43.4	31.2	9.4	59.4	sicl	5.0	3.6
2Bt4	80-110	1.9	2.1	0.9	0.6	2.1	11.4	45.9	35.1	7.6	57.3	sicl	4.9	3.6
2BtC1	110-147	2.2	1.9	0.8	0.9	2.2	8.5	40.1	43.4	8.0	48.6	sic	4.4	3.6
2BtC2	147-182	1.1	1.1	0.5	0.6	2.0	3.1	44.4	47.2	5.3	47.5	sic	4.7	3.5
2BtC3	182-240	1.8	2.3	1.4	1.7	9.4	2.6	32.8	48.0	16.6	35.4	sic	4.6	3.5
PROFILE 2														
A1	0-9	2.1	2.1	1.8	7.3	14.3	16.9	36.3	19.2	27.6	53.2	sil	5.3	4.6
A2	9-15	3.1	3.4	2.4	7.0	12.6	14.2	35.6	21.7	28.5	49.8	l	5.0	4.2
BA	15-26	2.4	1.9	2.1	6.9	12.5	14.8	37.5	21.9	25.8	52.3	sil	4.9	4.0
BE	26-33	3.1	2.2	1.3	6.6	13.0	17.5	35.4	20.9	26.2	52.9	sil	4.1	3.8
2Btx1	33-50	3.1	2.8	1.5	5.1	14.0	18.3	31.6	23.6	26.5	49.9	l	4.9	3.7
2Btx2	50-72	3.0	2.1	1.4	5.1	13.7	18.1	31.7	24.9	25.3	49.8	l	4.9	3.6
2BtC1	72-88	4.0	3.6	2.2	2.8	14.9	21.0	28.3	23.2	27.5	49.3	l	4.8	3.6
2BtC2	88-97	3.6	1.9	1.9	2.5	14.3	24.2	25.0	26.6	24.2	49.2	l	4.7	3.5
2BtC3	97-116	2.8	2.5	1.1	1.2	8.0	25.2	31.5	27.7	15.6	56.7	sicl	4.7	3.5
2BtC4	116-130	1.0	1.1	1.0	0.6	1.7	26.4	31.3	26.9	5.4	57.7	sil	4.6	3.5
2CB	130-142	3.2	3.6	2.1	2.5	12.5	24.1	31.5	20.5	23.9	55.6	sil	4.7	3.5

Table 4. Soil textures and pH values for Catoosa bottom soil profiles.

Soil Horizon	Horizon Depth	Sand Fraction					Silt		Clay	Total Sand	Total Silt	Texture	pH	
		Very Coarse	Coarse	Medium	Fine	Very Fine	Coarse	Fine					H_2O	KCl
	(cm)	------------------	------------------	------------------	------------------	------------------	(%) ------------------	------------------	------------------	------------------	------------------		--(1:1)--	
PROFILE 1														
A	0-7	1.3	2.6	15.1	19.6	9.7	18.7	20.2	12.8	48.3	39.4	l	4.2	3.6
Bw	7-20	0.6	2.1	9.4	25.0	15.6	11.2	24.2	11.9	52.7	35.4	sl	4.3	4.0
2A'	20-29	0.2	2.3	16.6	26.0	11.9	10.7	21.9	10.5	56.9	32.6	fsl	4.3	4.0
2Bg1	29-46	0.4	2.9	18.1	27.9	12.8	8.3	17.7	11.9	62.2	25.9	fsl	4.3	3.9
2Bg2	46-82	0.3	3.3	24.3	28.9	10.4	6.7	14.8	11.3	67.2	21.5	fsl	4.2	3.8
2BC	82-104	0.2	2.6	17.5	26.8	12.3	8.5	18.6	13.5	59.4	27.1	fsl	4.4	3.9
PROFILE 2														
A	0-8	1.9	4.4	23.1	22.8	7.6	12.9	17.6	9.7	59.8	30.5	ls	4.3	3.7
AB	8-19	1.5	4.9	23.3	24.9	10.3	7.5	18.1	10.3	64.1	25.6	ls	4.5	4.0
Bw	19-30	0.9	4.1	20.6	24.4	9.9	8.1	21.4	10.6	59.9	29.5	ls	4.4	4.0
2Bg	30-37	0.4	3.6	18.6	23.3	10.9	9.8	23.1	10.3	56.8	32.9	ls	4.4	4.0
2Cg1	37-59	0.2	0.8	3.5	23.1	12.9	13.2	35.9	11.5	39.4	49.1	l	4.1	3.5
2Cg2	59-84	0.5	1.1	9.1	26.6	10.6	9.3	29.4	13.4	47.9	38.7	l	4.4	3.9
2Cg3	84-99	0.4	1.3	10.1	26.2	10.5	8.8	28.7	14.0	37.5	48.5	l	4.5	3.9

Table 5. Soil textures and pH values for Fall Creek Falls upland soil profiles.

Soil	Horizon	Sand Fraction					Silt			Total	Total		pH	
Horizon	Depth	Very Coarse	Coarse	Medium	Fine	Very Fine	Coarse	Fine	Clay	Sand	Silt	Texture	H₂O	KCl
	(cm)	(%)											(1:1)	
PROFILE 1														
A1	0-3	0.6	0.3	0.8	11.3	22.4	17.7	34.4	12.6	35.4	52.0	sil	4.0	3.7
Bw	3-7	0.8	1.4	1.7	10.3	20.2	11.4	40.1	14.1	34.4	51.5	sil	4.2	4.0
Bt1	7-18	0.5	0.4	0.9	9.6	19.4	13.1	37.2	19.0	30.8	50.2	sil	4.3	4.0
Bt2	18-32	0.5	0.9	1.5	12.0	17.7	12.4	33.2	21.8	32.6	45.6	l	4.2	3.8
2Bt3	32-53	1.1	2.5	3.6	15.5	23.2	11.7	24.5	17.9	45.9	36.2	l	4.3	3.8
2BtC1	53-59	2.7	3.1	4.3	20.5	22.0	10.2	21.7	15.5	52.6	31.9	l	4.4	3.8
2BtC2	59-86	0.3	3.3	8.5	38.5	26.9	6.4	10.3	5.8	77.5	16.7	fsl	4.4	3.9
Cr†	86	0.3	0.3	0.4	5.0	17.4	19.6	34.2	22.8	23.4	53.8	l	---	---
PROFILE 2														
A	0-3	0.6	0.6	0.9	6.5	13.4	25.8	39.3	12.9	22.0	65.1	sil	4.2	3.8
Bt1	3-16	0.5	0.6	1.1	5.0	12.1	21.0	42.4	17.3	19.3	63.4	sil	4.3	4.0
Bt2	16-32	0.5	0.6	0.9	4.6	12.0	18.9	41.5	21.0	18.6	60.4	sil	4.3	3.9
Bt3	32-42	0.4	0.6	0.9	4.5	13.7	18.2	42.8	18.9	20.1	61.0	sil	4.5	3.9
2BE	42-56	0.3	0.2	0.2	2.2	4.9	34.8	40.8	16.6	7.8	75.6	sil	4.8	3.8
2Btx1	56-80	0.3	0.4	0.4	4.4	13.0	22.6	37.3	21.6	18.5	59.9	sil	4.5	3.7
2Btx2	80-97	0.1	0.1	0.2	4.1	11.4	22.9	34.6	26.6	15.9	57.5	sil	4.3	3.7
2Btx3	97-112	0.2	0.2	0.2	3.1	8.8	27.9	34.3	25.3	12.5	62.2	sil	4.4	3.7
2B	112-127	0.2	0.2	0.3	4.6	18.1	20.6	33.1	22.9	23.4	53.7	sil	4.5	3.7
2B't1	127-157	0.4	0.2	0.5	4.9	16.6	25.8	32.0	19.6	22.6	57.8	sil	4.5	3.7
2B't2	157-240	0.1	0.1	0.1	3.8	12.9	28.1	32.8	22.1	17.0	60.9	sil	4.5	3.7
3Bt	240-270	0.3	0.1	0.3	3.8	11.9	27.7	31.5	24.4	16.4	59.2	sil	4.0	3.3

†Texture of coatings scraped from horizontally stratified bedrocks and of soil material between Cr fragments.

Table 6. Soil textures and pH values for Fall Creek Falls slope soil profiles.

Soil Horizon	Horizon Depth	Sand Fraction Very Coarse	Sand Fraction Coarse	Sand Fraction Medium	Sand Fraction Fine	Sand Fraction Very Fine	Silt Coarse	Silt Fine	Clay	Total Sand	Total Silt	Texture	pH H₂O	pH KCl
	(cm)	----------	----------	----------	----------	----------	(%)	----------	----------	----------	----------		—(1:1)—	
PROFILE 1														
A1	0–4	2.9	1.5	0.8	2.5	16.6	21.2	33.4	21.1	24.3	54.6	sil	5.1	4.7
A2	14–26	3.2	1.6	0.8	2.6	15.8	17.0	36.4	22.6	24.0	53.4	sil	5.1	4.4
Bw	26–36	1.2	1.3	0.7	1.5	13.5	18.9	39.8	23.1	18.2	58.7	sil	4.7	3.8
Bt1	36–62	7.1	1.2	0.8	1.8	12.5	16.1	39.9	26.6	17.4	56.0	sil	4.7	3.7
Bt2	62–88	1.0	1.0	0.5	2.0	10.4	17.3	40.9	26.9	14.9	58.2	sil	4.7	3.6
BE	88–105	1.9	2.0	0.9	2.1	16.3	18.1	34.9	23.8	23.2	53.0	sil	4.7	3.6
2Bx1	105–140	4.1	3.4	1.8	4.0	18.6	14.9	27.4	25.8	31.9	42.3	l	4.7	3.6
2Bx2	140–168	3.4	2.7	1.7	3.6	18.4	14.9	30.2	25.1	29.8	45.1	l	4.7	3.6
2C	168–195	2.4	2.0	1.3	4.6	17.3	14.4	32.1	25.9	27.6	46.5	l	4.8	3.6
PROFILE 2														
A1	0–8	2.8	2.2	1.1	2.4	15.1	23.2	31.5	21.4	23.9	54.7	sil	5.8	5.0
A2	8–15	2.3	1.6	1.1	2.8	14.5	27.0	29.6	21.1	22.3	56.6	sil	5.5	4.7
BA	15–23	1.8	1.5	1.1	2.4	17.3	18.2	38.3	19.4	24.1	56.5	sil	5.0	4.0
Bw	23–46	3.3	2.0	0.9	2.8	19.4	16.0	35.5	20.1	28.4	51.5	sil	4.9	3.8
Bt1	46–86	3.2	1.9	0.9	2.1	19.7	22.2	31.8	19.2	26.8	54.0	sil	4.8	3.6
2Bt2	86–114	3.9	2.7	1.1	1.6	16.2	19.3	30.9	24.3	25.5	50.2	sil	4.9	3.8
2Bt3	114–150	1.4	1.4	0.7	1.1	6.3	14.4	36.0	38.7	10.9	50.4	sicl	5.0	3.8
2Bt4	150–181	3.6	3.0	1.4	1.3	5.4	17.4	26.7	41.2	14.7	44.1	sic	4.9	3.6
2Bt5	181–204	5.6	4.6	2.1	1.7	11.6	17.4	30.0	27.0	25.6	47.4	c	4.8	3.5
2BtC	204–230	1.0	1.3	0.5	0.5	2.7	23.1	41.3	29.6	6.0	64.4	sicl	4.7	3.5
2CBt1	230–260	1.3	1.6	0.7	0.7	2.1	20.2	42.7	30.7	6.4	62.9	sicl	4.7	3.5
2CBt2	260–280	3.6	3.7	1.9	1.3	4.4	23.9	35.1	26.1	14.9	59.0	sil	4.6	3.6

Table 7. Soil textures and pH values for Fall Creek Falls bottom soil profiles.

Soil Horizon	Horizon Depth	Sand Fraction					Silt		Clay	Total Sand	Total Silt	Texture	pH	
		Very Coarse	Coarse	Medium	Fine	Very Fine	Coarse	Fine					H_2O	KCl
	(cm)	------------------	------------------	------------------	------------------	---------- (%)	----------	------------------	------------------	------------------	------------------		--(1:1)--	
PROFILE 1														
A1	0-9	1.2	2.5	1.8	1.9	10.1	28.4	36.2	17.9	17.5	64.6	sil	4.0	3.3
Bt	9-20	0.5	0.7	0.6	1.4	8.5	24.5	41.5	22.3	11.7	66.0	sil	4.2	3.5
2A'1	20-30	0.1	0.5	0.9	1.5	6.3	20.0	49.0	21.7	9.3	69.0	sil	4.3	3.5
2A2	30-42	0.1	0.4	1.1	2.0	10.9	20.8	44.7	20.0	14.5	65.5	sil	4.6	3.6
2Bw	42-56	0.8	0.8	0.9	2.1	10.7	30.3	40.7	13.7	15.3	71.0	sil	4.2	3.5
2Btg1	56-76	0.5	0.7	0.6	1.4	8.5	24.6	41.5	22.2	11.7	66.1	sil	4.6	3.6
2Btg2	76-113	0.7	1.1	0.9	2.5	12.5	29.5	39.1	13.7	17.7	68.6	sil	4.9	3.8
2Btg3	113-141	1.7	1.8	1.2	2.6	16.7	21.2	40.7	15.9	24.2	59.9	sil	4.9	3.7
3B't	141--	1.1	1.8	1.4	2.8	8.1	36.2	28.7	19.9	15.2	64.9	sil	4.9	3.7
PROFILE 2														
A1	0-7	0.9	0.9	4.2	5.0	7.2	28.1	39.1	14.6	18.2	67.2	sil	4.7	3.8
Bw	7-18	1.9	1.5	0.9	1.5	13.1	29.8	35.1	16.2	18.9	64.9	sil	4.5	3.6
2A'1	18-38	0.3	0.7	0.9	1.6	13.0	23.0	41.6	18.9	16.5	64.6	sil	4.5	3.7
2Btg1	38-56	0.7	1.0	1.5	3.4	18.0	20.8	34.9	19.5	24.8	55.7	sil	4.6	3.7
2Btg2	56-78	3.3	2.2	1.0	3.0	13.0	26.8	35.0	15.7	22.5	61.8	sil	4.8	3.7
2BCg1	78-94	2.1	2.1	1.1	2.2	20.7	21.0	33.0	17.7	29.2	53.1	sil	4.9	3.8
2BCg2	94-122	1.6	1.7	1.1	2.5	26.9	23.4	26.5	16.3	33.8	49.9	l	4.9	3.8
2BCg3	122-158	1.7	2.8	2.1	4.1	26.7	19.4	25.6	17.6	37.4	45.0	l	4.8	3.7
3Bt	158--	1.0	2.1	2.0	6.1	25.8	13.9	23.2	25.9	37.0	37.1	l	4.7	3.6

silt to fine silt ratio ranging from 0.2 to 0.9. He also observed lithologic discontinuities in the soils he studied. Jared's mineralogical investigations of the silt fraction revealed detectable quantities of K-feldspars in the silt cap, but none below the lithologic discontinuities. Jared concluded from his mineralogical results, combined with observations of heavy metal distribution with the profiles, that the silt cap probably resulted from deposition of Pleistocene loess, which has sinced been mixed with the underlying paleosols to varying degrees and to various depths.

Silt content generally decreased with depth in the soils investigated. The most abrupt decreases in silt were apparent in the upland soils closest to the summit--the Catoosa and Fall Creek Falls number one profiles. A decrease in both soils of more than 10 percent total silt occurred from the A1 horizons to the observed lithologic discontinuities. These soils were on the most stable landtypes investigated, and were probably subjected to less alluvial/colluvial soil movement. Additionally, both soils were acid and exhibited limited evidence of soil faunal activity. More mixing had apparently occurred in the downslope extremities of the upland soils and in the slope soils, although decreasing silt content with increasing depth remained evident. Surface horizons in slope soils were less acid than the other soils investigated, and contained evidence of abundant soil faunal activity. This activity probably enhanced mixing of the overburden materials with the residuum and may have somewhat retarded formation and accumulation of secondary clay minerals.

Parent Materials

The Fall Creek Falls upland site two soil apparently formed entirely in silty parent material. A second, very abrupt, lithologic discontinuity was observed at a depth of 240 cm. This soil was in a bowl position between two summits, and considerable aeolian material could have been moved onto the site after deposition on the surrounding landscape. Morphological similarities of the fragipan in this soil to fragipans formed in loess in west Tennessee were striking. Occasional tongues of albic material were observed on vertical faces of prisms within the fragipan. The fragipan in this soil may be considerably younger than West Tennessee fragipans, however, because it lacked the strongly expressed B/E horizon which is sometimes found above the West Tennessee fragipans and which frequently tongues vertically between polygons (Buntley et al., 1977). A BE horizon was present which contained less iron than adjacent horizons (Table 8), an indication of leaching by a seasonally perched water table. The soil contained prisms rather than polygons, and except where the occasional tongues existed, the prisms were not prominant in the undisturbed soil matrix. The possibility exists that this fragipan developed or was strongly enhanced subsequent to deposition of material eroded from the surrounding landscape after forest removal for agricultural purposes. Attribution of such perturbation to either white settlers or to native Americans would be a matter of extreme conjecture, but if confirmation were possible, would give an indication of the time required for the development of the observed fragipan features. The Cumberland Plateau

Table 8. Some chemical properties of Fall Creek Falls upland soils.

Horizon	Depth	Exchangeable Bases and Acidity Ca	Mg	Na	K	Acidity	C.E.C.	B.S.	Total C	Extractable Fe	Mn	Al	P
	(cm)	(cmol (p+) kg^{-1})						(%)	(g kg^{-1})				(mg kg^{-1})
PROFILE 1													
A1	0-3	0.41	0.19	0.08	0.19	20.30	21.17	4.3	32.5	4.21	0.13	1.75	10.25
Bw	3-7	0.09	0.05	0.06	0.12	11.70	12.02	2.7	12.7	4.97	0.17	2.54	6.45
Bt1	7-18	0.07	0.04	0.06	0.13	11.05	11.35	2.7	7.5	6.01	0.05	2.58	2.95
Bt2	18-32	0.09	0.08	0.06	0.13	14.41	14.77	2.5	4.8	7.11	0.05	2.80	1.85
2Bt3	32-53	0.19	0.39	0.06	0.12	11.91	12.67	6.0	2.7	10.29	0.03	2.38	3.90
2BtC1	53-59	0.05	0.16	0.02	0.04	9.98	10.25	2.7	2.1	13.77	0.03	2.68	0.65
2BtC2	59-86	0.10	0.44	0.03	0.08	8.04	8.69	8.1	0.3	4.87	0.11	1.20	1.95
R	86--												
PROFILE 2													
A	0-3	0.16	0.09	0.03	0.16	17.50	17.99	2.5	26.7	6.30	0.79	2.28	2.75
Bt1	3-16	0.13	0.06	0.03	0.14	13.50	13.86	2.7	11.9	8.67	0.34	2.78	3.95
Bt2	16-32	0.20	0.19	0.03	0.19	11.57	12.18	5.3	5.3	10.92	0.18	3.03	1.90
Bt3	32-42	0.25	0.37	0.03	0.16	12.77	13.58	6.3	5.8	11.56	0.12	3.04	3.80
2BE	42-56	0.10	0.33	0.03	0.10	11.78	12.34	4.8	2.0	9.13	0.02	2.23	3.35
2Btx1	56-80	0.04	0.14	0.04	0.08	11.62	11.92	2.6	0.9	12.11	0.01	3.22	1.30
2Btx2	80-97	0.03	0.17	0.03	0.09	12.79	13.08	2.4	0.9	13.86	0.01	3.43	1.75
2Btx3	97-112	0.03	0.12	0.03	0.08	13.38	13.64	1.9	0.8	12.44	0.02	2.95	1.50
2B	112-127	0.04	0.08	0.03	0.08	13.38	13.61	1.7	0.9	10.96	0.01	2.86	5.40
2B't1	127-157	0.03	0.06	0.03	0.05	11.82	11.99	1.4	0.7	14.80	0.01	2.33	1.90
2B't2	157-240	0.07	0.08	0.06	0.05	13.38	13.64	1.9	1.3	14.58	0.01	2.62	2.05
3Bt	240-270	0.03	0.08	0.08	0.06	12.60	12.85	2.0	1.3	12.17	0.01	2.70	3.51

was first settled by white pioneers prior to the turn of the 19th century (Hubbard et al., 1950).

The remaining upland soils and all slope soils formed in mixtures of silty materials over residuum. Colluvial processes apparently affected upper solum characteristics in slope soils, because sandstone fragments were found throughout A and B horizons at both sites. These fragments were probably remnants of the sandstone caprock. Upland ridges on the Plateau are commonly underlain by resistant sandstone bedrock which frequently is horizontally stratified, while slopes and coves are underlain by less resistant shales and siltstones. Decreases in sand content occurred with depth in three of the four slope profiles (Tables 3 and 6). The exception was Catoosa slope two, which as previously discussed, was on a bench caused by the influence of interbedded resistant sandstone.

Bottom soils at both sites were formed in alluvial/colluvial materials washed from the surrounding landscapes. Morphological features in bottom soils at both sites were expressed less strongly than soil features on uplands and slopes, indicating the relative youth of the bottoms and the influence of prolonged saturation during winter. The Catoosa bottom was narrower, contained less relief, and was within a smaller watershed than the Fall Creek Falls bottom. The surrounding landscape at Catoosa was dominantly underlain by sandstone, and the residual soils in the watershed were coarse-textured. The smaller watershed and loamy parent materials at the Catoosa site resulted in the bottom soils forming in loamy sands and sandy loams derived from the sandstone residuum.

Conversely, the Fall Creek Falls watershed contained extensive area underlain by shale, and many soils in the landscape formed in shale residuum. The silt loam texture of these soils may have resulted in part from the finer textured parent material of the residual paleosols. Silty overburden materials washed in from the surrounding landscape probably were incorporated into these bottom soils. The Fall Creek Falls bottom was underlain at a depth of 140 to 160 cm by a strong brown (7.5YR 5/8) paleosol (Appendix B11 and B12) very similar in appearance to the paleosol underlying Fall Creek Falls upland site two. The likelihood exists that the present soils in Fall Creek Falls bottom are the same age as the Fall Creek Falls upland site two soil. Dominant/codominant trees on both sites were approximately the same ages (Appendix C3).

Soil Chemical Properties

Soils on all landtypes at both sites were characterized by acid reaction, low CEC, and low base saturation (Tables 8 through 13). These findings agree with previously reported results (Bailey and Avers, 1971; Francis and Loftus, 1977; Franzmeier et al., 1969; Hutchins et al., 1976; Jared, 1973). Highest CEC and base saturation levels were in surface horizons, and resulted from nutrient cycling by the forest vegetation and from high levels of organic matter (indicated by high total C levels). Generally, CEC and base saturation increased with increasing clay and increasing C. Distribution of soil chemical properties and clay with depth are graphed in Appendix D.

Table 9. Some chemical properties of Fall Creek Falls slope soils.

Horizon	Depth	Exchangeable Bases and Acidity Ca	Mg	Na	K	Acidity	C.E.C.	B.S.	Total C	Extractable Fe	Mn	Al	P
	(cm)	(cmol (p+) kg^{-1})						(%)	(g kg^{-1})				(mg kg^{-1})
PROFILE 1													
A1	0–14	11.22	2.29	0.05	0.61	18.79	32.96	43.0	46.7	10.53	2.26	2.63	2.65
A2	14–26	4.24	0.86	0.03	0.48	20.30	25.91	21.7	25.5	12.19	2.60	3.19	2.40
Bw	26–36	0.40	0.24	0.02	0.17	18.15	18.98	4.4	10.4	13.11	2.21	3.16	2.15
Bt1	36–62	0.37	0.43	0.07	0.19	16.43	17.49	6.1	4.7	13.09	1.25	3.08	1.70
Bt2	62–88	0.50	0.81	0.08	0.20	16.86	18.45	8.6	2.5	13.07	1.05	2.31	1.50
BE	88–105	0.44	0.78	0.07	0.18	17.50	18.97	7.7	1.8	15.35	1.17	2.25	1.10
2Bx1	105–140	0.33	0.59	0.07	0.16	13.85	15.00	8.7	1.3	17.67	2.64	2.95	2.60
2Bx2	140–168	0.31	0.62	0.07	0.13	12.56	13.69	8.3	0.9	19.75	0.17	2.09	1.30
2C	168–195	0.30	0.74	0.07	0.13	11.48	12.72	9.7	1.6	16.18	0.15	1.99	1.95
R	R												
PROFILE 2													
A1	0–8	14.28	2.75	0.07	0.65	19.01	36.76	48.3	46.0	11.29	2.28	3.59	2.45
A2	8–15	5.29	1.12	0.07	0.40	15.35	22.23	30.9	21.6	13.14	2.41	3.69	3.15
BA	15–23	1.03	0.51	0.05	0.24	13.42	15.25	12.0	11.7	11.74	2.07	3.29	1.60
Bw	23–46	0.45	0.96	0.05	0.19	12.99	14.64	11.3	5.1	14.15	1.33	2.47	1.55
Bt1	46–86	0.69	1.09	0.13	0.21	9.12	11.24	18.7	2.6	15.13	1.16	2.45	3.90
2Bt2	86–114	1.33	1.46	0.06	0.21	11.05	14.11	21.7	1.5	27.88	0.18	2.49	3.80
2Bt3	114–150	0.73	1.73	0.06	0.32	15.87	18.71	15.2	1.8	29.45	0.07	2.97	2.90
2Bt4	150–181	0.38	1.01	0.06	0.36	21.59	23.40	7.7	1.7	39.19	0.20	3.28	2.85
2Bt5	181–204	0.15	0.61	0.06	0.32	15.22	16.36	7.0	1.6	19.98	0.46	2.41	3.40
2BtC	204–230	0.07	0.36	0.07	0.30	16.64	17.44	4.6	1.6	18.30	0.08	2.35	2.05
2CBt1	230–260	0.09	0.52	1.09	0.29	17.93	18.92	5.2	2.2	16.46	0.30	2.03	1.75
2CBt2	260–280	0.12	0.51	0.10	0.31	16.43	17.47	6.0	1.5	30.84	1.00	3.07	4.20

Table 10. Some chemical properties of Fall Creek Falls bottom soils.

		Exchangeable Bases and Acidity							Total	Extractable			
Horizon	Depth	Ca	Mg	Na	K	Acidity	C.E.C.	B.S.	C	Fe	Mn	Al	P
	(cm)	(cmol (p+) kg^{-1})						(%)	(g kg^{-1})				(mg kg^{-1})
PROFILE 1													
A1	0-9	0.63	0.36	0.07	0.23	20.01	21.30	6.1	31.3	9.20	0.29	2.72	4.15
Bt	9-20	0.18	0.35	0.03	0.07	16.69	17.32	3.6	3.4	10.77	0.28	3.11	3.60
2A1	20-30	0.17	0.14	0.06	0.15	11.05	11.57	4.4	12.4	9.54	0.93	2.35	1.90
2A2	30-42	0.13	0.11	0.03	0.12	7.61	8.00	4.9	12.8	5.96	0.57	1.42	2.55
2Bw	42-56	0.11	0.08	0.05	0.07	12.21	12.52	2.5	6.6	7.46	0.30	1.29	2.80
2Btg1	56-76	0.36	0.34	0.06	0.07	12.21	13.04	6.4	2.5	7.92	0.20	1.50	2.20
2Btg2	76-113	0.53	0.83	0.05	0.08	11.27	12.71	11.3	2.7	10.76	0.36	1.93	2.05
2Btg3	113-141	0.55	0.97	0.11	0.09	9.63	11.35	15.2	1.7	13.26	0.88	2.18	1.70
3Bt	141--	0.52	1.56	0.06	0.06	8.56	10.76	20.4	1.4	13.27	0.12	2.19	1.75
PROFILE 2													
A1	0-7	4.30	1.45	0.07	0.30	17.07	23.19	26.4	29.7	11.21	0.57	1.91	3.10
Bw	7-18	0.56	0.46	0.07	0.14	14.28	15.51	8.1	16.0	13.81	0.30	2.53	2.30
2A1	18-38	0.29	0.26	0.05	0.10	14.06	14.76	4.7	13.8	7.87	0.23	2.14	2.65
2Btg1	38-56	0.40	0.46	0.05	0.09	9.20	10.20	9.8	5.1	9.33	0.77	1.60	1.85
2Btg2	56-78	0.50	0.62	0.04	0.09	7.61	8.86	14.1	2.9	12.69	0.72	2.13	1.50
2BCg1	78-94	0.57	0.73	0.05	0.10	9.12	10.57	13.7	2.1	15.99	0.59	2.20	1.50
2BCg2	94-122	0.42	0.72	0.04	0.08	8.17	9.43	13.4	1.5	9.63	0.50	1.56	1.55
2BCg3	122-158	0.27	0.93	0.06	0.09	12.99	15.34	8.8	1.1	15.19	0.71	1.84	2.25
3Bt	158--	0.17	1.44	0.05	0.10	9.33	11.09	15.9	1.4	32.74	0.28	2.48	2.90

Table 11. Some chemical properties of Catoosa upland soils.

		Exchangeable Bases and Acidity							Total	Extractable			
Horizon	Depth	Ca	Mg	Na	K	Acidity	C.E.C.	B.S.	C	Fe	Mn	Al	P
	(cm)	(cmol (p+) kg^{-1})						(%)	(g kg^{-1})				(mg kg^{-1})
PROFILE 1													
A	0-5	3.28	0.17	0.07	0.29	11.06	14.87	25.6	29.0	6.49	0.51	2.46	6.45
BA	5-33	0.75	0.10	0.04	0.10	6.11	7.10	13.9	7.7	5.49	0.06	1.94	3.95
Bt	33-48	0.47	0.16	0.11	0.13	9.98	10.85	8.0	2.6	7.10	0.06	2.09	1.50
2BtX1	48-60	0.52	0.27	0.05	0.15	11.05	12.04	8.2	1.9	10.59	0.03	3.14	0.90
2BtX2	60-73	0.45	0.33	0.06	0.20	12.99	14.03	7.4	1.6	14.42	0.01	3.93	0.60
2Bt1	73-85	0.32	0.76	0.05	0.25	16.00	17.38	7.9	1.4	34.17	0.01	1.93	0.40
2Bt2	85-95	0.16	0.91	0.04	0.28	27.09	28.48	4.9	2.1	3.55	0.46	5.09	0.55
R	95--												
PROFILE 2													
A	0-7.5	1.11	0.07	0.05	0.11	14.84	15.18	8.8	21.9	21.03	0.01	4.16	3.40
E	7.5-20	0.15	0.10	0.02	0.12	12.58	12.97	3.0	10.6	4.92	0.38	2.06	2.05
Bt1	20-30	0.67	0.33	0.03	0.15	13.98	15.16	7.8	6.1	7.02	0.15	2.65	1.75
Bt2	30-55	0.31	0.37	0.03	0.12	12.79	13.62	5.5	2.8	6.31	0.07	2.12	1.75
2BX1	55-70	0.13	0.22	0.03	0.08	9.57	10.03	4.8	1.4	5.19	0.06	1.30	1.65
2BX2	70-90	0.07	0.19	0.02	0.08	10.64	11.00	3.3	0.8	4.72	0.03	1.23	1.30
2B/Cr	90-120	0.07	0.19	0.06	0.08	8.60	9.00	4.4	1.0	5.07	0.03	1.16	1.45
R	120--												

Table 12. Some chemical properties of Catoosa slope soils.

		Exchangeable Bases and Acidity							Total	Extractable			
Horizon	Depth	Ca	Mg	Na	K	Acidity	C.E.C.	B.S.	C	Fe	Mn	Al	P
	(cm)	(cmol (p+) kg^{-1})						(%)	(g kg^{-1})				(mg kg^{-1})
PROFILE 1													
A1	0-7	9.35	2.04	0.04	0.57	14.62	26.62	45.1	33.7	10.5	1.99	3.39	9.25
A2	7-15	3.43	0.89	0.03	0.47	14.84	19.66	24.5	22.6	15.0	1.71	3.44	7.30
AB	15-26	1.22	0.45	0.02	0.21	15.48	17.38	10.9	13.5	12.3	1.70	3.02	3.20
Bt1	26-47	1.41	1.07	0.03	0.22	14.30	17.03	16.0	2.6	14.5	0.67	2.16	3.10
Bt2	47-71	1.24	1.29	0.04	0.20	13.87	16.64	16.6	1.7	18.8	0.54	2.41	8.35
2Bt3	71-80	1.02	1.36	0.03	0.19	16.99	19.59	13.3	1.4	19.3	0.18	2.63	7.45
2Bt4	80-110	0.77	1.35	0.03	0.20	18.92	21.28	11.1	1.9	18.2	0.12	2.53	2.40
2BtC1	110-147	0.61	1.23	0.03	0.22	20.21	22.30	9.4	1.8	40.1	0.18	3.31	1.85
2BtC2	147-182	0.32	0.92	0.04	0.25	20.86	22.39	6.8	1.4	19.0	0.06	2.06	2.20
2BtC3	182-240	0.21	0.75	0.04	0.26	23.22	24.48	5.1	1.2	18.2	1.29	2.43	2.05
PROFILE 2													
A1	0-9	4.83	1.16	0.04	0.35	20.10	26.48	24.1	32.3	12.5	2.75	3.42	3.10
A2	9-15	1.71	0.74	0.04	0.20	21.39	24.08	11.2	15.9	11.0	2.65	3.22	2.45
BA	15-26	0.89	0.56	0.05	0.16	16.13	17.79	9.3	8.0	12.8	2.12	2.60	1.80
BE	26-33	0.87	0.76	0.05	0.16	12.69	14.53	12.7	3.8	12.3	1.30	2.61	1.50
2Btx1	33-50	1.11	1.18	0.03	0.16	13.76	16.24	15.3	1.9	11.4	0.41	2.05	1.80
2Btx2	50-72	0.95	1.03	0.04	0.15	13.98	16.15	13.4	1.7	14.8	0.33	2.09	1.85
2BtC1	72-88	0.73	1.08	0.04	0.15	13.33	15.33	13.0	1.3	14.2	0.05	1.57	1.85
2BtC2	88-97	0.46	0.98	0.04	0.15	15.89	17.52	9.3	1.5	10.1	0.07	1.47	4.80
2BtC3	97-116	0.33	0.92	0.05	0.16	18.17	19.63	7.4	1.8	12.3	0.03	1.91	2.55
2BtC4	116-130	0.21	0.79	0.04	0.16	17.31	18.51	6.5	1.6	7.4	0.02	1.24	1.90
2CB	130-142	0.19	0.63	0.04	0.15	17.42	18.43	5.5	1.3	6.6	0.02	1.15	1.90

Table 13. Some chemical properties of Catoosa bottom soils.

Horizon	Depth	Exchangeable Bases and Acidity					C.E.C.	B.S.	Total	Extractable			
		Ca	Mg	Na	K	Acidity			C	Fe	Mn	Al	P
	(cm)	(cmol (p+) kg^{-1})						(%)	(g kg^{-1})				(mg kg^{-1})
PROFILE 1													
A	0-7	1.26	0.37	0.05	0.31	23.76	25.75	7.7	43.7	3.25	0.23	1.18	1.25
Bw	7-20	0.03	0.03	0.03	0.06	16.34	16.49	0.9	15.0	8.54	0.05	1.13	1.10
2A'	20-29	0.02	0.03	0.03	0.05	14.94	15.07	0.9	12.2	4.10	0.17	1.86	2.75
2Bg1	29-46	0.01	0.03	0.03	0.06	13.12	13.24	0.9	5.1	3.26	0.02	1.16	2.30
2Bg2	46-82	0.01	0.03	0.04	0.12	7.53	7.72	2.5	3.4	4.53	0.02	1.39	2.20
2BC	82-104	0.05	0.06	0.03	0.06	6.56	6.76	3.0	2.4	3.42	0.01	1.01	2.10
PROFILE 2													
A	0-8	0.36	0.15	0.05	0.09	11.72	12.37	5.3	26.6	3.49	0.16	1.74	1.70
AB	8-19	0.16	0.08	0.05	0.15	13.22	13.66	3.2	19.3	4.02	0.31	1.94	1.20
Bw	19-30	0.09	0.06	0.03	0.12	12.37	12.67	2.4	14.2	3.57	0.34	1.88	3.15
Bg	30-37	0.06	0.04	0.04	0.07	11.95	12.16	1.7	14.7	3.63	0.48	1.69	3.45
Cg1	37-59	0.05	0.03	0.04	0.05	13.94	14.11	1.2	10.9	2.92	0.08	0.67	3.00
Cg2	59-84	0.16	0.07	0.04	0.08	10.48	10.83	3.2	4.2	1.08	0.02	0.72	2.95
Cg3	84-99	0.18	0.08	0.04	0.08	10.37	10.75	3.5	3.8	0.95	0.02	0.67	2.95

The highest levels of CEC and base saturation were found on slope sites, and ranged from 15-18 cmol(p+)kg^{-1} and 16 percent in the solum to 33 cmol(p+)kg^{-1} and 45 percent in surface horizons. Carbon content of slope soils was generally less than 2 g kg^{-1} in the solum but ranged from 47 g kg^{-1} to 10 g kg^{-1} in A and AB horizons, respectively, with the largest amounts in the soil surface. Uplands were intermediate in CEC and base saturation, and were lowest in A-horizon C. Cation exchange capacity in these soils ranged from 10 to about 15 cmol(p+)kg^{-1} in the solum, and base saturation ranged from about 25 percent in the A horizon at Catoosa upland site one, to a more typical 2 to 5 percent in the lower profile. Carbon levels in upland soils reached a maximum of 25 to 30 g kg^{-1} in surface horizons, but declined rapidly to less than 5 g kg^{-1}. Bottoms were generally lowest in CEC and base saturation and were intermediate in A-horizon C. Maximum CEC of about 20 cmol(p+)kg^{-1} in bottom surface horizons declined rapidly to common levels of 10-15 cmol(p+)kg^{-1} in solums. Accompanying base saturation typically ranged between 5 and 10 percent. Soil reaction (mol KCl) was greatest on slopes, lowest on bottoms, and intermediate on uplands, and typically ranged from 3.3 to 4.0 beneath A horizons, with occasional levels as high as 4.5 in surface horizons. Previous research on these soils (Hammer et al., 1984) revealed that pH in KCl was more positively correlated with other subsurface soil properties than pH in H_2O. Soil pH in all profiles was highest in surface horizons and decreased with depth.

Higher pH, CEC, base saturation and C levels on north slopes were reported by Bailey and Avers (1971) and Hutchins et al. (1976). Franzmeier et al. (1969) reported increasing C levels with lower slope positions. Carbon levels did not increase downslope in this study, but A horizon thicknesses, hence total C within the profiles, increased downslope within north slope landtypes. First order bottoms, however, were lower in C levels and had thinner A horizons than slopes.

Previous researchers have discussed the "chicken or egg" question of whether the observed soils properties on slopes result from the influence of yellow-poplar and associated species, or whether the yellow-poplar forest communities inhabit these sites because of favorable soil conditions (Bailey and Avers, 1971; Hutchins et al., 1976). Yellow-poplar is known for its ability to cycle and retain Ca, and for the beneficial effects to surface soil structure, CEC, base saturation, pH, and organic matter content derived from the influence of established stands (Auten, 1945). The highest yellow-poplar site index observed in this study (Hammer et al., 1985) was on the relatively nutrient-poor bottoms. Apparently, available soil moisture during the growing season was more important to yellow-poplar growth than nutrient availability, provided that certain minimum nutrient levels were available. It seems likely that north slope sites provide sufficient available soil moisture in combination with low potential evapotranspiration to allow the establishment and growth of yellow-poplar, which subsequently modifies the site through the beneficial attributes of its nutrient-rich litter. Soil moisture and temperature conditions on the north slope sites are favorable for optimum expression of the enhanced soil conditions.

Soil P was very low in all profiles. Maximum P levels were observed in A horizons at most sites, although higher P was observed at depth in Catoosa bottom soils. Secondary P peaks were observed at lithologic discontinuities (Appendix D, Figures D2 through D12) in most profiles. This condition could have resulted from existence of A horizons at the surfaces of the buried soils. Mixing during and subsequent to deposition of overburden materials, and subsequent soil processes could have obliterated indications of the buried A horizons, while leaving "peaks" of immobile P.

Clay Mineralogy

For the horizons selected for determination of clay mineralogy, quartz and kaolinite were present in the clay fraction in all horizons in all soils at both sites (Tables 14 and 15). Muscovite was present in all observed horizons except in Catoosa upland soils. Chlorite was frequently observed in A horizons of upland and slope soils, but was absent in bottoms. Hydroxy-interlayered vermiculite (HIV) was commonly found in upland and slope soils, particularly at Catoosa, but was generally absent from bottoms. Illite was present in most horizons within Catoosa soils, but within Fall Creek Falls soils was detected only in the Bt horizon of one slope soil. Gibbsite was found only within the most strongly weathered horizons, was detected in both paleosols, and was more frequently detected at Fall Creek Falls than at Catoosa. Vermiculite was found throughout Fall Creek Falls soils, but

Table 14. Minerals detected in the clay fractions from selected horizons of Catoosa soils.

Catoosa soils		Minerals Detected in the Clay Fraction								
PROFILE	HORIZON	Q	K	Chl	HIV	V	G	Ill	Mus	Mont
CU1	A	X	X	X	X			X		
	2Btx2	X	X	X	X	X			X	
	2Bt2	X	X		X		X		X	
CU2	A	X	X		X			X		X
	Bt2	X	X		X			X		X
	2Bt2	X	X		X			X		X
	2B/CR	X	X		X		X			
CS1	A1	X	X		X			X	X	X
	Bt2	X	X			X		X	X	
	2Bt3	X	X			X		X	X	
	2BtC2	X	X		X				X	
CS2	A1	X	X	X	X				X	
	2Btx2	X	X		X	X			X	
	2BtC3	X	X		X	X			X	
CB1	A	X	X		X			X	X	X
	2Bg1	X	X				X	X	X	
	2BC	X	X		X			X	X	
CB2	A	X	X						X	X
	Cg1	X	X			X			X	X
	Cg3	X	X			X			X	X

Profiles
CU - Catoosa Upland
CS - Catoosa Slope
CB - Catoosa Bottom

Minerals
Q - Quartz
K - Kaolinite
Chl- Chlorite
V - Vermiculite
HIV- Hydroxy-Interlayered Vermiculite
G - Gibbsite
Ill - Illite
Mus - Muscovite
Mont- Montmorillonite

Table 15. Minerals detected in the clay fractions from selected horizons of Fall Creek Falls soils.

Fall Creek Falls soils										
		Minerals Detected in the Clay Fraction								
PROFILE	HORIZON	Q	K	Chl	HIV	V	G	Ill	Mus	Mont
FCU1	A	X	X	X	X	X			X	X
	Bt2	X	X	X		X			X	
	2BtC2	X	X	X		X			X	X
FCU2	A1	X	X	X	X	X			X	X
	Bt2	X	X	X	X	X			X	X
	2Bt2	X	X	X	X	X	X			X
	3Bt	X	X			X	X		X	X
FCS1	A1	X	X	X		X	X		X	
	Bt2	X	X		X	X	X	X	X	X
	2C	X	X		X		X		X	X
FCS2	A1	X	X	X	X	X	X		X	X
	2Bt3	X	X			X	X		X	X
	2Bt5	X	X			X			X	X
	2BtC	X	X			X			X	
FCB1	A1	X	X			X			X	
	2Btg1	X	X			X			X	
	3Bt	X	X			X	X		X	X
FCB2	A1	X	X	X		X			X	
	2A1	X	X		X	X			X	
	2BCg1	X	X			X	X		X	X
	3Bt	X	X			X	X		X	X

Profiles
FCU - Fall Creek Falls Upland
FCS - Fall Creek Falls Slope
FCB - Fall Creek Falls Bottom

Minerals
Q - Quartz
K - Kaolinite
Chl- Chlorite
V - Vermiculite
HIV- Hydroxy-Interlayered Vermiculite
G - Gibbsite
Ill - Illite
Mus - Muscovite
Mont- Montmorillonite

was infrequently detected at Catoosa, where it was present at depth in both slope soils.

Presence of chlorite in surface horizons could have resulted from higher base levels caused by high organic matter content and by nutrient cycling by the woody vegetation. Between site differences in vermiculite and illite could have resulted from parent material differences. Pennsylvanian strata underly both sites, but the Catoosa site is underlain by the Crooked fork group, while Fall Creek Falls is underlain by the older Crab Orchard Mountains group (Wilson et al., 1956). Both upland sites are acid, probably a result of the leaching environment in conjunction with the presence of acid tolerant vegetation (upland oaks and pines), so the presence of HIV in upland soils is not unexpected.

Mineralogical composition of the clay fractions of these soils suggests a somewhat younger weathering product than would have been expected for residual soils on old landscapes. It appears likely that the silty overburden on these landscapes is mineralogically young, and some "recharge" of the soil has resulted from the addition of this material and its subsequent mixing into the residual soils.

Taxonomic Classifications

Soils in the landscapes studied were dominantly Ultisols (Table 16). Base saturations were consistently far too low to allow Alfisol classification of any soils containing argillic horizons. Upland soils commonly contained fragipans, and were classified as

Table 16. Taxonomic classifications of 12 mid-Cumberland Plateau forest soils.

Site	Classification
Catoosa Upland One	fine-loamy, mixed, mesic Typic Fragiudults
Catoosa Upland Two	fine-loamy, mixed, mesic Typic Fragiudults
Fall Creek Upland One	coarse-loamy, mixed, mesic Typic Hapludults
Fall Creek Upland Two	fine-silty, mixed, mesic Typic Fragiudults
Catoosa Slope One	fine-silty, mixed, mesic Humic Hapludults
Catoosa Slope Two	fine-silty, mixed, mesic Typic Fragiudults
Fall Creek Slope One	fine-silty, mixed, mesic Typic Fragiumbrepts
Fall Creek Slope Two	fine-silty, mixed, mesic Humic Hapludults
Catoosa Bottom One	coarse-loamy, mixed, mesic Aquic Dystrochrepts
Catoosa Bottom Two	coarse-loamy, mixed, mesic Typic Haplaquept
Fall Creek Bottom One	fine-silty, mixed, mesic Aquic Hapludults
Fall Creek Bottom Two	fine-silty, mixed, mesic Aquic Dystrochrepts

Fragiudults. Fragipans were most frequently observed with convex micro-relief in depositional topographic positions. All the observed fragipans occurred at lithologic dicontinuities.

Thick, dark surface horizons on slope landtypes resulted in two of the four soils being classified as Humic Hapludults, another was a Typic Fragiumbrept, and the fourth was a Typic Fragiudult. The strongest soil structure in slope soils was observed at depths below the taxonomic control section (Soil Survey Staff, 1975), and suggested that these are relatively stable landscapes. Presence of live tree roots at depths below the control section suggested that the currently defined taxonomic control section is too shallow to define parameters of these soils important for forest tree growth, particularly soil morphological features related to water movement.

Bottom soils were dominantly Inceptisols, and three of the four soils were in the Aquic subgroup. All four soils contained discernible structure, although it was very weak in Catoosa bottom site two. Clay skins were evident in Fall Creek Falls bottom soils, where both prismatic primary structure and secondary blocky structure were observed.

Conclusions

Soils were moderately deep to deep at all sites. Older Cumberland Plateau soil surveys indicate large areas of rock outcrop and shallow-to-bedrock soils (Hubbard et al., 1950; Love et al., 1959). This may have resulted from forested land having been mapped without having been adequately transected. Presence of fragipans in much of the landscape, and occurrence of sandstone "floaters" in the upper solum of slope soils would cause soils to appear shallower, particularly if soils were mapped with probes or augers during the dry season.

Tree roots and well developed soil morphological features were commonly observed at depths below the taxonomic control section. Current taxonomic criteria may not address deep forested soils with sufficient precision for classification relevant to potential site productivity. This may be a moot point, however, since economic and mapping scale restraints limit the amount of time mappers can spend in an area, and limit the sizes of delineations possible on field mapping sheets. This may be why previous researchers have reported the soil series to inadequately group soils on the basis of forest site productivity for various species (Carmean, 1967; Esu and Grigal, 1979; Farnsworth and Leaf, 1965; Shetron, 1972; Van Lear and Hosner, 1967). Such limitations of soil survey information can be somewhat alleviated with the addition of information gained from detailed soil/landscape studies.

The deep-rooting capacities of dominant and codominant forest species, and the apparently unrestricted growth of trees sampled in previously cited site index studies, indicate that native species are adapted to adverse site conditions. The capacity of tree roots to exploit the entire volume of these soils indicates that forestry may be the most suitable use of fragipan soils on the Cumberland Plateau.

Soil chemical and physical properties were strongly related to landtypes, an observation previously confirmed by discriminant analysis of a large data base from the same sites (Parks et al., 1984). Upland soils were acid, low in CEC and base saturation, but commonly contained argillic horizons. North slope soils contained thicker, darker A horizons than upland or bottom soils, and had higher C, CEC, base saturation and pH levels, and were very deep. The most strongly developed soil structure in slope soils was in underlying residuum at depths below the taxonomic control section. Fragipans were commonly found at lithologic discontinuities in upland and slope soils. Bottom soils were the most acid and had the lowest C, CEC, base saturation, and clay levels of all investigated soils. Textures of bottom soils appeared to be strongly influenced by characteristics of bedrock and soils in surrounding watersheds, and by watershed size. Soils at both bottom sites appeared to have formed in materials relatively young geologically.

Surface soil horizons at both sites were relatively young mineralogically, and probably have been "recharged" by additions of relatively unweathered aeolean materials. More detailed studies are necessary to precisely define relative proportions of minerals present in the clay fraction. Some mineralogical differences were noticed between sites. Gibbsite was found only in underlying paleosols and in the most strongly leached residual soils. Paleosols were found at two locations at the Fall Creek Falls site. Upland and slope soils were dominantly Ultisols, but Inceptisols were common on bottoms.

Soils at both sites appeared to have been influenced by aeolean depositions. The thickest aeolean deposition appears to have been on the Fall Creek Falls site, since two soils appeared to have formed completely within aeolean materials subsequently moved and redeposited by colluvial/alluvial processes. Results of this study confirm Jared's (1973) theory that Pleistocene loess was deposited on the Cumberland Plateau.

CHAPTER III

SOIL MORPHOLOGY, SOIL WATER, AND FOREST TREE GROWTH ON THREE CUMBERLAND PLATEAU LANDTYPES

Abstract

Relationships among soil morphology, soil water, citrate-dithionate extractable Fe and Mn, and tree growth were examined on three forested mid-Cumberland Plateau landtypes at two locations. Soil pits on the upslope and downslope ends of each study area were opened on each of the selected landtypes. Detailed soil morphological descriptions were made, including quantitative assessments of type, grade, and class of soil structure; thickness, orientation, and abundance of color coats and clay skins on ped faces; mottles on ped faces and in ped interiors; and size, morphology, and distribution of tree roots within profiles. Soils were dominantly Typic Fragiudults, Humic Hapludults, and Aquic Dystrochrepts on uplands, slopes, and first order bottoms, respectively. Soil moisture cells were inserted with respect to selected soil morphological features in upslope faces of all profile pits and moisture readings were taken at monthly intervals for two years after pits were closed. Soil moisture distribution in profiles was related to soil morphology and landtypes. Soil morphologic features indicated probable pathways of vertical water movement within profiles, and of horizontal downslope water movement within landscapes. These observations were confirmed by data from soil moisture cells. Distribution of Fe and Mn soil profiles and landtypes was related to apparent patterns of soil moisture movement and distribution. Generally, Mn travelled farther vertically within profiles and downslope within landforms than did Fe, and magnitudes of Mn accumulation increased downslope. Stem analysis of dominant forest trees revealed that height growth within and among landtypes was related to the soil moisture gradient. Site index of white oak and yellow-poplar on uplands and slopes, respectively, increased downslope. Yellow-poplar height on bottoms increased with increasing depth to the winter water table. Soil morphological features, when precisely described and interpreted with respect to landtypes, are indicators of patterns of movement and relative amounts of available soil moisture, and can be a valuable aid in predicting potential site productivity for mid-Cumberland Plateau forest soils.

Introduction

Matching tree species to sites is a key requirement in optimizing productivity of America's forests (Megehan et al., 1981; President's Advisory Panel on Timber and the Environment, 1973). Much of the southern hardwood region has been subjected to high-grading, grazing, and burning, and vast forest areas no longer support quality timber (Smith and Linnartz, 1980). This problem is frequently compounded by a lack of modern soil survey information and of forest inventory data. Smalley (1984) noted this lack of published data when he developed his forest land classification system for the mid-Cumberland Plateau (Smalley, 1982). Assessing potential site productivity in the absence of preferred species is therefore a critical concern in optimization of forest productivity.

Ecological studies (Braun, 1950; Cabrera, 1969; Martin, 1971; Wade, 1977) and soil-site investigations (Carmean, 1965, Carmean, 1975; Ike and Huppuch, 1968; Smalley and Pierce, 1972) have revealed that forest species indigenous to the mid-Cumberland Plateau occur and exhibit height growth patterns along gradients representing available soil moisture and potential evapotranspiration.

Water movement through soils in forested landscapes is not well understood, although the importance of soil structure to vertical and horizontal subsurface soil water movement was recognized in early studies (Hursh and Fletcher, 1942). Hewlett (1961) demonstrated that unsaturated soil moisture flow in sloping mountain soils was capable of sustaining streamflow for extended periods. Beasley (1976) confirmed Hewlett's observations and noted the restricting effect of "the clay layer" (argillic horizon) on subsurface water flow. Lateral soil water movement was also observed above the fragipan in a mountainous Pennsylvania watershed (Palkovics and Petersen, 1977). Soil structure affected saturated (Anderson and Bouma, 1973, 1977a) and unsaturated (Anderson and Bouma, 1977b) water flow in soil columns, where blocky soil structure allowed greater moisture dispersion than prismatic structure. Water movement through a vertisol soil profile occurred primarily along prism faces, while water within prisms was "inactive in the flow process" (Ritchie et al., 1972).

Distribution of Fe and Mn within soil profiles and landscapes has also been shown to be related to soil moisture conditions. Studies of prairie and forest soils revealed that within well drained soils, Mn maxima generally occurred below the zone of maximum Fe accumulation (Daniels et al., 1962). Manganese generally travels farther than Fe within landscapes and, under uniform pH conditions, increases in abundance downslope, usually reaching a maximum in footslopes (Childs and Leslie, 1977; Yaalon et al., 1972; Yaalon et al., 1974), where precipitation as nodules can occur under seasonal reducing conditions (Yaalon et al., 1972). The periodicity of wetting and drying cycles apparently influences Mn precipitation in soils. Solubility of Mn is pH-dependent, with Mn becoming water soluble and mobile below pH 5 (Gotoh and Patrick, 1972; Runge and De Leon, 1960; Sims et al., 1979).

Downslope water movement in forested landscapes has been demonstrated, and species distribution and growth substantiate this phenomenon. Soil morphological features in the profile (Simonson, 1959) and in the landscape (Hall, 1983) result from, and can subsequently affect, soil water movement through soils and the landscape. Soil morphological features should be indicators of patterns of moisture movement and distribution as well as indicators of potential forest site productivity.

Objectives of this research were to (1) examine the relationships of soil morphological features and tree root distribution to soil moisture distribution within three selected forested landtypes, (2) to compare soil morphological features with the distribution of Fe and Mn within soil profiles and landtypes, and (3) to examine the effects of landtypes and position within landtypes on height growth of dominant trees.

Materials and Methods

Site Selection, Soil Descriptions and Moisture Cell Placement

Three landtypes conforming to Smalley's (1982) forest land classification system were selected at each of two locations on the Cumberland Plateau in Tennessee: the Catoosa Wildlife Management Area, approximately 20 km northeast of Crossville, and Fall Creek Falls State Park, approximately 40 km southwest of Crossville. The selected landtypes, broad undulating sandstone uplands, north-facing sandstone slopes, and first order bottoms with good surface drainage, will be referred to as uplands, slopes, and bottoms, respectively. A study area was identified on each selected landtype, and boundaries were marked with stakes. Uplands were characterized by white oak (*Quercus alba* L.) dominants and codominants, and slopes and bottoms contained yellow-poplar (*Liriodendron tulipifera* L.) dominants and codominants. A minimum of five dominant/codominant trees of the desired species were scattered through the selected study areas. Selected trees showed no visible signs of previous biological or physical damage or suppression.

Soil pits located at the upslope and downslope extremities of each landtype were dug during late July and early August 1982. Excavation during the dry season minimized smearing pit faces, which would have affected subsequent soil water movement. Soil horizons on upslope pit faces were identified, marked, and measured. A profile slice was removed from each selected pit face and was placed on a plastic tarp. Horizons were then remeasured to insure that no expansion of the slice had occurred during removal. Describing removed slices allowed observation and description of primary, subprimary, secondary, and subsecondary peds while retaining the integrity of ped placement and orientation within the soil matrix. Standards and nomenclature used to assess and describe soil morphological features were developed by Buntley (1963). Particular attention was given to thickness, orientation, and abundance of clay skins, and to color coats and patterns on horizontal and vertical faces of all soil structural units. Soil colors were read from field moist samples using a Munsell color book. Samples from each soil horizon were returned to the laboratory for characterization.

Resistance-reading soil moisture cells (Soiltest models 310 and 314) containing fiberglass sensors (Colman and Hendrix, 1949) were carefully placed in upslope faces of pits after the pits had air-dried sufficiently to allow some soil shrinking with concomitant opening along ped faces. Individual cells were placed and oriented with respect to soil horizons and to ped development and orientation. Some cells were placed in interstitial voids between peds. Cells placed in ped interiors were inserted into slits prepared with an Exacto knife. Care was taken to avoid compacting the soil during cell placement. Cells were placed at varying depths throughout each soil profile, and depths and locations of individual cells were measured and recorded. Soil pits were filled and allowed to settle and rewet for three months. Moisture cell readings began after leaf fall, and after autumn rainfall had begun, and continued at monthly intervals, or as closely as weather permitted, for two years.

Laboratory Procedures

Soils were air-dried and ground to pass a 2 mm sieve and nonsoil fragments larger than 2 mm were separated and weighed. Particle size was determined by pipette (Day, 1956). Soil pH was measured with a combination electrode in 1:1 slurries of soil with water and soil with 1 mol KCl. Extractable bases were determined using standard procedures (Soil Conservation Service, 1982) with a mechanical vacuum extractor (Holmgren et al., 1977), but with modified extraction times (Hammer and Lewis, in review). Calcium and Mg were determined by atomic absorption of the lanthanum-buffered extracts, and K and Na were determined by flame emission. Extractable acidity was determined by titrating $BaCl_2$-TEA to a pH endpoint (Soil Conservation Service, 1982). Total carbon was determined with a Leco Model CR-12 carbon analyzer. Citrate dithionite extractable Fe and Mn were obtained using procedures modified for the vacuum extractor (Holmgren, 1967) and were measured by atomic absorption.

Stem Analysis

Stem analysis was performed after soil moisture studies had been completed. Five healthy dominant or codominant trees showing no signs of suppression or damage were selected from each landtype, and their locations within landtypes were measured and recorded. No trees were cut from the Fall Creek Falls slope site because park personnel had requested that felled trees be removed, and the site was remote. Only four trees were cut from the Catoosa bottom site because two selected dominants were killed by lightening in July, 1983. Stem analysis trees were felled and bucked into 1.22 m (4 foot) sections, and a slice was taken from the lower end of each section, and labelled and returned to the laboratory for ring counts. Age-height curves were constructed for individual trees. Average tree growth curves within landtypes were developed by averaging tree heights at five year intervals.

Results

Similar soil morphology, soil Fe and Mn distribution, relationships of soil moisture movement and distribution with soil morphological features, and tree growth within landtypes were observed between Fall Creek Falls and Catoosa sites. Exceptions to observed trends in Mn and Fe distribution occurred within soils containing strongly developed fragipans. The peak in extractable Mn often did not occur where expected in these fragipan soils. However, Mn nodules were common within the interiors of fragipan prisms, and were so large that they were removed during sieving. Were the Mn within these nodules included within the data the result for the fragipan soils would likely have been similar to those obtained for other profiles.

For purpose of brevity, the ensuing discussions are based mostly upon Catoosa site observations and measurements which were representative of soil-site features observed at both sites. An exception was made for Fall Creek Falls bottoms, where pronounced differences between Catoosa sites were observed in soil morphological features and Mn distribution. It was felt that the observed differences warranted brief discussion. The term "soil moisture distribution" implies the relative abundance of soil water within horizons in a profile at a particular time, with the consequent implication that seasonal moisture distribution and movement may be inferred when several profiles within a landscape are examined.

Detailed soil morphological descriptions for the two sites are in Appendix B. An abbreviated nomenclature is presented (Table 17) for purposes of discussion. Soil structure represents the structural unit showing the thickest clay skins within respective soil horizons. The "clay" column indicates the thickness and orientation of the thickest clay skins in each horizon when clay skins are present, and the "root" column indicates the presence and orientation of roots.

Soil Morphological Features and Root Distribution

Upland soils. Catoosa upland pit one (fine-loamy, mixed, mesic Typic Fragiudults) contained granular structure within the A horizon (Table 17a) which graded to compound prismatic-blocky structure in the underlying horizons above and within the fragipan. Clay skins were absent on A and AB horizon peds, but thin clay skins were found on vertical ped faces in the Bt horizon and on vertical and horizontal ped faces in the fragipan. Clay skins in the 2Bt1 horizon were moderately thick on both horizontal and vertical faces of the angular blocky peds. Horizontal blocky peds in the 2Bt2 displayed very thick clay skins on their horizontal faces. Ped type and distribution in conjunction with

Table 17. Soil structure type, orientations and thicknesses of clay skins, and orientations of roots on primary peds in three mid-Cumberland Plateau forest soils.

CATOOSA UPLAND[†]

HORIZON	STRUCTURE	CLAY	ROOTS
A	GRAN.	----	↯
BA	PRISM	----	↓→
Bt	PRISM	- ↓	↓→
2Btx1	PRISM	- ↓→	↓
2Btx2	PRISM	- ↓→	↓
2Bt1	A-BLOCK	o ↓→	↓
2Bt2	H-BLOCK	++ →	→

CATOOSA SLOPE

HORIZON	STRUCTURE	CLAY	ROOTS
A1	BLOCK	----	↯
A2	BLOCK	----	↯
AB	BLOCK	o ↓	↓→
Bt1	PRISM	- ↓→	→
Bt2	PRISM	o ↓→	↓
2Bt3	PRISM	o ↓→	↓
2Bt4	PRISM	+ ↓→	↓→
2BtC1	H-BLOCK	++ →	↓→
2BtC2	H-BLOCK	++ →	↓→
2BtC3	H-BLOCK	++ →	↓→

CATOOSA BOTTOM

HORIZON	STRUCTURE	CLAY	ROOTS
A	BLOCK	----	↯
Bw	PRISM	----	↓→
2A	BLOCK	----	↓
2Bg1	PRISM	----	↓→
2Bg2	PRISM	----	↓
2BgC	BLOCK	----	↓→

[†] Clay skins are absent (----), thin, (-), moderately thick (o), thick (+), or very thick(++). Roots and clay skins are vertical (↓), horizontal (→), or throughout (↯). Thicknesses of root arrows indicates relative root abundance within horizons.

clay skin thicknesses and orientations tend to indicate that water movement was apparently dominantly downward in the upper profile and became lateral over the competent sandstone bedrock.

Root abundance and distribution seemed to confirm this conclusion. Many multidirectional roots were found throughout the A horizon, but root abundance decreased in the BA horizon where roots were primarily on horizontal and vertical ped faces. Root distribution in the Bt was similar to the BA, but fewer roots were observed. Unbranched roots were distributed vertically on primary ped faces within the two fragipan horizons and the 2Bt1 horizon. Within the 2Bt2 horizon, roots increased in abundance and commonly occurred on horizontal ped faces.

Slope soils. The selected Catoosa slope soil (Table 17b) revealed morphological features and root distribution similar to the upland soil, but soil depth increased from 100 cm in the upland to 240 cm in the slope. The fine-silty, mixed, mesic Humic Hapludult slope soil contained a thick A horizon characterized by small angular blocks devoid of clay skins. The upper argillic horizon displayed prismatic structure which became stronger with depth and with increasing clay skin thicknesses. The lower profile contained 2BtC horizons with horizontal blocky peds.

The Bt1 horizon exhibited moderately thick clay skins on vertical ped faces. Thin clay skins on horizontal and vertical ped faces in the Bt2 horizon graded to moderately thick clay skins on horizontal and vertical ped faces in the Bt2 and 2Bt3 horizons. Clay skins on horizontal and vertical ped faces within the 2Bt4 horizon were thick. Very thick clay skins on horizontal ped faces were characteristic within 2BtC horizons. Soil structure and clay skin distribution indicated soil water movement in a downward direction above and in the upper portion of the argillic horizon. Soil water movement within the argillic appeared to be dominantly downward, but some lateral movement was indicated by clay skin thicknesses on horizontal ped faces. In the lower profile, the horizontal blocky structure and thick clay skins on horizontal ped faces indicated soil water movement primarily in the horizontal (downslope) direction. It should also be noted that clay skin thicknesses increased with increasing depth in the horizon and with increasing proximity to the bedrock.

Distribution of roots was characterized both by the depth of penetration and by root distribution along ped faces throughout the profile. Many branched roots were distributed in all directions in the A horizons. Roots were distributed along vertical and horizontal ped faces in the AB horizon. The dominantly horizontal distribution of roots in the Bt1 indicated the probability of lateral water movement along the same horizontal "paths of least resistance" occupied by the roots above the prisms in the lower argillic horizons. The more strongly developed underlying argillic horizons apparently restricted water infiltration during portions of the year. The decrease in clay skin thickness in the Bt1 horizon, when compared to clay skin thickness within both overlying and underlying horizons, seemed to support this hypothesis. Root distribution within the Bt2 and 2Bt3 horizons occurred primarily along vertical faces of the prisms, another indication of downward water movement. Beneath these two horizons lateral water movement appeared to recur and roots, although finer in size, were again located on both horizontal and vertical ped faces.

Tree roots were commonly observed below the taxonomic control section (Soil Survey Staff, 1975). Live tree roots were found at depths greater than 3 m in these soils. All soils contained live tree roots throughout the profile.

First order bottom soils. More variability in soil morphological and chemical features was observed between bottom sites than between uplands and slopes. Color was the most important soil morphological feature indicative of water relations in Catoosa bottom sites. The light yellowish-brown (10YR 5/4) to light brownish-gray matrix (2.5Y 6/2) (Appendix B), when compared to colors of the well-drained upland and slope soils, indicated prolonged soil saturation. Primary ped surfaces were more reduced in appearance than ped interiors, indicating water movement primarily along interstitial voids between peds as well as prolonged periods of wetness. Primary structure was weak, and secondary structure was frequently absent. Blocky structure occurred in surface and in buried A horizons (Table 17c), but the B horizons had prismatic structure. Clay skins were thin, discontinuous, and dull, which seemed to indicate that stripping, rather than deposition, was the active process. Some live roots were found throughout the profile to the depth of the summer water table, but few roots were found beneath the Bw horizon. Roots, when present, were usually between primary ped faces.

Soil morphological features indicated directions of water movement within profiles. Ped grade and clay skin thicknesses appeared to be indicators of soil water movement and frequencies of wet-dry cycles. Deeper profiles and stronger peds indicated greater available water-holding capacities in slopes than in uplands. Soil colors, weak peds, absence of clay skins, and presence of the water table indicated that bottom soils are wet for prolonged periods.

Iron and Manganese Distribution

Distribution of Fe and Mn followed similar patterns within the well-drained upland and slope profiles (Figures 1 and 2). Two Mn maxima occurred, one in A horizons and the second deeper in the profile where soil morphological features had indicated that downslope lateral water movement occurred. High levels of Mn in A horizons could have resulted from the reported affinity of Mn for organic matter (Yaalon et al., 1972), from cycling by the deciduous forest vegetation, a phenomenon suspected by Daniels et al. (1962) and Runge and DeLeon (1960), or from a combination of both factors. The deepest Mn maxima in both profiles occurred below the Fe maxima, indicating that water periodically moves vertically through the profile. The increase in extractable Fe and Mn downslope concurs with previous observations (Childs and Leslie, 1977; Yaalon et al., 1972; Yaalon et al., 1974).

Catoosa bottom soils revealed a Mn maximum below the Fe maximum, but no Mn peak was associated with the surface horizon. Two Mn peaks were observed, the largest in the 2A horizon, and a second, smaller

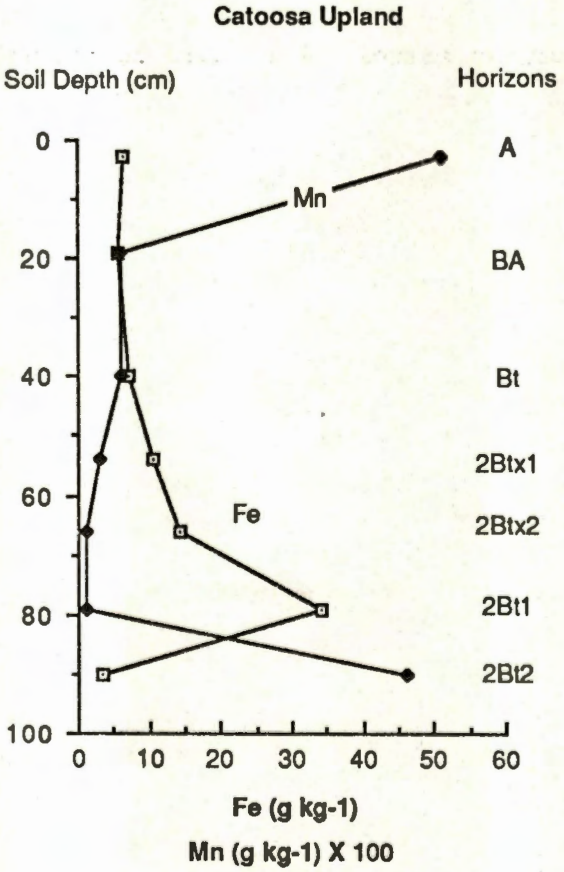

Figure 1. Distribution of citrate-dithionite extractable Fe and Mn in a Catoosa upland soil profile.

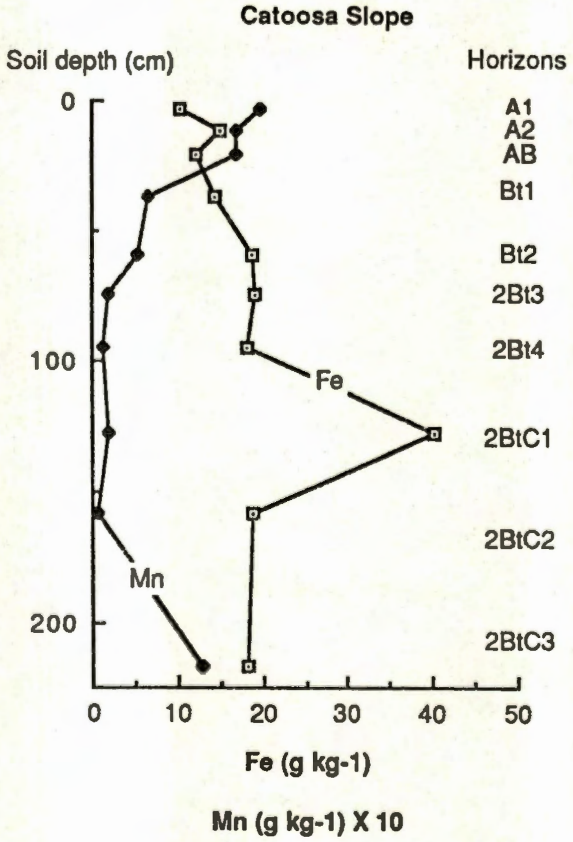

Figure 2. Distribution of citrate-dithionite extractable Fe and Mn in a Catoosa slope soil.

peak in the 2Bg2 horizon (Figure 3). This soil contained a summer water table at the approximate depth of the 2Bg2 horizon. During winter the water table rose to the 2A horizon. The large Mn peak associated with the 2A horizon may have developed because considerable organic matter was present in this horizon, because more Mn was in solution in the winter after upslope soils have been flushed following leaf fall and soil saturation, or from a combination of both effects. Similar Mn distribution was observed in all four bottom profiles. Manganese levels in Fall Creek Falls bottom exceeded Mn levels in all upland and slope profiles. This observation supports previous findings (Childs and Leslie, 1977; Yaalon et al., 1972), and indicates that downslope Mn accumulation may have resulted from downslope water movement. Manganese levels in Catoosa bottom, however, did not exceed levels observed in uplands and slopes. The Catoosa bottom is in a smaller watershed than Fall Creek Falls, and the Catoosa bottom soils are coarser, so these factors may explain the relatively lower Mn retention at this site.

Catoosa bottom soils contained no Mn nodules, although nodules occurred in abundance in the Fall Creek bottoms. The level of extractable Mn at Fall Creek also exceeded Catoosa. The Fall Creek bottoms were located in a larger watershed and the soils were finer textured than the coarse-loamy, mixed, mesic Aquic Dystrochrepts at Catoosa. Additionally, the period of soil saturation at Fall Creek was several weeks shorter than at Catoosa, and soil pH was somewhat higher (Tables 4 and 7, pp. 38 and 41). Although relationships between soil

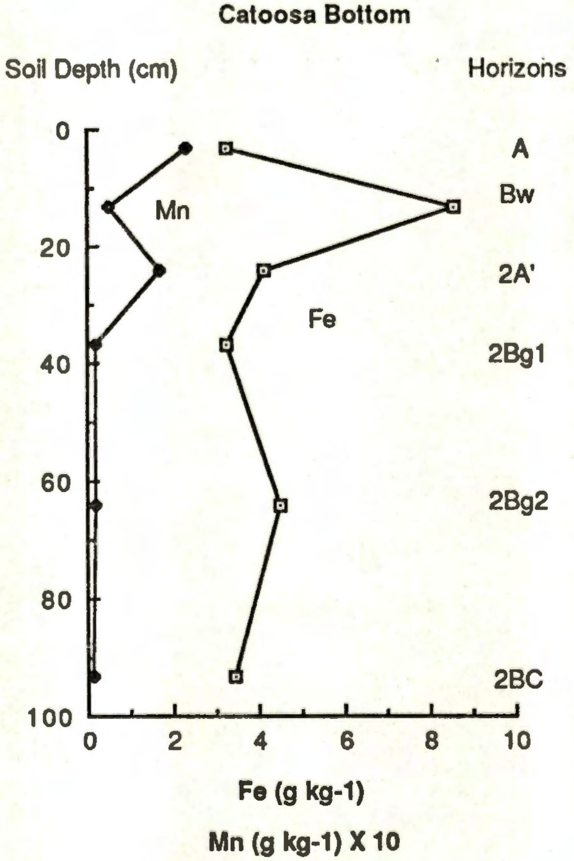

Figure 3. Distribution of citrate-dithionite extractable Fe and Mn in a Catoosa bottom soil.

Mn and soil texture have not been precisely defined for the spectrum of soil drainage and pH-Eh conditions, Mn levels are sometimes correlated with the soil clay fraction (Yaalon et al., 1972). Occurrence of Mn as nodules at the Fall Creek Falls sites probably resulted from a combination of environmental factors more favorable to Mn precipitation. These results seem to support the hypothesis that periodicity of wetting and drying cycles is important to Mn precipitation.

Distribution of Mn and Fe within soil profiles and landtypes on the Cumberland Plateau study sites resulted from soil moisture levels and from patterns of soil moisture distribution and movement, and can be used in conjunction with soil morphological features to obtain a better understanding of seasonal soil water distribution in the landscape.

Soil Moisture Cells

Soil moisture cells cannot measure soil water flux, and the accuracy of readings varies somewhat with soil texture and soil moisture levels. Results of this study indicate that when carefully placed with respect to soil morphological features, and when monitored over time, several cells within a soil profile can give an indication of seasonal soil moisture distribution. Moisture cell readings from a number of profiles can indicate patterns of seasonal moisture distribution within the landscape.

Seasonal patterns of moisture distribution within soil profiles were related to soil depth, soil morphology, and landtype. Moisture cell resistance readings in ohms were plotted against time in months to compare relative soil wetness with respect to depth and positions of individual moisture cells within profiles. Lower resistance indicates greater soil moisture. Throughout this manuscript the term "drier" refers to higher resistance readings, and conversely, the terms "more moist" and "wetter" refer to lower resistance readings.

Upland soils. Readings at three depths within the selected Catoosa upland profile revealed that soil moisture was generally greater at increased depths (Figure 4). The wettest horizon for much of the sampling period was the horizon above the bedrock, where horizontal blocky structure, thick clay skins on horizontal ped faces, and root distribution had indicated that lateral water movement occurred. This horizon dried during the prolonged drought of summer 1983 and remained relatively dry until the soil rewet following leaf-fall and autumn rains in October 1983. Leaf-out and initiation of evapotranspiration in March 1984 resulted in a drying of the lower profile, but late spring rains were sufficient to rewet the lower soil horizons. Additional drying followed during the summer, but leaf absicion reduced evapotranspiration, and autumn rains recharged soil moisture in October.

These patterns of soil moisture distribution in the profile indicated that the 2Bt2 horizon generally undergoes pronounced seasonal wetting and drying, a process required for illuviation and deposition of clay during argillan formation (Soil Survey Staff, 1975). This

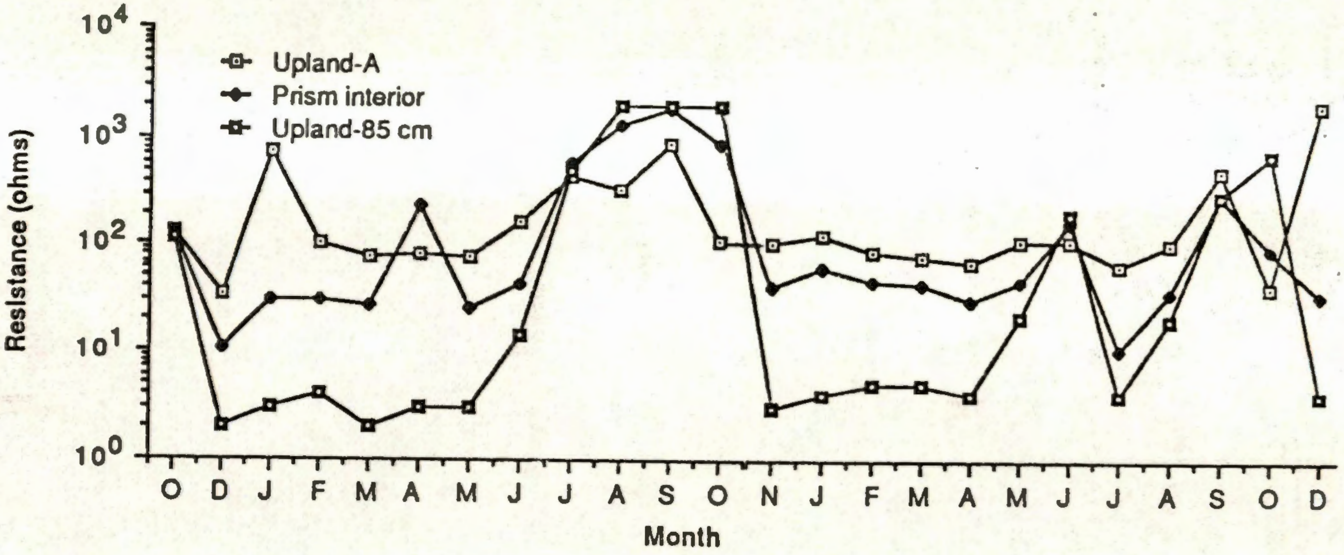

Figure 4. Soil moisture cell resistance readings (ohms) at monthly intervals for two years at three depths in a Catoosa upland soil profile.

finding substantiated the interpretation that the structure and clay skins in the 2Bt2 horizon resulted from periodic wetting and drying and lateral moisture movement over the bedrock. No pronounced trends of interhorizon "lags" in soil moisture levels were observed in the upland soil.

Slope soils. Seasonal moisture distribution in the slope soil (Figure 5) was similar to trends in upland soils. Periods of relative dryness associated with summer evapotranspiration were followed by profile wetting concurrent with leaf fall and autumnal rains. A lag in wetting and drying was observed in the deeper horizons. The deepest horizon did not appear to become so dry for so long a time as the deepest horizon in the upland, this indicated that the deeper soil was either being recharged by a lag in downslope soil moisture seepage, and/or the deeper profile provided a larger reservoir of plant-available moisture and was therefore slower to be depleted of moisture. Similarly, Helvy et al., (1972) reported that seasonal soil moisture changes at all depths were greatest upslope and least downslope in Appalachian forest soils, and that soil moisture levels at depth were correlated to precipitation events occurring in previous weeks, while surface moisture levels were correlated to daily events. Resistance readings indicated that the surface of the slope was consistently more moist than the A horizon of the upland soil. Periodic wetting and drying of the lower horizons indicated that the clay skin formation resulted from pedogneic processes still active in the soil.

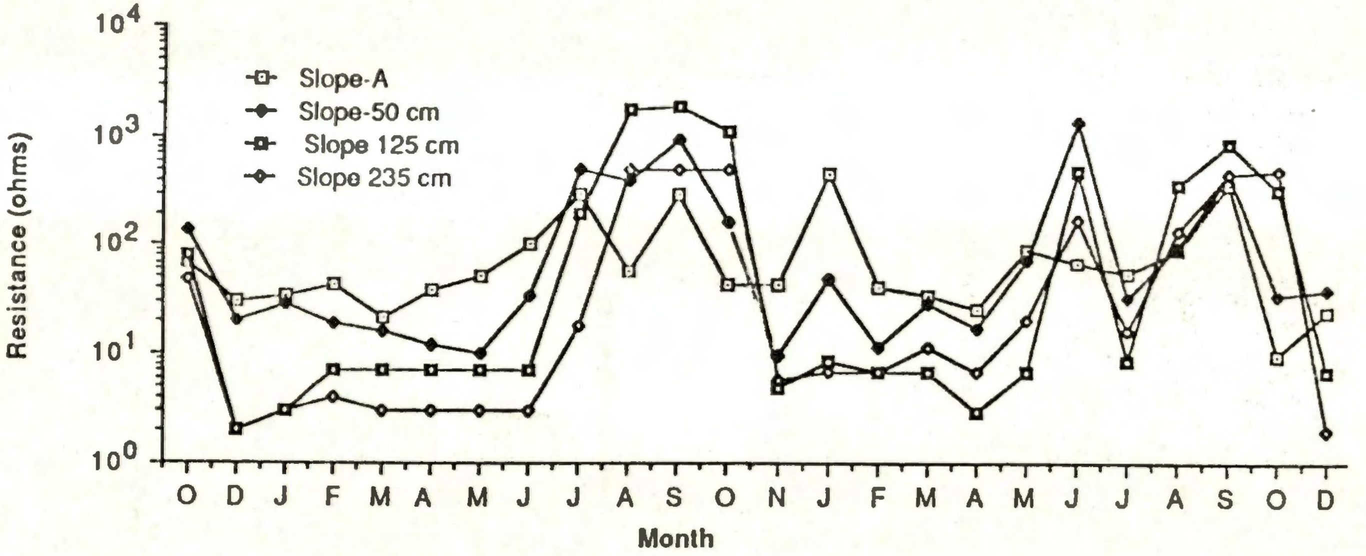

Figure 5. Soil moisture cell resistance readings (ohms) at monthly intervals for two years at four depths in a Catoosa slope soil profile.

First order bottom soils. Soil moisture distribution in the first order bottom soil (Figure 6) indicated that the site was more moist than the upland and slope. The drought of 1983 slightly lowered the water table and caused the soil to be markedly drier at the 50 cm depth than in the following year. The very low resistances at the 120 cm depth, beginning in November 1983, resulted from soil saturation at that depth. The moisture cell indications of soil saturation were confirmed by probing. Note the pronounced lag in dry cycles between the 50 cm and 120 cm depths during summer 1983. This lag, similar to the lag observed on the slope, indicates the possibility of soil moisture recharge from lateral water movement from the surrounding landscape. The rapid recharge of soil moisture following leaf abscision and the onset of autumn rains was also evident in this soil. The winter of 1983-84 was wetter than normal, resulting in a higher than normal winter water table, indicated by soil saturation at the 50 cm depth in May of 1984.

Soil Moisture Distribution with Respect to Soil Morphological Features

Soil moisture distribution within profiles was related to morphological features. Prism interiors were drier than prism surfaces during most of the study, and were more moist than the prism surfaces only during summer drought conditions. The Catoosa upland example (Figure 7) showed that the interior of a prism in the Bt horizon was drier than the prism surface, where two cells were placed at different depths. This indicates that during most of the year water movement

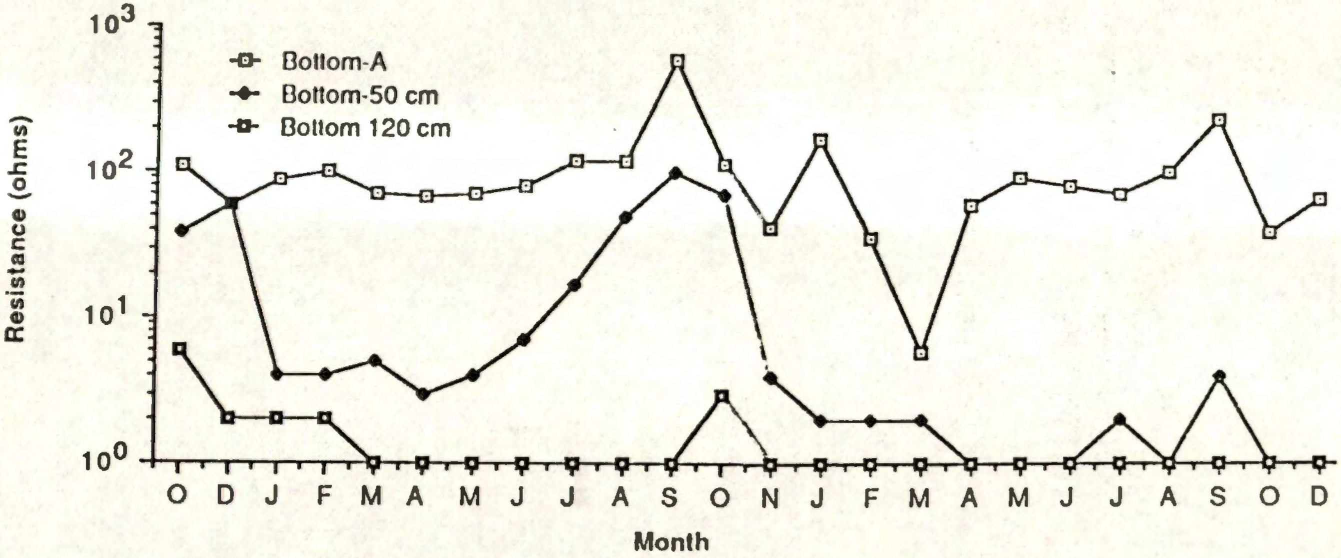

Figure 6. Soil moisture cell resistance readings (ohms) at monthly intervals for two years at three depths in a Catoosa bottom soil profile.

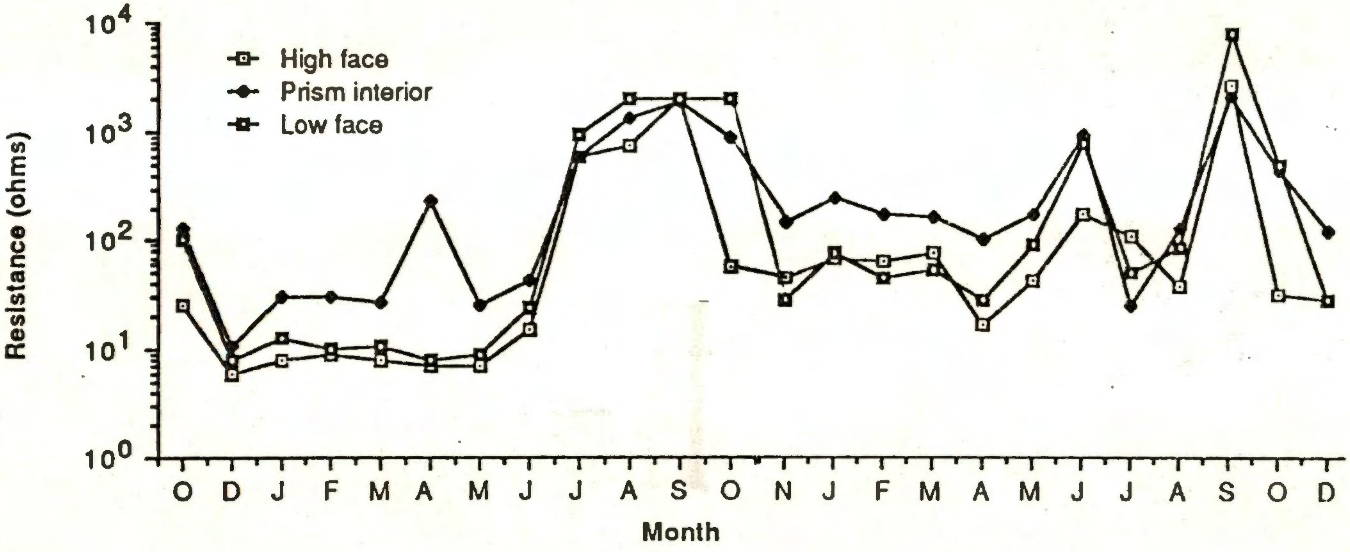

Figure 7. Moisture cell resistance readings for cells placed in a prism interior (50 cm) and at high (25 cm) and low (42 cm) depths on the prism face in a Catoosa upland soil.

along ped faces keeps ped surfaces relatively more moist than ped interiors. Only when the soil became extremely dry was a moisture gradient between the prism surface and interior sufficient to cause further drying of the prism interior. This finding substantiates reports that interiors of peds from South Dakota grassland soils developed in a "more arid" microenvironment than surfaces of the same peds (Heil and Buntley, 1963).

Moisture cells placed on surfaces of horizontal blocky peds in the 2Bt2 horizon of the Catoosa upland profile also revealed moisture distribution related to morphological features (Figure 8). The horizontal blocky structure and thick clay skins on horizontal ped faces indicated lateral water movement over the bedrock through this horizon. The moisture cell placed on horizontal ped faces consistently yielded a more moist reading than the cell placed on vertical ped faces, an indication that the horizontal ped surface was more moist than the vertical ped face. Both cells in the 2Bt2 horizon produced more moist readings than the cells on prism surfaces higher in the profile, indicating that percolation associated with summer precipitation events is primarily along vertical ped faces. Water movement along ped faces during and after summer thunderstorm events is apparently adequate to keep the lower part of the profile relatively moist in years of normal rainfall distribution.

Soil Moisture Distribution Among Landtypes

A comparison of soil moisture cells at the 50 cm depth in all three profiles (Figure 9) revealed that the first order bottom soil is

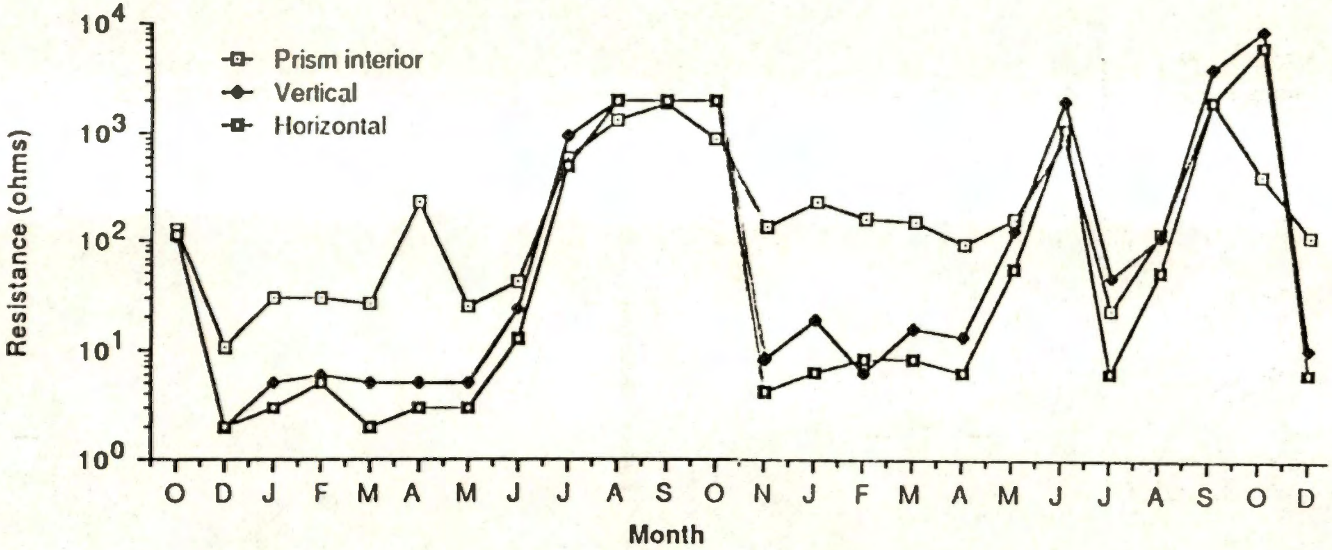

Figure 8. Moisture cell resistance readings for cells placed in the prism interior and within horizontal and vertical voids between peds above the bedrock in a Catoosa upland soil.

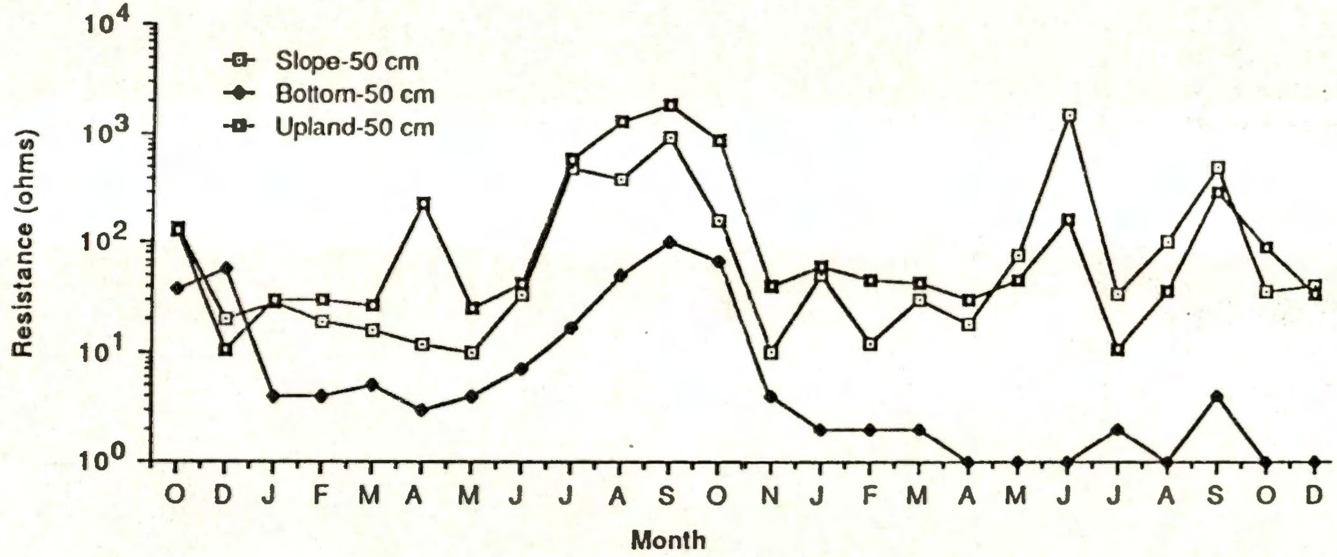

Figure 9. Soil moisture cell resistance readings from cells placed at 50 cm depths in upland, slope, and bottom soils on the Catoosa site.

more moist at that depth than the upland or slope profiles. Very little difference was observed between upland and slope soils, but a pronounced lag in drying was obvious in the first order bottom. This lag could have resulted from soil moisture recharge due to lateral flow or from moisture recharge from capillary rise from the water table.

Moisture cells placed above the bedrock in the 2Bt2 in the upland, in the 2BtC3 horizon in the slope (240 cm), and at 120 cm in the first order bottom (Figure 10) indicated the possibility of downslope lateral water movement within the landscape. The upland soil was generally drier than the slope and bottom. The slope soil showed moisture cell resistance readings very similar to the upland, but an obvious lag in drier readings persisted throughout the study. No lag in rewetting was observed during 1983 or 1984. The driest resistance reading in the first order bottom lagged the driest readings in the slope and upland sites by two months. Although the observed lag between slope and upland readings could be attributed to a longer time required to extract moisture from the deeper soil profile, the data, when considering all three soils, seem to favor downslope lateral water movement through the landscape.

Stem Analysis

Comparison of heights of dominant white oak at index age 50 on Catoosa upland indicate increased height with downslope position (Figure 11). Tree five was about 80 m downslope from tree one, and trees numbered two through four were intermediate in position. Trees

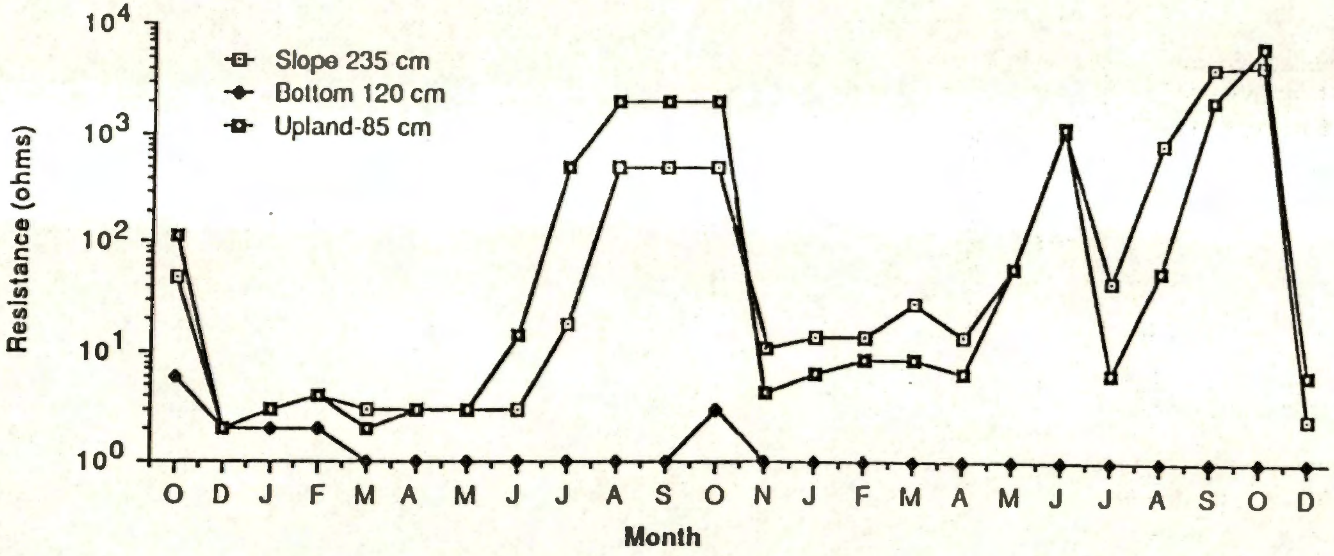

Figure 10. Soil moisture cell resistance readings from cells placed above bedrock in upland and slope soils and at the summer water table in the bottom soil at the Catoosa site.

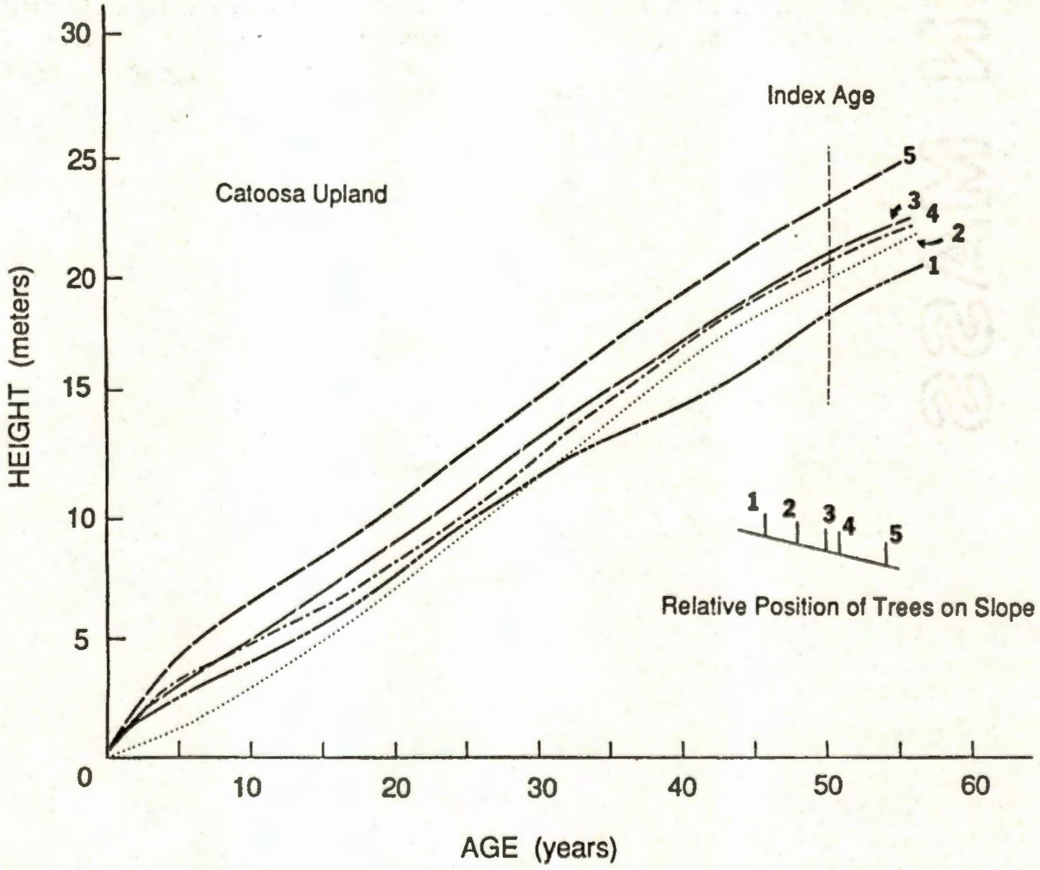

Figure 11. Age-height curves developed from stem analysis of dominant and codominant white oak trees at various positions on the Catoosa upland landtype.

three and four were adjacent to each other, about 60 m downslope from tree one. The nearly linear growth patterns of these oaks is very similar to growth patterns reported for black oak (Quercus velutina Lam.) in southeastern Ohio (Carmean, 1965).

Yellow-poplar height at index age (Figure 12) on the slope was also related to tree position on the landscape. Tree one, on the upslope end of the landtype was nearly 8 m shorter at index age than tree five, 60 m downslope. Intermediate trees were intermediate in height. These observations seem to indicate increasing site index with increasing available soil moisture within landtypes.

Yellow-poplar height at index age on the first order bottoms (Figure 13) was related to depth of the winter water table, with increasing height resulting from increased water table depth. Depth to the water table increased from about 45 cm beneath tree four to nearly 120 cm beneath tree two. These results are similar to those reported for yellow-poplar growth on poorly drained New Jersey soils (Phillips, 1966).

Average tree growth on landtypes (Figure 14) revealed increasing height at index age as available soil moisture increased. White oak site index on uplands (about 15 m) was exceeded by yellow-poplar site index on slopes (about 20 m) and on first order bottoms (about 27 m). Previous research on white oak (Carmean, 1965; Einspahr and McComb, 1951; Graney, 1977; Hannah, 1968; McClurkin, 1963; Smalley, 1967; Trimble and Weitzman, 1956) and yellow-poplar (Ike and Huppuch, 1968; Munn and Vimmerstedt, 1980; Smalley, 1964, 1969; Smalley and Pierce,

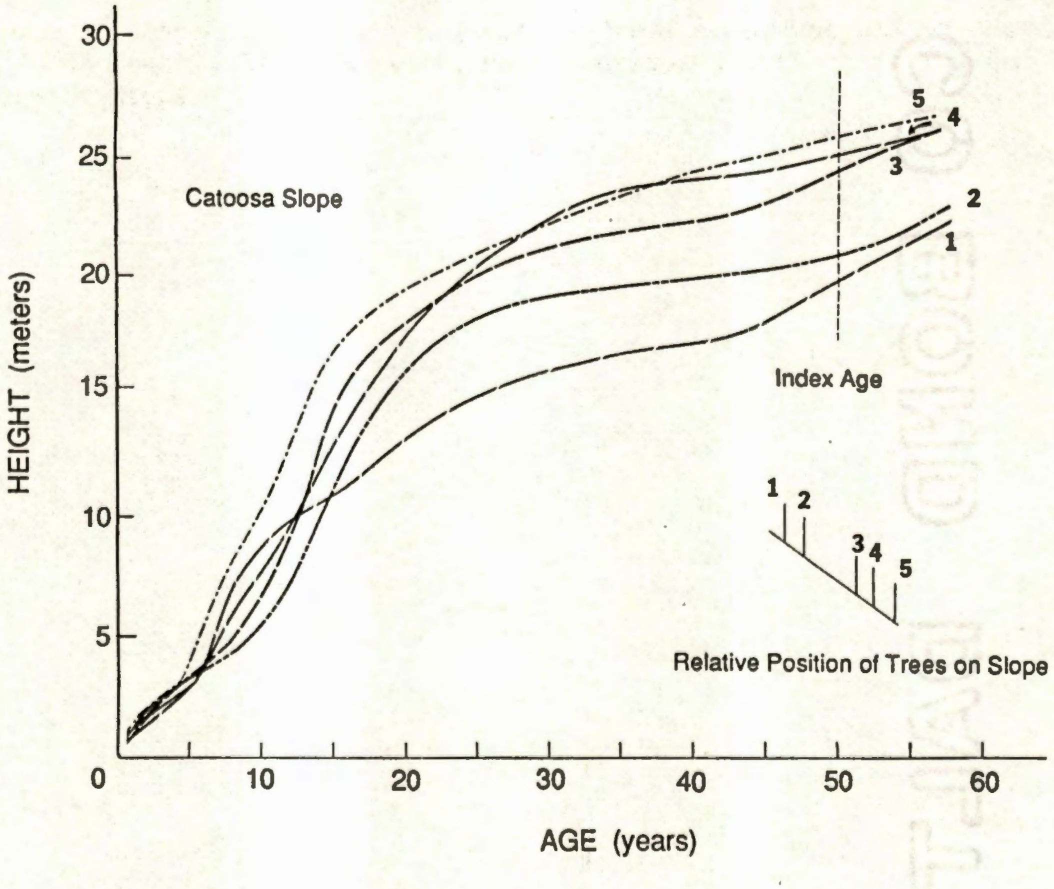

Figure 12. Age-height curves developed from stem analysis of dominant and codominant yellow-poplar trees at various positions on the Catoosa slope landtype.

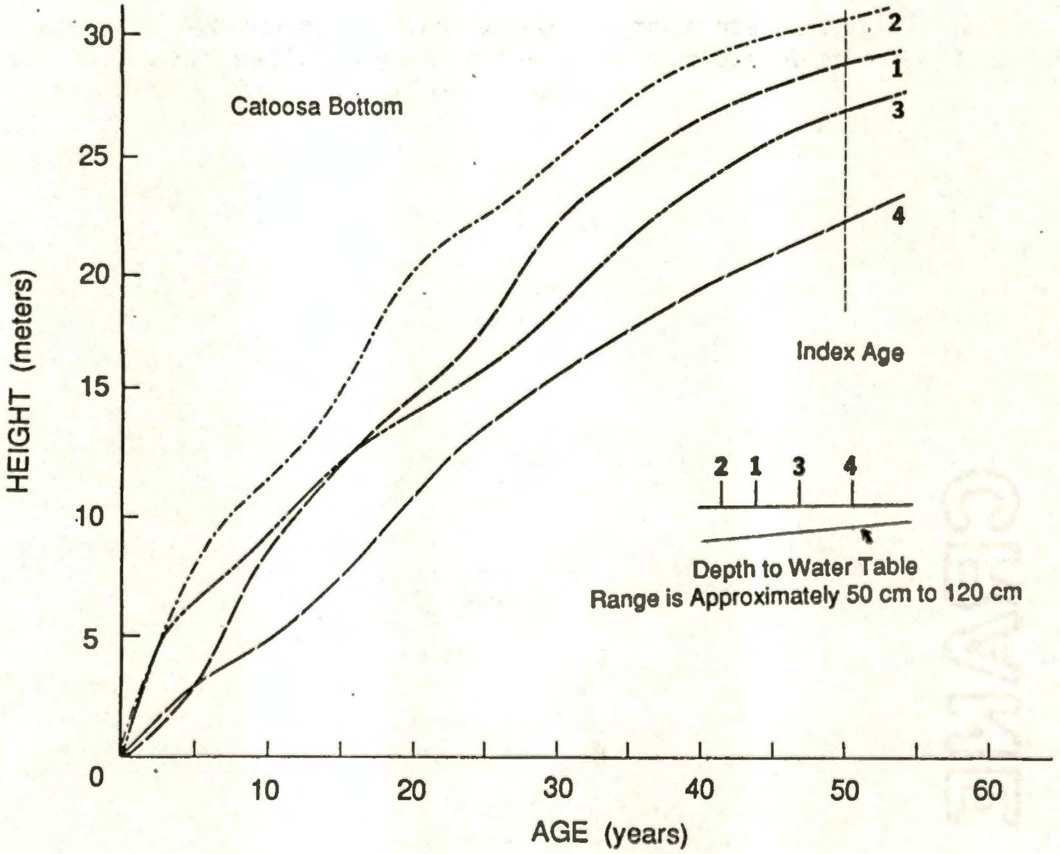

Figure 13. Age-height curves developed from stem analysis of dominant and codominant yellow-poplar trees with various depths to the summer water table on the Catoosa bottom landtype.

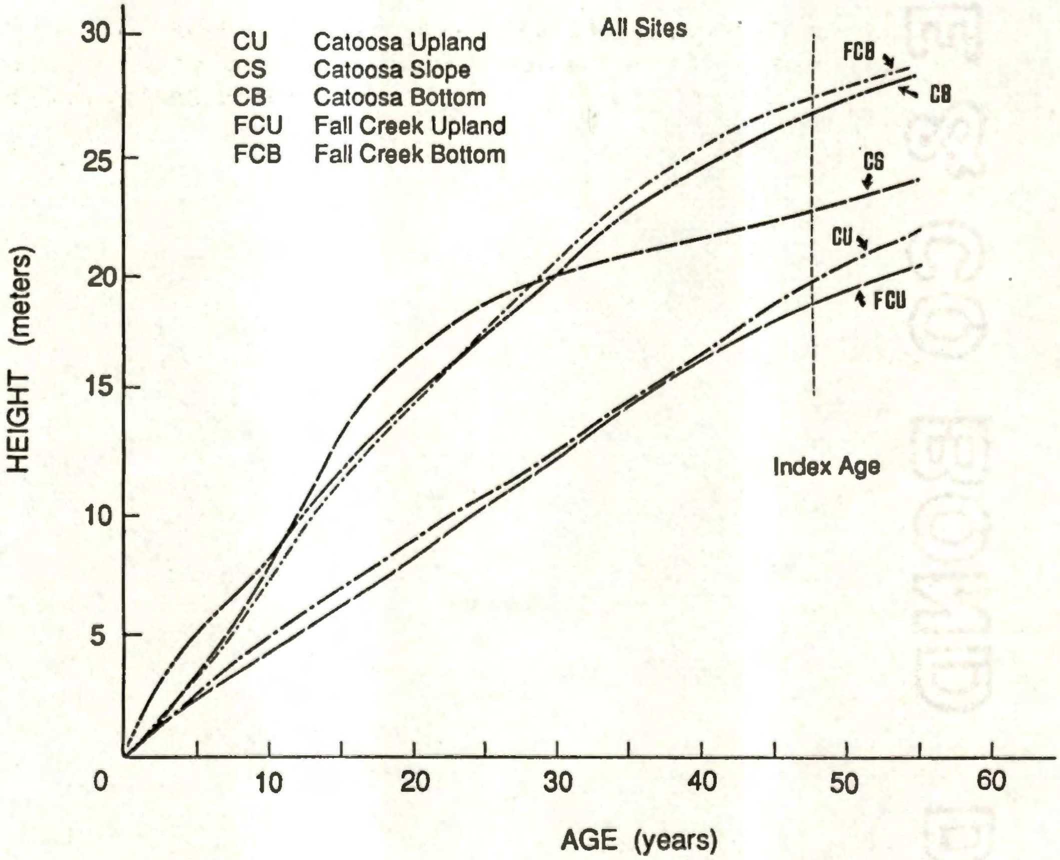

Figure 14. Average site index curves developed from stem analysis of dominant white oaks and yellow-poplars on three forested landtypes at two Cumberland Plateau locations.

1972) has shown that mean site index of timber stands is related to topographic position. Results of this study show the effect of slope position on individual trees. Mean growth curves within landtypes are very similar, suggesting that the forest land classification system is a viable method of grouping Cumberland Plateau forest sites into units of relatively homogeneous site productivity. Yellow-poplar growth curves suggest polymorphic growth among landtypes on the Cumberland Plateau.

Discussion

Live tree roots were found throughout all investigated soil profiles, and were found below the taxonomic control sections (Soil Survey Staff, 1975) of some soil profiles. Although the abundance of roots decreased with increasing soil depth, the volume of soil within respective horizons usually increased with depth. The actual root biomass at depth in these soils may be great. More comprehensive studies are needed to determine the distribution of total root biomass within these soils and to attempt to ascertain their importance for water and nutrient uptake. The great soil volume available for tree root exploitation may compensate for the low inherent soil fertility. Tree growth-site relations may not be fully understood until root distribution throughout the entire soil profile is more completely investigated. Studies investigating only the surface meter, or less, of soil occupied by tree roots to depths of several meters, cannot be expected to explain all important soil-site factors nor to consistently and precisely predict potential site productivity for hardwood management.

The best yellow-poplar growth occurred on the bottoms, where CEC and base saturation were lower than within soils on the other investigated landtypes (Tables 8-13, pp. 44, 47-51). Depth to the water table was apparently more important to yellow-poplar growth on bottoms than soil texture, soil structure, or extractable nutrients. Height of white oak and yellow poplar at index age on uplands and slopes, respectively, was dependent on slope position, and tree height apparently increased with increasing water supplying capacity downslope. Available water supplying capacity appears to be the most important soil property affecting yellow-poplar and white oak growth on the mid-Cumberland Plateau. Observed yellow-poplar growth among landtypes is highly suggestive of polymorphic growth. Additional research is needed to further investigate this possibility, and to determine the precision of existing site index curves for measuring yellow-poplar growth on the Cumberland Plateau.

Distribution of Fe and Mn within profiles and landtypes strongly suggests downslope lateral water movement within the landscape. Evidence of soil water distribution and movement was woven throughout the morphological fabric of the investigated soils. Patterns of soil moisture distribution indicated by soil morphology were substantiated by soil moisture cell readings. Results indicate that soil morphological features resulted from and affect soil moisture distribution, both within individual soil profiles and in the soil landscape. Soil morphological features, in conjunction with landtypes, are indicators of soil moisture distribution, and when precisely observed can be a valuable aid in assessing potential site productivity for forest tree growth on the Cumberland Plateau.

Results of this study indicate that soils in first order bottoms on the mid-Cumberland Plateau can be expected to be highly variable within and among sites. Pronounced between-site differences in soil morphological features and amounts and forms of Mn distribution were observed. The best yellow-poplar growth was observed on bottoms, however, and little difference was observed in height growth between bottoms. Adequate soil moisture during the growing season may be more important to yellow-poplar growth than certain soil chemical and physical properties. Variability in alluvial soils may not be an important consideration for forest management if the site is occupied by species adapted to existing site conditions. Yellow-poplar appears to be well-adapted to the range of chemical and physical soil properties in these bottoms.

CHAPTER IV

FACTOR ANALYSIS EVALUATION OF THE LANDTYPE CLASSIFICATION

Abstract

A hierarchical forest land classification system has been developed to group forest soils into units of homogeneous site productivity on the Mid-Cumberland Plateau in Tennessee. This research was conducted to evaluate the forest land classification system. Objectives of this study were (1) to use factor analysis (FA) to determine correlated soil chemical and physical properties among three extensive landtypes; (2) to use FA to reduce a large number of variables to a smaller number of factors for further statistical analyses; (3) to compare the results of several FA methods and principal components analysis (PCA); and (4) to discuss methodology of a FA solution. Three forested landtypes--a broad undulating upland, a north slope and a first order bottom with good surface drainage--were selected for study at each of two locations. Dominant white oak (Quercus alba L.) or yellow-poplar (Liriodendron tulipifera L.) stands characterized the sites. A grid system was established on each landtype and the three uppermost genetic horizons were sampled at each grid point. Thirty-two soil chemical and physical properties from the 132 sampling points were subjected to Maximum Likelihood (ML), Minimum Residuals (MINRES), and IMAGE factor analyses and to PCA. All four methods produced four logical factors which represented subsurface cations, A-horizon properties, soil texture, and soil drainage and thickness. ML and MINRES

retained 25 variables and extracted 71 percent of the variance. IMAGE and PCA retained 22 variables and extracted 79 percent of the variance. A-horizon properties should be considered when assessing site productivity of forest soils, particularly those on the Cumberland Plateau.

Introduction

About one-half of Tennessee is privately owned nonindustrial forest land, much of which reverted to forest after eroded agricultural land was abandoned. Generations of high-grading, grazing and burning reduced genetic quality and the frequency of occurrence of the more desirable species, resulting in forests which are understocked, contain trees of poor form, or which contain less desirable species (Smith and Linnartz, 1980). The President's Advisory Panel on Timber and the Environment (1973) estimated that "the forest lands of the nation as a whole are producing probably no more than 25 percent of their biological potential" and recommended that efforts to increase productivity be concentrated on "those sites, types, and age classes that yield the highest return . . ." Megahan et al. (1981) recommended that research is needed ". . . to match the various forest sites with the proper tree species."

Problems exist in attempting to determine site potential in the absence of the desired species, particularly on eroded upland hardwood sites. Many attempts to use soil series or soil mapping units are predictors of site index or tree productivity have failed (Esu and Grigal, 1979; Farnsworth and Leaf, 1965; Shetron, 1972; Van Lear and

Hosner, 1967). Carmean (1967) reported that topographic features within soil mapping units were more reliable predictors of black oak (*Quercus velutina* Lam.) site index than were soil mapping units alone. Daniels et al. (1971) and Ruhe (1975) have predicted that future attempts to sort soil units into more usable entities with reduced variability will rely more heavily upon geomorphology than have past efforts.

A hierarchical forest land classification system for the Cumberland Plateau and Highland Rim-Pennyroyal physiographic provinces (Fenneman, 1938), based on physiography, geology, soils, topography and vegetation, has been developed by Smalley (1984a). Six regional guides have been published (Smalley, 1979; 1980; 1982; 1983; 1984b; 1986).

The intent of this study was to investigate the ability of Smalley's system to utilize geomorphic surfaces and other site factors to group soils into units with relatively homogeneous site productivity. Soils are three-dimensional bodies with chemical and physical properties which vary and co-vary across landscapes. Multivariate statistics offer an intuitively appealing methodology for investigating soil properties and relationships because large sets of variables are analyzed on the basis of variability inherent in the data. In fact, principal components analysis (PCA) and factor analysis (FA) begin with the variance-covariance matrix.

Arkley (1976) reviewed applications of multivariate statistics in soils research. More recent applications include the use of FA by Arp (1984) to attempt to find the "cause and nature of the correlation pattern between various forest floor properties." PCA has been used by Severson (1981) to assess mine spoils for suitability as topsoil in reclamation; by Sondheim et al. (1981) to evaluate important soil chemical and physical properties in a beach chronosequence in British Columbia; and by Richardson and Bigler (1984) to identify soil properties which could be used to differentiate wetland sites and vegetative zones in North Dakota.

Objectives of this study were (1) to use maximum likelihood factor analysis (ML) to determine correlated soil chemical and physical properties which may be important to forest tree growth among three landtypes on the mid-Cumberland Plateau in Tennessee; (2) to reduce a large number of soil variables with FA to a smaller number of factors for use in further statistical analyses; (3) to compare the results of other FA methods and PCA to ML; and (4) to discuss the methodology of a FA solution.

Materials and Methods

Study Sites and Sampling Procedures

Three landtypes capable of growing commercially valuable hardwoods of reasonable quality and which occupy extensive area were selected for study at each of two locations about 60 km apart on the Cumberland Plateau--the Catoosa Wildlife Management Area 20 km north of Crossville, Tennessee, and Fall Creek Falls State Park 40 km south of Crossville. Landtypes selected were broad undulating sandstone uplands, north-facing sandstone slopes, and first order terraces and stream bottoms with good surface drainage (Smalley, 1982). Individual sites were located using topographic maps and were selected for study on the basis of landtype definitions, forest stand stocking, and the composition and quality of the dominant and codominant trees. Soils were not observed, sampled or classified until after the sites had been selected. Upland plots were dominated by white oak (Quercus alba L.) and north slope and bottom sites were dominated by yellow-poplar (Liriodendron tulipifera L.).

Plots were centrally located within landtypes to minimize "edge effect." Plot boundaries were marked with stakes and a grid sampling system with sampling points at 10 m intervals was established on each plot. A total of 132 sampling points resulted, with 32 points on each upland, 18 points on each slope and the Catoosa bottom and 14 points on the Fall Creek Falls bottom. Equal sample sizes among landtypes may have been preferable, however the landtypes were of different sizes and it was deemed more important for this study to maintain a uniform sampling intensity across landtypes.

A 2.5 cm diameter soil probe was used to obtain soil samples from the three uppermost genetic soil horizons at each sampling point. The A, AB, and Bt horizon nomenclature is used throughout this paper, although this horizon sequence was not encountered everywhere. Maximum sampling depth was 120 cm.

Laboratory Methods

Soil samples were air-dried, crushed, and sieved to remove fragments larger than 2 mm. Analyses performed on each soil horizon and means and ranges for all measured soil properties on each landtype are shown in Tables 18 through 20. The variable "silt" for all horizons includes fine sands, very fine sands and coarse silts. The variable "clay" includes fine silts and clays. These groupings were made to combine soil particle size fractions with similar mineralogy and chemical properties. The remaining sand fraction was omitted because it would have been linearly dependent upon silt and clay variables.

Particle size analyses were by the pipette method of Day (1965) after samples treated with $(NaPO_3)_{13} \cdot Na_2O$ were shaken in a reciprocating shaker for 18 hours. Sands were removed by wet-sieving after shaking and sand fractions were separated by dry-sieving. Organic carbon was determined with the modified Walkley-Black procedure (Allison, 1965). Extractable cations and extractable acidity were determined following vacuum extraction (Holmgren et al., 1977) using procedures developed by the National Soil Survey Laboratory (Soil Conservation Service, 1982). Extractable acidity was determined by titrating the buffered (pH 8.2) $BaCl_2$-TEA solution to a pH 4.6 endpoint with 0.08 N HCl. Cations were determined by atomic absorption analysis of lanthanum-buffered NH_4OAc (pH 7.0) extracts. Soil pH was determined with a combination electrode in both a 1:1 soil-water paste and a 1:1 soil-N KCl paste. The pH values were converted to H+ ion activities for statistical analyses. Soil colors were obtained from crushed dry samples with the aid of a Munsell chart. Quantitative numerical soil colors used in statistical analyses were obtained by multiplying soil chroma by Buntley and Westin's (1965) quantitative values for soil hues.

Table 18. Mean, maximum, and minimum values for soil properties from three horizons within mid-Cumberland Plateau upland soils.

		Upland					
		Catoosa			Fall Creek		
Variable	Horizon	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$
Org. C (g/kg)	A	76.1	24.7	43.1	61.1	19.7	45.1
pH - H_2O	"	4.9	3.9	4.4	4.5	3.2	3.8
pH - KCl	"	4.5	3.4	3.9	4.0	2.9	3.4
Ca (µg/g)	"	1278.3	38.6	318.3	392.9	35.1	130.4
Mg "	"	105.5	5.2	31.4	61.8	12.5	22.8
Na "	"	18.9	7.1	11.7	25.2	7.8	16.6
K "	"	123.9	52.2	89.0	162.2	54.2	95.7
Thickness (cm)	"	7.5	1.3	4.3	8.8	2.5	5.4
Color	"	12.0	6.0	8.2	6.0	6.0	6.0
Ex. Acid. [cmol(p^+)/kg]	"	33.5	10.8	18.3	20.9	9.8	14.0
Silt (%)	"	62.1	43.4	53.8	54.1	28.1	44.8
Clay (%)	"	54.2	34.7	43.4	64.1	44.2	52.5
pH - H_2O	AB	4.9	4.7	4.8	4.9	4.6	4.7
pH - KCl	"	4.0	3.6	3.8	3.9	3.5	3.7
Ca (µg/g)	"	217.9	16.8	67.8	69.9	0.0	24.5
Mg "	"	72.6	6.5	30.2	85.5	14.9	51.6
Na "	"	20.8	8.0	14.4	26.9	10.4	16.9
K "	"	79.7	29.9	47.6	105.4	22.8	51.4
Thickness (cm)	"	30.0	7.5	17.0	37.5	12.5	21.6
Color	"	12.0	9.0	10.8	21.0	12.0	15.2
Ex. Acid. [cmol(p^+)/kg]	"	14.5	5.6	9.0	20.3	5.6	9.7
pH - H_2O	Bt	5.8	4.6	5.4	4.6	3.9	4.3
pH - KCl	"	5.8	4.0	5.1	3.7	3.4	3.6
Ca (µg/g)	"	182.8	5.2	64.3	235.8	9.3	52.0
Mg "	"	100.7	9.5	46.9	80.0	13.9	46.5
Na "	"	24.1	7.8	14.0	26.4	9.6	16.2
K "	"	63.8	35.7	48.8	83.6	39.8	60.1
Thickness (cm)	"	45.0	5.0	17.0	55.0	17.5	31.5
Color	"	18.0	9.0	12.3	18.0	12.0	15.8
Ex. Acid. [cmol(p^+)/kg]	"	33.5	10.8	18.3	15.4	8.6	10.6
Silt (%)	"	61.8	42.6	52.7	48.5	28.1	40.6
Clay (%)	"	51.6	36.2	45.3	70.6	44.2	56.1

Table 19. Mean, maximum, and minimum values for soil properties from three horizons within mid-Cumberland Plateau slope soils.

		Slope					
		Catoosa			Fall Creek		
Variable	Horizon	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$
Org. C (g/kg)	A	53.9	36.1	47.4	98.6	42.6	61.8
pH - H_2O	"	6.1	5.4	5.8	6.1	4.9	5.7
pH - KCl	"	5.4	4.6	5.0	6.0	5.0	5.3
Ca (μg/g)	"	2293.3	826.1	1635.1	3726.0	615.4	2221.7
Mg "	"	351.5	106.8	221.0	556.8	138.0	353.8
Na "	"	29.1	10.8	19.1	24.3	12.0	18.0
K "	"	232.2	60.8	121.0	339.3	198.3	279.9
Thickness (cm)	"	20.0	7.5	13.6	27.5	10.0	16.0
Color	"	9.0	6.0	7.3	9.0	6.0	6.3
Ex. Acid. [cmol(p^+)/kg]	"	17.3	10.6	12.9	19.3	7.8	12.8
Silt (%)	"	41.0	32.3	35.7	46.0	37.3	42.7
Clay (%)	"	65.4	52.9	59.7	59.1	50.5	53.6
pH - H_2O	AB	5.7	4.8	5.2	4.9	4.6	4.8
pH - KCl	"	4.9	4.0	4.3	3.9	3.5	3.7
Ca (μg/g)	"	1306.6	138.7	559.8	184.1	34.2	88.5
Mg "	"	206.0	34.0	112.7	130.0	31.9	75.8
Na "	"	19.5	7.8	11.7	19.9	8.6	12.7
K "	"	232.2	60.8	121.0	147.6	59.7	97.4
Thickness (cm)	"	35.0	10.0	18.9	30.0	17.5	22.9
Color	"	12.0	9.0	10.5	12.0	8.0	10.0
Ex. Acid. [cmol(p^+)/kg]	"	16.8	6.6	11.7	17.0	5.1	8.4
pH - H_2O	Bt	5.6	4.7	5.0	4.9	4.6	4.8
pH - KCl	"	4.9	3.8	4.1	3.9	3.7	3.8
Ca (μg/g)	"	1668.1	334.6	674.3	375.2	97.0	229.8
Mg "	"	245.2	68.9	142.2	143.6	55.5	95.8
Na "	"	28.0	11.0	16.6	36.5	11.5	22.9
K "	"	196.4	66.0	119.1	147.6	59.7	97.4
Thickness (cm)	"	97.5	20.0	53.3	87.5	35.0	58.8
Color	"	18.0	9.0	11.7	18.0	8.0	16.1
Ex. Acid. [cmol(p^+)/kg]	"	23.4	18.3	20.8	16.8	7.8	11.2
Silt (%)	"	38.5	24.5	32.5	57.3	25.0	35.7
Clay (%)	"	65.4	52.9	59.7	69.5	54.8	60.6

Table 20. Mean, maximum, and minimum values for soil properties from three horizons within mid-Cumberland Plateau bottom soils.

		Bottom					
		Catoosa			Fall Creek		
Variable	Horizon	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$
Org. C (g/kg)	A	86.0	24.5	38.6	80.2	35.8	57.1
pH - H_2O	"	4.3	3.9	4.1	4.9	4.0	4.5
pH - KCl	"	3.8	3.5	3.6	4.0	3.3	3.7
Ca (µg/g)	"	317.8	33.9	131.4	2811.6	230.5	922.9
Mg "	"	74.0	11.9	26.6	382.3	87.8	246.5
Na "	"	31.7	15.0	21.4	24.8	10.2	16.3
K "	"	185.4	46.8	90.9	303.3	78.7	150.2
Thickness (cm)	"	12.5	2.5	5.8	5.0	1.3	3.2
Color	"	9.0	6.0	6.8	9.0	6.0	8.4
Ex. Acid. [cmol(p^+)/kg]	"	29.0	13.6	18.1	28.8	14.5	21.0
Silt (%)	"	51.2	37.4	46.4	66.5	25.1	35.8
Clay (%)	"	49.6	26.5	38.5	76.6	43.9	60.4
pH - H_2O	AB	4.7	4.4	4.6	4.9	4.3	4.5
pH - KCl	"	4.1	3.7	3.9	3.7	3.5	3.6
Ca (µg/g)	"	58.2	0.0	21.6	139.0	27.1	55.9
Mg "	"	19.2	1.8	8.3	111.0	9.5	43.2
Na "	"	24.7	4.1	17.0	12.9	5.1	9.5
K "	"	56.8	11.5	29.7	72.5	22.0	36.1
Thickness (cm)	"	30.0	10.0	16.8	30.0	15.0	19.8
Color	"	10.0	2.0	6.7	8.0	4.0	5.7
Ex. Acid. [cmol(p^+)/kg]	"	14.1	5.5	8.4	12.0	5.7	9.2
pH - H_2O	Bt	4.8	4.4	4.6	4.8	4.3	4.5
pH - KCl	"	4.1	3.7	3.9	3.9	3.5	3.6
Ca (µg/g)	"	113.9	9.7	33.5	439.0	29.6	100.4
Mg "	"	21.8	4.1	9.0	211.2	15.6	56.6
Na "	"	22.1	7.0	12.7	12.5	5.0	8.2
K "	"	75.9	18.6	39.3	134.3	39.9	67.7
Thickness (cm)	"	97.5	75.0	89.6	97.5	65.0	89.6
Color	"	10.0	2.0	6.0	12.0	5.0	8.6
Ex. Acid. [cmol(p^+)/kg]	"	26.6	18.5	21.9	18.7	10.0	13.7
Silt (%)	"	53.9	20.6	44.9	43.6	23.2	34.3
Clay (%)	"	45.6	31.0	35.8	76.6	43.9	60.4

Comparison of Statistical Strategies

Factor analysis and PCA begin with the correlation matrix of the data set and are mathematically similar in many respects. The major difference in the two methods is that PCA attempts to extract maximum variance and FA attempts to reproduce the correlation matrix. The reproduced correlation matrix generated during FA (Figure 15) is characterized by the substitution of communalities (h_j^2) for "1's" on the diagonal. The general FA model (Harman, 1976) can be represented by

$$z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots a_{jm}F_m + u_jY_j,$$

where any variable (z_j) is represented by the sum of its loadings ($a_{j1} \ldots a_{jm}$) onto the factors ($F_1 \ldots F_m$), and u_jY_j represents error variance. A single factor is composed of the loadings upon it of all variables in the data set, but the factor is characterized by those variables which load primarily on it. These "primary loaded" variables should account for most of the variance extracted by the factor. The total variance (s_1^2) the factor extracts from the data is the sum of the squared variable loadings, or:

$$s_1^2 = a_{j1}^2 + \ldots a_{n1}^2,$$

where j through n represent individual variable. A single factor is a vector in space which contains positive and negative loadings. These "directions," as well as the variables themselves, will determine the user's interpretation of the factor.

Original Correlation Matrix

1	r_{12}	r_{13}
r_{21}	1	r_{23}
r_{31}	r_{32}	1

Reproduced Correlation Matrix

h_j^2	r_{12}	r_{13}
r_{21}	h_j^2	r_{23}
r_{31}	r_{32}	h_j^2

Figure 15. An example of original and reproduced correlation matrices.

Factor analysis methods differ in the ways in which communalities are generated and in strategies for reproducing the correlation matrix. The communality, or variance, of a variable is the sum of its squared factor loading coefficients (Harman, 1976):

$$h_j^2 = a_{j1}^2 + a_{j2}^2 + . . . a_{jm}^2.$$

The IMAGE communality estimate is the sum of the squared multiple correlations of the variable with the other variables in the data set. MINRES produces communalities as a consequence of the overall procedure strategy of best reproducing the off-diagonal elements of the correlation matrix. The "best" MINRES solution minimizes residuals (differences) between corresponding elements of the original and reproduced correlation matrices. ML derives communalities during the process of determining the likelihood of sampling the correlation matrix from a normally distributed population.

Statistical Methods

Factor analysis and PCA were performed with the Factor procedure of the Statistical Analysis System (SAS Institute Inc., 1982) software. Maximum likelihood factor analysis was chosen as the primary analysis because it is most "intuitively appealing" (Tabachnick and Fidell, 1983) to statisticians, most of whom prefer ML over other FA methods (SAS Institute Inc., 1982). Minimum residual factor analysis (MINRES), image factor analysis (IMAGE) and PCA were performed for comparison and to insure the robustness of the ML analysis.

Iteration to a final PCA or FA solution requires determining the optimum number of factors to extract and deciding which variables to keep in the data set. The ideal FA solution should consist of factors which each contain several correlated variables. The number of salient loadings should be low. Each variable will load onto all factors in the solution but should load primarily onto one factor. The primary loading of a variable in its loading score with the largest absolute value. Other loading scores of that variable are its secondary loadings. A salient loading occurs if the primary loading score of a variable is exceeded by a secondary loading score of another variable. Salient loadings in an analysis create ambiguity and decrease the reliability of interpretations.

The initial number of factors to extract was determined from a scree plot produced with a PCA analysis of the 32 original variables and 11 components. The scree plot indicated that five factors would probably be sufficient, so all FA analyses and the PCA analysis were begun with five factors (FA) or components (PCA) and 32 soil chemical and physical properties (variables) from each of the 132 sampling points (observations). Varimax (orthogonal) rotation was used throughout the analyses. The final number of factors to retain was determined by the number of variables loaded onto each factor, which included at least two variables per factor.

Two criteria were used to determine which variables to retain--variable "behavior" and the distance of the communality of each variable from the mean data set communality. After each extraction in each method, variable loading onto factors or components was examined by inspecting the rotated factor pattern matrix. Variables which were highly correlated with other variables should have aligned with correlated variables onto common factors within two extractions. If variables jumped from factor to factor during extractions, they were dropped. Variables were also dropped whose communalities were lower than the mean communality of the data set minus two standard deviations.

The fifth factor in each statistical method, after uncorrelated variables had been screened and dropped in previous extractions, contained only two primary variables. Factor five in IMAGE and ML was loaded by pH in H_2O and KCl in the A horizon, MINRES was loaded by organic matter and exchangeable acidity in the A horizon, and PCA was loaded by exchangeable acidity in the A horizon and H_2O pH in the Bt horizon. The correlation (variance-covariance) matrix was examined to determine the correlation between the pairs of variables. The correlation coefficient for the A horizon pH variables was 0.91. Although the loading of highly correlated variables onto common factors is an FA objective, an exception was made. Both variables were measures of pH in the same horizon, so they were considered to be one variable in this case. The fifth factor was dropped in IMAGE and ML. Exchangeable acidity in the A horizon had correlation coefficients of -0.14 with H_2O pH in the Bt horizon and 0.22 with organic carbon. These low values indicated that the pairs of variables were not highly correlated enough to be considered to be a "factor." Consequently the fifth factor was dropped in MINRES and PCA. Exchangeable acidity in the A horizon was dropped in subsequent four-factor extractions because its communality was too low. Reduction to four factors was therefore justified.

The final solution for each of the procedures contained four orthogonal factors or components loaded with several highly correlated variables whose communalities were within two standard deviations of the mean communality for that set of variables.

A subsequent ML solution was obtained for a reduced set of variables in which cations within horizons were combined to form cation exchange capacity (CEC). Procedures for determining which variables to retain and the number of factors to extract were as previously described.

Results

The Maximum Likelihood Solution

Five iterations were required to reach an ML solution. Three variables were dropped after both the first and second iterations, a seventh variable was dropped after the third iteration, and one factor was dropped after the fourth iteration. The fifth iteration produced the optimum result--a four-factor solution with 25 variables and no salient loadings.

As the number of variables was systematically reduced (Table 21), the percent of extracted variance increased, the number of salient loadings decreased and the lowest primary loading value increased. These trends indicate that ambiguity was reduced and the factor

Table 21. Comparisons of variances extracted, primary loading values and numbers of salient loadings using Maximum Likelihood analysis with several variables and factors.

Iteration	Variables	Factors	Variance Extracted	Low Primary Loading	Salient Loadings
	Number	Number	Percent		Number
1	32	5	64.0	0.236	52
2	29	5	67 8	0.310	15
3	26	5	73.1	0.412	3
4	25	5	75.3	0.464	1
5†	25	4	71.3	0.533	0
6	25	3	60.0	0.345	17

†Final Solution

extraction process became more precise as variables were eliminated which were not correlated with other variables or groups of variables. The percent of variance extracted increased because the discarded variables accounted for a small portion of the total variance in the original data. In fact, these seven variables represented only 5.2 percent of the total variance.

The number of factors was reduced from four to three to test variable loading and variable behavior. The three-factor solution produced a loss of extracted variance, a decrease in the value of the lowest primary loading, and a large increase (from zero to 17) in the number of salient loadings. The three-factor extraction had compressed the data beyond the optimum factor level and thus confirmed that a minimum of four factors was required.

The accepted ML solution is the rotated factor pattern matrix of the 25 variables on the four factors (Table 22). Factor pattern rotation should increase high loadings and decrease low loadings, thus increasing the variance of each factor and making factor interpretations easier. High variable loading scores should increase the user's confidence in the final result. Unrotated factor pattern scores are not so strongly aligned with factors as the rotated scores. For example, the unrotated scores for organic matter reveal similar loading onto Factors 1 (0.411) and 2 (0.526). After rotation organic matter was loaded strongly onto Factor 2 (0.623) and its loading onto Factor 1 was reduced to -0.072. No difference in factor loading patterns was observed when oblique rotation was compared with orthogonal rotation. Harman (1976) provides a detailed treatise on factor pattern rotation.

Table 22. Rotated and unrotated factor pattern matrices for Maximum Likelihood analysis with 25 variables and four factors.

Variable and Horizon	Factor Pattern Matrix							
	Factor 1		Factor 2		Factor 3		Factor 4	
	Rotated	Unrotated	Rotated	Unrotated	Rotated	Unrotated	Rotated	Unrotated
Org. Matter-A	-0.071	0.411	0.623†	0.526	0.276	-0.134	0.066†	-0.095
pH-A (H_2O)	-0.298	-0.565	-0.601†	0.065	0.270	0.472	0.162	0.067
pH-A (KCl)	-0.211	-0.473	-0.536†	0.017	0.217	0.447	0.213	-0.011
Ca-A	0.356	0.871	0.889†	0.302	0.137	-0.266	-0.014	-0.122
Mg-A	0.190	0.791	0.889†	0.492	0.298	-0.239	-0.098	0.009
K-A	0.290	0.861	0.848†	0.385	0.238	-0.187	0.008	-0.099
pH-AB (H_2O)	-0.718†	-0.536	-0.134	0.467	0.216	-0.143	-0.363	0.431
pH-AB (KCl)	-0.652†	-0.343	0.072	0.732	0.448	0.153	0.223	-0.069
Ca-AB	0.938†	0.788	0.148	-0.152	0.022	0.169	-0.166	0.134
Mg-AB	0.772†	0.800	0.308	-0.147	0.260	0.336	0.201	-0.155
K-AB	0.819†	0.730	0.176	-0.338	0.128	0.267	0.036	-0.022
pH-Bt (H_2O)	-0.273	-0.315	-0.341	0.367	0.574†	0.577	0.225	0.060
pH-Bt (KCl)	-0.316	-0.132	-0.123	0.664	0.868†	0.601	0.091	0.238
Ca-Bt	0.898†	0.859	0.274	-0.375	0.104	0.152	-0.154	0.124
Mg-Bt	0.773†	0.850	0.412	-0.182	0.135	0.155	0.094	-0.121
K-Bt	0.673†	0.851	0.457	-0.001	0.315	0.188	-0.001	0.018
Thickness-A	0.454	0.691	0.533†	0.040	0.082	-0.059	0.058	-0.133
Thickness-Bt	-0.134	0.154	0.196	0.330	0.370	-0.140	-0.663†	0.693
Color-AB	0.140	-0.122	-0.282	-0.111	0.058	0 519	0.754†	-0.612
Color-Bt	0.075	0.126	0.146	0.207	0.149	0.371	0.845†	-0.753
Silt-A	-0.318	-0.537	-0.223	-0.288	-0.679†	-0.342	0.293	-0.457
Clay-A	0.274	0.517	0.260	0.389	0.714†	0.450	0.015	0.179
Silt-Bt	-0.285	-0.533	-0.265	-0.360	-0.697†	-0.390	0.113	-0.290
Clay-Bt	0.271	0.539	0.340	0.430	0.644†	0.477	0.292	-0.108
Ex. Acid.-Bt	0.330	0.231	-0.045	-0.374	-0.117	-0.223	-0.711†	0.623

† Indicates primary loading.

Loading scores indicate that Factor 1 is characterized by cations in the AB and Bt horizons and pH in the AB horizon. Negative AB horizon pH loading scores denote a negative correlation between pH and cation levels. This apparent anomaly arose because pH values were converted to H+ ion activities for statistical analyses. Since pH is the negative log of H+ ion activity, the correlation of pH with the cations is actually positive.

Factor 2 consists of all A-horizon properties except texture variables. Factor 3 is composed of silts and clays in the A and Bt horizons and pH in the Bt horizon. These highly weathered Ultisols have low CEC values. The very strong loading of KCl pH indicates that it is a more accurate measure of Bt horizon acidity in these soils than pH in H_2O. The negative correlation of the silt values indicates that as silt content decreases the clay content increases.

Factor 4 represents soil color in the AB and Bt horizons and thickness and extractable acidity in the Bt. Soil color variables are the products of multiplying chroma by quantitative values for hue (Buntley and Westin, 1965) in an effort to represent the effect of the hue-chroma interaction on developmental color. As soils become redder, the numerical notation of hue increases, increasing the soil color variable. The negative correlation between Bt thickness and soil colors indicates that the deeper soils had yellower hues and lower chromas. The well-drained (redder hue-higher chroma) upland soils contained intermittent fragipans which frequently prevented sampling to 120 cm with a probe. North slope soils were skeletal in the upper part and large sandstone "floaters" commonly limited sampling depth. Bottom soils contained no impedances to sampling depth and were sampled to 120 cm. Extractable acidity in the Bt horizons was positively correlated with soil color, an indication that soils on uplands and slopes contained higher levels of extractable acidity than soils on bottoms.

Variables dropped from the data set during ML analysis included Na in all three horizons, extractable acidity in the A and AB horizons, and A-horizon color. Extractable Na was so low in all soils, in comparison to other ions, that it was essentially a constant. A-horizon hue-chroma values and extractable acidity in the A and AB horizons were relatively uniform among sites, so they did not co-vary with other measured soil properties. Future studies of soil properties on the Cumberland Plateau could probably omit these uncorrelated variables.

Factors can be named according to loaded variables, and the amount of variance extracted by each factor determines its relative importance. Factor 1, entitled "Subsurface cations," extracted 34.7 percent of the total variance (Table 23). Factor 2, entitled "A-horizon properties," extracted 27 percent of total variance. Factor 3, "Soil texture," and Factor 4, "Drainage and thickness," together accounted for the remaining 38.3 percent of extracted variance. Since soil colors are an indication of soil drainage, Factor 4 was named accordingly. Maximum likelihood analysis extracted 71.3 percent of the variance in the data.

Results were pedologically sound. The percentage of extractable bases on the exchange complex is important in the classification of

Table 23. Factor names and amounts of variance extracted by factors in Maximum Likelihood analysis.

Factor	Factor Name	Variance Extracted from Data Set	Factor Variance as A Portion of Extracted Variance
		--------------Percent--------------	
1	Subsurface cations	24.8	34.7
2	A horizon properties	19.3	27.0
3	Soil texture	15.9	22.3
4	Drainage & thickness	11.4	16.0
	Total	71.3	100.0

three soil orders. The importance of soil texture, soil depth and drainage for soil classification and management have long been recognized by pedologists. The importance of the forest floor and the A horizon to nutrient cycling and forest productivity are recognized by forest soils researchers. The very strong correlation of A-horizon properties among three forested landtypes, and the high percent of variance this factor extracted from the data indicate that A-horizon properties should be given more consideration in assessment of forest soil productivity on the Cumberland Plateau. More research is necessary to determine the validity of this observation to upland hardwood sites in other physiographic provinces.

Comparison of Factor Analysis and Principal Components

Principal components, IMAGE and MINRES compared favorably with ML (Table 24) and confirmed the robustness of the ML solution. The four methods aligned variables onto factors in nearly identical patterns, although IMAGE Factors 2 and 3 were Factors 3 and 2, respectively, for the other methods. Maximum likelihood and MINRES retained 25 variables and extracted over 71 percent of the variance while IMAGE and PCA retained 22 variables and extracted 79 percent of the variance.

In addition to the variables dropped by ML and MINRES, PCA dropped three A horizon variables--pH in H_2O, pH in KCl and thickness. IMAGE dropped thickness and organic matter in the A horizon and pH in H_2O in the Bt. Examination of the ML rotated factor pattern matrix (Table 22) reveals that variables dropped by PCA and IMAGE had the lowest primary

Table 24. Comparison of variable retention and loading using several factor analysis methods and principal components analysis.

	Variable Loadings onto Factors			
Variable	Maximum Likelihood	Image	Minimum Residuals	Principal Components
A-Horizon				
Org Matter	2†	-	2	2
pH-(H_2O)	2	3	2	-
pH-(KCl)	2	3	2	-
Ca	2	3	2	2
Mg	2	3	2	2
Na	-‡	-	-	-
K	2	3	2	2
Thickness	2	-	2	-
Color	-	-	-	-
Ex. Acidity	-	-	-	-
Silt	3	2	3	3
Clay	3	2	3	3
AB-Horizon				
pH-(H_2O)	1	1	1	1
pH-(KCl)	1	1	1	1
Ca	1	1	1	1
Mg	1	1	1	1
Na	-	-	-	-
K	1	1	1	1
Thickness	-	-	-	-
Color	4	4	4	4
Ex. Acidity	-	-	-	-
Bt Horizon				
pH-(H_2O)	3	-	3	3
pH-(KCl)	3	2	3	3
Ca	1	1	1	1
Mg	1	1	1	1
Na	-	-	-	-
K	1	1	1	1
Thickness	4	4	4	4
Color	4	4	4	4
Ex. Acidity	4	4	4	4
Silt	3	2	3	3
Clay	3	2	3	3
Variables Retained	25	22	25	22
	Percent Variance Extracted			
	71.3	79.2	71.7	79.5

† Factor onto which the variable loaded.

‡ Variable was not retained in analysis.

factor loading scores. Principal components attempts to extract maximum variance, so it is logical that some variables retained in ML and MINRES would be dropped by PCA and that PCA would extract a higher percentage variance.

Maximum likelihood analysis was most similar to MINRES, and PCA was most similar to IMAGE. User preference and research objectives should determine which FA or PCA methods are used in multivariate analysis.

Variable Selection and Methodology

Previous discussion demonstrated the subjective nature of FA. The user chooses the FA or PCA method, the software package, the number of factors to extract and which variables to include and retain in the analysis. Webster (1974) suggested that multivariate statistics are valuable as an "exploratory tool" in pedological studies. Indeed, FA was conceived in the 1930s as an exploratory method in psychological research. Multivariate statistics, like conventional statistical analyses, cannot be expected to separate order from chaos. Researchers should use caution and thoughtful experimental design as preludes to multivariate analysis in order to insure that subjective choices carry high probability of success. Harman (1976) pointed out that although factor analysis application has

> been exploratory almost exclusively, in the hope of bringing order out of the relationships among the many variables . . . there is no substitute for understanding, at least in principle, what is going on (in the data) . . . if the objective is to draw meaningful conclusions . . . .

The decision to use individual cations rather than BS or CEC was made for two reasons. First, BS and CEC are low in Cumberland Plateau soils. Additionally, ions move at different rates in soil solution, and behavior of a particular ion may vary from one soil to another (Kurtz and Melsted, 1973). Tree species differentially accrue and retain nutrient ions (Day and McGinty, 1975), and nutrient uptake within species may vary among soils and parent materials (Green and Grigal, 1980). It seemed logical to treat cations as individual variables among landtypes and forest cover types.

Soil morphological features result from soil-forming processes (Simonson, 1959), and soil chemical and physical properties are correlated with morphological features. It also seemed logical to sample soils by space diagnostic horizons rather than from depth increments (0-10 cm, 10-20 cm, etc.) and to consider horizon thicknesses as variables.

To test the first of these hypotheses, an ML analysis was performed in which extractable bases were converted to cm(p+)kg^{-1} and summed with extractable acidity to determine CEC, which was then used as a variable. The resulting matrix (Table 25) was less precise than the previous ML matrix (Table 22, p. 119). The lowest primary loading dropped from 0.533 to 0.396, salient loadings increased from zero to six, and variable alignment on factors was less logical. A-horizon thickness loaded with subsurface cations (Factor 2) and H_2O-pH in the Bt loaded with A-horizon properties (Factor 4). The total variance extracted remained the same, but organic matter, previously retained,

Table 25. Rotated factor pattern matrix of the Maximum Likelihood analysis with horizon cations represented as cation exchange capacities.

	Rotated Factor Pattern			
Variable	Factor 1	Factor 2	Factor 3	Factor 4
pH-A (H_2O)	-0.056	-0.123	0.152	-0.900†
PH-A (KCl)	-0.048	-0.222	0.095	0.963†
CEC-A	0.503‡	0.285	0.009	-0.523†
pH-AB (H_2O)	0.257	-0.747†	0.184	0.115
pH-AB (KCl)	-0.024	-0.727†	-0.396‡	0.180
CEC-AB	0.383	0.863†	-0.016	-0.193
pH-Bt (KCl)	0.633†	-0.507‡	0.041	0.357
pH-Bt (H_2O)	0.295	-0.399‡	0.171	0.410‡
CEC-Bt	0.443‡	0.820†	-0.036	-0.210
Thickness-A	0.347	0.396†	0.086	-0.395‡
Thickness-Bt	0.342	-0.164	-0.686†	-0.016
Color-AB	-0.024	0.067	0.725†	0.169
Color-Bt	0.185	0.001	0.829†	0.007
Ex. Acid-Bt	-0.051	0.378	-0.707†	-0.101
Silt-A	-0.795†	-0.119	0.286	0.047
Silt-Bt	-0.809†	-0.077	0.099	0.063
Clay-A	0.853†	0.036	0.042	-0.059
Clay-Bt	0.815†	0.043	0.326	-0.082
	Percent Variance Extracted			
	22.8	19.0	14.7	14.7

† Indicates primary loading.

‡ Indicates salient loading.

was dropped. Two additional iterations were required to produce this less precise result. Had sampling been conducted by depth increments rather than by soil horizons, results would likely have been more occluded.

Factor analysis and PCA are powerful multivariate statistical methods which are more subjective than most univariate statistical procedures. Consequently, these methods require carefully conceived experimental design and reported results should describe methodology as completely as possible.

Further research utilizing multivariate statistics in pedological investigations should specifically address the optimum ratio of observations to variables in large data sets. The importance of sample size does not appear to have been adequately addressed in the literature. This study produced robust results with about four observations (132) per variable (32). Tabachnick and Fidell (1983) suggested a sample size of 100-200, but cautioned that there should be "notably more" samples than variables.

Conclusions

Maximum likelihood analysis of a large set of soil variables produced a robust solution of four logical factors upon which variables aligned in pedologically sound patterns. The analyses revealed how soil properties co-vary among selected forested landtypes on the Cumberland Plateau and provided a reduced set of variables for use in further statistical analyses. The four factors consisted of variables representing subsurface cations, soil texture, soil drainage and thickness, and A-horizon properties. The A-horizon factor accounted for 27 percent of the total variance extracted. These results would seem to indicate that A-horizon properties should be considered when appraising forest soils for its productivity on the Cumberland Plateau.

Treating extractable cations as individual variables as opposed to summing them into CECs enhanced the analyses. Sampling from diagnostic soil horizons and treating horizon thicknesses as variables probably contributed to sound pedological alignment of variables onto factors.

CHAPTER V

DISCRIMINANT ANALYSIS EVALUATION OF THE LANDTYPE CLASSIFICATION

Abstract

A forest land classification system developed for the mid-Cumberland Plateau was evaluated for its suitability of grouping soils into relatively homogeneous landform units. Objectives were to classify landtypes on the basis of soil properties. Discriminant analysis was used to classify landtypes, to determine the minimum number of soil properties required for statistical classification of the landtypes, and to evaluate factor analysis data reduction. Soil chemical and physical properties were measured from samples of A, AB and Bt horizons taken from three forested landtypes at each of two locations. Sampling was from a grid with intervals at 10 m. Discriminant analysis classified all 132 sampling points into correct landtypes using the original 32 soil variables, using 25 variables retained in maximum likelihood factor analysis, and with 15 variables retained in stepwise discriminant analysis. Discriminant analysis of factor scores produced 97 percent correct classification. Plotted canonical discrimination analyses revealed discrete clustering of soils within landtypes. Variable loading scores from canonical structure matrices revealed nine soil variables, including chemical and physical properties from each sampled horizon, to be the most important discriminators. The forest land

classification system appears to be a viable method of grouping Cumberland Plateau forest soils into relatively homogeneous entities. Maximum likelihood factor analysis allowed data reduction with little loss in precision of statistical classification and was a valuable screening tool prior to stepwise analysis. Fifteen soil variables were required for statistical classification. A combination of chemical and physical properties from the entire soil profile is necessary for precise statistical classification of Cumberland Plateau forest soils.

Introduction

Diminishing forest land, increased per-capita consumption of forest products, and increasing public demand for forest recreation are requiring that foresters become more efficient multiple use planners and managers. A need for forest land classification has resulted in research and debate regarding parameters, criteria, and implementation of classification systems (Bockheim, 1984).

Smalley (1984a) developed a hierarchical forest land classification system which utilized physiography, geology, soils, topography and vegetation to define forest land units of relatively homogeneous potential site productivity in the Interior Uplands (Fenneman, 1938). Soil survey information, forest inventory data, and forest site information were lacking for many areas, and meager, often poorly documented tree-soil-site information was used to develop forest management criteria for individual landtype units. Available data were extrapolated across a variety of landtypes.

This research was conducted to evaluate Smalley's forest land classification system for the Mid-Cumberland Plateau in Tennessee (Smalley, 1982), where few accessible, well-stocked stands of commercially valuable hardwoods exist. Relationships among topographic features, soil properties, and forest tree productivity are well documented (Carmean, 1975), and correlations among landscape features and soil properties have been observed and reviewed (Hall, 1983).

Discriminant analysis was used in this study to classify selected forest landtypes on the basis of measured soil chemical and physical properties. Discriminant analysis is a multivariate statistical procedure which has been successfully used as a classification method in investigations of soil morphological features, forest soil-site relations, and land classification. Webster and Burrough (1974) used discriminant analysis to classify soils from soil surveys in England and Sabah, and Paton and Little (1974) used discriminant analysis to confirm that sedimentary materials could be distinguished by chemical properties as well as by visible morphological features. Berg (1980) used soil chemical and physical properties as classification variables in a stepwise discriminant analysis to quantitatively evaluate pedogenesis in Illinois sand dunes. Discriminant analysis has been used in forest site productivity research to classify phosphorus-deficient slash pine (_Pinus_ _elliottii_ var. _elliottii_) sites in Florida (Comerford and Fisher, 1982), and to identify and group site descriptors for white spruce (_Picea_ _glauca_ (Moench) Voss) in Minnesota (Harding et al., 1985). Discriminant analysis has been used to identify parameters important for wildland classification in Colorado (Raloff and Betters, 1978), for fire management in California (Omi et al., 1979), and to verify a hierarchical ecological land classification based on landforms in Canada (Rowe and Sheard, 1981).

Objectives of this study were (1) to statistically classify three extensive Mid-Cumberland Plateau forest landtypes on the basis of soil properties; (2) to use factor analysis scores from soil properties in discriminant landtype classification; (3) to use stepwise discriminant analysis to determine the minimum number of measured soil properties necessary to statistically classify the landtypes; and (4) to use canonical discrimination to examine relationships between soil properties among landtypes.

Materials and Methods

Site Selection, Soil Sampling, and Laboratory Analyses

Soil properties used as variables in this study are listed with univariate statistics in Table 26. Detailed site selection criteria and laboratory procedures have been reported.[1] Soil samples were collected in July, 1982 from three of Smalley's (1984a) defined forested landtypes at each of two locations on the Cumberland Plateau in Tennessee, and Smalley's landtypes nomenclature will be used throughout this manuscript. Two landtypes, north-facing slopes and first order

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[1] Hammer, R. D., G. W. Smalley and W. L. Parks. Using multivariate statistics in forest land classification: I. Data reduction with factor analysis. In review. S.S.S.A.J.

Table 26. Means ($\bar{x}$), standard deviations (S.D.), and coefficients of variation (C.V.) for soil chemical and physical properties from three forested landtypes on the mid-Cumberland Plateau.

	- - - - -Upland- - - - -			- - - -North Slope- - -			- - - - Bottom - - - -		
Soil Variable	$\bar{x}$	S.D.	C.V.	$\bar{x}$	S.D.	C.V.	$\bar{x}$	S.D.	C.V.
					A Horizons				
Organic Carbon (g kg^{-1})	44.1	0.10	22.1	54.6	0.13	23.3	46.7	0.16	34.6
pH-H_2O	4.0	4.0	100.9	5.7	5.7	104.5	4.2	4.5	58.1
pH-KCl	3.6	3.7	78.9	5.1	5.3	70.2	3.7	4.0	43.3
Ca ($\mu g\ g^{-1}$)	224.4	227.8	101.5	1928.4	630.2	32.7	477.7	576.8	120.7
Mg ($\mu g\ g^{-1}$)	27.1	15.5	57.3	287.4	109.0	37.9	122.8	131.6	107.2
Na ($\mu g\ g^{-1}$)†	14.2	4.3	30.7	18.6	3.7	19.7	19.2	5.4	28.1
K ($\mu g\ g^{-1}$)	92.4	21.1	22.8	242.6	51.9	21.4	116.8	57.4	49.1
Thickness (cm)	4.8	1.9	38.6	14.8	4.5	30.3	4.7	2.8	59.4
Color†	7.1	1.4	20.4	6.8	1.4	19.9	7.5	1.5	20.3
Ex. Acidity [cmol(p+)kg^{-1}]+	16.2	3.9	24.2	12.8	2.0	16.0	19.3	3.7	19.3
Silt (%) ‡	49.3	6.9	14.0	39.2	4.4	11.3	41.8	8.8	21.2
Clay (%)§	47.9	6.9	14.4	55.9	3.5	6.3	49.4	13.9	28.2
					AB Horizons				
pH-H_2O	4.8	5.5	20.2	4.9	5.2	51.1	4.6	5.1	30.5
pH-KCl	3.8	4.3	26.8	3.9	4.1	66.4	3.7	4.1	38.8
Ca ($\mu g\ g^{-1}$)	46.1	40.4	87.6	324.2	302.4	93.3	36.6	31.3	85.6
Mg ($\mu g\ g^{-1}$)	40.9	20.5	50.2	94.2	40.3	42.8	23.5	26.3	111.8
Na ($\mu g\ g^{-1}$)†	15.6	3.5	22.1	11.9	3.0	25.1	13.7	5.8	42.4
K ($\mu g\ g^{-1}$)†	49.5	14.6	29.5	91.3	43.9	48.1	32.5	13.5	41.8
Thickness (cm)†	19.3	5.6	29.3	20.9	5.1	24.6	18.1	5.3	29.3
Color	13.0	3.3	25.7	10.3	1.8	17.7	6.3	2.1	33.3
Ex. Acidity [cmol(p+)kg^{-1}]+	9.3	2.6	28.4	10.1	3.5	35.0	8.8	2.4	27.7
					Bt Horizons				
pH-H_2O	4.6	4.5	103.8	4.9	5.3	37.7	4.5	5.1	30.5
pH-KCl	3.9	3.9	97.1	3.9	4.3	40.2	3.7	4.1	38.8
Ca ($\mu g\ g^{-1}$)	58.1	48.2	82.9	452.1	338.3	74.8	3.7	4.1	38.8
Mg ($\mu g\ g^{-1}$)	46.7	19.4	41.5	119.0	47.6	40.0	36.6	31.3	85.6
Na ($\mu g\ g^{-1}$)†	15.1	3.9	25.9	19.7	6.2	31.6	23.5	26.3	111.8
K ($\mu g\ g^{-1}$)	54.5	10.9	20.0	108.3	30.7	28.4	13.7	5.8	42.4
Thickness (cm)	24.2	11.4	47.1	56.0	22.8	40.7	89.6	8.8	9.8
Color	14.0	2.5	17.9	13.9	3.5	25.2	7.2	2.5	35.0
Ex. Acidity [cmol(p+)kg^{-1}]+	11.6	2.2	19.3	16.0	5.3	33.0	18.3	4.8	26.2
Silt (%) ‡	46.7	7.7	16.4	34.1	5.5	16.0	40.2	10.0	24.8
Clay (%)§	50.7	7.6	15.0	60.1	3.5	5.9	46.6	14.3	30.8

‡Variable "silt" includes particles from 0.25 to 0.02 mm in diameter.
§Variable "clay" includes particles smaller than 0.02 mm in diameter.
†Variables dropped during factor analysis data reduction.

bottoms with good surface drainage, were characterized by forest stands containing yellow-poplar (Liriodendron tulipifera L.) dominants. The third landtype, broad undulating sandstone uplands, was characterized by white oak (Quercus alba L.) dominants. The sampling scheme, a grid with sampling points at 10 m intervals (Figure 16), was chosen to provide representation of soil variability inherent in a three-dimensional landscape. The three uppermost soil horizons at each sampling point were measured and samples for laboratory analysis. The A, AB, Bt horizon notation is used throughout this paper. This horizon sequence was not encountered at all sampling points, but was used for consistency in coding for statistical analyses.

Thirty-eight soil chemical and physical properties were measured for each of the 132 sampling points. Factor analysis screening of the 38 measured soil properties[2] revealed that fine sands, very fine sands and coarse silts were chemically and mineralogically similar in A and Bt horizons. These three textural variables were combined into a single soil variable called "silt." Fine silt and clay fractions in A and Bt horizons were also similar and were combined into a single soil variable called "clay." Combining soil textural variables reduced the variable list to 32. Each sampling point was coded by landtype, resulting in a 33 x 132 data matrix.

Upland landtypes soils were dominantly Typic Hapludults and Typic Fragiudults. Soils on slopes were dominantly Humic Hapludults but

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[2] Ibid.

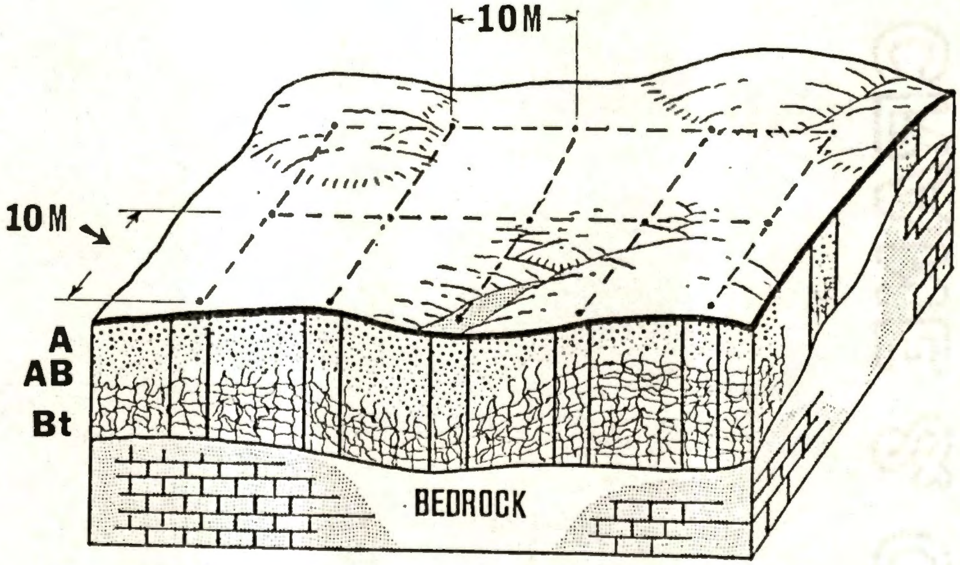

Figure 16. Representation of the 10 meter grid sampling scheme for obtaining soils from A, AB, and Bt horizons on three Cumberland Plateau landtypes.

contained Typic Fragiudults and bottom soils were dominantly Aquic Dystrochrepts.

Statistical Methods

Theory and application of discriminant analysis have been discussed in previous papers. Interested readers should refer to reports cited herein or to textbooks such as Harris (1975), Tatsuoka (1971) or Tabachnick and Fidell (1983).

Statistical analyses were performed with the Statistics package of Statistical Analysis System Software (SAS Institute Inc., 1982). Procedures used included Candisc, Discrim, Factor, Score, Stepdisc, and Plot.

Stepwise discriminant analysis (Stepdisc) was performed to determine and identify the minimum number of variables required to classify landtypes on the basis of soil properties. The Stepdisc procedure was forward selection with a significance level of 0.05 for the F-test for covariance. Tabachnick and Fidell (1983) cautioned that cross-validation of results is very important after stepwise discriminant analysis since it is susceptible to misleading results produced by sample differences not found in the population. They recommended using large data sets split into subsets, one for analysis and the second for verification. The sample to variable ratio in this experiment is too low to maintain robustness after splitting the data, so Stepdisc was performed on 25 soil variables retained by data reduction with maximum likelihood factor analysis. This insured that only highly correlated variables were subjected to Stepdisc.

The Discrim procedure was used to produce a discriminant analysis classification of landtypes by soil properties. Five sets of soil variables were classified using Discrim--the original 32 variables, 25 variables retained by maximum likelihood factor analysis, 15 variable selected with Stepdisc, and factor scores produced by maximum likelihood factor analysis using both five and four factors. Factor scores produced with Factor were retained as output and multiplied by the original data using Score. The resulting linear combinations of factor scores and original data were subjected to discriminant analysis. Discrim computes a posterior probability score or "goodness of fit" determination for each classified observation. The observation is scored against each class variable (landtype) using the least squared distance of the observation from class centroids. Each observation is then classified into the landtype with which it has the greatest posterior probability.

The four sets of soil variables were subjected to canonical discrimination (Candisc), again using landtypes as discriminant classes. Canonical discrimination is similar to canonical correlation, but dependent and independent variables are not specified. Output data were plotted using Plot software, and resulting graphs were used to display groupings of individual soil sampling points on canonical variate axes. Group centroids were plotted using class means on canonical data scores. Loading scores from canonical structure matrices were used to determine which soil variables were most important in grouping observations within landtypes.

Results

Stepwise Discriminant Analysis

Stepwise discriminant analysis revealed 15 of the 25 analyzed soil variables were necessary for statistical classification of the landtypes on the basis of soil properties. Most of the retained variables (Table 27) were from subsurface (AB and Bt) horizons, and 7 of the 15 were Bt-horizon soil properties.

Statistical classification of landtypes on the basis of soil properties should produce results heavily influenced by Bt-horizon properties. Water retention, distribution and movement are the primary reasons for soil differences within landscapes (Hall, 1983) because differential subsurface water movement is the driving force in processes of soil development (Hall, 1983; Simonson, 1959; Stone, 1975). Cumberland Plateau landtypes influence soil water movement, which in turn influences both subsoil morphological and chemical properties (Hammer et al., 1985).

The importance of the retained Bt-horizon properties in Cumberland Plateau soils is substantiated by previous research and by Soil Taxonomy (Soil Survey Staff, 1975). Slope position influences particle size distribution and base saturation (BS) in Cumberland Plateau soils (Franzmeier et al., 1969), and aspect influences soil temperature, organic matter content, soil color, clay content, available soil moisture during the growing season, BS, pH of surface horizons, Ca levels, and horizons developed (Franzmeier et al., 1969; Hutchins et al.,

Table 27. Variables retained in stepwise discriminant analysis of 25 soil properties from three horizons on three forested landtypes.

Horizon	Variables Retained by Stepwise Analysis		
	A	AB	Bt
	Ca	Ca	Ca
	Mg	K	Color
	Thickness	Color	Thickness
		pH-H_2O	Clay
		pH-KCl	Silt
			Exchangeable Acidity
			pH-KCl

1976). Soil variables retained by stepwise discriminant analysis are represented in this list of aspect-affected soil properties.

Sampled Bt horizons of these soils are generally analogous to the taxonomic control section (Soil Survey Staff, 1975), and the list of Bt-horizon soil variables retained as classification discriminators includes soil properties used in taxonomic classification. Soil color is an indication of drainage; clay and silt variables represent soil texture; and Bt-horizon thickness represents soil depth. Soil pH in salt solution is the most accurate measure of acidity in these highly weathered subsoils because Al on the exchange complex usually controls soil acidity (Thomas and Hargrove, 1984). The most abundant nutrient cation in these soils is Ca, which, with exchangeable acidity, accounts for most of the cation exchange capacity (CEC). Statistical retention of taxonomically important Bt-horizon soil variables, shown by previously cited research (Franzmeier et al., 1969; Hutchins et al., 1976) to be affected by slope aspect and position, indicates that these statistical results are pedologically sound.

Soil horizons sampled and coded "AB" included AB, BA and Bw. Specific soil horizons form as a result of dominance of one or more soil-forming processes (Simonson, 1959), so a variety of processes probably resulted in pedological significance of the retained AB-horizon variables. This may explain why pH in both water and KCl was retained in AB horizons, but not in A or Bt horizons. The variety of weathering processes associated with AB horizon formation produced a range of soil colors, making this variable a strong discriminator.

Statistical retention of Ca as a discriminator in all three horizons is noteworthy. Correlation coefficients of Ca with other retained cations were high--0.91 with Mg in A horizons and 0.86 with K in AB horizons. Chemical and physical properties were retained as discriminators in all three sampled horizons.

Retention of three A-horizon variables by stepwise discriminant analysis substantiates previously reported factor analysis results which revealed the importance of considering A-horizon soil properties when statistically classifying Cumberland Plateau forest soils (Hammer et al., 1984). This conclusion is supported by retention of AB-horizon variables, providing additional evidence that statistical evaluation of these landtypes and soils would be incomplete without inclusion of properties from the entire soil profile.

Retained A-horizon variables were horizon thickness and Ca and Mg levels. Previously cited research (Franzmeier et al., 1969; Hutchins et al., 1976) has shown the two former discriminators are positively correlated to Cumberland Plateau soils on north aspects. North slopes in this study were characterized by thicker A horizons and much higher Ca levels than upland or bottom sites (Table 26), and by stands composed mostly of yellow-poplar. The capacity of yellow-poplar to cycle and retain calcium and to enhance A-horizon development are long-recognized traits (Auten, 1945). Flowering dogwood (Cornus florida L.), a major shrub component on north slope sites, is also a recognized calciophile (Thomas, 1969).

North slope and bottom landtypes not currently supporting yellow-poplar, and uplands not dominated by oak may exhibit surface soil properties different than those observed in this study. Different combinations of soil variables may prove more suitable in statistical analyses of such sites.

Stepwise discriminant analysis of 32 soil variables produced results which retained several variables shown by factor analysis to be poorly correlated. Tabachnick and Fidell's (1983) warning regarding use of stepwise discriminant analysis without testing results appears valid. This study indicates that screening data with factor analysis and dropping uncorrelated variables prior to stepwise analysis should be a necessary precautionary measure.

Discriminant Analysis and Canonical Discrimination

Discriminant analysis classified all 132 observations from the grid sampling points into correct landtypes using the original 32 soil variables, using 25 variables retained by maximum likelihood factor analysis, and with 15 variables retained by stepwise discriminant analysis (Table 28). Discriminant classification of factor scores was slightly less precise, as 128 of 132 observations (97 percent) were correctly classified using both five and four factors. Results indicate the forest land classification system is a reliable method of grouping Cumberland Plateau forest soils into discrete landform units with similar soil chemical and physical properties. Factor analysis is a valuable method of reducing large data sets without causing appreciable loss of precision in subsequent discriminant analyses.

Table 28. Discriminant analyses classifications of several sets of soil variables and of factor analysis scores.

Variables	Source of Variables	Observations Classified	Correct Classification
32	Original list	132	132
25	Retained by MLFA†	132	132
15	Retained by Stepdisc‡	132	132
25	MLFA Factor Scores	5 Factors	128
25	MLFA Factor Scores	4 Factors	128

†MLFA is maximum likelihood factor analysis.

‡Stepdisc is stepwise discriminant analysis.

Discriminant analysis of factor scores indicates that the decision to retain four factors rather than five in maximum likelihood solution[3] was sound and produced no additional loss of precision. The same observations were misclassified into adjacent landtypes in both cases, and posterior probability scores on misclassified observations were nearly identical. Factor scores matrices are much smaller than corresponding raw data matrices and require less computer memory for storage and analyses. This factor score matrix was 5 x 132 compared to the 33 x 132 original data matrix. Matrix size is particularly important when analysis involves matrix inversion.

Plotting canonical discrimination results allowed examination of relationships of observations within and among landtypes, permitted visual evaluation of effects of data reduction and, when combined with canonical structure matrix scores, provided insight into relationships of individual variables (soil properties) with grouping variables (landtypes).

Canonical plots are shown in Figures 17 through 20. Group centroids were located by plotting mean canonical variate scores (Table 29) on canonical axes. Distances between group centroids (Mahalanobis' Distance) are given in Table 29.

Canonical discrimination of 32 soil variables (Figure 17) revealed that observations are clustered into discrete groups around clearly separated landtype centroids. This plot provides striking visual

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[3] Ibid.

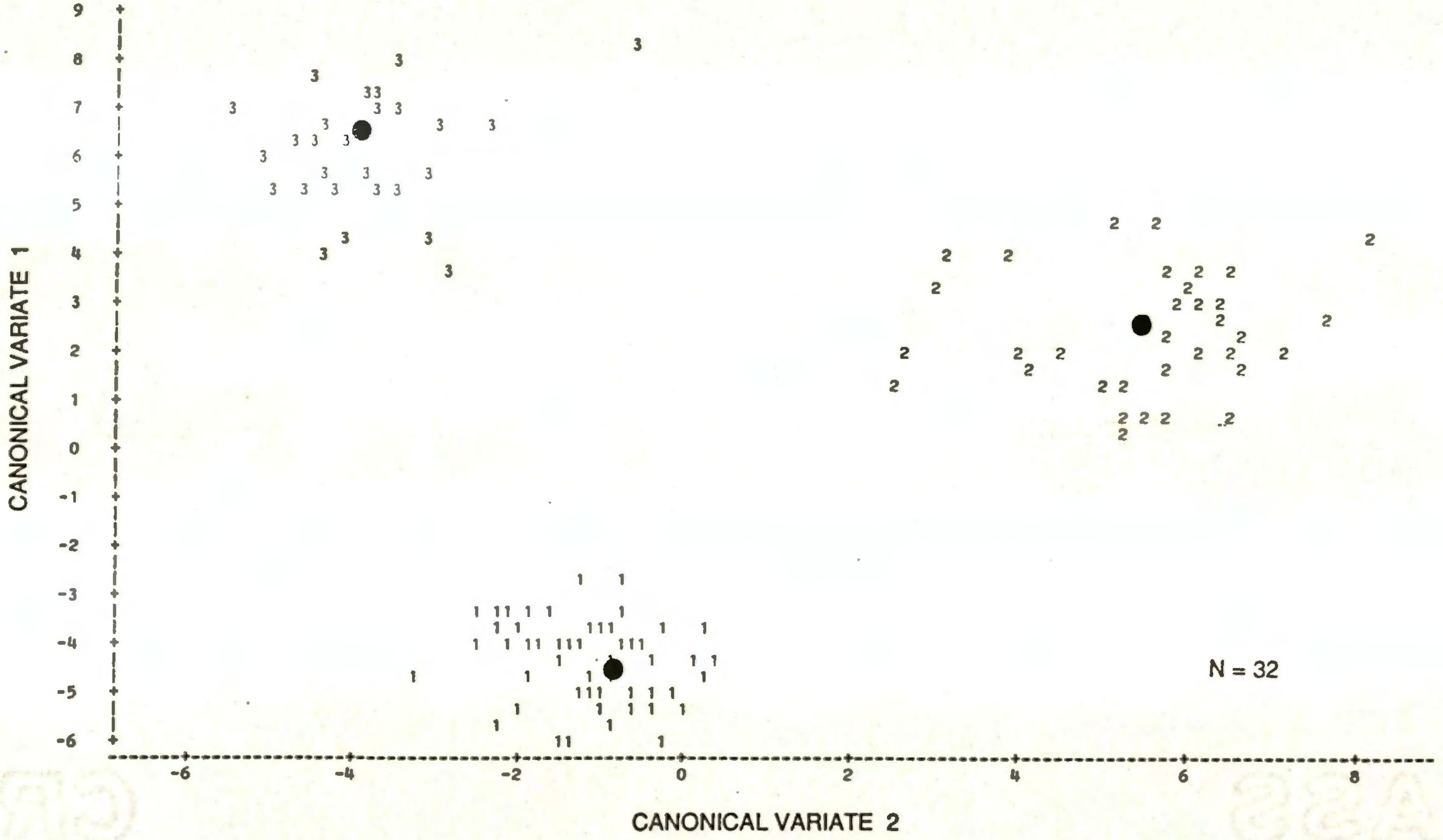

Figure 17. Canonical plots of 32 soil variables and their group centroids (●) representing upland (1), slope (2), and bottom (3) landtypes on the Cumberland Plateau.

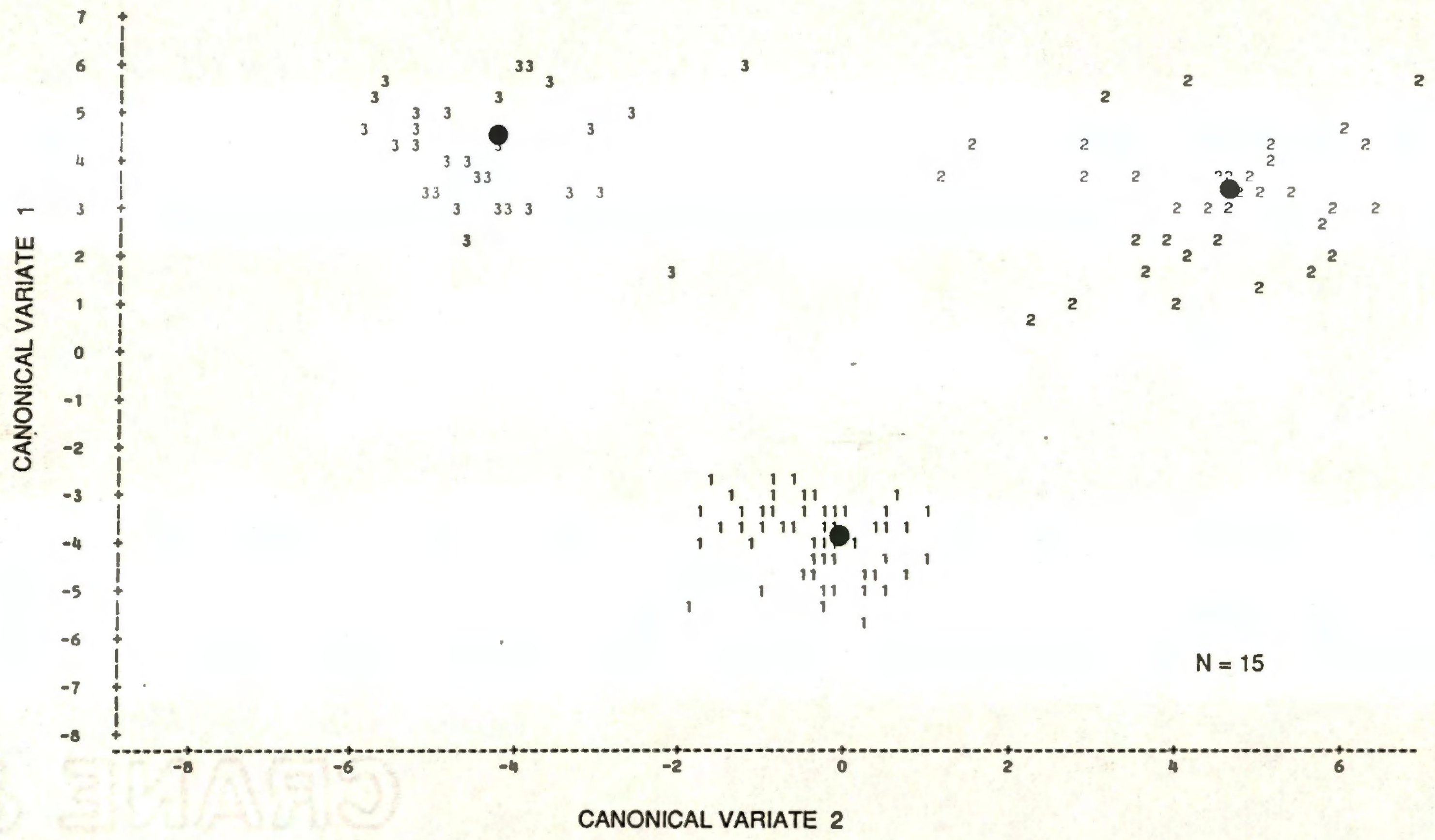

Figure 18. Canonical plots of 25 soil variables and group centroids (●) representing upland (1), slope (2), and bottom (3) landtypes on the Cumberland Plateau.

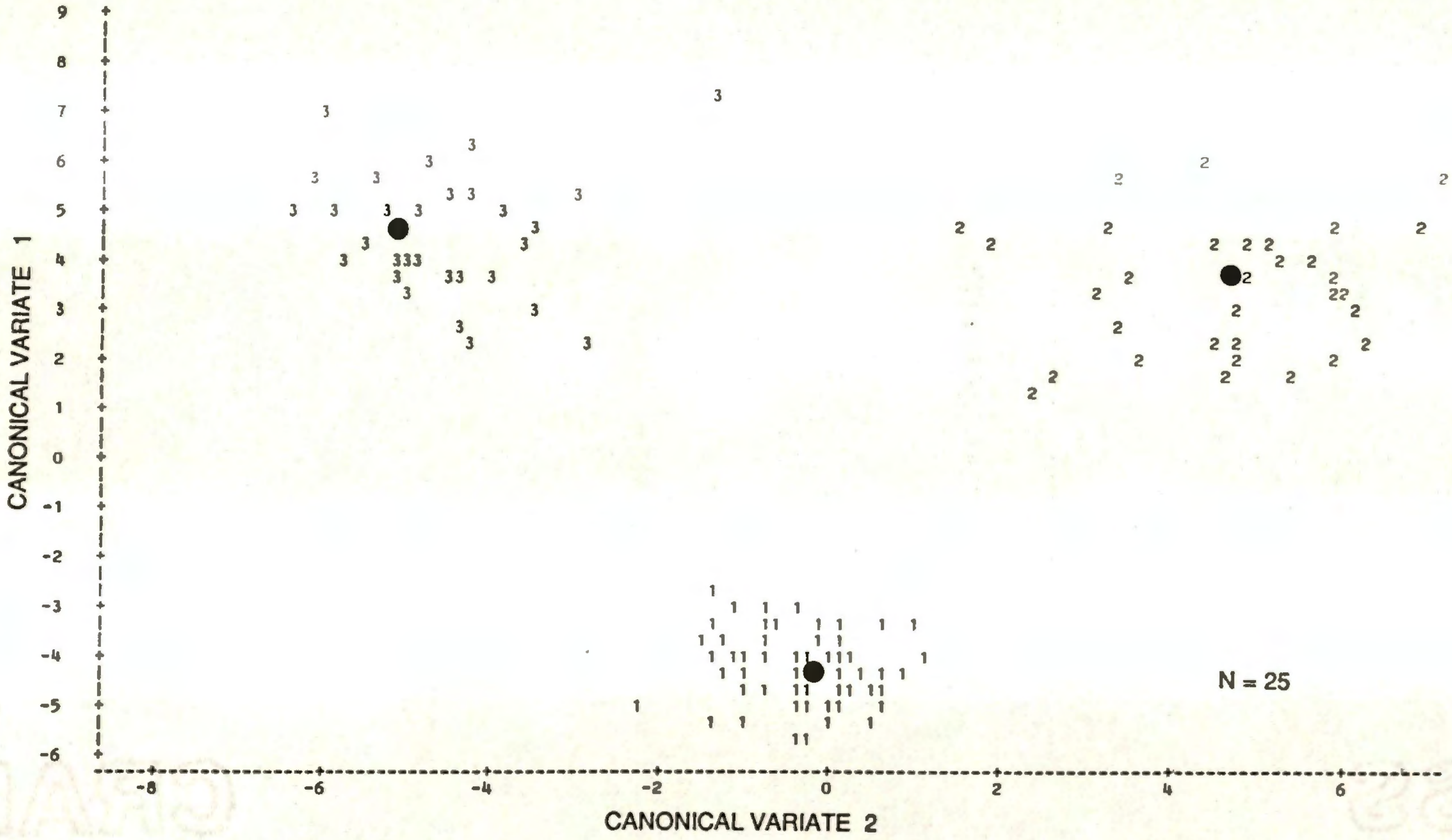

Figure 19. Canonical plots of 15 soil variables and group centroids (●) representing upland (1), slope (2), and bottom (3) landtypes on the Cumberland Plateau.

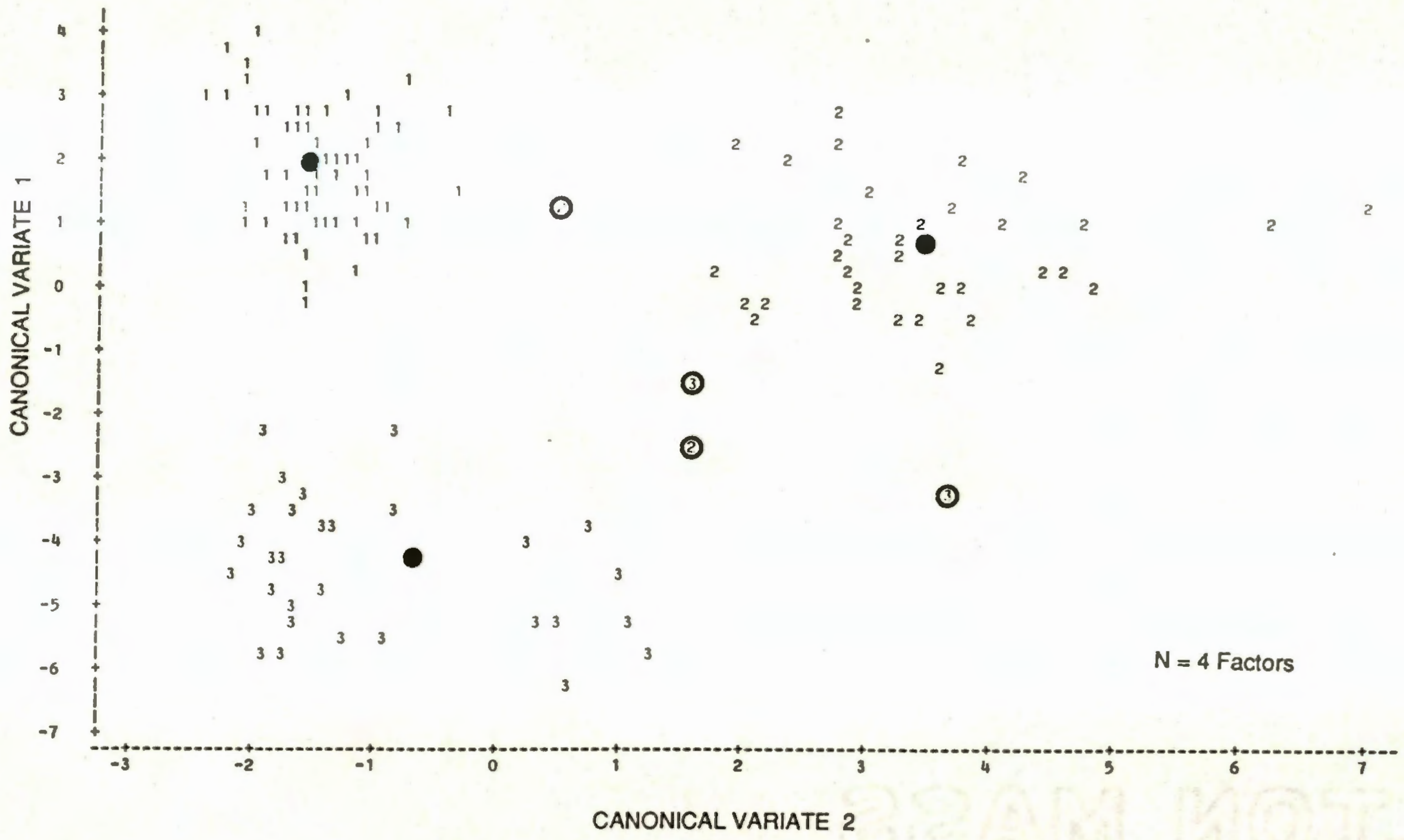

Figure 20. Canonical plots of factor scores and their centroids (●) from 32 soil variables from upland (1), slope (2), and bottom (3) landtypes on the Cumberland Plateau.

Table 29. Canonical structure matrix loading scores of selected soil variables from three data sets.

Soil Variable	Number of Soil Variables Analyzed					
	32 †		25		15	
	Can 1	Can 2	Can 1	Can 2	Can 1	Can 2
Ca (A)	-	.782	-	.683	-	.691
Mg (A)	-	.625	.637	-	.636	-
K (A)	-	.770	-	.670	-	-
pH-H O (AB)	-	-.681	-	-.730	-	.733
Ca (AB)	-	.613	-	-	-	-
Mg (AB)	-	.720	-	.695	-	-
K (AB)	-	.680	-	.665	-	.670
Ca (Bt)	-	.678	-	.614	-	.620
Mg (Bt)	-	.739	-	.703	-	-
K (Bt)	-	.749	-	.688	-	-
Ex. Acidity (Bt)	.606	-	.600	-	.600	-
Color (AB)	-.705	-	-.653	-	-.659	-
Thickness (A)	-	.820	-	.748	-	.755
Thickness (Bt)	.883	-	.835	-	.843	-

† Can 1 and Can 2 are canonical variates 1 and 2 respectively.

evidence of the close relationship of soil chemical and physical properties to individual landtypes. Patterns of observations around respective landtype centroids reflect soil variability within landtypes. Observations are uniformly clustered about the upland centroid (group 1), indicating normal variable distribution and relatively low variability. Slope observations (group 2) are elongated along canonical variable 2, indicating skewed distribution and greater soil variability. Several observations from the first order bottom (group 3) are outliers from one site, and occurred along the edge of the sampling grid where the adjacent slope graded into the bottom.

Although limited inferences regarding within landtype soil variability can be made from the canonical plots, such inferences must be tempered with caution. Uniform sampling density across landtypes was selected for this study. The first order bottoms were the smallest of the three studies landtypes, so the 10 m sampling scheme permitted fewer samples. Future research should investigate the possibility that different sampling densities across landtypes may be more desireable.

Loading scores from the total canonical structure matrix are useful when interpreting plotted data, and are interpreted much like variable loading scores from factor analysis rotated structure matrices. Canonical structure matrix loading scores with maximum absolute values of 0.6 are shown in Table 30. Although all analyzed variables load to some extent onto both canonical variables, the most important are those with the highest scores.

Canonical variate 1 in Figure 17 is a vector composed primarily of AB-horizon color at the negative end and thickness and exchangeable

Table 30. Mean canonical variate scores and Mahalonobis' distances between soil property centroids for uplands, slopes, and bottoms.

Soil Variables	Canonical Variate	Mean Canonical Variate Scores †			Landtype	Mahalanobis' Distance	
Number		Landtype				Landtype	
		1	2	3		2	3
32	1	-4.41	2.41	6.11	1	9.43	10.90
	2	-1.08	5.45	-3.97	2	-	10.12
25	1	-4.25	3.52	4.54	1	9.21	9.79
	2	-0.30	4.64	4.62	2	-	9.32
15	1	-3.89	-3.18	4.21	1	8.50	9.04
	2	-0.32	4.41	-4.33	2	-	8.81
4 factors	1	1.82	0.57	-4.27	1	4.93	6.13
	2	-1.47	3.30	-0.76	2	-	6.31

† Landtypes 1, 2, and 3 are uplands, slopes, and bottoms respectively.

acidity of the Bt horizon at the positive end. These three variables are the strongest discriminators along canonical variate 1 and are most responsible for separation of projected landtype centroids on this axis. Canonical variate 2 is composed primarily of A-horizon thickness and Ca, Mg, and K levels in all three horizons on the positive end with water pH of the AB horizon on the negative end.

Comparison of canonical discrimination of landtypes using 25 variables (Figure 18) and 15 variables (Figure 19) reveals that data reduction minimally affected the discrete grouping of landtype soil properties. Separation of landtypes 1 and 3 along canonical variate 2 appears to have been enhanced, and a slight loss of separation occurred on canonical variate 1. Examination of structure matrix loading scores (Table 30) reveals that A-horizon Mg shifted canonical axes with data reduction and now loads onto canonical variate 1. The Mg shift probably accounts for the slight shift of centroid relative positions. Factor analysis and stepwise discriminant analysis data reduction removed several variables from the data without appreciable loss of precision and allowed identification of the strongest discriminators, which are listed in Table 30 under the column of 15 variables. Strong discriminators on canonical variate 2 include A-horizon thickness and Ca, AB-horizon K and water pH, and Bt-horizon Ca. Canonical variable 1 is composed primarily of A-horizon Mg, AB-horizon color, and thickness and extractable acidity of the Bt horizon.

Loading scores (Table 30) of the strong discriminators and Mahalanobis' distance (Table 29) remained relatively constant at data reduction proceeded, indicating little loss of discriminating power. Both canonical axes of the 15-variable solution are loaded by at least one soil variable from each sampled horizon, and both chemical and physical properties are represented. Although 15 soil variables were needed for discriminant classification of the landtypes, the 9 variables in Table 30 were most responsible for the discrete clustering of landtypes on canonical axes.

Canonical plots of factor analysis scores are in Figure 20. Landtype centroids remain discrete, but are closer, and data spread within landtypes has apparently increased. The reduced centroid spread is substantiated by reduced Mahalanobis' distances (Table 29). Misclassified variables are indicated on the plot. The bottom observations misclassified into slopes were the previously noted outliers. Eight bottom observations have separated from the main group and are clustered to the right of the centroid. These observations came from a portion of the landtype with poor internal drainage adjacent to an ephemeral stream channel.

Tests of significance accompanying analyses revealed that canonical variates 1 and 2 are statistically different for all four canonical solutions, and group centroids were also statistically discrete. Data reduction produced no statistically significant changes in canonical structure or centroid separation.

Results of analyses were not so precise when CEC and base saturation were used as variables rather than individual cations. Kurtz and Melsted (1973) observed that individual ions vary in movement and retention within soils, and a particular ion may behave differently from soil to soil. Results of this study indicate that multivariate statistical analyses of soils encompassing a variety of landscape elements and differing forest cover types may be most revealing when nutrient cations are considered as discrete entities rather than combined into more general categories such as CEC or base saturation.

Different soil A and AB-horizon variables may be statistically important under different forest cover and landtype combinations, in soils with different weathering environments, different soil moisture regimes, or as a consequence of management practices affecting the forest floor and surface mineral horizons. Forest species differentially cycle and accrue nutrient ions, thereby affecting nutrient accumulation and distribution in surface mineral horizons (Alban, 1979; Alban et al., 1978; Johnson and Swank, 1973), although no conclusive evidence exists that forest vegetation significantly affects subsoil properties (Alban et al., 1978; Stone, 1975). Topographic features such as aspect, slope shape, and position on slope have been shown to affect forest tree species distribution (Bailey and Avers, 1971; Brown, 1950; Hutchins et al., 1976) and growth (Bailey and Avers, 1971; Hammer et al., 1985). Hutchins and his co-workers (Hutchins et al., 1976), determined that soils on northeast slopes were different from soils on southwest slopes in similar parent materials; they also reported more diverse, more mesophytic forest communities containing yellow-poplar on northeast-facing sites. This observation caused them to consider that certain soil-site differences may have been caused by differences in forest composition. Stone's (1975) observation that "The reciprocal influences of soil upon forest and forest upon soil are not easily disentangled" is apropos to A-horizon soil properties observed in this study.

Success of these discriminant classifications can probably be partially attributed to methodology. This research was designed specifically to test the forest land classification system. An effort was made to separate landtypes into discrete units, and soils were sampled on the basis of coded genetic horizons rather than by arbitrary depths. Precision of this discriminant classification supports Webster and Burrough's (1974) conclusion that discriminant analysis appears to offer the best potential in situations which ". . . allow man and machine to do what they do best; the man to use his experience and intuition for the major decisions, the machine to handle large quantities of data. . . ." Results also appear to confirm Rowe's (1984) contention that multivariate statistics are most useful in land classification after natural landform patterns have been recognized and separated.

Conclusions

The forest land classification appears to be a viable method of grouping mid-Cumberland Plateau forest soils into landform units with relatively homogeneous chemical and physical properties. Statistical classification of these forest soils would apparently be incomplete without consideration of certain chemical and physical properties from the entire soil profile.

Discriminant analysis correctly classified all 132 observations from three forested landtypes at two locations. Maximum likelihood factor analysis provided a method of identifying and removing uncorrelated variables without loss of precision, and was a valuable screening tool prior to stepwise discriminant analysis. Factor score matrices provided a reduced data set which allowed discriminant classification with slight, but statistically insignificant loss of precision.

Stepwise discriminant analysis offered a method of further reducing the data without loss of precision in discriminant classification, but was most effective when preceeded by factor analysis data reduction. Canonical discrimination, in conjunction with stepwise discrimination, provided identification of the nine soil variables which were the strongest discriminators among landtype soil properties. These variables included chemical and physical properties from all three sampled horizons.

Plots of canonical discrimination results allowed visual examination of soil relationships within and among landtypes and enhanced interpretations of results.

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LITERATURE CITED

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APPENDIXES

APPENDIX A

SOIL TEMPERATURE MEASUREMENTS

Soil Temperature (°F) Measurements for Two Years in Cumberland Plateau Forest Soils

SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE	MONTH	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5
CU1	29OCT82	49.0	52.0	56.0	.	.
CU1	1DEC82	54.0	52.5	54.0	.	.
CU1	7JAN83	40.0	46.5	51.0	.	.
CU1	16FEB83	42.0	44.0	47.0	.	.
CU1	21MAR83	44.5	48.0	49.0	.	.
CU1	13APR83	52.0	50.5	50.0	.	.
CU1	11MAY83	60.0	54.0	52.0	.	.
CU1	16JUN83	63.0	59.0	56.0	.	.
CU1	20JUL83	75.0	65.0	61.0	.	.
CU1	22AUG83	72.0	66.5	63.5	.	.
CU1	19SEP83	68.5	64.0	62.0	.	.
CU1	27OCT83	51.5	56.0	58.0	.	.
CU1	30NOV83	44.5	48.5	52.0	.	.
CU1	6JAN84	33.0	38.5	44.0	.	.
CU1	3FEB84	38.0	40.0	44.0	.	.
CU1	15MAR84	46.0	40.0	44.0	.	.
CU1	5MAY84	60.0	54.0	53.0	.	.
CU1	4JUN84	63.5	56.0	54.5	.	.
CU1	26JUN84	63.5	60.0	59.5	.	.
CU1	24JUL84	66.5	61.0	60.0	.	.
CU1	22AUG84	61.0	62.5	62.0	.	.
CU1	24SEP84	58.0	58.0	61.0	.	.
CU1	25OCT84	62.0	56.5	62.0	.	.
CU1	4DEC84	46.0	44.0	52.0	.	.
CU2	29OCT82	50.0	54.0	56.0	.	.
CU2	1DEC82	54.0	53.5	54.0	.	.
CU2	7JAN83	41.0	47.5	49.5	.	.
CU2	6FEB83	42.0	44.0	46.5	.	.
CU2	21MAR83	44.0	48.5	45.0	.	.
CU2	13APR83	52.0	50.0	51.5	.	.
CU2	11MAY83	60.0	54.0	52.5	.	.
CU2	16JUN83	63.0	58.0	56.0	.	.
CU2	20JUL83	69.5	63.0	60.0	.	.
CU2	22AUG83	71.0	65.0	62.0	.	.
CU2	19SEP83	68.0	63.5	61.0	.	.
CU2	27OCT83	49.0	56.5	57.0	.	.
CU2	30NOV83	43.0	50.5	52.0	.	.
CU2	6JAN84	32.0	38.5	43.0	.	.
CU2	3FEB84	36.5	43.0	43.5	.	.
CU2	15MAR84	45.5	44.5	44.0	.	.
CU2	5MAY84	58.5	54.5	50.0	.	.
CU2	4JUN84	61.5	56.0	52.0	.	.
CU2	26JUN84	60.5	60.5	56.0	.	.
CU2	24JUL84	64.0	62.5	57.5	.	.
CU2	22AUG84	64.0	63.5	58.0	.	.
CU2	24SEP84	60.0	61.0	58.5	.	.

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        SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE     MONTH      DEPTH1    DEPTH2    DEPTH3    DEPTH4    DEPTH5

CU2     25OCT84      58.5      60.5      54.5        .         .
CU2     4DEC84       43.0      50.0      46.0        .         .
CS1     29OCT82      49.0      52.0      58.0      58.0        .
CS1     1DEC82       41.0      50.0      54.0      54.0        .
CS1     7JAN83       36.0      42.0      49.5      51.0        .
CS1     16FEB83      40.0      40.0      46.0      47.0        .
CS1     21MAR83      41.5      46.5      46.5      47.0        .
CS1     13APR83      53.0      49.0      47.5      47.0        .
CS1     11MAY83      61.0      54.0      50.0      49.0        .
CS1     16JUN83      64.5      61.0      55.0      53.0        .
CS1     20JUL83      74.0      68.5      59.0      56.5        .
CS1     22AUG83      74.0      69.5      62.5      60.0        .
CS1     19SEP83      52.0      62.0      62.5      61.0        .
CS1     27OCT83      50.0      56.5      58.5      58.5        .
CS1     30NOV83      41.5      46.5      52.0      54.0        .
CS1     6JAN84       32.0      38.5      46.0      48.0        .
CS1     3FEB84       34.0      36.0      42.0      45.5        .
CS1     15MAR84      43.5      41.5      42.5      44.0        .
CS1     5MAY84       60.0      55.0      49.5      49.0        .
CS1     4JUN84       63.5      56.5      54.0      53.0        .
CS1     26JUN84      64.5      63.5      56.0      54.0        .
CS1     24JUL84      69.0      65.0      58.5      57.0        .
CS1     22AUG84      70.0      66.0      60.0      59.0        .
CS1     24SEP84      58.5      60.5      60.0      59.5        .
CS1     25OCT84      62.5      60.0      57.5      58.0        .
CS1     4DEC84       44.0      44.0      50.0      54.0        .
CS2     29OCT82      50.0      52.0      56.0        .         .
CS2     1DEC82       44.0      50.0      53.5        .         .
CS2     7JAN83       38.0      45.5      49.0        .         .
CS2     16FEB83      40.0      40.0      44.0        .         .
CS2     21MAR83      42.0      46.0      47.5        .         .
CS2     13APR83      51.0      48.5      48.0        .         .
CS2     11MAY83      60.0      52.0      50.0        .         .
CS2     16JUN83      63.0      58.5      54.5        .         .
CS2     20JUL83      73.5      66.0      60.0        .         .
CS2     22AUG83      73.5      68.0      62.5        .         .
CS2     19SEP83      53.0      61.0      62.0        .         .
CS2     27OCT83      50.0      53.0      58.0        .         .
CS2     30NOV83      44.0      49.0      52.0        .         .
CS2     6JAN84       32.0      38.0      41.0        .         .
CS2     3FEB84       36.5      38.5      42.0        .         .
CS2     15MAR84      43.5      41.0      42.0        .         .
CS2     5MAY84       60.0      53.5      50.0        .         .
CS2     4JUN84       64.0      58.0      52.0        .         .
CS2     26JUN84      64.0      62.0      58.5        .         .
CS2     24JUL84      68.0      64.0      60.0        .         .
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SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE	MONTH	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5
CS2	22AUG84	69.0	66.0	61.5	.	.
CS2	24SEP84	58.5	62.0	61.0	.	.
CS2	25OCT84	62.5	60.5	59.0	.	.
CS2	4DEC84	45.0	48.5	51.0	.	.
CB1	29OCT82	51.0	52.5	56.5	.	.
CB1	1DEC82	53.5	54.0	54.0	.	.
CB1	7JAN83	38.0	45.5	49.0	.	.
CB1	16FEB83	42.0	42.5	46.0	.	.
CB1	21MAR83	43.0	48.5	48.0	.	.
CB1	13APR83	54.0	55.0	49.0	.	.
CB1	11MAY83	62.0	54.0	52.0	.	.
CB1	16JUN83	63.5	58.5	55.0	.	.
CB1	20JUL83	69.0	64.5	60.0	.	.
CB1	22AUG83	72.0	67.0	73.0	.	.
CB1	19SEP83	67.5	64.0	62.0	.	.
CB1	27OCT83	50.0	56.5	58.0	.	.
CB1	30NOV83	38.5	46.5	51.5	.	.
CB1	6JAN84	32.0	40.5	43.5	.	.
CB1	3FEB84	44.5	42.0	43.0	.	.
CB1	15MAR84	48.0	44.0	44.0	.	.
CB1	5MAY84	55.0	53.5	52.0	.	.
CB1	4JUN84	64.0	56.0	54.0	.	.
CB1	26JUN84	64.5	61.0	58.0	.	.
CB1	24JUL84	64.5	63.0	60.0	.	.
CB1	22AUG84	66.0	63.5	61.0	.	.
CB1	24SEP84	56.0	60.5	60.0	.	.
CB1	25OCT84	62.5	.	59.0	.	.
CB1	4DEC84	44.0	.	50.0	.	.
CB2	29OCT82	56.2	54.0	57.0	.	.
CB2	1DEC82	54.0	52.5	53.0	.	.
CB2	7JAN83	40.0	48.5	52.0	.	.
CB2	16FEB83	43.0	44.0	45.0	.	.
CB2	21MAR83	43.0	48.5	48.0	.	.
CB2	13APR83	51.0	51.0	50.0	.	.
CB2	11MAY83	64.0	54.0	52.0	.	.
CB2	16JUN83	65.0	59.0	56.0	.	.
CB2	20JUL83	70.0	66.0	61.0	.	.
CB2	22AUG83	73.0	68.0	62.5	.	.
CB2	19SEP83	69.0	65.0	62.0	.	.
CB2	27OCT83	49.5	56.5	56.5	.	.
CB2	30NOV83	42.0	48.5	50.0	.	.
CB2	6JAN84	32.0	38.0	42.0	.	.
CB2	3FEB84	40.0	42.0	42.0	.	.
CB2	15MAR84	53.0	46.0	44.5	.	.
CB2	5MAY84	62.5	54.0	51.0	.	.
CB2	4JUN84	66.0	57.0	53.0	.	.

SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE	MONTH	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5
CB2	26JUN84	64.0	62.0	58.0	.	.
CB2	24JUL84	66.0	64.0	59.5	.	.
CB2	22AUG84	66.0	65.5	61.5	.	.
CB2	24SEP84	55.5	62.0	60.0	.	.
CB2	25OCT84	62.5	61.0	58.0	.	.
CB2	4DEC84	42.0	48.5	48.5	.	.
FCU1	29OCT82	59.0	57.0	56.0	.	.
FCU1	1DEC82	54.0	52.5	52.0	.	.
FCU1	7JAN83	41.5	47.5	48.0	.	.
FCU1	16FEB83	39.5	47.0	47.0	.	.
FCU1	21MAR83	44.0	47.5	47.0	.	.
FCU1	13APR83	56.5	52.5	52.0	.	.
FCU1	11MAY83	58.0	54.5	52.5	.	.
FCU1	16JUN83	64.0	59.5	58.0	.	.
FCU1	20JUL83	74.0	65.0	63.0	.	.
FCU1	22AUG83	74.5	68.5	66.0	.	.
FCU1	19SEP83	68.0	65.0	64.0	.	.
FCU1	27OCT83	50.5	58.5	58.0	.	.
FCU1	30NOV83	41.5	50.0	50.5	.	.
FCU1	6JAN84	35.0	40.0	41.0	.	.
FCU1	3FEB84	38.0	38.0	41.0	.	.
FCU1	15MAR84	52.0	43.0	44.0	.	.
FCU1	5MAY84	54.5	54.5	53.5	.	.
FCU1	4JUN84	64.0	57.0	55.5	.	.
FCU1	26JUN84	64.0	62.0	60.0	.	.
FCU1	24JUL84	69.5	64.5	63.5	.	.
FCU1	22AUG84	68.0	66.0	64.5	.	.
FCU1	24SEP84	56.5	61.5	62.0	.	.
FCU1	25OCT84	63.5	61.0	61.0	.	.
FCU1	4DEC84	38.4	49.0	50.5	.	.
FCU2	29OCT82	58.0	57.0	57.0	57.0	58.0
FCU2	1DEC82	52.5	52.5	54.0	54.0	55.0
FCU2	7JAN83	41.0	47.5	48.5	50.0	52.5
FCU2	16FEB83	39.0	44.0	46.0	48.5	48.5
FCU2	21MAR83	44.0	48.0	48.0	48.0	48.0
FCU2	13APR83	56.0	50.0	49.5	49.5	49.0
FCU2	11MAY83	60.0	54.0	53.5	53.0	51.0
FCU2	16JUN83	64.0	59.0	58.0	56.5	54.0
FCU2	20JUL83	73.0	64.5	63.0	61.0	58.0
FCU2	22AUG83	69.5	67.5	65.5	64.0	64.0
FCU2	19SEP83	66.0	64.5	64.0	63.0	61.0
FCU2	27OCT83	50.0	58.0	58.0	59.5	58.5
FCU2	30NOV83	40.0	50.0	51.0	52.5	54.5
FCU2	6JAN84	34.0	40.5	42.0	44.5	48.0
FCU2	3FEB84	36.0	41.0	42.0	43.5	46.0
FCU2	15MAR84	51.0	45.5	44.0	44.5	46.0

SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE	MONTH	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5
FCU2	5MAY84	53.5	55.0	54.0	53.5	50.5
FCU2	4JUN84	62.0	56.0	54.5	54.5	52.5
FCU2	26JUN84	63.0	62.0	60.0	58.5	54.5
FCU2	24JUL84	68.0	64.0	61.0	61.0	58.0
FCU2	22AUG84	67.0	65.5	63.0	63.0	60.0
FCU2	24SEP84	56.0	61.0	60.5	62.0	59.5
FCU2	25OCT84	62.0	61.5	59.0	61.5	59.5
FCU2	4DEC84	39.0	50.0	48.5	52.0	54.0
FCS1	29OCT82	57.0	56.0	56.0	57.0	57.0
FCS1	1DEC82	52.0	52.0	53.0	54.5	55.0
FCS1	7JAN83	39.5	46.0	50.0	52.0	54.0
FCS1	16FEB83	41.0	43.0	49.0	49.0	52.0
FCS1	21MAR83	42.0	48.0	48.0	48.5	49.5
FCS1	13APR83	58.0	50.0	49.5	49.5	50.0
FCS1	11MAY83	60.0	54.0	53.0	51.0	51.0
FCS1	16JUN83	64.5	59.0	56.0	54.0	54.0
FCS1	20JUL83	73.0	65.0	61.0	58.0	58.0
FCS1	22AUG83	71.0	66.5	64.0	60.5	60.0
FCS1	19SEP83	65.5	63.0	61.0	61.0	60.5
FCS1	27OCT83	49.0	55.5	58.5	59.0	58.5
FCS1	30NOV83	40.0	46.5	51.5	54.0	54.0
FCS1	6JAN84	33.0	38.0	44.5	48.0	49.5
FCS1	3FEB84	36.5	40.0	44.0	48.0	48.0
FCS1	15MAR84	50.5	43.5	45.5	46.5	47.0
FCS1	5MAY84	52.0	52.0	52.0	50.5	50.0
FCS1	4JUN84	63.0	54.0	54.0	53.0	52.0
FCS1	26JUN84	64.0	59.5	59.5	56.0	55.0
FCS1	24JUL84	68.0	60.5	61.0	58.0	57.5
FCS1	22AUG84	66.0	62.0	62.0	60.0	59.0
FCS1	24SEP84	55.0	56.5	61.0	60.0	59.0
FCS1	25OCT84	60.0	56.5	60.0	59.5	58.5
FCS1	4DEC84	36.5	44.0	52.0	54.5	54.0
FCS2	29OCT82	58.0	55.0	56.0	56.5	58.0
FCS2	1DEC82	52.0	51.0	52.0	55.0	55.0
FCS2	7JAN83	40.0	44.0	48.0	49.5	52.5
FCS2	16FEB83	39.0	40.5	45.0	45.0	44.0
FCS2	21MAR83	39.5	45.5	46.0	46.0	43.0
FCS2	13APR83	56.5	49.0	48.5	48.5	48.0
FCS2	11MAY83	58.0	52.0	50.5	50.0	48.5
FCS2	16JUN83	64.5	59.0	56.5	56.0	52.0
FCS2	20JUL83	73.0	66.0	63.0	61.0	56.0
FCS2	22AUG83	72.0	68.0	65.0	64.0	59.0
FCS2	19SEP83	68.0	64.5	64.0	64.0	60.0
FCS2	27OCT83	50.5	56.0	58.0	59.0	58.0
FCS2	30NOV83	42.0	48.0	51.0	52.0	55.0
FCS2	6JAN84	34.0	37.5	41.0	44.0	48.0

SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE	MONTH	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5
FCS2	3FEB84	37.0	38.0	40.0	42.0	46.0
FCS2	15MAR84	48.5	42.0	42.0	43.0	45.0
FCS2	5MAY84	52.5	54.0	53.5	52.5	50.0
FCS2	4JUN84	64.0	56.0	54.0	54.0	51.0
FCS2	26JUN84	64.5	62.0	58.5	58.5	54.0
FCS2	24JUL84	69.0	64.0	61.5	61.0	56.0
FCS2	22AUG84	67.0	65.0	63.0	63.0	58.0
FCS2	24SEP84	57.0	60.0	61.0	62.0	58.5
FCS2	25OCT84	61.5	60.0	59.0	61.0	58.0
FCS2	4DEC84	37.0	43.0	48.0	51.5	54.0
FCB1	29OCT82	58.0	56.5	56.5	58.0	.
FCB1	1DEC82	53.0	52.0	53.0	56.0	.
FCB1	7JAN83	40.5	46.0	48.0	53.0	.
FCB1	16FEB83	41.0	41.0	49.0	52.0	.
FCB1	21MAR83	40.5	47.0	47.5	48.0	.
FCB1	13APR83	56.5	50.0	49.0	49.0	.
FCB1	11MAY83	61.5	55.5	53.0	50.5	.
FCB1	16JUN83	62.5	60.0	58.0	54.0	.
FCB1	20JUL83	73.0	66.0	64.0	58.0	.
FCB1	22AUG83	72.0	68.0	66.0	61.0	.
FCB1	19SEP83	68.5	66.5	64.5	62.0	.
FCB1	27OCT83	51.0	57.5	58.0	59.5	.
FCB1	30NOV83	42.5	49.0	51.0	54.0	.
FCB1	6JAN84	34.5	40.0	42.0	48.0	.
FCB1	3FEB84	38.0	39.5	40.0	46.0	.
FCB1	15MAR84	52.0	44.0	43.0	46.0	.
FCB1	5MAY84	54.5	55.5	54.0	51.0	.
FCB1	4JUN84	64.5	56.5	54.5	52.0	.
FCB1	26JUN84	66.0	63.0	61.0	57.0	.
FCB1	24JUL84	70.0	64.5	62.5	58.0	.
FCB1	22AUG84	69.5	66.0	64.0	60.0	.
FCB1	24SEP84	58.0	61.5	61.5	60.0	.
FCB1	25OCT84	64.0	62.0	60.0	58.0	.
FCB1	4DEC84	39.5	48.0	49.5	54.0	.
FCB2	29OCT82	58.0	56.5	57.0	58.0	60.0
FCB2	1DEC82	45.0	46.0	46.0	46.0	59.0
FCB2	7JAN83	38.0	46.5	47.0	47.0	56.0
FCB2	16FEB83	45.0	46.0	46.0	46.0	49.0
FCB2	21MAR83	38.0	46.5	47.0	47.0	56.0
FCB2	13APR83	57.0	49.0	48.5	59.0	60.0
FCB2	11MAY83	64.0	52.0	52.0	51.5	60.0
FCB2	16JUN83	64.0	59.0	56.0	55.5	61.0
FCB2	20JUL83	75.0	66.5	62.0	60.0	61.0
FCB2	22AUG83	76.0	68.5	64.5	63.0	60.5
FCB2	19SEP83	69.0	65.0	64.0	63.5	61.5
FCB2	27OCT83	53.0	57.0	59.0	59.0	59.0

SOIL TEMPERATURE DATA FOR CUMBERLAND PLATEAU SOIL PITS

SITE	MONTH	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5
FCB2	30NOV83	44.0	49.0	52.0	53.5	55.0
FCB2	6JAN84	36.0	41.0	44.0	46.0	49.0
FCB2	3FEB84	42.0	40.0	42.0	44.0	47.0
FCB2	15MAR84	56.5	44.5	44.0	44.5	46.0
FCB2	5MAY84	54.0	54.5	53.0	56.5	50.5
FCB2	4JUN84	66.5	56.5	54.0	53.5	52.0
FCB2	26JUN84	66.5	63.0	58.0	57.0	62.0
FCB2	24JUL84	72.5	65.0	60.5	60.0	57.0
FCB2	22AUG84	70.0	66.5	62.5	62.0	59.0
FCB2	24SEP84	59.5	61.0	61.0	61.5	59.5
FCB2	25OCT84	66.0	62.0	60.0	60.0	58.0
FCB2	4DEC84	40.5	49.0	50.5	52.0	54.0

APPENDIX B

SOIL PROFILE DESCRIPTIONS

Appendix B1. Description of Catoosa Upland, Site One

Location: Catoosa Upland, site one.
Classification: fine-loamy, mixed, mesic Typic Fragiudults.
Physiographic position: Upslope extremity of upland landtype.
Convex ridgetop, 13 percent slope with aspect dominantly north.
Convex micro-relief
Parent material: Loess over residuum from competent, horizontally bedded sandstone bedrock.
Drainage: Well drained.

Described by: R.D. Hammer and G.J. Buntley.

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory

Oa 3 - 0 cm. Very dark brown (7.5YR 2/2) and dark reddish brown (5YR 3/2) decomposed leaf litter; very many, fine and very fine, and many, medium, multidirectionally, branched roots throughout; very many, very fine, subangular, translucent quartz grains lightly stained with organic matter; abrupt smooth boundary.

A 0 - 5 cm. Brown (10YR 4/3) loam; very fine granular structure; very friable; very many, fine and very fine, and common, medium, multidirectionally, branched roots throughout; very many, very fine, subangular, translucent quartz grains, lightly stained with organic matter, in ped interiors and on ped faces; very strongly acid (pH 4.7); clear irregular boundary.

BA 5 - 33 cm. Yellowish brown, (10YR 5/4) loam; weak, very coarse, short vertical axis, rough-surface, subangular prisms, parting to weak, coarse and medium, rough-surface, subangular blocks, parting to moderate, fine, and very fine, rough-surface, subangular blocks, and to single grains;

friable; common, very fine, and few, fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical ped faces; very few, medium and fine, moderately long, round, straight, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; few, very fine, unstained, transparent, subangular, quartz grains, and many, medium and fine, and common, coarse, lightly iron-stained, translucent, subangular quartz grains on ped faces, few, medium and fine, subangular dark minerals in ped interiors; very strongly acid (pH 4.7); gradual smooth boundary.

Bt 33 - 48 cm. Dark yellowish brown (10YR 4.5/5) loam; weak, very coarse, rough-surface, subangular prisms, parting to weak, coarse and medium, rough-surface, subangular blocks, parting to moderate, fine, rough-surface, subangular blocks; friable; few, fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds, and few, fine and very fine, multidirectionally branched roots throughout; very thin, very patchy, clay skins on vertical faces and very thin, extremely patchy, clay skins on horizontal faces of primary peds, very thin, very patchy, clay skins on horizontal and vertical faces of secondary peds, and very thin, moderately patchy, clay skins on horizontal and vertical faces of subsecondary peds; common, fine and very fine, long and moderately long, round, linear, multidirectional, compound, unobstructed, tubular pores in ped interiors and opening to ped faces; many, fine and very fine, lightly iron-stained, subangular, quartz grains, and few, fine and very fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary, secondary, and subsecondary peds, and few, medium and fine, subangular, dark minerals in ped interiors; very strongly acid (pH 4.5); gradual smooth boundary;

2Btx1 48 - 60 cm. Yellowish brown (10YR 4/6) loam; moderate to weak; very coarse, short vertical axis, rough-surface, subangular prisms, parting to moderate to weak, coarse and medium, rough-surface, subangular blocks, parting to strong to moderate, fine, rough-surface, subangular blocks; firm and brittle; few, medium and fine, unbranched, vertically oriented roots on vertical faces of primary peds; very thin, very patchy, clay skins on horizontal and vertical faces of primary peds, and very thin, moderately patchy, clay skins on horizontal and vertical faces of secondary peds; very few, very fine, short, round, linear, horizontal, simple, obstructed, tubular pores in ped interiors; many, fine and very fine, lightly iron-stained, translucent, subangular quartz grains, and few, fine and very fine, unstained transparent, subangular quartz grains on faces of primary, secondary, and subsecondary peds, and few, medium and fine, subangular, dark minerals in ped interiors; extremely acid (pH 4.4); gradual smooth boundary.

2Btx2 60 - 73 cm. Yellowish brown (10YR 5/6) clay loam; moderately thick, moderately patchy, dark yellowish brown (10YR 4/6) color coatings on vertical faces of primary peds; weak, very coarse, short vertical axis, rough-surface, subangular prisms, parting to moderate to weak, very coarse and coarse, rough-surface, angular blocks, parting to strong, coarse and medium, rough-surface, angular blocks; firm and brittle; very few, medium, unbranched, vertically oriented roots on vertical faces of primary peds; thin, nearly continuous, clay skins on horizontal and vertical faces of primary peds, and moderately thick, moderately patchy, clay skins on vertical faces of secondary and subsecondary peds; very few, very fine, short, round, linear, horizontal and vertical, simple, obstructed, tubular pores in ped interiors and opening to horizontal ped faces; few, fine and very fine, and very few, medium, unstained, translucent, subangular, quartz grains in ped interiors, and very few, very fine, unstained, translucent, subangular, quartz grains on horizontal and vertical faces of primary peds; extremely acid (pH 4.4); clear smooth boundary.

2Bt1 73 - 85 cm. Dark yellowish brown (10YR 4/6) and yellowish brown (10YR 5/6) clay loam; few, medium and fine, distinct, abrupt-boundary, strong brown (7.5YR 5/8) and yellowish red (5YR 5/8) iron stains on faces and in interiors of peds; weak, very coarse and coarse, rough-surface, angular blocks; very friable; few, medium and fine, moderately branched, vertically oriented roots on ped faces, and very few, fine, unbranched, horizontally oriented roots on ped faces; moderately thick, continuous, clay skins on horizontal and vertical faces of primary peds, and thick, slightly patchy, clay skins on vertical faces of secondary peds; many, fine, and very fine, and few, medium, unstained, translucent, angular, quartz grains, and few, fine and very fine, and very few, medium, lightly iron-stained, translucent, angular quartz grains in interiors and on horizontal and vertical faces of primary and subprimary peds; very strongly acid (pH 5.0); abrupt smooth boundary.

2Bt2 85 - 95 cm. Dark yellowish brown (10YR 4/4) and olive brown (2.5Y 4/4) clay; common, medium, distinct, sharp-boundary, light olive brown (2.5Y 5/8) and yellowish red (5YR 5/8) iron stains on horizontal and vertical faces of primary and secondary peds, and few, medium, distinct, sharp-boundary, strong brown (7.5YR 4/4) organic matter stains on horizontal faces of primary and secondary peds; weak, very coarse, smooth-surface, horizontal blocks, parting to moderate to weak, coarse and medium, smooth-surface blocks, parting to moderate, fine, smooth-surface, angular blocks; common, fine, and very fine, multidirectionally branched, horizontally oriented roots on horizontal and vertical faces of primary and secondary peds, and few, fine and very fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary, secondary and subsecondary peds; thick, continuous, clay skins on horizontal faces, and moderately thick, patchy, clay skins on vertical faces of primary peds, and very thick, moderately patchy clay skins on horizontal faces of secondary and subsecondary peds; common, fine and very fine, and few, medium, unstained, translucent, angular quartz grains on vertical faces of primary peds and on horizontal and vertical faces of secondary and subsecondary peds, and very few, medium, fine, and very fine, unstained, translucent, angular quartz grains in ped interiors, and few, fine and very fine, and very few, medium, lightly iron-stained, translucent, angular quartz grains on vertical faces of primary peds and on horizontal and vertical faces of secondary and subsecondary peds; very strongly acid (pH 4.5); abrupt smooth boundary.

R 95 cm. Competent, horizontally bedded sandstone bedrock.

Appendix B2. Description of Catoosa Upland, Site Two

Location: Catoosa Upland, site two.
Classification: fine-loamy, mixed, mesic Typic Fragiudults.
Physiographic position: Shoulder slope of convex ridge, approximately 120 meters from ridge summit, 10 percent slope with aspect dominantly north.
Parent material: Loess over colluvium and residuum from sandstone bedrock.
Drainage: Well drained.

Described by: R.D. Hammer and G.J. Buntley.

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

Oa 2.5 - 0 cm. Very dark brown (7.5YR 2/2) and dark reddish brown (5YR 2/2) decomposed leaf litter; many medium, fine, and very fine, multi-directionally branched roots throughout; very many, very fine, subangular, translucent quartz grains lightly stained with organic matter; abrupt smooth boundary.

A 0 - 7.5 cm. Dark brown to dark yellowish brown (10YR 4/3.5) loam; strong to moderate, very fine, smooth-surface, subangular blocky structure; very friable; common, fine and very fine, and few, medium, multidirectionally branched roots throughout, and very few, coarse, horizontal roots vertically branched; common, very fine, subangular, translucent quartz grains lightly stained with organic matter on ped faces; very many, very fine, subangular, transparent quartz grains in ped interiors; extremely acid (pH 4.4); gradual smooth boundary.

E 7.5 - 20 cm. Dark yellowish brown (10YR 4/4.5) and yellowish brown (10YR 5/4) loam; weak, medium, rough-surface, subangular blocks parting to moderate to weak, fine and very fine, rough-surface, subangular blocks parting to strong to moderate, fine and very fine, rough-surface granules; very friable; common, medium, multidirectionally branched roots on horizontal and vertical ped faces, and fine, multidirectionally branched roots throughout, and few, coarse, infrequently branched, vertically oriented roots; very few, fine and very fine, multidirectional, unbranched, linear, unobstructed, tubular pores in ped interiors and opening to faces of primary and subprimary peds; common, fine and very fine, subangular, translucent quartz grains lightly stained with organic matter, on ped faces, and common, very fine and few, fine, subangular, transparent quartz grains in ped interiors; extremely acid (pH 4.4); clear smooth boundary.

Bt1 20 - 30 cm. Dark yellowish brown (10YR 4/4.5) loam; weak, coarse and medium, rough-surface, subangular blocks parting to moderate to weak, fine and very fine, rough-surface subangular blocks; friable; few, fine and medium, multidirectionally branched roots on horizontal and vertical faces of primary peds, and very few, fine and very fine, multidirectionally branched roots on vertical faces of subprimary peds; very thin, very patchy, clay skins on horizontal and vertical faces of primary peds, and very thin, extremely patchy, clay skins on vertical faces of subprimary peds; very few, fine and very fine, multidirectional, unbranched, linear, unobstructed, tubular pores in ped interiors and opening to faces of primary and subprimary peds; common, fine and very fine, subangular, translucent quartz grains lightly stained with organic matter, on ped faces, and common, very fine and few, fine, subangular, transparent quartz grains in ped interiors; extremely acid (pH 4.5); gradual wavy boundary.

Bt2 30 -55 cm. Yellowish brown (10YR 5/6) loam; weak, very coarse, rough-surface, short vertical axis, subangular prisms parting to weak, coarse and medium, rough-surface, subangular blocks parting to weak and very weak, fine and very fine, rough-surface, subangular blocks; friable; few, medium and fine, branched roots on horizontal and vertical faces of primary peds, and few, fine and very fine, branched roots on horizontal and vertical faces of secondary and subsecondary peds; thin, moderately patchy clay skins on horizontal and vertical faces of primary and secondary peds, and thin, extremely patchy clay skins on horizontal and vertical faces of subsecondary peds; common, very fine, and few, fine, subangular, transparent quartz grains in ped interiors; 20 percent, medium, unoriented, angular, sandstone channers; extremely acid (pH 4.5); abrupt smooth boundary.

2Bx1 55 - 70 cm. Yellowish brown (10YR 5/6 and 10YR 5/5) loam; few, medium and fine, faint to very faint, sharp-boundary, light yellowish brown (10YR 6/4) and pale brown (10YR 6/3) mottles on ped faces; weak to moderate, very coarse, rough-surface, short vertical axis, subangular prisms with conchoidal fracture planes in ped faces, parting to weak, very coarse, rough-surface, angular blocks, parting to moderate to weak, medium, rough-surface, angular blocks; firm and brittle; very few, fine, vertical, unbranched roots on vertical faces of primary peds; 15 percent, medium, unoriented, angular, sandstone channers; extremely acid (pH 4.4); gradual smooth boundary.

2Bx2 70 - 90 cm. Yellowish brown (10YR 5/6 and 10YR 5/5) and dark yellowish brown (10YR 4/6) loam; common, medium, faint, sharp-boundary, pale brown (10YR 6/3) mottles and few, fine, faint, clear-boundary, yellowish brown (10YR 5/8) mottles on ped faces; moderate, very coarse, rough-surface, short vertical axis, subangular prisms with conchoidal fracture planes in ped faces, parting to weak, coarse, rough-surface, angular blocks, parting to moderate, medium and fine, rough-surface, angular blocks; firm and brittle; very few, fine, unbranched roots on vertical faces of primary peds; thin, nearly continuous clay skins on horizontal faces of primary peds, thin, moderately patchy clay skins on horizontal faces of secondary peds and on horizontal and vertical faces of secondary and subsecondary peds; 15 percent, coarse and medium, oriented, subangular, sandstone channers; extremely acid (pH 4.4); abrupt irregular boundary.

2B/C 90 - 120 cm. Brownish yellow (10YR 6/6) loam; few, medium and fine, faint, clear boundary, dark yellowish brown (10YR 6/6) mottles on ped faces; weak, very coarse, rough-surface, angular blocks, parting to moderate, coarse and medium, rough-surface, angular blocks; firm; few, fine and very fine branched roots on horizontal ped faces, and very few, fine and very fine, unbranched roots on vertical ped faces; thick to moderately thick, continuous clay skins on horizontal faces, and thin, moderately patchy clay skins on vertical faces of primary peds, and on horizontal and vertical faces of subprimary peds; 25 percent, coarse and medium, oriented, subangular, sandstone channers; extremely acid (pH 4.4).

R 120 cm. Slightly fractured sandstone bedrock.

Remarks:

A stone line was present in the B2 horizon just above the fragipan, and gave the appearance that the soil had been truncated during or prior to deposition of the overlying soil material.

Appendix B3. Description of Catoosa Slope, Site One

Location: Catoosa Slope, site one.
Classification: fine-silty, mixed, mesic, Humic Hapludults.
Physiographic position: North-facing, 32 percent slope with horizontally stratified shale bedrock. Nearly linear micro-relief.
Parent material: Loess mixed with colluvium containing sandstone fragments over residuum from shale.
Drainage: Well drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

A1 0 - 7 cm. Dark brown (7.5YR 3.5/2) silt loam; moderately thick, nearly continuous, dark reddish brown (5YR 3/2) organic matter coatings on horizontal and vertical faces of primary and subprimary peds, and thin, slightly patchy, dark reddish brown (5YR 3/2) organic matter coatings on horizontal and vertical faces of secondary peds; moderate, medium and fine, oriented, rough-surface, subangular-angular blocks, parting to strong, fine and very fine, rough-surface granules; friable; many, fine and very fine, multidirectionally branched roots throughout; few, small worm casts and filled worm channels; common, fine and very fine, unstained, translucent, quartz grains on horizontal and vertical faces of primary, subprimary, and secondary peds; 15 percent, large and medium, unoriented, angular, sandstone fragments; medium acid (pH 6.0); abrupt, wavy boundary.

A2 7 - 15 cm. Dark yellowish brown (10YR 3.5/3) silt loam; thick, slightly patchy and very patchy, and thin, continuous, dark brown (7.5YR 3/2) organic matter coatings on vertical faces of primary and subprimary peds; weak, medium and fine, oriented, irregular-surface, subangular-angular blocks, parting to moderate, fine and very fine, rough-surface granules; friable; common, fine and very fine, moderately branched, multidirectional roots throughout, and few, medium, moderately branched, vertically oriented roots on vertical faces of primary peds; few, small worm casts and filled worm channels; many, fine and very fine, unstained, translucent, quartz grains on horizontal and vertical faces of primary, subprimary and secondary peds, and common, very fine, and few, fine, unstained, translucent, subangular quartz grains, in interiors of peds; 15 percent, medium, unoriented, angular, sandstone fragments; strongly acid (pH 5.5); clear irregular boundary.

AB 15 - 26 cm. Dark yellowish brown (10YR 4/4) silt loam; moderately thick, slightly patchy, dark yellowish brown (10YR 3/3) color coatings on vertical faces of primary and subprimary peds, and thin, extremely patchy, dark yellowish brown (10YR 4/6) color coatings on horizontal faces of primary peds; weak, coarse, irregular-surface, subangular blocks, parting to weak, medium and fine, oriented, irregular-surface, subangular-angular blocks; friable; few, fine and very fine, multidirectionally branched roots throughout, and few, medium, horizontally oriented roots, moderately vertically branched, onto vertical faces of primary peds; moderately thick, very patchy, clay skins on vertical faces, and lining root channels in ped interiors, and thin, nearly continuous, clayskins on horizontal and vertical faces of primary peds, and moderately thick, very patchy clay skins lining root channels in interiors of, and thin, nearly continuous, clay skins on horizontal and vertical faces of subprimary peds; few, fine, short, round, linear, horizontal and vertical, simple, unobstructed, tubular pores in interiors and opening to faces of primary and subprimary peds; few, small, worm casts and filled worm channels; few, fine and very fine, unstained, translucent, subangular quartz grains on faces and in interiors of primary and subprimary peds; 15 percent, medium and small, unoriented, angular, sandstone fragments; strongly acid (pH 5.3); clear wavy boundary.

Bt1 26 - 47 cm. Yellowish brown (10YR 5/6) silt loam; thin, nearly continuous, dark yellowish brown (10YR 3/6) color coatings on horizontal and vertical faces of primary and secondary peds, and thin, moderately patchy, dark yellowish brown (10YR 3/6) color coatings on horizontal and vertical faces of subsecondary peds; moderate to weak, very coarse, oriented, short vertical axis, rough-surface, subangular-angular prisms, parting to moderate, medium and fine, oriented, irregular-surface, subangular-angular blocks; firm and brittle; few, medium and fine, moderately branched, horizontally oriented roots along horizontal and vertical faces of primary peds; moderately thick, very patchy, clay skins on vertical faces, and lining pores in, and thin, nearly continuous, clay skins on horizontal and vertical faces of primary peds, moderately thick, very patchy, clay skins on vertical faces of secondary peds, and thin to very thin, continuous, clay skins on horizontal and vertical faces of subsecondary peds; common, medium, long, round, linear and curved, multidirectional, simple, unobstucted, tubular pores in ped interiors and opening to ped faces; very few, fine and very fine, unstained, translucent, subangular quartz grains on vertical faces of primary and secondary peds, and very few, very fine, unstained, translucent, subangular quartz grains in ped interiors; 10 percent, small, unoriented, angular, sandstone fragments; strongly acid (pH 4.2); abrupt irregular boundary.

Bt2 47 - 71 cm. Yellowish brown (10YR 5/6) silt loam; thin, nearly continuous, dark yellowish brown (10YR 3/6) color coatings on horizontal and vertical faces of primary and secondary peds; moderate, coarse, oriented, short vertical axis, irregular-surface, subangular-angular prisms, parting to strong to moderate, coarse and medium, smooth-surface, subangular blocks; firm and brittle; few, medium and fine, moderately branched, vertically oriented roots on vertical faces of primary peds; thick, very patchy, clay skins on vertical faces, and moderately thick, nearly continuous clay skins on horizontal and vertical faces, and lining pores and root channels in interiors of primary peds, and thin, continuous, clay skins on horizontal and vertical faces of secondary and subseconary peds; very few, very fine, short, round, linear, horizontal and vertical, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; very few, very fine, unstained, translucent, subangular quartz grains on vertical faces and in interiors of primary and secondary peds; 10 percent, small, unoriented, angular, sandstone frangments; strongly acid (pH 5.1); gradual smooth boundary.

2Bt3 71 - 80 cm. Yellowish red (5YR 4/6) silt loam; thick, nearly continuous, reddish brown (5YR 4/4) color coatings on horizontal and vertical faces of subsecondary peds, and moderately thick, moderately patchy, strong brown (7.5YR 4/6 and 5/8) color coatings on horizontal and vertical faces of primary peds; weak, coarse, short vertical axis, rough-surface, angular prisms, parting to moderate to weak, fine and very fine, rough-surface, angular blocks; firm; few, medium and fine, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, very patchy, and moderately thick, continuous, clay skins on horizontal and vertical faces of primary peds, and thick, continuous, clay skins on horizontal and vertical faces of secondary and subsecondary peds; very few, very fine, unstained, translucent, subangular, quartz grains on vertical faces of primary peds; 20 to 25 percent, small, unoriented, angular, shale and sandstone channers; very strongly acid (pH 5.0); gradual wavy boundary.

2Bt4 80 - 110 cm. Yellowish red (5YR 6/4) silty clay loam; common, medium, distinct, sharp-boundary, reddish yellow (7.5YR 6/8) mottles in interiors and on faces of subsecondary peds; thick, nearly continuous, yellow (10YR 7/6) color coatings on horizontal and vertical faces of primary peds, and thick, nearly continuous, reddish yellow (7.5YR 7/6 and 6/6) color coatings on horizontal and vertical faces of secondary and subsecondary peds; moderate to weak, coarse, short vertical axis, smooth-surface, angular prisms, parting to moderate, medium and fine, smooth-surface, angular blocks; firm; few, medium, infrequently branched, vertically oriented roots on vertical faces of primary peds, branching to few, very fine, infrequently branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds; thick, continuous, clay skins on horizontal and vertical faces of primary and secondary peds; very few, very fine, unstained, translucent, subangular, quartz grains on vertical faces of primary peds; 15 to 20 percent, small, unoriented, angular and subangular, shale and sandstone channers; very strongly acid (pH 4.9); clear smooth boundary.

2BtC1 110 - 147 cm. Strong brown (7.5YR 5/6) silty clay loam;

common, medium, distinct, sharp-boundary, reddish yellow (7.5YR 7/8) mottles in interiors of primary, secondary, and subsecondary peds; thick, nearly continuous, brownish yellow (10YR 6/6) color coatings on horizontal and vertical faces of primary peds, and thick, moderately patchy, brownish yellow (10YR 6/6) and reddish yellow (7.5YR 6/6) color coatings on horizontal and vertical faces of secondary and subsecondary peds; moderate, coarse, rough-surface, horizontal blocks, parting to strong to moderate, medium and fine, smooth-surface, angular blocks, firm; few, fine, unbranched, horizontally and vertically oriented roots on horizontal and vertical faces of primary peds; very thick, continuous, clay skins on horizontal ped faces, and thick, continuous, clay skins on vertical faces of primary, secondary, and subsecondary peds,; extremely acid (pH 4.4); clear smooth boundary.

2BtC2 147 - 182 cm. Light yellowish brown (2.5Y 6/4), light gray (5Y 7/2), and brownish yellow (10YR 6/8) silty clay; thick, slightly patchy, very pale brown (10YR 7/4), and moderately thick, very patchy, light gray (2.5Y 7/2) color coatings on horizontal faces of primary peds, and moderately thick, moderately patchy, brownish yellow (10YR 6/6) color coatings on horizontal and vertical faces of subprimary peds; moderate, coarse, irregular-surface, horizontal blocks, parting to moderate, medium and fine, smooth-surface, angular blocks; firm; very few, fine, unbranched, horizontally and vertically oriented roots on horizontal and vertical faces of primary peds; very thick, continuous, clay skins on horizontal ped faces, and thick, continuous, clay skins on vertical faces of primary, subprimary peds; very strongly acid (pH 4.7); clear smooth boundary.

2BtC3 182 - 240 cm. Light yellowish brown (2.5Y 6/4) silty clay; common, fine, faint, clear-boundary, brownish yellow (10YR 6/6) and yellow (10YR 7/6) mottles in interiors of primary, subprimary peds, and on faces of subprimary peds; thick, nearly continuous, light gray (2.5Y 7/2) and moderately thick, extremely patchy, white (2.5Y 8/2) color coatings on horizontal faces of primary peds, and thick, slightly patchy, very pale brown (10YR 7/4) and moderately thick, very patchy, light gray (2.5Y 7/2) color coatings on horizontal and vertical faces of subprimary peds; strong to moderate, coarse, smooth-surface, horizontal blocks, parting to moderate, medium and fine, smooth-surface, angular blocks; firm; very few, fine, unbranched, horizontally oriented roots on horizontal faces of primary and subprimary peds; very thick, continuous, clay skins on horizontal faces, and thick, continuous, clay skins on vertical faces of primary and subprimary peds; very strongly acid (pH 4.6).

Remarks:

2BtC1 horizon and all sampled underlying horizons have weak, relict, horizontally stratified shale structure in ped interiors, and have abrupt boundaries to clay skins on ped surfaces.

Soil was augured to 280 cm. Roots and clay skins were observed in soils to this depth.

Appendix B4. Description of Catoosa Slope, Site Two

Location: Catoosa Slope, site two.
Classification: fine-silty, mixed, mesic Typic Fragiudults.
Physiographic position: Upslope extremity of 37 percent north-facing slope. Slightly convex micro-relief.
Parent material: Loess mixed with colluvium from sandstone, over residuum from shale bedrock.
Drainage: Well drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values determined in the laboratory.

A1 0 - 9 cm. Dark brown (10YR 3/3) silt loam; weak, medium, rough-surface, angular blocks, parting to moderate, fine, rough-surface, angular blocks and rough-surface granules; friable; many, very fine, and common, medium and fine, multidirectionally branched roots throughout, and few, coarse, horizontal roots vertically branched; moderately thick, nearly continuous, organic matter coatings on horizontal and vertical faces of primary and subprimary peds; few, fine, unstained, translucent, subangular quartz grains on faces of primary and subprimary peds; 25 percent, large and medium, unoriented, angular, sandstone fragments; strongly acid (pH 5.3); clear smooth boundary.

A2 9 -15 cm. Dark brown (10YR 3/3) loam; moderately thick, moderately patchy, brown (10YR 4.5/3) color coats on horizontal and vertical faces of primary and subprimary peds; moderate, medium, rough-surface, oriented, subangular-angular blocks and moderate to weak, fine and very fine, rough-surface, subangular blocks; firm; common, fine and very fine, and few, medium, multidirectionally branched roots throughout, and few, coarse, horizontal roots, branching to medium, vertically oriented roots on vertical faces of primary peds; moderately thick to thin, nearly continuous organic matter coatings on horizontal and vertical faces of primary and subprimary peds; few, fine, unstained, translucent, subangular quartz grains on faces of primary and subprimary peds; 20 percent, coarse and medium, unoriented, angular sandstone fragments; very strongly acid (pH 5.0); gradual irregular boundary.

BA 15 - 26 cm. Dark brown to brown (10YR 4/3) silt loam; thin, very patchy, dark brown (10YR 3/3) organic matter coatings on horizontal and vertical faces of primary and subprimary peds; weak, coarse, rough-surface subangular blocks, parting to moderate to very fine, rough-surface subangular blocks; very friable; common, very fine, and few, fine, multidirectionally branched roots throughout, and few, medium, and very few, coarse, moderately branched roots on horizontal and vertical faces of primary peds; common, fine and very fine, short, round, curved, multidirectional, simple, unobstructed tubular pores in ped interiors and opening to ped faces; few, fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and subprimary peds; 20 percent, medium, unoriented, angular sandstone fragments; very strongly acid (pH 4.9); gradual irregular boundary.

BE 26 - 33 cm. Yellowish brown (10YR 5/5) silt loam; moderately thick, very patchy, dark yellowish brown (10YR 4/4) color coats on horizontal and vertical faces of primary and subprimary peds; moderate, coarse, rough-surface subangular blocks, parting to strong to moderate, medium and fine, rough-surface, subangular blocks; firm and weakly brittle; common, very fine, and few, medium and fine, moderately branched roots on horizontal faces of primary and subprimary peds; thin, moderately patchy, clay skins on horizontal and vertical faces of primary and subprimary peds; common, medium and fine, short, round, curved, multidirectional, compound, unobstructed tubular pores in ped interiors; few, fine, unstained, translucent, subangular quartz grains on faces of primary and subprimary peds; common, medium and fine, subangular dark minerals on faces and interiors of primary and subprimary peds; 15 percent, medium, unoriented, angular sandstone fragments; extrememly acid (pH 4.1); abrupt smooth boundary.

2Btx1 33 - 50 cm. Yellowish brown (10YR 5.5/6) loam; thick, moderately patchy, yellowish brown (10YR 5/4), and thin, very patchy, light gray (10YR 7/2) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; moderate, medium, rough-surface, short vertical axis, angular prisms parting to moderate to weak, medium, rough-surface, subangular blocks, parting to moderate, fine and very fine, rough-surface blocks; firm and brittle; few, medium and fine, vertically oriented, unbranched roots on vertical faces of primary peds; thick, continuous, clay skins on horizontal and vertical faces of, and lining pores in primary peds, moderately thick, continuous, clay skins on horizontal and vertical faces of secondary peds, and thin, continuous clay skins on horizontal and vertical faces of subsecondary peds; very many, very fine, and common, fine, short, round, curved, horizontal, simple, unobstructed, tubular pores in ped interiors; thin, moderately patchy coatings of very fine and fine, unstained, translucent, subangular quartz grains on vertical faces of primary, secondary, and subsecondary peds; very strongly acid (pH 4.9); abrupt wavy boundary.

2Btx2 50 - 72cm. Yellowish brown (10YR 5.5/6) loam; thick, very patchy, yellowish brown (10YR 5/4), and moderately thick, slightly patchy, light gray (10YR 7/2) color coatings on hoirzontal and vertical faces of primary, secondary, and subsecondary peds; strong to moderate, coarse to medium, rough-surface, short vertical axis, angular prisms parting to moderate, coarse, rough-surface, subangular blocks parting to strong to moderate, medium and fine, rough-surface, subangular blocks; firm and very brittle; few, medium and fine, vertically oriented, unbranched roots on vertical faces of primary peds; thick, continuous, clay skins on horizontal and vertical faces of primary, secondary and subsecondary peds; few, very fine, short, oblong, curved, horizontal, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; thick to moderately thick, slightly patchy, coatings of fine and very fine, unstained, translucaent, subangular quartz grains on vertical faces of primary, secondary, and subsecondary peds; very strongly acid (pH 4.9); gradual smooth boundary.

2BtC1 72 - 88 cm. Brownish yellow (10YR 6/6) loam; thin, moderately patchy, very pale brown (10YR 7/3) color coatings on horizontal and vertical faces of primary peds, and moderately thick, nearly continuous, yellowish red (5YR 4/6), color coatings on horizontal and vertical faces of subprimary peds; moderate, coarse, smooth-surface, horizontally oriented, angular blocks parting to strong to moderate, medium and fine, smooth-surface angular blocks; few, medium, fine, and very fine, horizontally oriented, moderately branched roots on horizontal faces of primary and subprimary peds; thick, continuous clay skins on horizontal and vertical faces of primary peds, and thick, nearly continuous clay skins on horizontal and vertical faces of subprimary peds;

thin, moderately patchy, coatings of fine and very fine, unstained, translucent, subangular quartz grains on vertical faces of primary and subprimay peds; very strongly acid (pH 4.8); gradual smooth boundary.

2BtC2 88 - 97 cm. Yellowish brown (10YR 5/6) loam; thin, moderately patchy, yellowish brown (10YR 5/4) and reddish brown (5YR 5/4) color coatings on horizontal and vertical faces of primary and subprimary peds; moderate, coarse, smooth-surface, horizontally oriented, angular blocks parting to moderate, medium, and fine, smooth-surface, horizontally oriented, angular blocks, parting to strong to moderate, medium to fine, irregular surface, subangular blocks; friable; few, fine and very fine, moderately branched, horizontally oriented roots on horizontal faces of primary and subprimary peds; moderately thick, continuous clay skins on horizontal faces of primary and subprimary peds; thin, extremely patchy coatings of very fine, unstained, translucent, subangular quartz grains on vertical faces of primary peds; very strongly acid (pH 4.7); gradual smooth boundary.

2BtC3 97 - 116 cm. Yellowish brown (10YR 5/6) and light gray (10YR 7/2) silty clay loam; moderately thick, moderately patchy, yellowish brown (10YR 5/8) and dark grayish brown (10YR 4/2) color coatings on horizontal and vertical faces of primary and subprimary peds; moderate to weak, medium, horizontally oriented, smooth-surface, angular blocks, parting to moderate to weak, medium and fine, rough-surface, subangular blocks; very friable; few, fine and very fine, moderately branched, horizontally oriented roots on horizontal faces of primary peds; thick, continuous, clay skins on horizontal faces of primary and subprimary peds; common, very fine, unstained, translucent, subangular quartz grains on horizontal faces of primary and subprimary peds; very strongly acid (pH 4.7); gradual smooth boundary.

2BtC4 116 - 130 cm. Light brownish gray (2.5Y 6/2) and yellowish brown (10YR 5/6) silt loam; thick, nearly continuous, light gray (2.5Y 7/2) color coatings on horizontal and vertical faces of primary and subprimary peds; strong to moderate, medium, smooth-surface, horizontally oriented, angular blocks, parting to strong fine, rough-surface, subangular blocks; firm; few, fine and very fine, multidirectionally branched roots on horizontal faces of primary peds; moderately thick, continuous, clay skins on horizontal faces of primary and subprimary peds; common, very fine, unstained, translucent, subangular quartz grains on horizontal faces of primary and subprimary peds; very strongly acid (pH 4.6); clear smooth boundary.

2CB 130 - 142 cm. Yellowish brown (10YR 5/4) silt loam; moderately thick, moderately patchy, light gray (10YR 7/2) and olive brown (2.5Y 3/6) color coatings on horizontal faces of primary and secondary peds; moderate, medium, horizontally oriented, smooth-surface angular blocks, parting to weak, fine, irregular-surface platelets; friable; very few, very fine, horizontally oriented, unbranched roots on horizontal faces of primary peds; thin, moderately patchy, clay skins on horizontal faces of primary and secondary peds; very few, very fine, unstained, translucent, subangular quartz grains on horizontal faces of primary peds; very strongly acid (pH 4.7).

Remarks:

Peds from 2BtC3, 2BtC4 and 2CB horizons possess very sharp boundaries between clay skins and ped interiors. Ped interiors display stratified, weathered shale fragments.

Orientation of soil sturctural units appears to have been influenced by the orientation of the shale bedrock.

Shale fragments were infrequently found in 2BtC1 and 2BtC2 horizons, but no evidence remains of internal stratification within the fragments.

Appendix B5. Description of Catoosa Bottom, Site One

Location: Catoosa Bottom, site one.
Classification: coarse-loamy, mixed, mesic, Aquic Dystrochrepts.
Physiographic position: Upslope extremity of first order botoom with 2 percent slope.
Parent material: Colluvial/alluvial sediments from surrounding uplands.
Drainage: Somewhat poorly drained.

Desribed by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

A 0 - 7 cm. Dark brown (10YR 3/3) loam; moderate to weak, medium, unoriented, rough-surface, subangular-angular blocks parting to moderate, fine, and very fine, rough-surface granules; very friable; many fine, and common, medium, multidirectionally branched roots throughout, but becoming horizontally oriented at the horizon boundary, and few, coarse, horizontally oriented, vertically branched roots; few, coarse, unstained translucent, subangular, quartz grains, lightly stained with organic matter, on horizontal and vertical faces of primary and secondary peds; extremely acid (pH 4.2); clear smooth boundary.

Bw 7 - 20 cm. Grayish brown (2.5Y 5/2) sandy loam; common, medium and fine, prominent, sharp-boundary, yellowish red (5YR 3/6) and strong brown (7.5YR 3/6) mottles on horizontal and vertical faces of primary, secondary, and subsecondary peds and lining insides of tubular pores, and moderately thick, moderately patchy, light yellowish brown (10YR 6/4) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; weak to very weak, rough-surface, short, angular prisms parting to weak, medium and fine, rough-surface, angular blocks; friable; common, fine and very fine, multidirectionally branched roots throughout; very thin, extremely patchy, clay skins on horizontal and vertical faces of primary peds; few, fine, short, round, curved, multidirectional, branched, unobstructed, tubular pores in ped interiors and opening to ped faces; many, medium and fine, and few, coarse and medium, translucent, subangular quartz grains lightly stained with organic matter, on horizontal and vertical faces of primary, secondary, and subsecondary peds, and very few, fine, unstained, translucent, subangular quartz grains on vertical faces of primary peds; very strongly acid (pH 4.5); abrupt smooth boundary.

2A' 20 - 29 cm. Gray (10YR 5/1) fine sandy loam; few, medium and fine, distinct, clear-boundary, light yellowish brown (10YR 6/4) mottles, and few medium and fine, distinct, sharp-boundary, yellowish red (5YR 3/6) iron stains in the soil matrix and lining insides of tubular pores; massive; firm; few, medium and fine, unbranched, vertically oriented roots; common, medium, fine, and very fine, short, round, curved, multidirectional, branched, unobstructed, tubular pores; many, medium and fine, translucent, subangular quartz grains lightly stained with organic matter; extremely acid (pH 4.4); clear wavy boundary.

2Bg1 29 - 46 cm. Brown (10YR 5/3) fine sandy loam; common, medium and fine, distinct, clear-boundary, strong brown (7.5YR 3/6) iron stains on horizontal and vertical faces of primary, secondary, and subsecondary peds, and thin, slightly patchy, light yellowish brown (10YR 6/4) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; very weak, coarse, rough-surface, short vertical axis, subangular prisms, parting to weak, medium, unoriented, rough-surface, subangular-angular blocks and to single grains, parting to weak, fine and very fine, unoriented, rough-surface, subangular-angular blocks and to single grains; very friable; common, medium and fine, multidirectionally branched roots throughout; thin, moderately patchy clay skins on vertical faces of primary peds, and very thin, moderately patchy clay skins on horizontal and vertical faces of secondary peds, and very thin, extremely patchy clay skins on horizontal and vertical faces of subsecondary peds; common, medium, fine, and very fine, short, round, curved, multidirectional, simple, unobstructed tubular pores in ped interiors and opening to ped faces; common, very fine, unstained, translucent, subangular quartz grains and many, medium and fine, lightly stained, translucent, subangular quartz grains in interiors and on horizontal and vertical faces of primary, secondary, and subsecondary peds; extremely acid (pH 4.3); clear broken boundary.

2Bg2 46 - 82 cm. Yellowish brown (10YR 5/4) fine sandy loam; moderately thick, slightly patchy, yellowish brown (10YR 5/8) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; weak to very weak, coarse, rough-surface, short vertical axis, subangular prisms parting to weak, coarse, rough-sruface, angular blocks and to single grains, parting to weak, medium, rough- surface, subangular blocks and to single grains; very friable; few, fine, and very few, medium, branched roots throughout; thin, continuous clay skins on vertical faces of primary peds and very thin, moderately patchy clay skins on horizontal and vertical faces of secondary and subsecondary peds; many, medium, and very few, fine, short, round, curved, horizontal and vertical, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; very few, fine, unstained, translucent, subangular, quartz grains in interiors and on horizontal and vertical faces of primary, secondary, and subsecondary peds; extremely acid (pH 4.2); diffuse irregular boundary.

2BC 82 - 104 cm. Grayish brown (2.5Y 5/2) fine sandy loam; few, medium, distinct, clear-boundary, yellowish brown (10YR 5/8) mottles on ped faces and in ped interiors and thin, moderately patchy, light olive brown (2.5Y 5/8) color coatings on horizontal and vertical faces of primary and subprimary peds; very weak, medium, rough-surface, subangular blocks parting to very weak, fine and very fine, rough-surface subangular blocks and to single grains; soft; few, medium and fine, moderately branched roots throughout; very thin, nearly continuous clay skins on horizontal and vertical faces of primary and subprimary peds; many, fine, lightly stained, translucent, subangular quartz grains in interiors and on horizontal and vertical faces of primary and subprimary peds; extremely acid (pH 4.4).

Appendix B6. Description of Catoosa Bottom, Site Two

Location: Catoosa Bottom, site two.
Classification: coarse-loamy, mixed, mesic Typic Haplaquepts.
Physiographic position: Downslope extremity of first order bottom with 2 percent slope, approximately 5 meters from ephemeral stream channel.
Parent material: Colluvial/alluvial sediments from surrounding uplands.
Drainage: Poorly drained.

Described by: R. D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

Oa 5 - 0 cm. Reddish gray (5YR 5/2) decomposed plant tissue; common, medium, fine and very fine, and few, coarse, multidirectionally branched roots throughout; abrupt smooth boundary.

A 0 - 8 cm. Dark brown (10YR 3/3) loamy sand; moderately thick, moderately patchy, very dark grayish brown (10YR 3/2), organic matter coatings on horizontal and vertical faces of primary peds; moderate, medium, smooth-surface, subangular blocks, parting to moderate, medium, fine, and very fine, irregular-surface granules; very friable; common, fine and very fine, and few, medium, multidirectionally branched roots throughout; common, fine and very fine, translucent, subangular quartz grains lightly stained with organic matter, and few, medium and fine, unstained, translucent, subangular quartz grains on horiozntal and vertical faces of primary peds; extremely acid (pH 4.3); clear smooth boundary.

AB 8 - 19 cm. Brown (10YR 4.5/3) loamy sand; moderately thick, very patchy, very dark grayish brown (10YR 3/2) organic matter coatings on horizontal and vertical faces of primary peds; moderate, medium, smooth-surface, subangular blocks parting to moderate, medium, irregular-surface granules; very friable; common, fine and very fine, and few, medium, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary peds; many, medium and fine, and few, coarse, lightly stained, translucent, subangular quartz grains in interiors and on faces of primary and secondary peds, and few, fine and very fine, unstained, translucent, subangular quartz grains on faces of primary and secondary peds; very strongly acid (pH 4.5); abrupt smooth boundary.

Bw 19 - 30 cm. Yellowish brown to dark yellowish brown (10YR 4.5/6) loamy sand; common, medium and fine, distinct, clear-boundary, dark brown (10YR 3/2), organic matter stains on vertical faces of primary peds; weak, medium, smooth-surface, unoriented, subangular-angular blocks parting to weak, fine and very fine, rough-surface granules and to single grains, friable; few, medium, fine, and very fine moderately branched, multidirectional roots throughout interiors, and vertically and horizontally oriented on horizontal and vertical faces of primary peds; common, fine and very fine, short, curved, horizontal and vertical, unobstructed, round tubular pores in ped interiors and opening to ped faces; many, fine and very fine, lightly stained, translucent, subangular quartz grains, and few, fine, unstained, translucent, subangular, dark minerals in interiors and on faces of primary and secondary peds; extremely acid (pH 4.4); abrupt smooth boundary.

2Bg 30 - 37 cm. Dark yellowish brown (10YR 4/4) loamy sand;

moderately thick, moderately patchy, dark yellowish brown (10YR 3/4) stains on horizontal and vertical faces of primary and secondary peds; common, medium, distinct, diffuse-boundary, yellowish brown (10YR 5/6) mottles on vertical faces of primary and subprimary peds; moderate, coarse, rough-surface, horizontally oriented, angular blocks parting to weak, medium, fine, and very fine, rough-surface, unoriented, subangular-angular blocks and to single grains; firm; common, fine and very fine, and few medium, moderately branched, horizontally oriented roots throughout; few, medium and fine, short, round, curved, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped surfaces; many, fine and very fine, lightly stained, translucent, subangular quartz grains and common, fine, unstained, translucent, subangular dark minerals in interiors and on horizontal and vertical faces of primary and subprimary peds; extremely acid (pH 4.4); clear smooth boundary;

2Cg1 37 - 59 cm. Grayish brown to light brownish gray (10YR 5.5/2) loam; weak, coarse, rough-surface, oriented, subangular-angular prisms parting to weak, medium, rough-surface, subangular blocks and to single grains; friable; few, medium and fine, unbranched roots on vertical faces of primary peds; few, fine, short, round, curved vertical, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; common, fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and secondary peds, and few, very fine, unstained, translucent, subangular quartz grains on vertical faces of primary peds; extremely acid (pH 4.1); gradual diffuse boundary;

2Cg2 59 - 84 cm. Light brownish gray (2.5Y 6/2) loam; common, fine, distinct, abrupt-boundary, dark yellowish brown (10YR 4/6), and prominent, abrupt-boundary, yellowish red (5YR 4/6) mottles on faces and interiors of primary peds; weak, coarse, short vertical axis, rough-surface, subangular prisms parting to weak, fine and very fine, unoriented, rough-surface, subangular-angular blocks and to single grains; friable; common, fine and very fine, and few, medium, moderately branched, horizontally and vertically oriented roots throughout; very many, fine, and many, medium, moderately long and long, round, complex, multidirectional, simple, unobstructed tubular pores in interiors and opening to faces of primary and secondary peds; common, fine, lightly stained, translucent, subangular quartz grains in interiors and on horizontal and vertical faces of primary and secondary peds; extremely acid (pH 4.4); gradual diffuse boundary.

2Cg3 84 - 99 cm. Light brownish gray to light yellowish brown (2.5Y 6/3) loam; common, medium and fine, distinct, sharp-boundary, dark yellowish brown (10YR 4/6) mottles in interiors and on horizontal and vertical faces of primary and subprimary peds; weak, coarse, fine and medium, rough-surface, subangular blocks; very friable; few, fine and very fine, multidirectionally branched roots throughout; few, fine, short, round, curved, diagonal, simple, unobstructed, tubular pores in interiors and opening to faces of primary and subprimary peds; common, fine, lightly stained, translucent, subangular quartz grains in interiors and on horizontal and vertical faces of primary and subprimary peds, very strongly acid (pH 4.5).

Appendix B7. Description of Fall Creek Falls Upland, Site One

Location: Fall Creek Falls Upland, site one.
Classification: coarse-loamy, mixed, mesic Typic Hapludults.
Physiographic position: Upslope extremity of shoulder of north-facing ridgetop with 12 percent slope. Convex micro-relief.
Drainage: Well drained.
Parent material: Loess mixed with residuum and colluvium from residuum, over residuum from sandstone.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

Oe 4 - 0 cm. Dark brown (7.5YR 3/2) partially decomposed leaf litter; very many, fine and very fine, and common, medium, multidirectionally branched roots throughout; clear smooth boundary.

A1 0 - 3 cm. Dark gray to gray (10YR 5.4/1) silt loam; strong, fine, rough-surface granules; very friable; many, fine, and very fine, multidirectionally branched roots throughout; many, medium and fine, translucent, subangular quartz grains lightly stained with organic matter on ped faces and as single grains; extremely acid (pH 4.0); abrupt smooth boundary.

Bw 3 - 7 cm. Brown to pale brown (10YR 5.5/3) silt loam; moderate to weak, fine and very fine, rough-surface, subangular blocks, very friable; many, fine and very fine, translucent, subangular quartz grains lightly stained with organic matter on horizontal and vertical ped faces, and very few, fine, unstained, translucent, subangular quartz grains on horizontal and vertical ped faces; extremely acid (pH

4.0); clear smooth boundary.

Bt1 7 - 18 cm. Yellowish brown (10YR 5/4) silt loam; thin, moderately patchy, dark brown to brown (10YR 4/3) color coatings on horizontal faces of primary, secondary, and subsecondary peds, and thin, slightly patchy, dark brown to brown (10YR 4/3) color coatings on vertical faces of primary, secondary, and subsecondary peds; weak, very coarse, short vertical axis, rough-surface, subangular prisms parting to weak, medium, rough-surface, subangular blocks, parting to moderate, fine and very fine, rough-surface, subangular blocks; firm; common, fine and very fine, and few, medium, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary, secondary, and subsecondary peds; very thin, nearly continuous, clay skins on vertical faces, and very thin, slightly patchy, clay skins on horizontal faces of primary and secondary peds, and very thin, nearly continuous, clay skins on vertical faces of subsecondary peds; common, medium, and many, fine, short, round, linear, multidirectional, branched, unobstructed tubular pores in ped interiors and opening to ped faces; many, medium, translucent, subangular quartz grains, lightly iron-stained, on horizontal and vertical faces of primary, secondary, and subsecondary peds, and few, very fine, unstained, translucent, quartz grains on horizontal faces of primary peds; extremely acid (pH 4.3); clear irregular boundary.

Bt2 18 - 32 cm. Dark yellowish brown (10YR 4/6) loam; weak, medium, short vertical axis, rough-surface, subangular prisms, parting to weak, medium and fine, rough-surface, subangular blocks; very friable; few, medium and fine, moderately branched, horizontally and vertically oriented roots on vertical faces of primary peds, and very few, medium and fine, moderately branched horizontally and vertically oriented roots on vertical faces of primary peds and on horizontal and vertical faces of secondary peds; thin, nearly continuous, clay skins on horizontal and vertical faces of primary and secondary peds; many, fine, short, round, linear, multidirectional, branched, unobstructed tubular pores in ped interiors and opening to ped faces; common, medium and fine, translucent, subangular quartz grains, lightly iron-stained, on horizontal and vertical faces of primary and secondary peds, and very few, very fine, unstained, translucent, subangular quartz grains on horizontal faces of primary peds; extremely acid (pH 4.2); clear wavy boundary.

2Bt3 32 - 53 cm. Yellowish brown (10YR 5/8) loam; weak, coarse, short vertical axis, rough-surface, subangular prisms, parting to moderate, medium, rough-surface, angular blocks, parting to moderate, fine and very fine, angular blocks; very few, fine, and very fine, moderately branched, horizontally oriented roots on horizontal and vetical faces of primary and secondary peds, and very few, fine, moderately branched, vertically oriented roots on vertical faces of primary peds; moderately thick, nearly continuous, clay skins on horizontal and vertical faces, and thick, moderately patchy, clay skins on horizontal and vertical faces of primary and secondary peds, and moderately thick, nearly continuous, clay skins on horizontal and vertical faces of subsecondary peds; few, medium and fine, short, round, straight, horizontal and vertical, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; common, medium and fine, translucent, subangular quartz grains, lightly iron-stained, on horizontal and vertical faces of primary, secondary, and subsecondary peds, and very few, very fine, unstained, translucent, subangular quartz grains on horizontal faces of primary and secondary peds; 20 percent, medium and fine, horizontally oriented, rounded, sandstone fragments; extremely acid (pH 4.3); clear smooth boundary.

2BtC1 53 - 59 cm. Brownish yellow (10YR 5/8) loam; weak, medium, rough-surface, subangular blocks, parting to moderate, fine, rough-surface granules; friable; few, very fine, moderately branched, horizontally oriented roots on horizontal and vertical faces of primary peds, and very few, fine, moderately branched, vertically oriented roots on vertical faces of primary peds; thin, moderately patchy, clay skins on horizontal and vertical faces of primary peds; very many, medium and fine, and many, coarse, translucent, subangular, quartz grains, lightly iron-stained, on horizontal and vertical faces of primary peds and on faces of secondary peds, and few, fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary peds, and on vertical faces of secondary peds; 50 percent, coarse and medium, horizontally oriented, subangular, sandstone fragments; extremely acid (pH 4.4); abrupt smooth boundary.

2BtC2 59 - 86 cm. Pink (5YR 7/4 and 7.5YR 7/4) fine sandy loam; thick, continuous, strong brown (7.5YR 5/6) color coatings on horizontal and vertical ped faces; strong, medium, irregular-surface, horizontal blocks; very firm; very few, very fine, moderately branched, horizontally oriented roots on horizontal ped faces; thick, continuous, clay skins on horizontal ped faces, and moderately thick, moderately patchy, clay skins on vertical ped faces; very many, medium and fine, unstained, translucent, subangular, quartz grains on horizontal and vertical ped faces; extremely acid (pH 4.4).

Cr Weathered, horizontally bedded sandstone bedrock.

Remarks:

Interiors of peds in 2BtC2 horizon are softened and weathered sandstone fragments.

Appendix B8. Description of Fall Creek Falls Upland, Site Two

Location: Fall Creek Falls Upland, site two.
Classification: fine-silty, mixed, mesic Typic Fragiudults.
Physiographic position: Downslope extremity of north-facing 12 percent ridgetop shoulder. Concave micro-relief.
Parent Material: Loess mixed with alluvial/colluvial deposits from loess, over residuum from sandstone parent material.
Drainage: Well drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

Oe 3 - 0 cm. Dark brown (7.5YR 3/2) partially decomposed leaf litter; very many, very fine, multidirectionally branched roots throughout; clear smooth boundary.

A 0 - 3 cm. Dark brown to brown (10YR 4/3) silt loam; weak, medium, unoriented, irregular-surface, subangular-angular blocks, parting to moderate to weak, medium, irregular-surface granules, parting to moderate, fine and very fine, irregular surface granules; very friable; many, very fine and fine, and common, medium, multidirectionally branched roots throughout; common, very fine, unstained, translucent, subangular quartz grains on surfaces of primary, secondary, and subsecondary peds; extremely acid (pH 4.2); clear smooth boundary.

Bt1 3 - 16 cm. Brown (10YR 5/3) silt loam; weak, very coarse, unoriented, irregular-surface, subangular-angular blocks, parting to moderate to weak, medium, unoriented, irregular-surface, subangular-angular blocks and to weak, fine, irregular-surface granules; very friable; common, fine and very fine roots throughout, and few, coarse and medium, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds; very thin, slightly patchy, clay skins on vertical faces of primary and subprimary peds; few, fine and very fine, short, round, curved, horizontal and vertical, branched, unobstructed, tubular pores in ped interiors and opening to ped faces; common, very fine, unstained, translucent, subangular quartz grains on vertical faces of primary and subprimary peds; extremely acid (pH 4.3); gradual smooth boundary.

Bt2 16 - 32 cm. Yellowish brown (10YR 5/6) silt loam; weak, very coarse and medium, unoriented, rough-surface, subangular-angular blocks, parting to moderate, medium and fine, rough-surface granules; friable; common, fine and very fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds; thin, slightly patchy, clay skins on horizontal and vertical faces, and moderately thick, extremely patchy, clay skins on vertical faces, of primary and secondary peds; common, medium, fine, and very fine, round, short, curved, multidirectional, branched, unobstructed tubular pores in ped interiors and opening to ped faces; common, very fine, unstained, translucent, subangular quartz grains on horizontal faces of primary and secondary peds, and few, very fine, unstained, translucent, subangular quartz grains on vertical faces of primary and secondary peds; extremely acid (pH 4.3); clear wavy boundary.

Bt3 32 - 42 cm. Yellowish brown to brownish yellow (10YR 5.5/6) silt loam; weak, medium, unoriented, rough-surface, subangular-angular blocks parting to weak, fine and very fine, unoriented, rough-surface, subangular-angular blocks, and to moderate, fine and very fine, rough-surface granules; very friable; few, fine and very fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds; common, very fine, round, short, curved, multidirectional, branched, unobstructed tubular pores in ped interiors and opening to ped faces; common, very fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and subprimary peds; very strongly acid (pH 4.5); clear smooth boundary.

2BE 42 - 56 cm. Light yellowish brown to olive yellow (2.5Y 6/5) silt loam; moderate to weak, short vertical axis, smooth-surface, angular prisms, parting to moderate to weak, very coarse and coarse, unoriented, irregular-surface, subangular-angular blocks, and to weak, medium and fine, irregular-surface granules; very friable; many, very fine, and common, medium and fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary peds; thin, nearly continuous, clay skins on horizontal and vertical faces of primary and secondary peds; common, very fine, round, short, curved, horizontal and vertical, branched, unobstructed tubular pores in ped interiors; few, fine, round, dark brown (7.5YR 3/2) manganese concretions in ped interiors; many, very fine, unstained, translucent, subangular quartz grains on horizontal and vertical surfaces of primary and secondary peds; very strongly acid (pH 4.8); abrupt irregular boundary.

2Btx1 56 - 80 cm. Light yellowish brown (2.5Y 6.4) silt loam; few, fine, faint, abrupt-boundary, light gray (2.5Y 7/2), and few, fine, distinct, abrupt-boundary, olive yellow (2.5Y 6/8) mottles in ped interiors; thick, continuous, light gray (2.5Y 7/2) tongues on vertical faces of primary peds; moderately thick, slightly patchy, light gray (10YR 7/2) color coatings on horizontal and vertical faces of primary and secondary peds, moderately thick, moderately patchy, darkyyellowish brown (10YR 4/6) color coatings on vertical faces of primary and secondary peds, and thin, moderately patchy, light yellowish brown to olive yellow (2.5Y 6.5) color coatings on horizontal and vertical faces of primary and secondary peds; moderate, very coarse, short vertical axis, smooth-surface, subangular prisms, parting to moderate to strong, very coarse, vertically oriented, irregular-surface, subangular-angular blocks; very firm and very brittle; few, medium and fine, vertically oriented, unbranched, roots on vertical faces of primary peds; moderately thick, nearly continous, clay skins on horizontal and vertical faces, and thick, very patchy, clay skins on vertical faces, of primary and secondary peds; few, medium, short, round, curved, horizontal, branched, unobstructed tubular pores in ped interiors; few, fine, round, dark brown (7.5YR 3/2) manganese concretions in ped interiors; thin, moderately patchy coatings of very fine, unstained, translucent, subangular quartz grains on vertical faces of primary peds, and common, very fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and secondary peds; very strongly acid (pH 4.5); clear irregular boundary.

2Btx2 80 - 97 cm. Yellowish brown (10YR 5/6) silt loam; thick, moderately patchy, light gray (2.5Y 7/2) and pale yellow (2.5Y 7/4) tongues on vertical faces of primary peds; thin, moderately patchy, light olive brown (2.5Y 5/6) color coatings on vertical faces of primary peds, and thin, extremely patchy, light olive brown (2.5Y 5/6) color coatings on horizontal and vertical faces of primary and secondary peds, and thin, moderately patchy, brownish yellow, (10YR 6/8) color coatings on vertical faces of primary peds; strong to moderate, very coarse, smooth-surface, short vertical axis, angular prisms, parting to moderate, very coarse, rough-surface, angular blocks, parting to strong, medium and fine, rough-surface, angular blocks; very firm and very brittle; very few, very fine, moderately branched, horizontally and vertically oriented roots on vertical faces of primary peds; thick, nearly continuous, clay skins on horizontal and vertical faces, and moderately thick, continuous, clay skins on vertical faces of primary peds, and thick, nearly continuous, clay skins on horizontal and vertical faces of secondary and subsecondary peds; few, medium, short, round, curved, horizontal, branched, unobstructed tubular pores in ped interiors; very few, very fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary, secondary, and subsecondary peds; extremely acid (pH 4.3); gradual smooth boundary.

2Btx3 97 - 112 cm. Yellowish brown (10YR 5/6) silt loam; thick, continuous, light gray (2.5Y 7/2) tongues on vertical faces of primary peds; moderately thick, moderately patchy, dark brown (7.5YR 3/4) and strong brown (7.5YR 4/6) color coatings on horizontal faces of primary peds, moderately thick, extremely patchy, dark brown (7.5YR 3/4) and strong brown (7.5YR 4/6) color coatings on vertical faces of primary peds, and thin, moderately patchy, brownish yellow (10YR 6/8) color coatings on vertical faces of primary peds; weak, very coarse, short vertical axis, smooth-surface, angular prisms, parting to moderate, very coarse, horizontally and vertically oriented, rough-surface, subangular-angular blocks, parting to strong, medium, unoriented, irregular-surface, subangular-angular blocks; very firm and brittle; very few, fine, unbranched, vertically oriented roots on vertical faces of primary peds; thick to moderately thick, nearly continuous, clay skins on horizontal and vertical faces of primary, secondary, and subsecondary peds; very few, medium, short, round, curved, horizontal, branched, unobstructed, tubular pores in ped interiors; very few, very fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and secondary peds, extremely acid (pH 4.4); abrupt irregular boundary.

2B 112 - 127 cm. Light olive brown (2.5Y 5/6) silt loam; moderately thick, continuous, light gray (2.5Y 7/2) tongues on horizontal and vertical faces of primary peds; common, medium, prominant, sharp-boundary, strong brown (7.5YR 4/6) mottles on ped faces, many, medium, prominant, sharp-boundary, strong brown (7.5YR 4/6) mottles in ped interiors, and many, medium, prominant, clear-boundary, pale brown (10YR 6/3) mottles on ped faces and in ped interiors; moderate, medium, irregular-surface, subangular blocks, parting to moderate, fine, irregular-surface, subangular blocks; very firm; few, fine and very fine, moderately branched, horizontally and vertically oriented roots on vertical faces of primary and subprimary peds; thick, very patchy, and moderately thick, moderately patchy, clay skins on horizontal and vertical faces of primary and subprimary peds; few, very fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and subprimary peds; very strongly acid (pH 4.5); gradual smooth boundary.

2B't1 127 - 157 cm. Brownish yellow (10YR 6/6) silt loam;

moderately thick, continuous, light gray (2.5Y 7/2) tongues on horizontal and vertical faces of primary peds; many, medium, prominant, clear-boundary, pale brown (10YR 6/3) and strong brown (7.5YR 5/8) mottles on faces and interiors of primary and subprimary peds; strong to moderate, smooth-surface, angular blocks, parting to moderate, medium and fine, rough-surface, angular blocks; very firm; few, fine, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, very patchy, clay skins on vertical faces of primary and subprimary peds, and moderately thick, slightly patchy, clay skins on horizontal and vertical faces of primary and subprimary peds; very few, very fine, unstained, translucent, subangular, quartz grains on horizontal and vertical faces of primary and subprimary peds; very strongly acid (pH 4.5); gradual smooth boundary.

2B't2 157 - 240 cm. Reddish yellow (7.5YR 6/6) silt loam; moderately thick, continuous, very pale brown (10YR 7/3) tongues on horizontal and vertical faces of primary peds; common, medium and fine, distinct, sharp-boundary, yellow (10YR 7/6) mottles on ped faces and in ped interiors; strong, medium and fine, irregular-surface, angular blocks; firm; few, very fine, infrequently branched, vertically oriented roots on vertical faces of primary peds; moderately thick, continuous clay skins on horizontal faces of primary and subprimary peds, and thin, nearly continous, clay skins on horizontal faces of primary and subprimary peds; very strongly acid (pH 4.5); abrupt smooth boundary.

3Bt 240 - 270 cm. Yellowish red (5YR 4/6) silt loam; moderately thick, continuous, white (10YR 8/2) tongues on horizontal and vertical faces of primary peds; common, medium and fine, distinct, sharp-boundary, very pale brown (10YR 7/4) mottles on faces and in interiors of peds; strong, medium and fine, irregular-surface, angular blocks; very firm; few, very fine, infrequently branched, vertically oriented roots on vertical faces of primary peds; moderately thick to thin, continuous clay skins on vertical faces of primary and subprimary peds, and moderately thick to thin, nearly continuous, clay skins on horizontal faces of primary and subprimary peds; very firm; extremely acid (pH 4.0).

Remarks:

Pit was augered to a depth of about 350 cm. Soil color and textures remained consistent with the 3Bt horizon, and live roots were found to the augered depth. Resistance of unknown cause was encounted at the 350 cm depth.

Appendix B9. Description of Fall Creek Falls Slope, Site One

Location: Fall Creek Falls Slope, site one.
Classification: fine-silty, mixed, mesic Typic Fragiumbrepts.
Physiographic position: Downslope extremity of 22 percent north-facing sandstone slope. Slightly convex micro-relief on narrow slope bench.
Parent Material: Loess mixed with colluvium over residuum from sandstone bedrock.
Drainage: Well drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

A1 0 - 14 cm. Dark brown (7.5YR 3/2) silt loam; strong, medium, fine and very fine, rough-surface granules; very friable; common fine and very fine, and few, coarse and medium, multidirectionally branched roots throughout; many, very fine, unstained, translucent, subangular quartz grains on faces of primary and subprimary peds; 10 percent, medium and small, unoriented, angular, sandstone fragments; strongly acid (pH 5.1); gradual irregular boundary.

A2 14 - 26 cm. Very dark brown to dark brown (10YR 2.5/3) silt loam; moderately thick, moderately patchy, dark reddish brown (5YR 3/2) organic matter coatings on horizontal and vertical faces of primary peds; strong to moderate, medium, rough-surface, subangular blocks, parting to strong, medium and fine, rough-surface granules; friable; common, medium, moderately branched, horizontally oriented roots on horizontal and vertical faces of primary peds, and few, fine and very fine, multidirectionally branched roots throughout; many, medium and fine, short, round, curved, multidirectional, linear, unobstructed, tubular pores in ped interiors and opening to ped faces; common, medium and fine, unstained, translucent, subangular, quartz grains on faces of primary, secondary, and subsecondary peds; 15 percent, medium and small, unoriented, angular, sandstone fragments; strongly acid (pH 5.1); gradual wavy boundary.

Bw 26 - 36 cm. Dark yellowish brown (10YR 4/4) silt loam; moderately thick, slightly patchy, dark brown (7.5YR 3/4) color coatings on horizontal and vertical faces of primary, subprimary, and secondary peds; moderate, medium and fine, unoriented, rough-surface, subangular-angular blocks parting to strong, coarse and medium, rough-surface granules; friable; few, medium and fine, multidirectionally branched roots throughout; moderately thick, moderately patchy, clay skins on horizontal and vertical faces of, and lining root channels, in primary peds, and moderately thick, moderately patchy clay skins on horizontal and vertical faces of subprimary peds, and thin, moderately patchy, clay skins on horizontal and vertical faces of secondary peds; common, medium and fine, short, round, curved, multidirectional, simple, unobstructed pores in interiors and opening to faces of primary and subprimary peds; common, medium, subangular, dark minerals on faces and interiors of primary and subprimary peds, and few, medium and fine, unstained, translucent, subangular, quartz grains on faces of primary, subprimary, and secondary peds; 20 percent, large and very large,unoriented, angular, sandstone fragments; very strongly acid (pH 4.7); clear wavy boundary.

Bt1 36 - 62 cm. Dark brown (7.5YR 3/4) silt loam; thin, very patchy, reddish brown (5YR 4/4) color coatings on horizontal and vertical faces of primary peds and on vertical faces of secondary peds; moderate, coarse, oriented, short vertical axis, rough-surface, subangular-angular prisms; parting to moderate to strong, medium, and moderate, fine and very fine, unoriented, rough-surface, subangular-angular blocks; friable; few, medium and fine, multidirectionally branched, vertically oriented roots on vertical faces of primary and secondary peds; moderately thick to thin, moderately patchy, clay skins on horizontal and vertical faces, and lining root channels of primary and secondary peds, and thin, slightly patchy, clay skins on horizontal and vertical faces of secondary peds; common, medium and fine, short, oblong, curved, multidirectional, simple, unobstructed, tubular pores, and tubular pores obstructed with clay, in ped interiors and opening to ped faces; common, medium, subangular, dark minerals in interiors and on faces of primary and subprimary peds, and few, medium and fine, unstained, translucent, subangular, quartz grains on faces of primary, secondary, and subsecondary peds; 25 percent, very large and large, unoriented, angular, sandstone fragments; very strongly acid (pH 4.7); gradual irregular boundary.

Bt2 62 - 68 cm. Strong brown (7.5YR 4.5/6) silt loam; moderately thick, moderately patchy, reddish brown (5YR 4/3) color coatings on horizontal and vertical faces of primary and secondary peds; moderate, very coarse, rough-surface, angular prisms, parting to moderate to weak, coarse and medium, rough-surface, angular blocks, parting to moderate, fine and very fine, rough-surface, angular blocks; friable; few, medium and fine, moderately branched, horizontally and vertically oriented roots roots on vertical faces of primary and secondary peds; thick, very patchy, and moderately thick, slightly patchy, clay skins on horizontal and vertical faces, and lining root channels in primary peds, and thick, very patchy, and moderately thick, slightly patchy clay skins on vertical faces of secondary peds, and moderately thick, slightly patchy, and thick, extremely patchy clay skins on horizontal and vertical faces of subsecondary peds; few, medium and fine, short oblong, multidirectional, simple, unobstructed pores and pores obstructed with clay in ped interiors and opening to faces of primary and secondary peds; common, medium, subangular, dark minerals in interiors and on faces of primary and secondary peds, and common, fine, unstained, translucent, subangular, quartz grains, on faces of primary, secondary, and subsecondary peds; 20 percent, very large and large, unoriented, angular, sandstone fragments; very strongly acid (pH 4.7); clear smooth boundary.

BE 88 - 105 cm. Dark yellowish brown (10YR 4/4) silt loam; few, fine, distinct, sharp-boundary, brownish yellow (10YR 6/6) mottles in interiors and on faces of primary and subprimary peds, and few, fine, prominant, sharp-boundary, strong brown (7.5YR 4/6) mottles in interiors of primary and subprimary peds; thick, nearly continuous, strong brown (7.5YR 4/6) color coatings on horizontal and vertical faces of primary and subprimary peds; weak, very coarse and coarse, rough-surface, horizontal blocks; very friable; few, medium, unbranched, vertically oriented roots on vertical faces of primary and subprimary peds; thick, nearly continuous, clay skins on horizontal and vertical faces of, and lining root channels in primary peds, and thick, nearly continuous, clay skins on horizontal and vertical faces of subprimary peds; common, medium, short, oblong, curved, horizontal, simple, unobstructed, tubular pores in ped interiors; common, medium, subangular, dark minerals in interiors and on faces of primary and subprimary peds, and very few, fine, unstained, translucent, subangular, quartz grains on faces of primary and subprimary peds; very strongly acid (pH 4.7); abrupt smooth boundary.

2Bx1 105 - 140 cm. Dark brown (7.5YR 3/4) loam; massive; few, medium, unbranched, vertically oriented roots; very firm and brittle; many, medium and fine, round, dark brown (7.5YR 3/2) manganese concretions; very strongly acid (pH 4.7); clear smooth boundary;

2Bx2 140 - 168 cm. Yellowish red (5YR 5/8) loam; common, medium, distinct, sharp-boundary, strong brown (7.5YR 5/6) mottles in interiors and on faces of primary and secondary peds; thick, slightly patchy, light brown (10YR 6/4) color coatings on horizontal and vertical faces of primary and secondary peds; moderate, medium, short vertical axis, unoriented, rough-surface, subangular-angular prisms, parting to strong, medium, rough-surface, angular blocks; very brittle; few, medium, unbranched, vertically oriented roots on vertical faces of primary peds; thick to moderately thick, moderately patchy, clay skins on horizontal and vertical faces of primary and secondary peds; few, medium, oblong, dark brown (7.5YR 3/2) manganese concretions; very strongly acid (pH 4.7); gradual wavy boundary.

2C 168 - 195 cm. Strong brown (7.5YR 5/8) loam; common, medium, faint, sharp-boundary, brown (7.5YR 5/4) mottles, and common, medium, distinct, sharp-boundary, brownish yellow (10YR 6/6) mottles in interiors and on faces of primary and secondary peds; thick, nearly continuous, light gray (2.5Y 7/2) color coatings on horizontal and vertical faces of primary and secondary peds; moderate, medium, short vertical axis, unoriented, rough-surface, subangular-angular prisms, parting to strong, medium and fine, rough-surface, angular blocks;

firm; few, medium and fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds; thick to moderately thick, moderately patchy, clay skins on horizontal and vertical faces of primary and secondary peds; very strongly acid (pH 4.8); clear irregular boundary.

Cr 195 cm. Weathered sandstone bedrock.

Appendix B10. Description of Fall Creek Falls Slope, Site Two

Location: Fall Creek Falls Slope, site two.
Classification: fine-silty, mixed, mesic Humic Hapludults.
Physiographic position: Upslope extremity of 38 percent north-facing sandstone slope. Slightly convex micro-site.
Parent Material: Loess mixed with colluvium over residuum from sandstone and shale bedrock.
Drainage: Well drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

A1 0 - 8 cm. Dark brown (7.5YR 3/3) silt loam; strong, medium and fine, rough-surface granules, very friable; many, fine and very fine, multidirectionally branched roots throughout; common, fine and very fine, unstained and lightly stained with organic matter, translucent, subangular, quartz grains on horizontal and vertical faces of primary and subprimary peds; medium acid (pH 5.8); abrupt irregular boundary.

A2 8 - 15 cm. Dark brown (7.5YR 3/2) silt loam; moderately thick, nearly continuous, dark reddish brown (5YR 2.5/2) organic matter stains on horizontal and vertical faces of primary and subprimary peds; weak, medium and fine, rough-surface, angular blocks, very friable; common, fine and very fine, multidirectionally branched roots throughout, and common, medium, horizontally oriented roots, vertically branched; common, fine, and very fine, unstained lightly stained with organic matter, translucent, subangular, quartz grains on horizontal and vertical faces of primary and subprimary peds; clear wavy boundary.

BA 15 - 23 cm. Dark brown to dark yellowish brown (10YR 3/3.5) silt loam; moderately thick, moderately patchy, dark yellowish brown (10YR 3/4 and 4/4) organic matter stains on horizontal and vertical faces of primary and subprimary peds; weak, coarse, and moderate, medium and fine, oriented, irregular-surface, subangular-angular blocks; friable; common, medium and fine, and very few, coarse, multidirectionally branched roots throughout; common, medium and fine, short, round, linear, multidirectional, simple, unobstructed tubular pores in ped interiors and opening to ped faces; common, fine, lightly stained, translucent, subangular, quartz grains, and few, fine, unstained, translucent, subangular quartz grains on horizontal and vertical faces of primary and subprimary peds; 10 percent, medium and small, unoriented, angular, sandstone fragments; very strongly acid (pH 5.0); clear wavy boundary.

Bw 23 - 46 cm. Yellowish brown (10YR 5/6) silt loam; moderately thick, slightly patchy, dark yellowish brown (10YR 4/6) color coatings on horizontal and vertical faces of primary peds, and moderately thick, moderately patchy, yellowish brown (10YR 5/8) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; weak, coarse, short vertical axis, rough-surface, subangular prisms, parting to moderate to weak, coarse, rough-surface, subangular blocks, parting to moderate, medium and fine, rough-surface, subangular blocks; firm; common, medium, and few, fine, moderately branched, vertically oriented roots on vertical faces of primary and secondary peds; few, medium, moderately long, round, linear, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; common, medium, subangular, dark minerals in interiors and on faces of primary, secondary, and subsecondary peds, and common, fine, and very fine, lightly stained, translucent, subangular, quartz grains, on horizontal and vertical faces of primary, secondary, and subsecondary peds; 10 percent, medium and small, unoriented, angular, sandstone fragments, very strongly acid (pH 4.9); gradual wavy boundary.

Bt1 46 - 86 cm. Dark yellowish brown (10YR 4/6) silt loam; few, medium, fine, clear-boundary, brownish yellow (10YR 6/8) and yellowish brown (10YR 5/8) mottles on horizontal and vertical faces of secondary and subsecondary peds; thick, moderately patchy, strong brown (7.5YR 4/6) and dark yellowish brown (10YR 4/6) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; weak, short vertical axis, rough-surface, subangular prisms, parting to moderate to weak, coarse, rough-surface, subangular blocks, parting to strong, medium and fine, rough-surface, angular blocks; firm and slightly brittle; common, medium, and few fine, moderately branched, vertically oriented roots on vertical faces of primary and secondary peds; thick, continuous, clay skins on horizontal and vertical faces of, and lining root channels in, primary peds, and moderately thick to thin, moderately patchy, clay skins on horizontal and vertical faces of secondary and subsecondary peds; few, medium, moderately long, round and oblong, linear, angular, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; common, medium, subangular dark minerals on faces and interiors of primary, secondary, and subsecondary peds, thin, slightly patchy coatings of fine, lightly stained, translucent, subangular quartz grains on horizontal and vertical faces of primary peds, and common, fine and very fine, lightly stained, tranclucent, subangular, quartz grains on horizontal and vertical faces of primary, secondary, and subsecondary peds;10 percent, medium and fine; unoriented, angular, sandstone fragments; very strongly acid (pH 4.8); clear irregular boundary.

2Bt2 86 - 114 cm. Red (2.5YR 5/8) silt loam; common, medium, distinct, sharp-boundary, strong brown (7.5YR 5/8) mottles on vertical faces of primary peds, few, medium, distinct, sharp-boundary, strong brown (7.5YR 5/8) mottles on horizontal faces of primary and subprimary peds, and few, fine, distinct, sharp-boundary mottles in interiors of secondary peds; thick, nearly continuous, red (2.5YR 4/8) color coatings on horizontal and vertical faces of primary, subprimary, and secondary peds; moderate to weak, very coarse and medium, rough-surface, angular prisms, parting to strong, medium and fine, rough-surface, subangular blocks, firm; few, medium, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, continuous, clay skins on horizontal and vertical faces of, and lining tubular pores and root channels in, primary, subprimary, and secondary peds; common, medium, round, moderately long, linear, horizontal, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; very strongly acid (pH 4.9); clear irregular boundary.

2Bt3 114 - 150 cm. Red (2.5YR 5/8) silty clay loam; common, medium, distinct, abrupt-boundary, reddish yellow (5YR 6/8) mottles on faces of primary peds and on faces and in interiors of secondary and subsecondary peds; thick to very thick, nearly continuous, dark red to red (2.5YR 3.5/6) color coatings on horizontal and vertical faces of primary, secondary, and subsecondary peds; moderate, very coarse, rough-surface, angular prisms, parting to moderate, coarse and medium, rough-surface, subangular blocks, parting to strong fine and very fine, rough-surface, subangular blocks; firm; few, medium, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, continuous, clay skins on horizontal and vertical faces of primary, secondary, and subsecondary peds; very firm; few, very fine, soft, unoriented, shale fragments; strongly acid (pH 5.0); gradual wavy boundary.

2Bt4 150 - 181 cm. Dark reddish brown (5YR 3/4) silty clay; few, medium and fine, disntinct, sharp- boundary, very dusky red (2.5YR 2.5/2) mottles on horizontal and vertical faces of primary, subprimary, and secondary peds; very thick, moderately patchy, darky reddish brown to dark red (2.5YR 3/5) color coatings on horizontal and vertical faces of primary peds, and thick, nearly continuous to slightly patchy, dark red (2.5YR 3/6) color coatings on horizontal and vertical faces of primary, subprimary, and secondary peds; moderate, coarse, rough-surface, horizontal blocks, and moderate, medium, rough-surface, angular blocks, parting to strong, medium, smooth-surface plates; few, medium, infrequently branched, vertically oriented roots, and few, fine, infrequently branched horizontally and vertically oriented roots; very thick, slightly patchy, and thick nearly continuous, clay skins on horizontal and vertical faces of primary peds, and thick, continuous, clay skins on horizontal and vertical faces of subprimary and secondary peds; very firm; common, fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of primary, subprimary, and secondary peds; very strongly acid (pH 4.9); gradual smooth boundary.

2Bt5 181 - 204 cm. Yellowish red (5YR 5/6) clay; few, medium, very prominant, sharp-boundary, very pale brown (10YR 7/4) mottles on horizontal and vertical faces of primary and subprimary peds; thick to moderately thick, slightly patchy, strong brown (7.5YR 5/6) color coatings on horizontal and vertical faces of primary peds and on horizontal faces of subprimary peds, moderately thick, continuous, dark red (2.5YR 3/6) color coatings on vertical faces of subprimary peds and on horizontal and vertical faces of secondary peds, and moderately thick to thin, very patchy, yellowish brown (10YR 5/6) color coatings on horizontal and vertical faces of primary peds and on horizontal faces of subprimary peds; moderate to weak, coarse, and moderate, medium and fine, rough-surface, horizontal blocks, parting to moderate, medium, smooth-surface plates; friable; few, medium, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, nearly continuous, clay skins on horizontal and vertical faces of primary peds, thick, nearly continuous clay skins on vertical faces, and thick, slightly patchy, to moderately thick, nearly continuous clay skins on horizontal faces of subprimary peds, and thick, nearly continuous, clay skins on vertical faces, and moderately thick, nearly continuous, clay skins on horizontal faces of secondary peds; common, fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of primary and subprimary peds, and few, fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of secondary peds; very strongly acid (pH 4.7); gradual smooth boundary.

2BtC 204 230 cm. Pale brown (10YR 6/3) silty clay loam; common, medium, very prominant, abrupt-boundary, yellowish brown (10YR 5/8) mottles on horizontal and vertical faces of secondary peds, and few, fine, faint, sharp-boundary, brownish yellow (10YR 6/6) mottles in interiors of primary, subprimary, and secondary peds; moderately thick, slightly patchy, yellow (10YR 7/6) color coatings on horizontal faces of primary peds; moderate to weak, medium, rough-surface horizontal blocks, and moderate to weak, medium and fine, rough-surface, angular blocks, parting to strong, medium and fine, smooth-surface plates; few, medium, infrequently branched, vertically oriented roots; thick, moderately patchy, to moderately thick, slightly patchy, clay skins on horizontal faces of primary peds, thick, very patchy, to moderately thick, nearly continuous, clay skins on vertical faces of primary peds and on horizontal and vertical faces of subprimary peds, and very thin, extremely patchy, clay skins on horizontal faces of secondary peds; firm; common, fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of primary and subprimary peds, and few, fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of secondary peds; very strongly acid (pH 4.7).

2CBt1 230 - 260 cm. Sampled with auger for laboratory analyses, but not described. Contained few, medium, moderately branched roots.

2CBt2 260 - 280 cm. Sampled with auger for laboratory analyses, but not described. Contained few, fine, moderately branched roots.

Remarks:

Stratification of shale parent material was visible in interiors of peds in 2Bt4 and all horizons beneath. Boundaries of clay films on ped surfaces were sharp.

Occassional, very thin, platy, dark reddish brown (2.5YR 2.5/2) veins were observed to be horizontally oriented in profile in 2Bt4 and 2Bt5 horizons.

Roots in lower profile were on ped surfaces.

Appendix B11. Description of Fall Creek Falls Bottom, Site One

Location: Fall Creek Falls Bottom, site one.
Classification: fine-silty, mixed, mesic Aquic Hapludults.
Physiographic position: Downslope extemity of 2 percent first-order bottom. Slightly covex micro-site.
Parent Material: Unsorted alluvial/colluvial material over residuum from sandstone and/or shale bedrock.
Drainage: Somewhat poorly drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory.

A1 0 - 9 cm. Dark brown to brown (10YR 4/3) silt loam; weak, fine, rough-surface, subangular blocks, parting to moderate, medium and fine, rough-surface granules; very friable; many, fine and very fine, multidirectionally branched roots throughout; common, very fine, unstained, transparent, angular quartz grains on faces of primary and secondary peds; common, medium, filled worm channels; extremely acid (pH 4.0); abrupt wavy boundary.

Bt 9 - 20 cm. Yellowish brown (10YR 5/6) silt loam; thin, moderately patchy, light yellowish brown (10YR 6/4) color coatings on horizontal and vertical faces of primary and secondary peds; weak, medium, short vertical axis, irregular-surface, subangular prisms, parting to moderate, coarse and medium, irregular-surface, subangular blocks; firm; few, coarse, horizontally oriented, vertically branched roots, and very few, fine and very fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds; thick, slightly patchy, clay skins on vertical faces, and moderately thick, extremely patchy, clay skins on horizontal faces of primary peds, and very thin, extremely patchy, clay skins on horizontal and vertical faces of secondary peds; common, medium and fine, short, round, linear, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; common, very fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of secondary peds; common, medium, filled worm channels; extremely acid (pH 4.2); clear irregular bounddary.

2A'1 20 - 30 cm. Light brownish gray (2.5Y 6/2) silt loam; few, fine, faint, clear-boundary, yellowish brown (10YR 5/4) mottles in interiors of primary and subprimary peds; weak, coarse, unoriented, smooth-surface, subangular-angular blocks, parting to moderate, unoriented, smooth-surface, subangular-angular blocks; friable; common, medium, horizontally oriented, vertically branched roots, and common, fine and very fine, multidirectionally branched roots throughout; moderately thick, extremely patchy, and thin, very patchy clay skins on vertical faces, and thin, extremely patchy, clay skins on horizontal faces of primary peds, and thin, very patchy clay skins on vertical faces, and very thin, extremely patchy, clay skins on horizontal faces, of subprimary peds; very few, fine, very short, round, linear, multidirectional, simple, unobstructed, tubular pores in interiors and opening to faces of primary and subprimary peds; extremely acid (pH 4.3); abrupt irregular boundary.

2A2 30 - 42 cm. Light brownish gray (10YR 6/2) silt loam; few, fine, faint, abrupt-boundary, grayish brown (10YR 5/2) and yellowish brown (10YR 5/6) mottles in ped interiors and on ped faces; weak, very coarse and coarse, irregular-surface, subangular blocks; friable; few, medium and fine, moderately branched, vertically oriented roots on horizontal and vertical ped faces; moderately thick, moderately patchy, clay skins on horizontal and vertical ped faces; very few, fine, very short, round, linear, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; very strongly acid (pH 4.6); abrupt clear boundary.

2Bw 42 - 56 cm. Brownish yellow (10YR 6/6) silt loam; common, medium, faint, sharp-boundary, light yellowish brown (10YR 6/4) mottles in interiors of primary and secondary peds; moderately thick, moderately patchy, light yellowish brown (10YR 6/4) color coatings on horizontal and vertical faces of primary and secondary peds; moderate to weak, medium, short vertical axis, rough-surface, angular prisms, parting to moderate, medium, rough-surface, angular blocks; firm and slightly brittle; common, medium, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secndary peds; moderately thick, slightly patchy, clay skins on horizontal and vertical faces of primary peds, and moderately thick, slightly patchy to moderately patchy, clay skins on vertical faces, and thin, moderately patchy, clay skins on horizontal faces, of secondary peds; very few, medium, short, round, linear, horizontal, simple, clay-obstructed, tubular pores in ped interiors; extremely acid (pH 4.2); clear wavy boundary.

2Btg1 56 - 76 cm. Brownish yellow (10YR 6/6) silt loam; common, medium and fine, faint, clear-boundary, very pale brown (10YR 7/4) mottles in interiors of primary and secondary peds; moderately thick, nearly continuous on vertical faces, and moderately thick on horizontal faces, very pale brown (10YR

7/3) color coatings on primary and secondary peds; strong, very coarse, short vertical axis, rough-surface, angular prisms, and strong, very coarse, rough-surface, angular blocks; very firm; few, medium, unbranched, vertically oriented roots on vertical faces of primary and secondary peds; thick, moderately patchy, and moderately thick, nearly continuous, clay skins on horizontal and vertical faces of primary peds, and thick, very patchy, to moderately thick, nearly continuous, clay skins on vertical faces of secondary peds; very fine, large, short, round, linear, horizontal, simple, clay-obstructed, tubular pores in ped interiors; few, medium, round, irregular-surface, concretions with dark reddish brown (5YR 2.5/2) centers with abrupt-boundary transitions to strong brown (7.5YR 5/8) coatings, in interiors of primary and secondary peds; very strongly acid (pH 4.6); clear wavy boundary.

2Btg2 76 - 113 cm. Brown (10YR 5/3) silt loam; few, medium, faint, sharp-boundary, very pale brown (10YR 7/3) mottles, and few, fine, faint, clear-boundary, strong brown (7.5YR 5/8) mottles in interiors of primary and secondary peds, and few, medium and fine, faint, clear-boundary mottles on horizontal and vertical faces of secondary peds; thick, nearly continuous, very pale brown (10YR 7/3) color coatings on horizontal and vertical faces of primary and secondary peds; moderate, very coarse, short vertical axis, rough-surface, angular prisms, parting to moderate, medium, rough-surface, angular blocks; firm; few, medium, unbranched, vertically oriented roots on vertical faces of primary peds; very thick, nearly continous, clay skins on vertical faces, and thick, slightly patchy, clay skins on horizontal and vertical faces of primary peds, and very thick, slightly patchy, and thick, moderately patchy, clay skins on vertical faces, and thick, moderately patchy, and moderately thick, slightly patchy, clay skins on horizontal faces of secondary peds; very few, large, short, linear, horizontal, simple, clay-obstructed, tubular pores in ped interiors; few, medium, round, irregular-surface concretions with dark reddish brown (5YR 2.5/2) centers with abrupt-boundary transitions to strong brown (7.5YR 5/8) coatings in interiors and on faces of primary and secondary peds; many, very fine, unstained, transparent, angular, quartz grains on vertical faces of primary and secondary peds; very strongly acid (pH 4.9); gradual irregular boundary.

2Btg3 113 - 141 cm. Light yellowish brown (10YR 6/4) silt loam; common, medium and fine, faint, clear-boundary, very pale brown (10YR 7/3) mottles, and few, fine, faint, clear-boundary, yellowish brown (10YR 5/8) mottles in interiors of primary, secondary and subsecondary peds, and few, fine, faint, clear-boundary, light yellowish brown (10YR 6/4) mottles on horizontal and vertical faces of subsecondary peds; very thick, continuous, very pale brown (10YR 7/3) color coatings, on horizontal and vertical faces of primary and secondary peds, and thick, nearly continuous, very pale brown (10YR 7/3) color coatings on horizontal and vertical faces of subsecondary peds; moderate to weak, very coarse, short vertical axis, rough-surface, angular prisms, parting to moderate, very coarse, rough-surface, angular blocks, parting to strong, medium and fine, rough-surface, angular blocks; firm; few, medium, unbranched, vertically oriented roots on vertical faces of primary peds; very thick, continuous, clay skins on horizontal and vertical faces of primary peds, and very thick, nearly continuous, clay skins on horizontal and vertical faces of secondary peds, and thick to moderately thick, very patchy, clay skins on horizontal and vertical faces of subsecondary peds; many, large and medium, round, irregular-surface, concretions with dark reddish brown (5YR 2.5/2) centers, with abrupt-boundary transitions to strong brown (7.5YR 5/8) coatings in interiors and on faces of primary and secondary peds; many, very fine, unstained, transparent, angular, guartz grains, on vertical faces of primary and secondary peds; very strongly acid (pH 4.9); clear smooth boundary.

3B't 141 - 180 cm. Strong brown (7.5YR 5/8) silt loam; few, medium and fine, prominant, abrupt-boundary, light gray (2.5Y 7/2) mottles in interiors of primary and secondary peds, and few, fine, faint, abrupt-boundary, light gray (2.5Y 7/2) mottles on faces of primary and secondary peds; very thick, nearly continuous to thick, continuous, light gray (2.5Y 7/2) color coatings on horizontal and vertical faces of primary and secondary peds; weak, very coarse, short vertical axis, rough-surface, angular prisms, parting to moderate to weak, coarse, rough-surface, angular blocks, parting to weak, medium and fine, rough-surface, angular blocks; friable; few, medium, infrequently branched, vertically oriented roots on vertical faces of primary peds, branching to few, fine, infrequently branched, vertically oriented roots on vertcial faces of secondary peds; moderately thick, nearly continuous, and thin, continuous, clay skins on horizontal and vertical faces of primary, secondary, and subsecondary peds; very few, fine, very short, round, linear, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; very strongly acid (pH 4.9).

Remarks:

3B't horizon was augured to depth of 280 cm, but was not described. Colors and apparent color patterns remained consistent, but presence of small shale channers in interiors of peds was observed with increasing depth. Roots were observed to depth of 280 cm.

Patterns of soil colors within the profile suggests that the winter water table perches above the 3Bt horizon, and moves vertically through the light gray streaks on faces of peds within the 3Bt horizon.

Clay skins appear to be undergoing stripping in 2Btg horizons. Surfaces of clay skins are dull, and clay skins lack "laminar" appearance of clay skins in upland soils.

Many concretions are coated with silt or clay.

Appendix B12. Description of Fall Creek Falls Bottom, Site Two

Location: Fall Creek Falls Bottom, site two.
Classification: fine-silty, mixed, mesic Aquic Dystrochrepts.
Physiographic position: Upslope extremity of first-order bottom. 2 percent slope. Slightly concave micro-relief.
Parent material: Unsorted alluvium over residuum from sandstone and/or shale.
Drainage: Somewhat poorly drained.

Described by: R.D. Hammer

Colors and consistencies are for moist soil.
Textures and pH values were determined in the laboratory

A 0 - 7 cm. Dark brown to brown (10YR 4/3) silt loam; moderately thick, slightly patchy, dark grayish brown (10 YR 4/2) organic matter coatings on horizontal and vertical faces of primary peds; weak, medium, rough-surface, angular blocks, parting to moderate coarse and medium, rough-surface granules, parting to moderate, fine, rough-surface granules; very friable; very many, very fine, and many, medium and fine, multidirectionally branched roots throughout; common, fine, short, round, curved, multidirectional, simple, unobstructed, tubular pores in interiors and opening to faces of primary and secondary peds; few, very fine, unstained, transparent, angular quartz grains, on faces of secondary and subsecondary peds; very strongly acid (pH 4.7); clear wavy boundary.

Bw 7 - 18 cm. Brownish yellow (10YR 6/6) silt loam; thick, moderately patchy, grayish brown (10YR 5/2) color coatings on horizontal and vertical faces of primary and secondary peds; weak, medium, short vertical axis, rough-surface, angular prisms, parting to medium, rough-surface, angular blocks, parting to moderate, fine and very fine, rough-surface, angular blocks; friable; common, medium, fine, and very fine, multidirectionally branched roots on horizontal and vertical faces of primary peds and throughout, and common, coarse, horizontally oriented, vertically branched roots; thick, very patchy, clay skins, and moderately thick, slightly patchy, clay skins on horizontal and vertical faces, and lining root channels and pores, of primary and secondary peds; few, fine, short, round, curved, multidirectional, simple, unobstructed, tubular pores in interiors and opening to faces of primary, secondary, and subsecondary peds; few, very fine, unstained, transparent, angular quartz grains on horizontal and vertical faces of primary, secondary, and subsecondary peds; very strongly acid (pH 4.5); clear wavy boundary.

2A'1 18 - 38 cm. Grayish brown to light olive brown (2.5Y 5/3) silt loam; few, large, prominant, sharp-boundary, olive yellow (10YR 6/6) mottles in interiors and on horizontal and vertical faces of primary and secondary peds; weak, medium, short vertical axis, rough-surface, angular prisms, parting to moderate to weak, medium, rough-surface, angular blocks; friable; few, medium and fine, moderately branched, horizontally and vertically oriented roots on horizontal and vertical faces of primary and secondary peds, and very few, very fine, multidirectionally branched roots throughout; moderately thick, extremely patchy, and very thin, moderately patchy clay skins on vertical faces of, and lining pores in, primary peds, and very thin, moderately patchy, clay skins on horizontal faces of primary peds and on horizontal and vertical faces of secondary peds; few, fine, short, round, horizontal, simple, unobstructed, tubular pores in interiors and opening to faces of primary and secondary peds; very strongly acid (pH 4.5); clear smooth boundary.

2Btg1 38 - 56 cm. Light yellowish brown (2.5Y 6/4) silt loam; few, medium, faint, clear-boundary, olive yellow (2.5Y 6/8) mottles in interiors and on vertical faces of peds; thin, nearly continuous, light brownish gray (2.5Y 6/2) color coatings on horizontal faces, and thin, slightly patchy, light brownish gray (2.5Y 6/2) color coatings on vertical ped faces; strong, coarse, rough-surface, horizontal blocky structure; very firm; common, fine, and few, medium, moderately branched, horizontally and vertically oriented roots on horizontal and vertical ped faces; moderately thick, extremely patchy, and thin, moderately patchy, clay skins on horizontal and vertical ped faces, and lining root channels and tubular pores; common, fine, short, round, multidirectional, simple, unobstructed, tubular pores in ped interiors and opening to ped faces; common, fine, round, rough-surface, strong brown (7.5YR 5/8) concretions; very strongly acid (pH 4.6); abrupt wavy boundary.

2Btg2 56 - 78 cm. Light brownish gray to light yellowish brown (2.5Y 6/3) silt loam; few, medium, faint, clear-boundary, light yellowish brown (2.5Y 6/4) mottles in interiors of primary and secondary peds; thick, nearly continuous, light gray (2.5Y 7/2) color coatings on horizontal and vertical faces of primary peds and on vertical faces of secondary peds, and thin, slightly patchy, light gray (2.5Y 7/2) and pale yellow (2.5Y 7/4) color coatings on horizontal faces of secondary peds; moderate, coarse; rough-surface, angular prisms, parting to moderate, coarse, and medium, rough-surface, angular blocks; firm; few, coarse and medium, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, continuous, clay skins on horizontal and vertical faces of, and lining root channels and tubular pores in primary peds, thick, continuous, clay skins on vertical faces, and thick to moderately thick, slightly patchy, clay skins on horizontal faces, of secondary peds; many, medium and fine, short, oblong and round, multidirectional, simple, unobstructed, tubular pores in interiors and opening to faces of primary and secondary peds; many, fine, round, rough-surface, yellowish brown (10YR 5/8) concretions; very strongly acid (pH 4.8); clear irregular boundary.

2BCg1 78 - 94 cm. Very pale brown (10YR 7/4) silt loam; common, fine, faint, clear-boundary, light yellowish brown (10YR 6/4) and brownish yellow (10 YR 6/8) mottles in ped interiors and on ped faces; moderately thick, moderately patchy, light gray to pale yellow (2.5Y 7/3) color coatings on horizontal and vertical ped faces; strong, very coarse, short vertical axis, irregular-surface, subangular prisms; very firm; few, coarse and medium, infrequently branched, vertically oriented roots on vertical ped faces; moderately thick, slightly patchy, clay skins on horizontal and vertical ped faces and lining root channels and tubular pores; common, fine, moderately long, round and oblong, curved, multidirectional, simple, unobstructed, tubular pores in interiors and opening to ped faces; few, very fine, round, smooth-surface, dark reddish brown (5YR 3/2) concretions, thickly coated with clay; common, very fine, unstained, transparent, angular, quartz grains on vertical ped faces; very strongly acid (pH 4.9); clear wavy boundary.

2BCg2 94 - 122 cm. Pale brown (10YR 6/3) loam; common, medium, faint, sharp-boundary, light yellowish brown (2.5Y 6/4) mottles in interiors and on vertical faces of primary and secondary peds, and few, medium and fine, faint, sharp-boundary, brownish yellow (10YR 6/8) mottles in interiors and on vertical faces of primary and secondary peds; thick, continuous, light gray (2.5Y 7/2) color coatings on horizontal faces of primary and secondary peds, and moderately thick, moderately patchy, light gray (2.5Y 7/2) color coatings on vertical faces of primary and secondary peds; strong, coarse, oriented, rough-surface, subangular-angular prisms, parting to moderate, coarse and medium, rough-surface, subangular blocks; very firm; few, coarse and medium, infrequently branched, vertically oriented roots on vertical faces of primary peds; thick, slightly patchy, clay skins on horizontal faces of, and lining pores and root channels in, and moderately thick, moderately patchy, clay skins on vertical faces, of primary and secondary peds; few, medium and coarse, short, round, curved, multidirectional, simple, unobstructed, tubular pores in interiors and opening to ped faces of primary and secondary peds; many, coarse and medium, round and oblong, smooth-surface, concretions having dark reddish brown (5YR 3/2) interiors with abrupt boundaries to strong brown (7.5YR 5/8) exteriors, thickly coated with clay; many, very fine, unstained, transparent, angular, quartz grains on vertical faces of primary and secondary peds; very strongly acid (pH 4.9); gradual irregular boundary.

2BCg3 122 - 158 cm. Light gray (10YR 7/2) loam; few, medium, faint, clear-boundary, brownish yellow (10YR 6/6) mottles in ped interiors, and few, medium, faint, clear-boundary, olive yellow (2.5Y 6/8) mottles on horizontal and vertical faces of secondary peds; very thick, nearly continuous, light gray (2.5Y 7/2) color coatings on vertical faces of primary peds, and moderately thick, slightly patchy, brownish yellow (10YR 6/6) color coatings on horizontal faces of primary peds and on horizontal and vertical faces of secondary peds; strong, very coarse, short vertical axis, rough-surface, subangular prisms, parting to strong, very coarse, unoriented, rough-surface, subangular-angular blocks; extremely firm; few, coarse, and medium, infrequently branched, vertically oriented roots on vertical faces of primary peds; very thick, continuous, clay skins on horizontal and vertical faces of, and lining pores and root channels in primary and secondary peds; common, medium and fine, short, round and oblong, curved, multidirectional, compound, unobstructed tubular pores in interiors and opening to faces of primary and secondary peds; many, very coarse; round and oblong, rough-surface, concretions having dark reddish brown (5YR 3/2) interiors with abrupt-boundary transitions to strong brown (7.5YR 5/8) exteriors, very thinly clay coated; many, very fine, unstained, transparent, angular quartz grains on vertical faces of primary and secondary peds; very strongly acid (pH 4.8); clear smooth boundary.

3Bt 158 ---cm. Strong brown (7.5YR 5/8) loam; common, medium and fine, very prominant, abrupt-boundary, pale yellow (5Y 7/4) shale concretions in ped interiors, and few, medium, faint, clear-boundary, light gray (2.5Y 7/2) mottles in interiors and on horizontal and vertical faces of primary and secondary peds; very thick, nearly continuous, to thick, continuous, light gray (2.5Y 7.2) color coatings on horizontal and vertical faces of primary and secondary peds; strong, very coarse, unoriented, short vertical axis, irregular-surface, subangular-angular prisms, parting to strong, coarse and medium, oriented rough-surface, subangular-angular blocks; extremely firm; few, coarse and medium, infrequently branched, vertically oriented, roots on vertical faces of primary peds; very thick, extremely patchy, and thick, slightly patchy, clay coatings on horizontal and vertical faces of, and lining tubular pores and root channels in primary and secondary peds,; common, medium and fine, long, round and oblong, curved, multidirectional, compound, slightly obstructed, tubular pores in interiors and opening to faces of primary and secondary peds; very strongly acid (pH 4.7).

Remarks:

Soil was augered to a depth of 280 cm. Clay skins and roots were observed throughout the augered samples. No bedrock was encountered. Pale yellow shale channers were observed in ped interiors in the augered samples.

A very thin "stone line" of oriented, angular, shale channers was observed at the interface between the 2BCg3 horizon and the 3Bt horizon. The interface containing the stone line appeared to be somewhat cemented and was brittle. The appearance was that the paleosol containing the 3Bt horizon had been truncated prior to, or during, deposition of the overburden. The interface between the paleosol and the overburden was very similar in appearance in the two sampled and described Fall Creek Bottom soils.

APPENDIX C

TIMBER INVENTORY AND STEM ANALYSIS DATA

Appendix C1. Basal Area and Total Stems Greater Than 2.5 cm Diameter on Cumberland Plateau Study Sites

SITE	DOMINANT SPECIES†	PLOT SIZE (ha)	STEMS† (ha^{-1})	BASAL AREA (m^2 ha^{-1})
Catoosa				
Upland	White Oak	0.26	270	24.7
Slope	Yellow Poplar	0.18	166	32.8
Bottom	Yellow Poplar	0.13	256	32.0
Fall Creek				
Upland	White Oak	0.32	286	27.4
Slope	Yellow Poplar	0.18	122	29.9
Bottom	Yellow Poplar	0.16	169	24.2

†Stem diameter ≥2.5 cm.

Appendix C2. Spies Distributions and Crown Classes of Trees on Cumberland Plateau Study Sites

Species and Crown Class†
Catoosa Slope

Diameter Breast Height (cm)	Yellow Poplar				Shortleaf Pine				Northern Red Oak				Virginia Pine				Hickory				White Oak				Black Gum				Sourwood				Sasafrass				Dogwood			
	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S
2.5																				1												1								10
5.0																				1																2				10
7.5																																1				2				29
10.0												1																												18
12.5				2																				1				2				2								23
15.0				4																1								2								1				4
17.5			1	3																								1			1	2				1				2
20.0			1	2																1								2												2
22.5			3	3																1																				
25.0			4				2												1																					
27.5			1			1	1																																	
30.0		2																																						
32.5		1	3				1																																	
35.0		2				2				1				1					1																					
37.5						2																																		
40.0		3																																						
42.5		2												2																										
45.0		1				1																																		
47.5														1																										
50.0																																								
52.5	1																																							
55.0																																								
57.5		1																																						
60.0																																								
62.5																																								
65.0																																								
67.5									1																															
Totals	1	12	13	14	-	6	4	-	1	1	-	1	-	4	-	-	-	-	2	5	-	-	-	1	-	-	-	7	-	-	1	6	-	-	-	6	-	-	-	98

† D = dominant; CD = codominant; I = intermediate; S = suppressed

Species and Crown Class†
Fall Creek Falls Upland

Diameter Breast Height (cm)	White Oak				Black Oak				Scarlet Oak				Black Gum				Hickory Species				Southern Red Oak				Post Oak				Dogwood				Sourwood				Sasafras				Red Maple				Persimmon			
	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S
2.5				28												5				6												4				14				6				23				2
5.0			5	85												3				13												10				13				3				5				1
7.5				49																3								1				6				17				1								
10.0			6	31				3				1								2								1				3			1	11												
12.5			9	10			3	3											1	2												2			1	7												
15.0			7	6			2	1												2								1							1	5												
17.5		2	7	2		1	3	1															1			1									1	3												
20.0		3	7	1		6	2	1			2							1	1							1	1	1							4	1												
22.5		3	3	1		6	2			1									1			1					2																					
25.0	1		1			2	2			1	1							2			1					1										1												
27.5	2		1			2																2					1																					
30.0	1					2				3																1																						
32.5			1			3			1	1		1		1																																		
35.0		1				1				1				1			1																															
37.5	1				1	3																																										
40.0										1																																						
42.5					1	1																																										
45.0									1	1																																						
47.5									1																																							
Totals	5	9	47	213	2	27	14	8	3	9	3	2	-	2	-	8	1	3	3	28	1	3	1	-	-	4	4	4	-	-	-	25	-	-	8	72	-	-	-	10	-	-	-	28	-	-	-	3

† D = dominant; CD = codominant; I = intermediate; S = suppressed

Species and Crown Class†
Catoosa Bottom

Diameter Breast Height (cm)	Yellow Poplar				Virginia Pine				Short Leaf Pine				White Pine				White Oak				Alder				Hickory				Red Maple				Sourwood				Black Gum				Dogwood				Black Cherry & Sasafras			
	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S
2.5																								1								20				3				3				23				1
5.0																				2												10				11				2				15				1‡
7.5				3												1																9				8				3				4				1
10.0			2	2																												3				3								4				
12.5			1	1			1	1												1											1	3				3				1				2				
15.0				1			1																								1	2				2				1				1				
17.5			1			1	1																								2	1																
20.0			1			2	1			1													1									1				1												
22.5								1		2	1																				3																	
25.0		1																																														
27.5		1																																														
30.0		1					1				1															1					1																	
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40.0																																																
42.5	1	2																																														
45.0	2																													1																		
47.5		2																																														
50.0	1																																															
52.5	2																																															
Totals	6	9	5	7	-	3	5	2	-	3	2	-	-	-	-	1	-	-	-	3	-	-	1	1	-	1	-	-	-	1	9	49	-	-	-	31	-	-	-	10	-	-	-	49	-	-	-	2

† D = dominant; CD = codominant; I = intermediate; S = suppressed

‡ Sassafras

Species and Crown Class†
Catoosa Upland

Diameter Breast Height (cm)	White Oak				Black Oak				Scarlet Oak				Chestnut Oak				Black Gum				Hickory				Yellow Poplar				White Pine				Dogwood				Sourwood				Red Maple			
	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S
2.5				1																4				10								6				58				1				100
5.0				1																				3								2				4				1				58
7.5				1												2								6								1				4				1			5	20
10.0				2				2								1								7												3				2				4
12.5			1	5			1	1												1			2	3												1				5				5
15.0			1												1								3													1			1	2			2	1
17.5			2				1								1									3																1			7	
20.0			2			1	1	1						1									2																			1	2	
22.5		1	1			1									1								1																				1	
25.0		1	1	1		2				1	1			3																														1
27.5						2								3																														
30.0						1								2																													1	
32.5		3																																									1	
35.0		1				1			1					1																														
37.5						2								1																														
40.0						2				1																																		
42.5														1																														
45.0		1			1				1				1								1																							
47.5																																												
50.0					1				1																																			
52.5																									1																			
Totals	-	7	8	11	2	12	3	4	3	2	1	-	1	12	3	3	-	-	-	5	1	-	8	32	1	-	-	-	-	-	-	9	-	-	-	71	-	-	1	13	-	3	17	189

† D = dominant; CD = codominant; I = intermediate; S = suppressed

Species and Crown Class†
Fall Creek Falls Slope

Diameter Breast Height (cm)	Yellow-Poplar				Chestnut Oak				Northern Red Oak				Southern Red Oak				Black Gum				Sugar Maple				Red Maple				Dogwood				Sasafrass				Virginia Pine				Black Walnut			
	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S
5.0																				8												10												
7.5				1								3								5												20												
10.0											1	1								2											1	12												
12.5																				2												16												
15.0																				2											6	8			1	2								
17.5																											1					2			1									
20.0															1																				1	4								
22.5																											1									1								
25.0																																												
27.5																																												
30.0																																						1				1		
32.5																						1																						
35.0																																												
37.5																										1																		
40.0																																												
42.5																																												
45.0						1																																						
47.5						1																																						
50.0																																												
52.5	1																																											
55.0																																												
57.5		1																																										
60.0		2																																										
62.5																																												
65.0		1																																										
67.5		1																																										
70.0		1																																										
72.5	1	1																																										
Totals	2	7	-	1	-	2	-	-	-	-	1	4	-	-	1	-	-	-	-	19	-	1	-	-	-	1	2	-	-	-	7	68	-	-	3	7	-	1	-	-	-	1	-	-

† D = dominant; CD = codominant; I = intermediate; S = suppressed

Species and Crown Class†
Fall Creek Falls Bottom

Diameter Breast Height (cm)	Yellow-Poplar				Black Gum				Hickory				Red Maple				Southern Red Oak				Dogwood				White Oak				Sweet Gum				Sourwood				Black Oak				Northern Red Oak			
	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S	D	CD	I	S
2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.0			1	11								2												23				1				2				1								
7.5				3				1				4												20				1												2				1
10.0			6	4				3			1													9				2											1	1				
12.5			2					3				1												1				1																
15.0		1	2	1				3											1					1																				
17.5		1	1					3																																				
20.0		1					1	3												1																						1		
22.5		2					1	2						1																														
25.0		1					1																																					
27.5								1						1																														
30.0		2				1								1				1																										
32.5		1				2	1							2																														
35.0																																												
37.5	1	1																																										
40.0														1																														
42.5						1																																						
Totals	1	10	12	19	-	4	4	19	-	-	1	7	†	6	-	-	-	1	†	1	-	-	-	54	-	-	-	5	-	-	-	2	-	-	-	1	-	-	1	3	-	1	-	1

† D = dominant; CD = codominant; I = intermediate; S = suppressed

‡ Seven cull trees, not included in these tables, were in the dominant and co-dominant crown classes.

Appendix C3. Stem Analysis Data for White Oaks and Yellow-poplars on Cumberland Plateau Study Sites

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
1	1	18.5	0.5	1	1	CU
1	1	13.0	4.5	6	1	CU
1	1	12.2	8.5	7	1	CU
1	1	12.1	12.5	12	1	CU
1	1	12.0	16.5	15	1	CU
1	1	11.4	20.5	18	1	CU
1	1	11.5	24.5	21	1	CU
1	1	11.0	28.5	25	1	CU
1	1	10.9	32.5	26	1	CU
1	1	10.6	36.5	30	1	CU
1	1	8.8	40.5	33	1	CU
1	1	7.9	44.5	35	1	CU
1	1	7.7	48.5	38	1	CU
1	1	7.2	52.5	40	1	CU
1	1	7.0	56.5	43	1	CU
1	1	5.6	60.5	46	1	CU
1	1	4.7	64.5	50	1	CU
1	1	3.5	68.5	53	1	CU
1	1	3.1	72.5	58	1	CU
1	1	1.8	76.5	63	1	CU
1	1	1.2	80.5	68	1	CU
1	1	0.2	84.5	69	1	CU
1	1	20.0	0.5	1	1	CU
1	2	13.4	4.5	2	2	CU
1	2	13.0	8.5	3	2	CU
1	2	12.2	12.5	5	2	CU
1	2	11.6	16.5	8	2	CU
1	2	11.6	20.5	10	2	CU
1	2	11.2	24.5	14	2	CU
1	2	10.9	28.5	16	2	CU
1	2	10.8	32.5	19	2	CU
1	2	10.3	36.5	22	2	CU
1	2	9.9	40.5	24	2	CU
1	2	9.9	44.5	26	2	CU
1	2	8.9	48.5	30	2	CU
1	2	8.3	52.5	33	2	CU
1	2	7.3	56.5	36	2	CU
1	2	6.6	60.5	39	2	CU
1	2	5.4	64.5	41	2	CU
1	2	5.2	68.5	45	2	CU
1	2	3.8	72.5	48	2	CU
1	2	3.3	76.5	50	2	CU
1	2	2.7	80.5	56	2	CU
1	2	1.3	84.5	62	2	CU
1	2	0.2	88.5	67	2	CU
1	3	17.8	0.5	1	3	CU

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
1	3	10.5	4.5	3	3	CU
1	3	9.7	8.5	7	3	CU
1	3	9.4	12.5	10	3	CU
1	3	9.2	16.5	13	3	CU
1	3	9.1	20.5	16	3	CU
1	3	8.8	24.5	19	3	CU
1	3	8.5	28.5	22	3	CU
1	3	8.1	32.5	25	3	CU
1	3	7.8	36.5	27	3	CU
1	3	7.7	40.5	30	3	CU
1	3	7.3	44.5	33	3	CU
1	3	6.9	48.5	36	3	CU
1	3	7.3	52.5	39	3	CU
1	3	5.7	56.5	41	3	CU
1	3	4.8	60.5	44	3	CU
1	3	3.9	64.5	47	3	CU
1	3	3.1	68.5	52	3	CU
1	3	2.2	72.5	56	3	CU
1	3	1.3	76.5	61	3	CU
1	3	0.8	80.5	64	3	CU
1	4	21.6	0.5	1	4	CU
1	4	13.6	4.5	2	4	CU
1	4	12.7	8.5	4	4	CU
1	4	12.5	12.5	8	4	CU
1	4	11.7	16.5	11	4	CU
1	4	11.4	20.5	13	4	CU
1	4	11.6	24.5	17	4	CU
1	4	11.0	28.5	19	4	CU
1	4	10.6	32.5	23	4	CU
1	4	10.3	36.5	26	4	CU
1	4	9.8	40.5	28	4	CU
1	4	9.9	44.5	31	4	CU
1	4	9.0	48.5	34	4	CU
1	4	7.2	52.5	38	4	CU
1	4	6.7	56.5	41	4	CU
1	4	6.1	60.5	45	4	CU
1	4	4.5	64.5	47	4	CU
1	4	3.5	68.5	51	4	CU
1	4	2.4	72.5	55	4	CU
1	4	1.5	76.5	60	4	CU
1	4	0.6	80.5	64	4	CU
1	5	18.2	0.5	1	5	CU
1	5	13.0	4.5	3	5	CU
1	5	12.3	8.5	5	5	CU
1	5	12.0	12.5	8	5	CU
1	5	11.9	16.5	11	5	CU

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
1	5	11.5	20.5	15	5	CU
1	5	11.3	24.5	20	5	CU
1	5	11.0	28.5	23	5	CU
1	5	10.4	32.5	25	5	CU
1	5	11.9	36.5	29	5	CU
1	5	6.6	40.5	33	5	CU
1	5	6.2	44.5	38	5	CU
1	5	5.3	48.5	42	5	CU
1	5	5.0	52.5	45	5	CU
1	5	4.5	56.5	49	5	CU
1	5	4.2	60.5	51	5	CU
1	5	2.9	64.5	55	5	CU
1	5	1.9	68.5	58	5	CU
1	5	1.3	72.5	62	5	CU
1	5	0.7	76.5	68	5	CU
2	1	19.4	0.5	1	6	CS
2	1	15.8	4.5	2	6	CS
2	1	15.3	8.5	4	6	CS
2	1	15.2	12.5	6	6	CS
2	1	14.8	16.5	8	6	CS
2	1	14.8	20.5	9	6	CS
2	1	14.3	24.5	9	6	CS
2	1	13.5	28.5	10	6	CS
2	1	13.2	32.5	12	6	CS
2	1	13.2	36.5	13	6	CS
2	1	12.4	40.5	14	6	CS
2	1	11.9	44.5	14	6	CS
2	1	11.6	48.5	15	6	CS
2	1	10.9	52.5	16	6	CS
2	1	10.4	56.5	18	6	CS
2	1	9.7	60.5	20	6	CS
2	1	8.7	64.5	26	6	CS
2	1	8.3	68.5	32	6	CS
2	1	7.0	72.5	37	6	CS
2	1	6.8	76.5	46	6	CS
2	1	5.1	80.5	50	6	CS
2	1	4.0	84.5	53	6	CS
2	1	3.0	88.5	61	6	CS
2	1	2.5	92.5	68	6	CS
2	1	1.0	96.5	70	6	CS
2	1	0.5	100.5	77	6	CS
2	2	19.3	0.5	1	7	CS
2	2	16.2	4.5	1	7	CS
2	2	15.8	8.5	5	7	CS
2	2	15.4	12.5	7	7	CS
2	2	15.1	16.5	8	7	CS

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
2	2	14.7	20.5	8	7	CS
2	2	14.2	24.5	10	7	CS
2	2	14.0	28.5	11	7	CS
2	2	13.6	32.5	12	7	CS
2	2	13.1	36.5	13	7	CS
2	2	13.0	40.5	14	7	CS
2	2	12.3	44.5	14	7	CS
2	2	11.6	48.5	16	7	CS
2	2	11.1	52.5	17	7	CS
2	2	10.6	56.5	19	7	CS
2	2	10.0	60.5	21	7	CS
2	2	9.1	64.5	22	7	CS
2	2	7.2	68.5	25	7	CS
2	2	6.8	72.5	29	7	CS
2	2	6.0	76.5	31	7	CS
2	2	5.0	80.5	45	7	CS
2	2	4.5	84.5	53	7	CS
2	2	3.3	88.5	62	7	CS
2	2	2.2	92.5	72	7	CS
2	2	1.3	96.5	75	7	CS
2	2	0.8	100.5	80	7	CS
2	3	13.8	0.5	1	8	CS
2	3	12.2	4.5	1	8	CS
2	3	11.7	8.5	5	8	CS
2	3	11.2	12.5	6	8	CS
2	3	11.1	16.5	7	8	CS
2	3	10.4	20.5	8	8	CS
2	3	10.2	24.5	8	8	CS
2	3	10.0	28.5	9	8	CS
2	3	9.5	32.5	12	8	CS
2	3	8.9	36.5	16	8	CS
2	3	8.9	40.5	17	8	CS
2	3	8.3	44.5	21	8	CS
2	3	7.7	48.5	23	8	CS
2	3	7.3	52.5	29	8	CS
2	3	7.2	56.5	38	8	CS
2	3	5.9	60.5	46	8	CS
2	3	5.3	64.5	49	8	CS
2	3	4.6	68.5	53	8	CS
2	3	4.3	72.5	57	8	CS
2	3	3.1	76.5	65	8	CS
2	3	2.3	80.5	69	8	CS
2	3	1.5	84.5	71	8	CS
2	3	0.8	88.5	76	8	CS
2	4	19.7	0.5	1	9	CS
2	4	17.7	4.5	1	9	CS

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
2	4	16.8	8.5	3	9	CS
2	4	16.0	12.5	7	9	CS
2	4	15.9	16.5	9	9	CS
2	4	15.0	20.5	11	9	CS
2	4	14.7	24.5	12	9	CS
2	4	14.0	28.5	14	9	CS
2	4	13.6	32.5	15	9	CS
2	4	13.5	36.5	15	9	CS
2	4	12.8	40.5	16	9	CS
2	4	12.0	44.5	18	9	CS
2	4	11.2	48.5	19	9	CS
2	4	10.8	52.5	20	9	CS
2	4	9.4	56.5	22	9	CS
2	4	8.6	60.5	25	9	CS
2	4	8.3	64.5	35	9	CS
2	4	6.3	68.5	49	9	CS
2	4	5.7	72.5	55	9	CS
2	4	4.5	76.5	57	9	CS
2	4	3.5	80.5	63	9	CS
2	4	2.6	84.5	70	9	CS
2	4	2.3	88.5	73	9	CS
2	4	1.3	92.5	76	9	CS
2	4	0.8	96.5	80	9	CS
2	5	15.3	0.5	1	10	CS
2	5	14.3	4.5	1	10	CS
2	5	13.9	8.5	4	10	CS
2	5	13.6	12.5	5	10	CS
2	5	13.3	16.5	6	10	CS
2	5	13.0	20.5	7	10	CS
2	5	12.9	24.5	7	10	CS
2	5	12.4	28.5	8	10	CS
2	5	12.0	32.5	9	10	CS
2	5	11.5	36.5	11	10	CS
2	5	11.1	40.5	12	10	CS
2	5	10.8	44.5	12	10	CS
2	5	10.1	48.5	13	10	CS
2	5	9.9	52.5	15	10	CS
2	5	9.4	56.5	15	10	CS
2	5	8.6	60.5	17	10	CS
2	5	8.1	64.5	21	10	CS
2	5	7.9	68.5	24	10	CS
2	5	6.8	72.5	31	10	CS
2	5	6.0	76.5	36	10	CS
2	5	5.3	80.5	40	10	CS
2	5	4.8	84.5	48	10	CS
2	5	3.3	88.5	57	10	CS

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
2	5	2.3	92.5	65	10	CS
2	5	1.4	96.5	69	10	CS
2	5	0.8	100.5	74	10	CS
3	1	20.8	0.5	1	11	CB
3	1	17.0	4.5	3	11	CB
3	1	16.4	8.5	5	11	CB
3	1	15.4	12.5	6	11	CB
3	1	15.2	16.5	7	11	CB
3	1	14.4	20.5	8	11	CB
3	1	13.9	24.5	9	11	CB
3	1	13.8	28.5	10	11	CB
3	1	12.4	32.5	12	11	CB
3	1	12.1	36.5	14	11	CB
3	1	13.7	40.5	16	11	CB
3	1	10.8	44.5	18	11	CB
3	1	9.9	48.5	19	11	CB
3	1	9.3	52.5	22	11	CB
3	1	8.3	56.5	25	11	CB
3	1	8.1	60.5	26	11	CB
3	1	6.7	64.5	27	11	CB
3	1	6.0	68.5	29	11	CB
3	1	3.9	72.5	30	11	CB
3	1	3.3	76.5	33	11	CB
3	1	2.3	80.5	35	11	CB
3	1	1.3	84.5	37	11	CB
3	1	0.5	88.5	42	11	CB
3	2	20.8	0.5	1	12	CB
3	2	17.2	4.5	1	12	CB
3	2	16.4	8.5	2	12	CB
3	2	15.7	12.5	3	12	CB
3	2	14.9	16.5	3	12	CB
3	2	14.6	20.5	4	12	CB
3	2	14.2	24.5	5	12	CB
3	2	13.5	28.5	6	12	CB
3	2	13.3	32.5	7	12	CB
3	2	12.4	36.5	8	12	CB
3	2	11.5	40.5	12	12	CB
3	2	11.1	44.5	13	12	CB
3	2	10.5	48.5	15	12	CB
3	2	9.8	52.5	16	12	CB
3	2	9.5	56.5	17	12	CB
3	2	8.2	60.5	18	12	CB
3	2	7.5	64.5	19	12	CB
3	2	7.2	68.5	21	12	CB
3	2	5.8	72.5	26	12	CB
3	2	4.8	76.5	28	12	CB

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
3	2	4.0	80.5	30	12	CB
3	2	3.1	84.5	32	12	CB
3	2	2.1	88.5	34	12	CB
3	2	1.1	92.5	36	12	CB
3	2	0.4	96.5	41	12	CB
3	3	20.8	0.5	1	13	CB
3	3	17.1	4.5	1	13	CB
3	3	16.4	8.5	2	13	CB
3	3	16.0	12.5	3	13	CB
3	3	15.4	16.5	4	13	CB
3	3	14.5	20.5	6	13	CB
3	3	14.0	24.5	8	13	CB
3	3	14.0	28.5	10	13	CB
3	3	13.6	32.5	12	13	CB
3	3	12.5	36.5	14	13	CB
3	3	12.8	40.5	18	13	CB
3	3	11.2	44.5	20	13	CB
3	3	10.5	48.5	22	13	CB
3	3	9.8	52.5	24	13	CB
3	3	9.0	56.5	26	13	CB
3	3	6.9	60.5	30	13	CB
3	3	6.1	64.5	32	13	CB
3	3	5.5	68.5	35	13	CB
3	3	4.2	72.5	38	13	CB
3	3	3.5	76.5	40	13	CB
3	3	2.1	80.5	43	13	CB
3	3	1.5	84.5	46	13	CB
3	3	0.6	88.5	50	13	CB
3	4	22.0	0.5	1	14	CB
3	4	17.7	4.5	3	14	CB
3	4	16.9	8.5	4	14	CB
3	4	16.3	12.5	8	14	CB
3	4	15.9	16.5	11	14	CB
3	4	15.5	20.5	14	14	CB
3	4	14.8	24.5	16	14	CB
3	4	14.8	28.5	18	14	CB
3	4	14.6	32.5	20	14	CB
3	4	14.0	36.5	22	14	CB
3	4	12.8	40.5	23	14	CB
3	4	12.6	44.5	27	14	CB
3	4	11.4	48.5	30	14	CB
3	4	9.3	52.5	33	14	CB
3	4	7.7	56.5	35	14	CB
3	4	6.8	60.5	40	14	CB
3	4	6.3	64.5	43	14	CB
3	4	5.0	68.5	46	14	CB

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
3	4	3.3	72.5	50	14	CB
3	4	2.6	76.5	53	14	CB
3	4	2.0	80.5	55	14	CB
3	4	1.1	84.5	62	14	CB
3	4	0.6	88.5	65	14	CB
4	1	20.1	0.5	1	15	FCU
4	1	13.8	4.5	8	15	FCU
4	1	12.6	8.5	15	15	FCU
4	1	11.9	12.5	18	15	FCU
4	1	11.5	16.5	22	15	FCU
4	1	11.2	20.5	23	15	FCU
4	1	10.5	24.5	25	15	FCU
4	1	10.2	28.5	28	15	FCU
4	1	10.4	32.5	32	15	FCU
4	1	9.3	36.5	34	15	FCU
4	1	8.1	40.5	38	15	FCU
4	1	7.9	44.5	41	15	FCU
4	1	6.9	48.5	44	15	FCU
4	1	5.6	52.5	48	15	FCU
4	1	5.1	56.5	50	15	FCU
4	1	3.6	60.5	56	15	FCU
4	1	3.3	64.5	58	15	FCU
4	1	1.7	68.5	65	15	FCU
4	1	0.7	72.5	68	15	FCU
4	2	14.5	0.5	1	16	FCU
4	2	9.5	4.5	2	16	FCU
4	2	8.4	8.5	6	16	FCU
4	2	7.9	12.5	8	16	FCU
4	2	7.6	16.5	10	16	FCU
4	2	7.4	20.5	14	16	FCU
4	2	7.0	24.5	16	16	FCU
4	2	6.6	28.5	18	16	FCU
4	2	6.3	32.5	22	16	FCU
4	2	5.8	36.5	24	16	FCU
4	2	4.2	40.5	28	16	FCU
4	2	3.8	44.5	30	16	FCU
4	2	2.8	48.5	33	16	FCU
4	2	2.3	52.5	36	16	FCU
4	2	2.0	56.5	41	16	FCU
4	2	1.4	60.5	44	16	FCU
4	2	0.6	64.5	48	16	FCU
4	3	15.0	0.5	1	17	FCU
4	3	10.4	4.5	5	17	FCU
4	3	9.5	8.5	7	17	FCU
4	3	8.6	12.5	9	17	FCU
4	3	8.3	16.5	14	17	FCU

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
4	3	8.1	20.5	16	17	FCU
4	3	7.5	24.5	18	17	FCU
4	3	7.4	28.5	22	17	FCU
4	3	7.4	32.5	24	17	FCU
4	3	6.6	36.5	26	17	FCU
4	3	8.3	40.5	32	17	FCU
4	3	5.0	44.5	34	17	FCU
4	3	4.2	48.5	37	17	FCU
4	3	3.2	52.5	40	17	FCU
4	3	2.8	56.5	45	17	FCU
4	3	1.7	60.5	49	17	FCU
4	3	1.1	64.5	52	17	FCU
4	3	0.2	68.5	56	17	FCU
4	4	14.4	0.5	1	18	FCU
4	4	10.5	4.5	3	18	FCU
4	4	9.5	8.5	5	18	FCU
4	4	9.0	12.5	6	18	FCU
4	4	8.8	16.5	10	18	FCU
4	4	8.5	20.5	13	18	FCU
4	4	8.2	24.5	15	18	FCU
4	4	8.1	28.5	19	18	FCU
4	4	7.6	32.5	22	18	FCU
4	4	7.3	36.5	24	18	FCU
4	4	6.1	40.5	29	18	FCU
4	4	5.8	44.5	32	18	FCU
4	4	4.6	48.5	35	18	FCU
4	4	3.8	52.5	38	18	FCU
4	4	2.6	56.5	42	18	FCU
4	4	2.2	60.5	46	18	FCU
4	4	1.1	64.5	49	18	FCU
4	4	0.6	68.5	55	18	FCU
4	5	17.0	0.5	1	19	FCU
4	5	11.3	4.5	3	19	FCU
4	5	10.5	8.5	6	19	FCU
4	5	9.7	12.5	8	19	FCU
4	5	9.7	16.5	12	19	FCU
4	5	9.2	20.5	14	19	FCU
4	5	9.0	24.5	18	19	FCU
4	5	8.7	28.5	21	19	FCU
4	5	9.7	32.5	23	19	FCU
4	5	6.5	36.5	27	19	FCU
4	5	5.5	40.5	32	19	FCU
4	5	4.5	44.5	35	19	FCU
4	5	3.1	48.5	38	19	FCU
4	5	2.3	52.5	41	19	FCU
4	5	1.5	56.5	47	19	FCU

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
4	5	0.7	60.5	54	19	FCU
6	1	14.9	0.5	1	20	FCB
6	1	12.0	4.5	3	20	FCB
6	1	12.0	8.5	3	20	FCB
6	1	11.3	12.5	5	20	FCB
6	1	11.0	16.5	6	20	FCB
6	1	10.5	20.5	9	20	FCB
6	1	10.1	24.5	10	20	FCB
6	1	9.6	28.5	10	20	FCB
6	1	9.2	32.5	11	20	FCB
6	1	8.9	36.5	14	20	FCB
6	1	8.4	40.5	15	20	FCB
6	1	8.2	44.5	17	20	FCB
6	1	7.6	48.5	20	20	FCB
6	1	7.1	52.5	24	20	FCB
6	1	6.0	56.5	25	20	FCB
6	1	5.5	60.5	26	20	FCB
6	1	5.2	64.5	27	20	FCB
6	1	3.4	68.5	28	20	FCB
6	1	2.3	72.5	29	20	FCB
6	1	1.6	76.5	31	20	FCB
6	1	1.0	80.5	35	20	FCB
6	1	0.2	84.5	38	20	FCB
6	2	20.7	0.5	1	21	FCB
6	2	15.3	4.5	1	21	FCB
6	2	14.8	8.5	2	21	FCB
6	2	13.9	12.5	4	21	FCB
6	2	13.5	16.5	6	21	FCB
6	2	12.9	20.5	7	21	FCB
6	2	12.3	24.5	7	21	FCB
6	2	11.5	28.5	10	21	FCB
6	2	11.2	32.5	13	21	FCB
6	2	10.4	36.5	14	21	FCB
6	2	10.1	40.5	15	21	FCB
6	2	9.5	44.5	18	21	FCB
6	2	8.7	48.5	19	21	FCB
6	2	8.9	52.5	21	21	FCB
6	2	7.2	56.5	24	21	FCB
6	2	6.5	60.5	27	21	FCB
6	2	6.5	64.5	27	21	FCB
6	2	3.4	68.5	28	21	FCB
6	2	2.5	72.5	29	21	FCB
6	2	1.5	76.5	32	21	FCB
6	2	1.0	80.5	34	21	FCB
6	2	0.4	84.5	37	21	FCB
6	3	16.1	0.5	1	22	FCB

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
6	3	13.6	4.5	4	22	FCB
6	3	13.0	8.5	6	22	FCB
6	3	12.9	12.5	7	22	FCB
6	3	12.3	16.5	9	22	FCB
6	3	12.0	20.5	10	22	FCB
6	3	11.6	24.5	12	22	FCB
6	3	11.1	28.5	13	22	FCB
6	3	10.5	32.5	16	22	FCB
6	3	10.8	36.5	18	22	FCB
6	3	9.4	40.5	20	22	FCB
6	3	9.6	44.5	23	22	FCB
6	3	8.1	48.5	26	22	FCB
6	3	7.5	52.5	28	22	FCB
6	3	7.3	56.5	32	22	FCB
6	3	5.0	60.5	34	22	FCB
6	3	4.1	64.5	36	22	FCB
6	3	2.9	68.5	40	22	FCB
6	3	1.8	72.5	42	22	FCB
6	3	1.0	76.5	44	22	FCB
6	3	0.4	80.5	47	22	FCB
6	4	13.8	0.5	1	23	FCB
6	4	11.1	4.5	3	23	FCB
6	4	10.6	8.5	5	23	FCB
6	4	10.3	12.5	7	23	FCB
6	4	10.0	16.5	8	23	FCB
6	4	9.6	20.5	11	23	FCB
6	4	9.4	24.5	14	23	FCB
6	4	9.0	28.5	15	23	FCB
6	4	8.5	32.5	17	23	FCB
6	4	8.1	36.5	18	23	FCB
6	4	7.6	40.5	22	23	FCB
6	4	7.2	44.5	25	23	FCB
6	4	6.8	48.5	27	23	FCB
6	4	6.0	52.5	28	23	FCB
6	4	6.2	56.5	30	23	FCB
6	4	4.9	60.5	31	23	FCB
6	4	3.7	64.5	32	23	FCB
6	4	2.9	68.5	35	23	FCB
6	4	1.7	72.5	38	23	FCB
6	4	1.1	76.5	40	23	FCB
6	4	0.7	80.5	42	23	FCB
6	5	20.2	0.5	1	24	FCB
6	5	15.6	4.5	2	24	FCB
6	5	15.0	8.5	4	24	FCB
6	5	14.8	12.5	5	24	FCB
6	5	13.9	16.5	6	24	FCB

TREE HEIGHTS, DIAMETERS, AND AGES

SITE	TREE	DIAM	HT	AGE	SAMPLE	LOC
6	5	13.5	20.5	8	24	FCB
6	5	13.2	24.5	9	24	FCB
6	5	12.6	28.5	10	24	FCB
6	5	11.9	32.5	12	24	FCB
6	5	11.4	36.5	14	24	FCB
6	5	10.9	40.5	16	24	FCB
6	5	10.3	44.5	18	24	FCB
6	5	9.8	48.5	19	24	FCB
6	5	8.9	52.5	19	24	FCB
6	5	8.5	56.5	20	24	FCB
6	5	7.6	60.5	23	24	FCB
6	5	7.1	64.5	26	24	FCB
6	5	5.5	68.5	28	24	FCB
6	5	4.0	72.5	30	24	FCB
6	5	2.7	76.5	34	24	FCB
6	5	1.5	80.5	38	24	FCB
6	5	1.0	84.5	42	24	FCB
6	5	0.2	88.5	44	24	FCB

APPENDIX D

DISTRIBUTION WITH DEPTH OF SELECTED SOIL CHEMICAL PROPERTIES

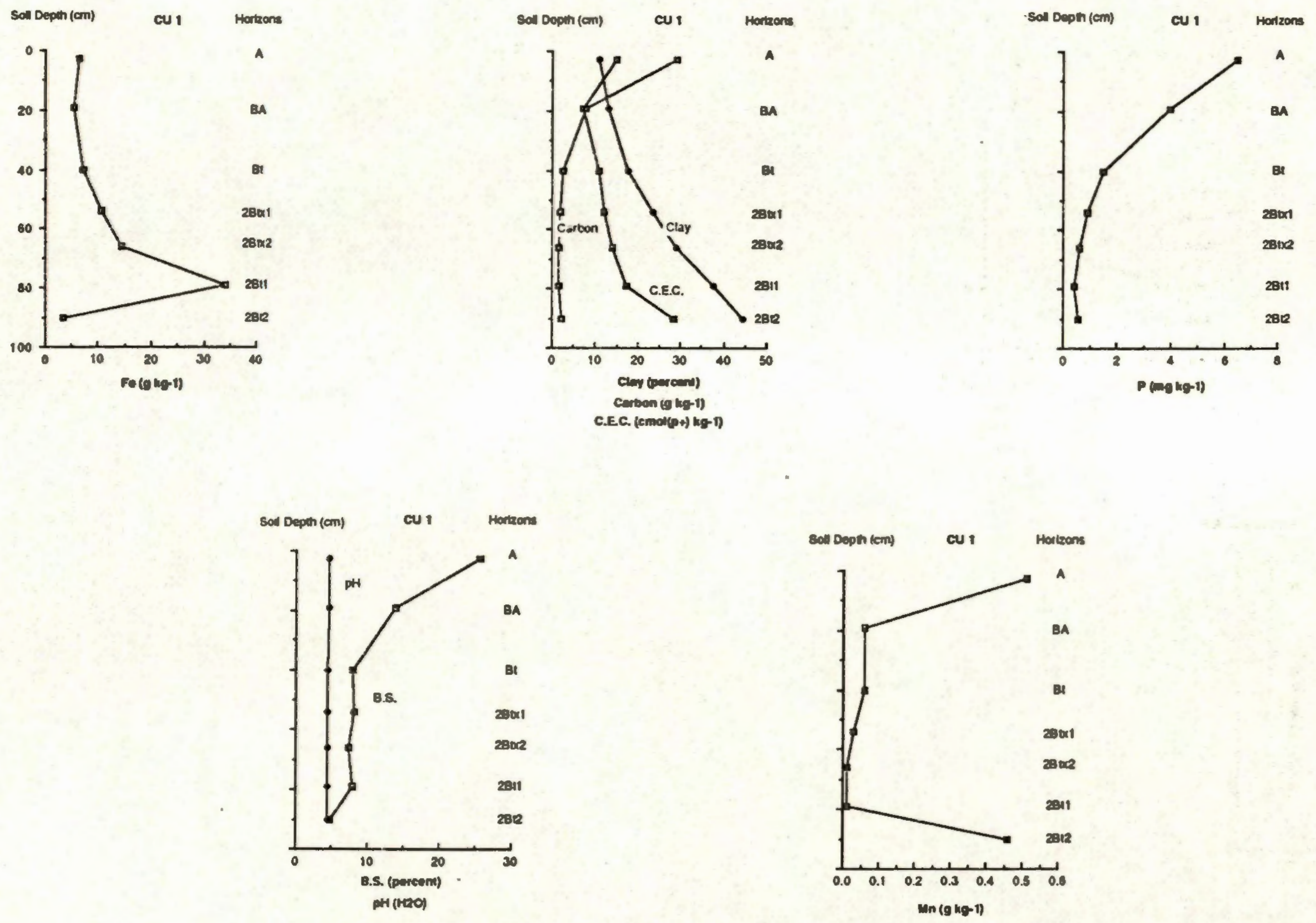

Figure D1. Catoosa upland profile one.

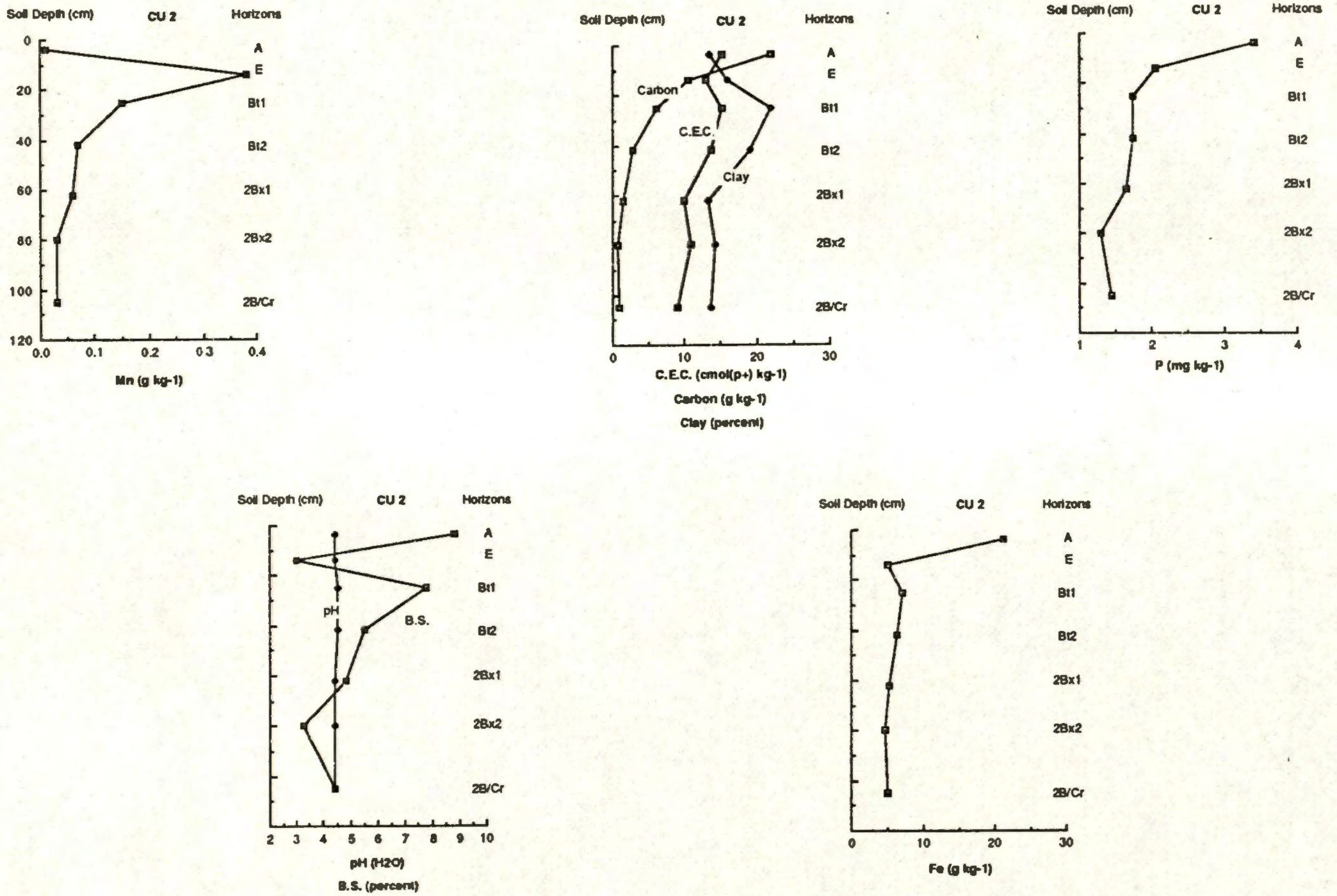

Figure D2. Catoosa upland profile two.

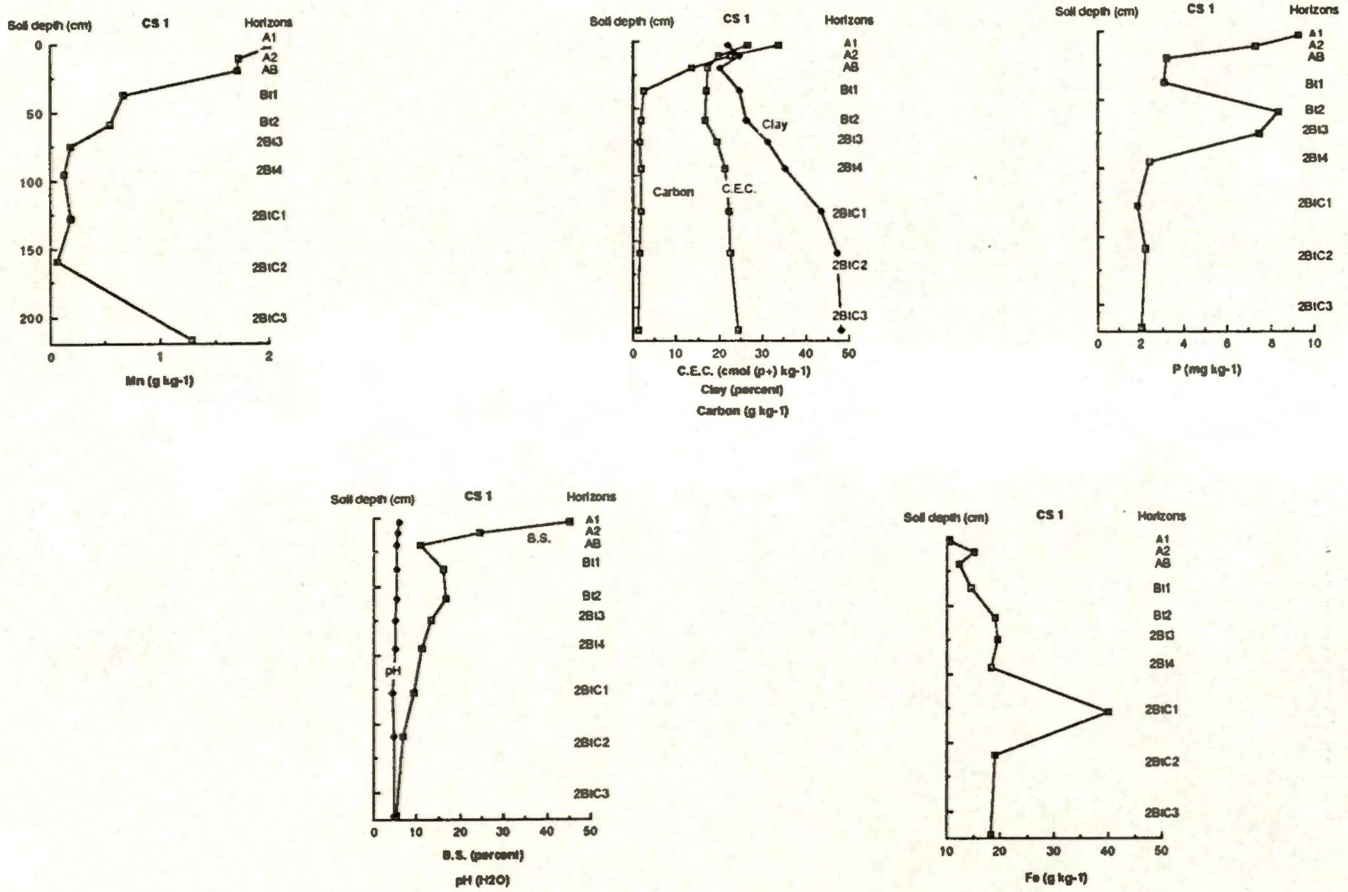

Figure D3. Catoosa slope profile one.

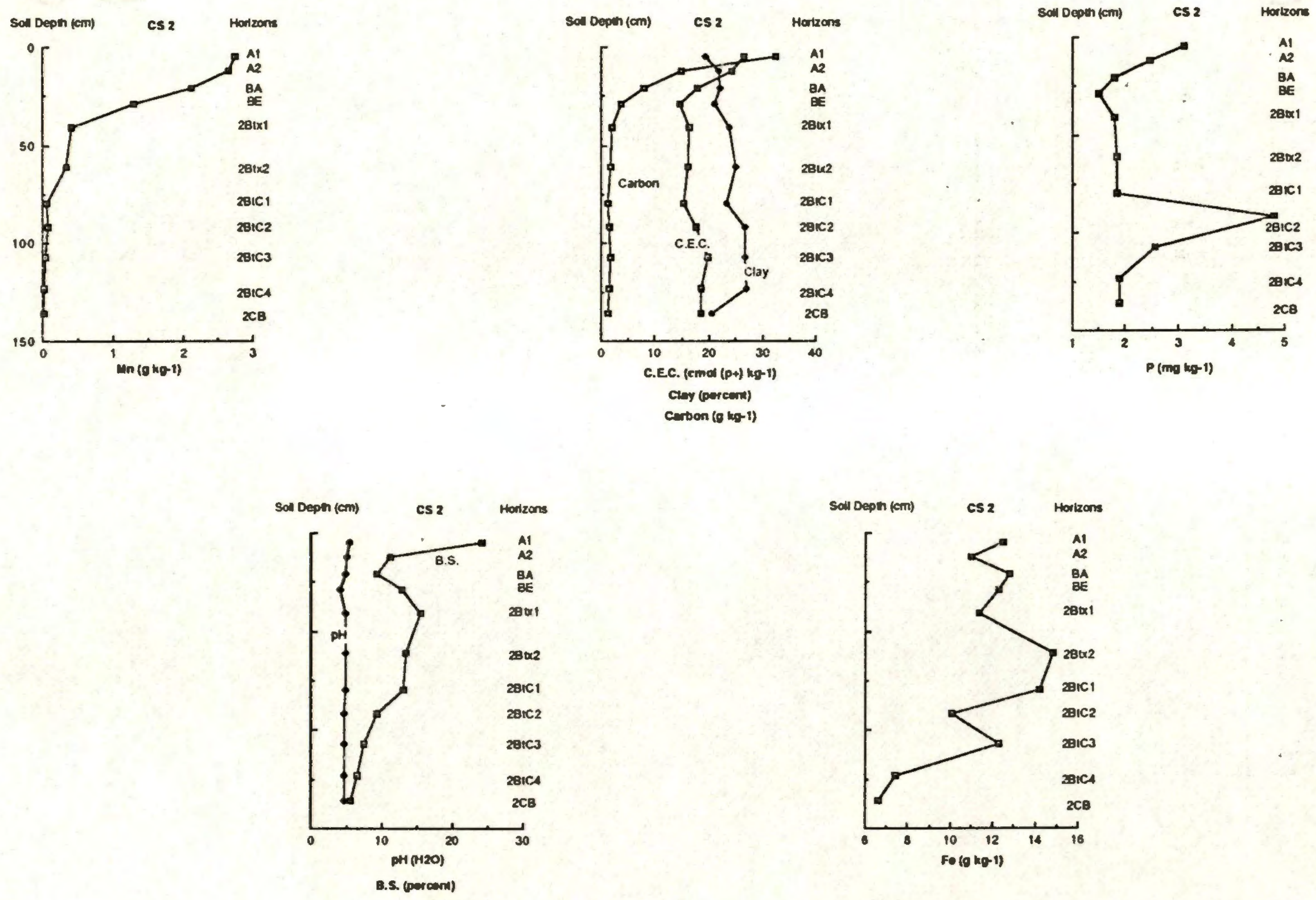

Figure D4. Catoosa slope profile two.

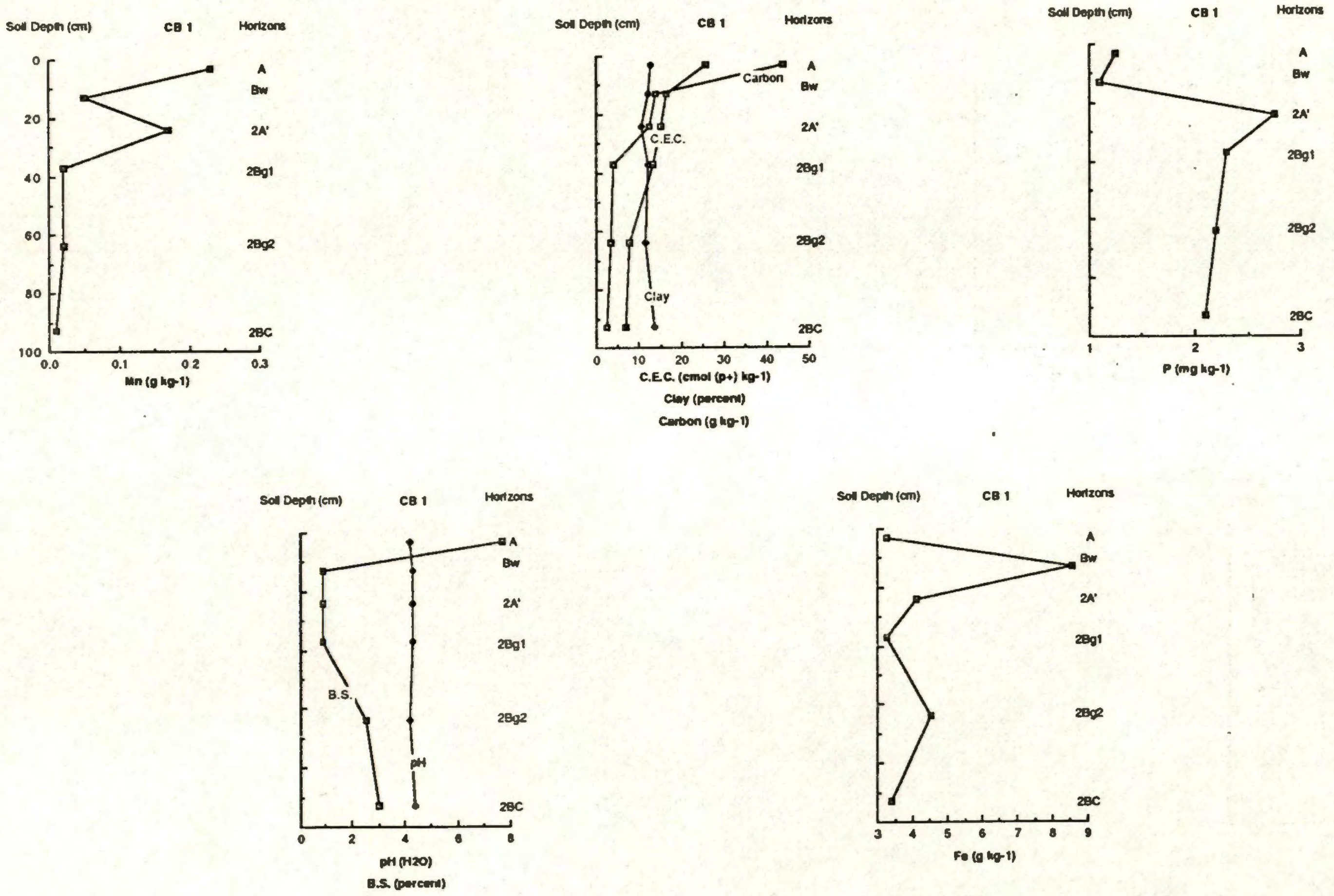

Figure D5. Catoosa bottom profile one.

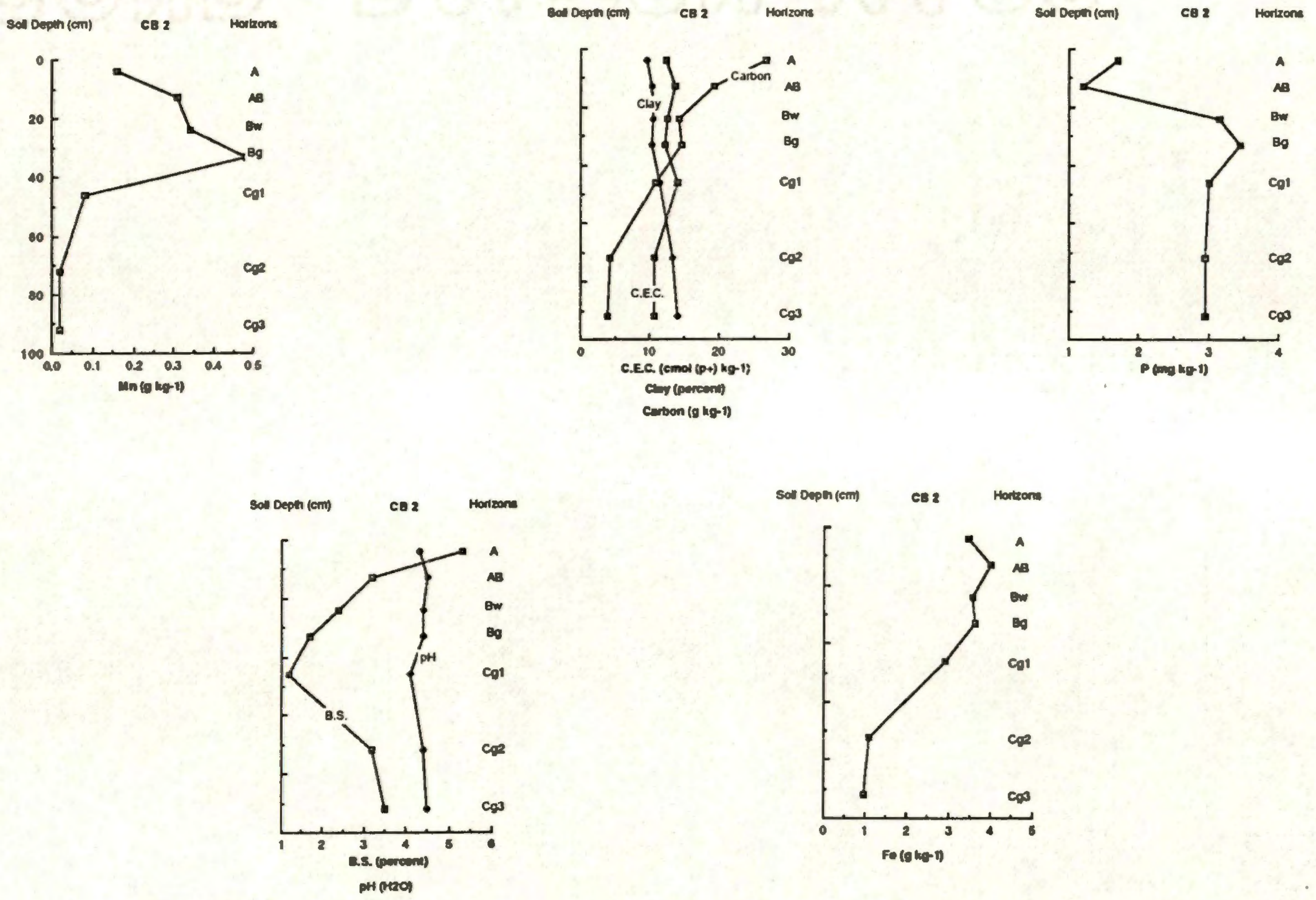

Figure D6. Catoosa bottom profile two.

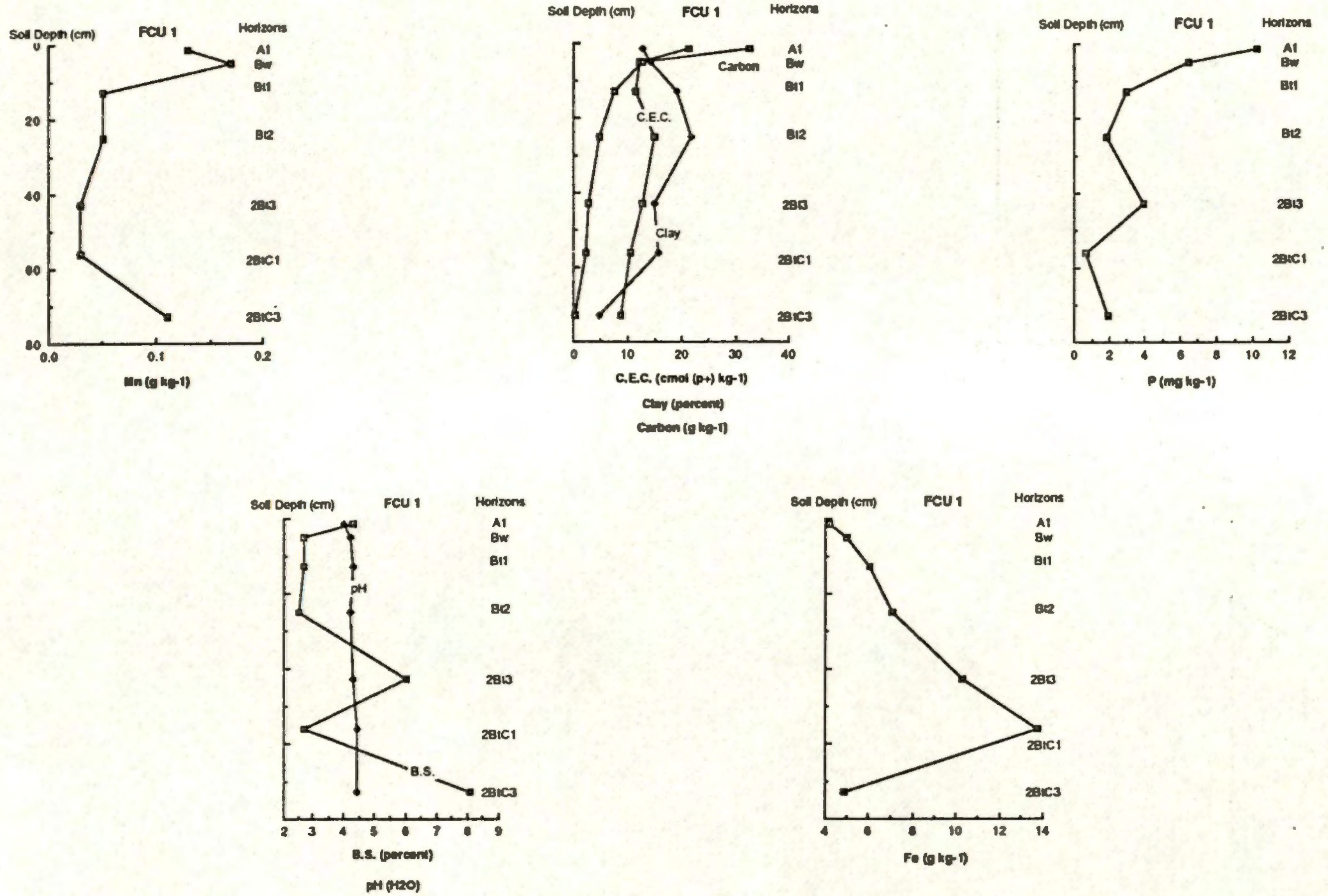

Figure D7. Fall Creek Falls upland profile one.

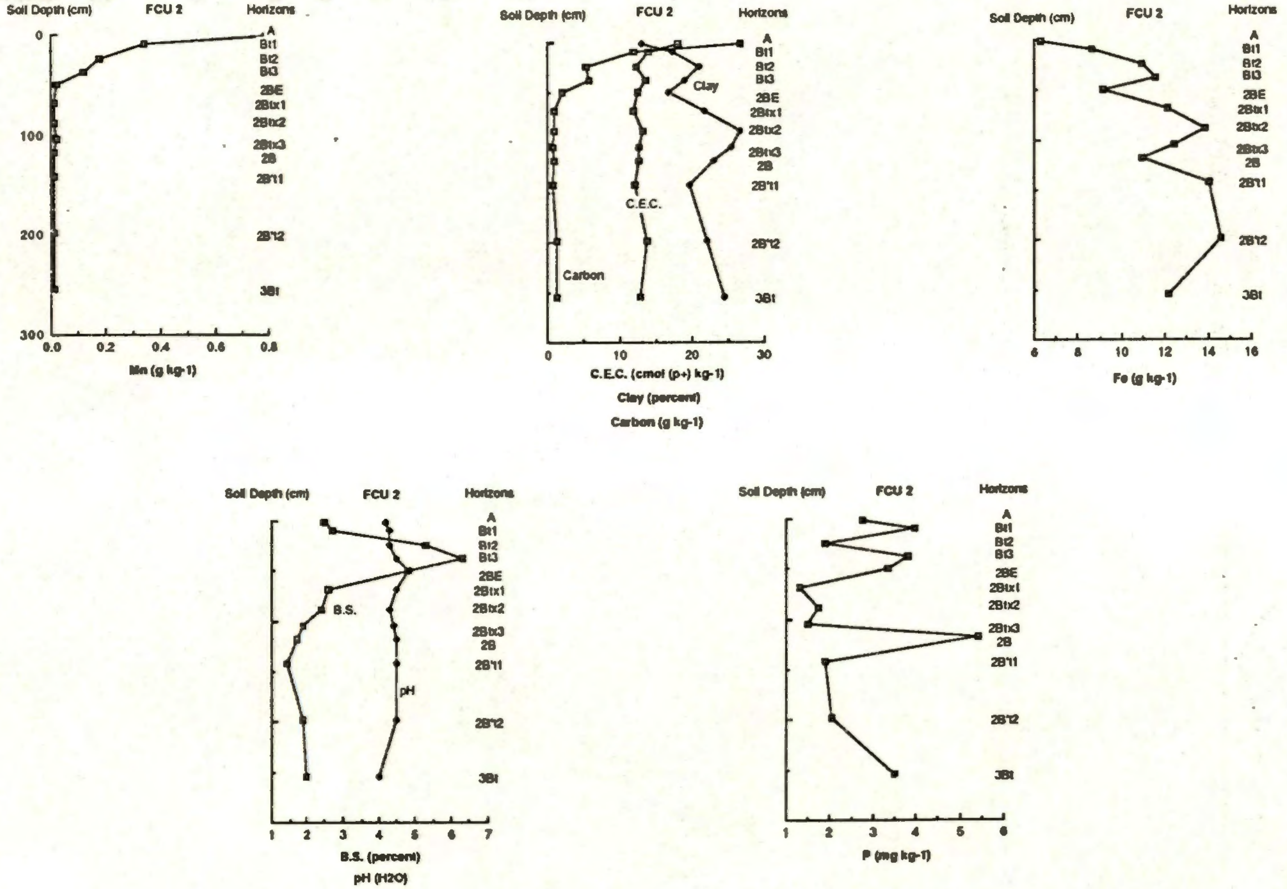

Figure D8. Fall Creek Falls upland profile two.

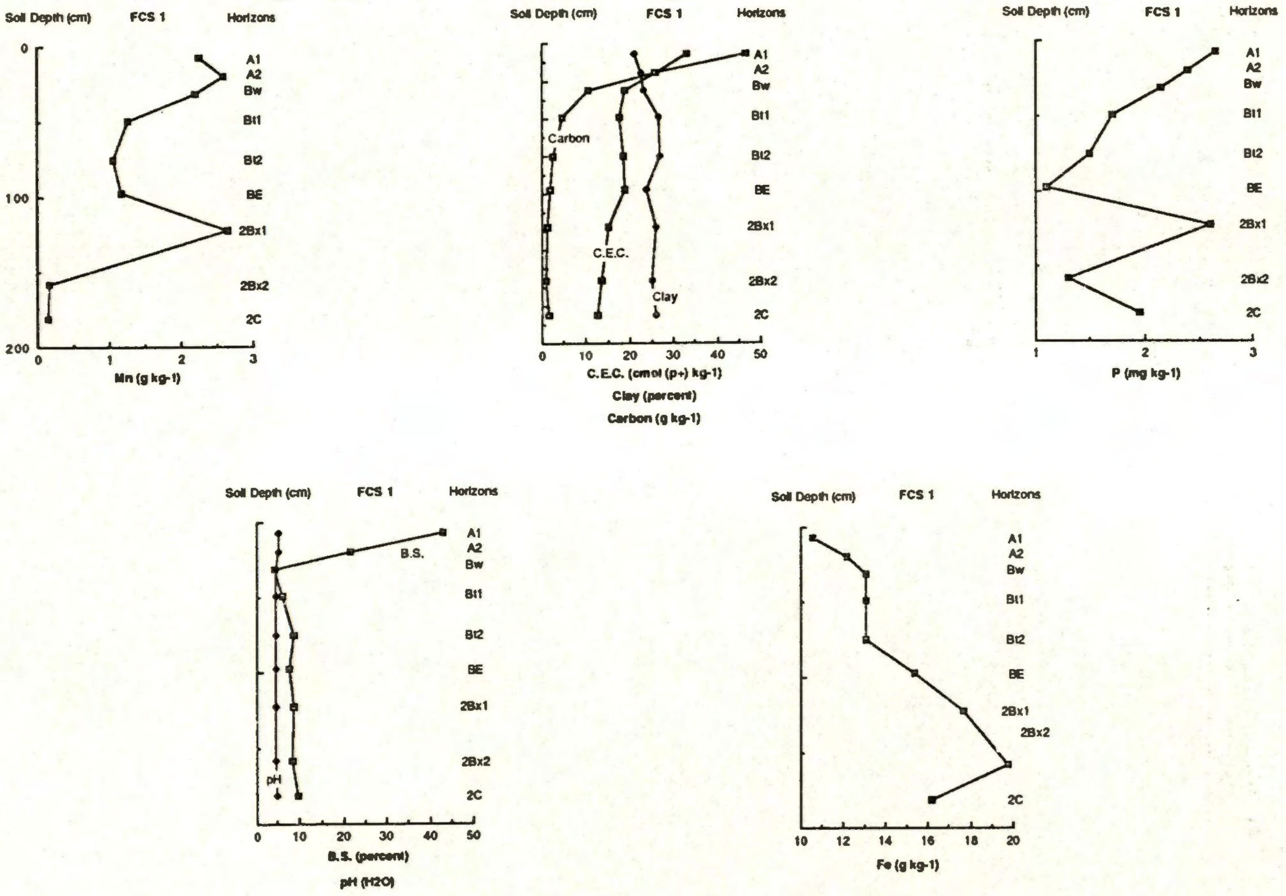

Figure D9. Fall Creek Falls slope profile one.

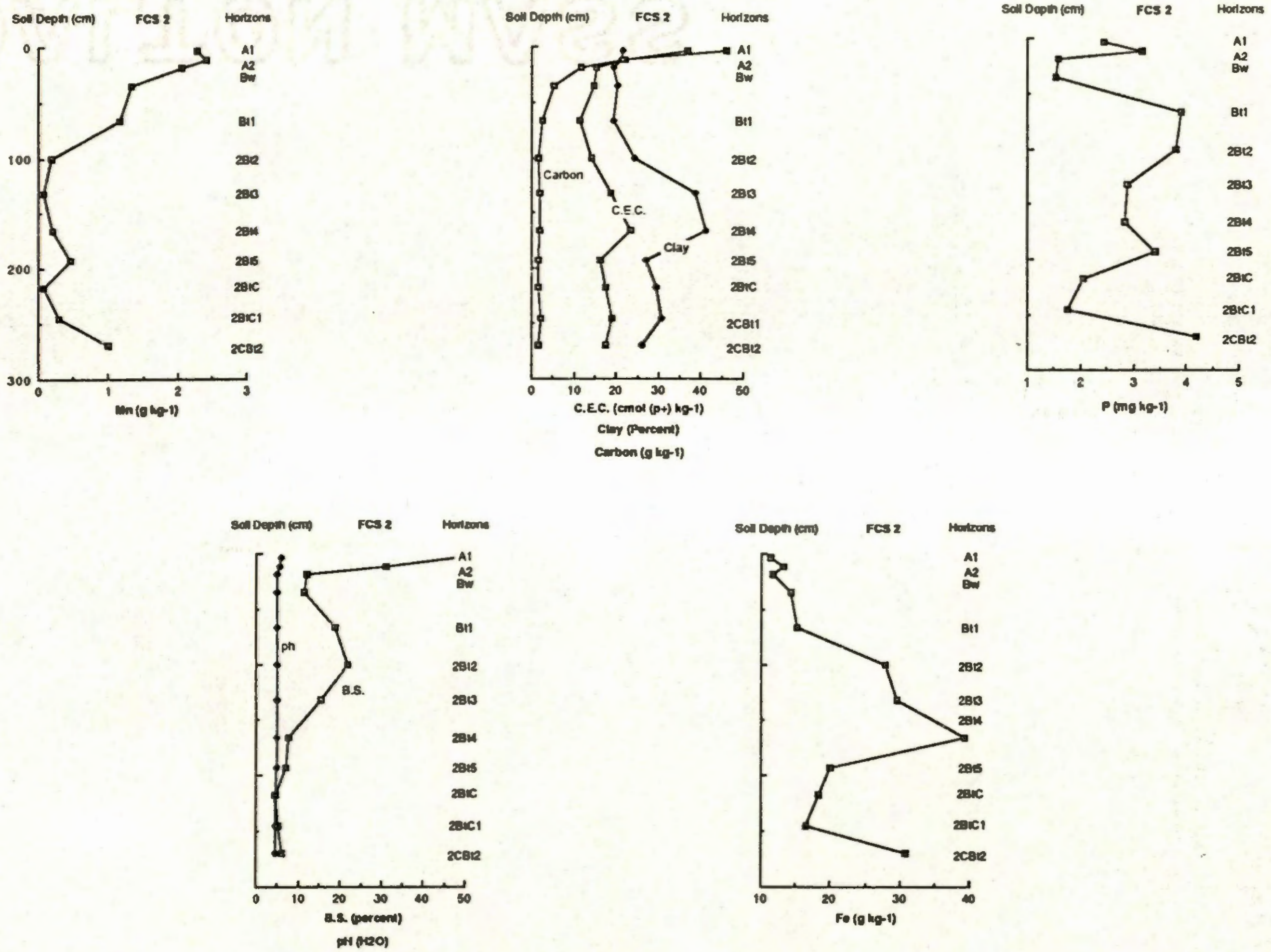

Figure D10. Fall Creek Falls slope profile two.

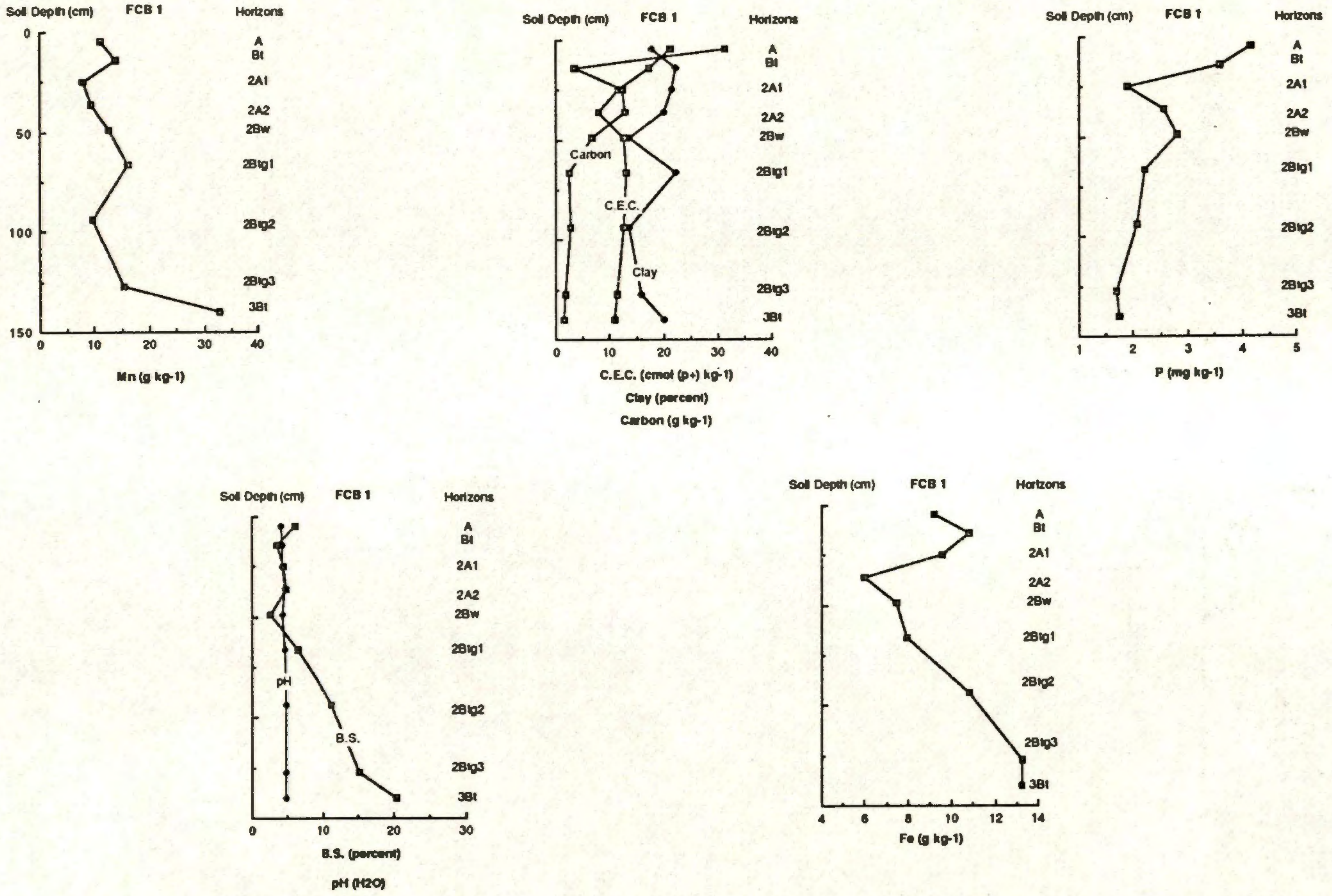

Figure D11. Fall Creek Falls bottom profile one.

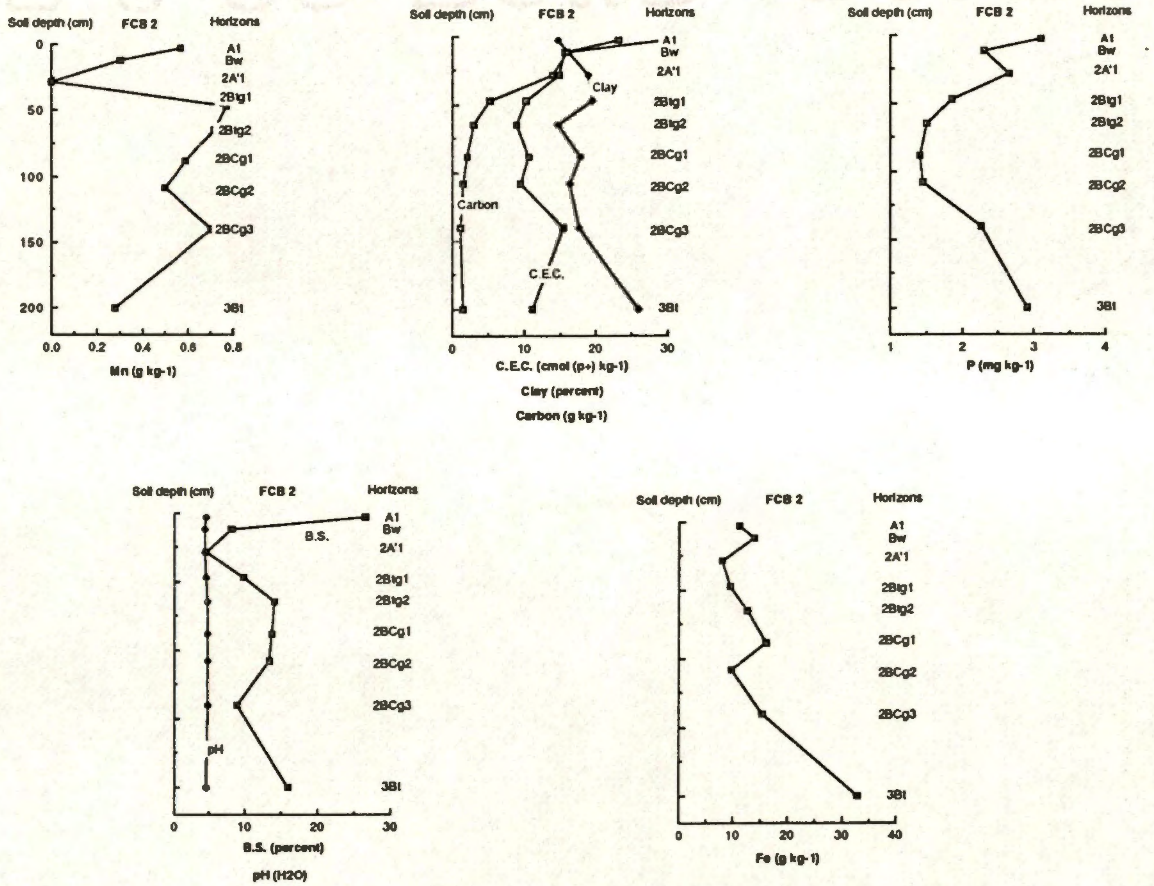

Figure D12. Fall Creek Falls bottom profile two.

APPENDIX E

SOIL MOISTURE CELL PLACEMENTS AND MONTHLY CELL READINGS

Appendix E1. Moisture Temperature Cell Placement in Catoosa Soils

Cell No.	Cell Type	Depth (cm)	Orientation	Comments
			Upland Pit 1	
1.	310A (0.91)	8	V	Beneath A horizon
2.	310A (1.08)	50	V	At top of argillic inside prism
3.	314	58	V	Between argillic prisms
4.	310A (1.09)	95	H	In boundary of Cr
			Upland Pit 2	
1.	310A (1.08)	8	V	Beneath A horizon
2.	314	25	V	Top of argillic
3.	314	42	V	Between prisms in argillic
4.	310A (1.04)	50	V	Inside prism in argillic
5.	314	65	V	Streak in pan
6.	314	120	V	In Cr horizon
7.	310A (1.09)	125	H	In horizontal clay seam
			Bottom Pit 1	
1.	310A (1.04)	5	V	Beneath A horizon
2.	314	30	V	Beneath Ab horizon
3.	310A (1.04)	50	V	Top of argillic horizon
4.	314	76	V	In prism face in argillic
5.	310A (1.08)	117	V	5 cm below water table
			Bottom Pit 2	
1.	310A (1.08)	5	V	Beneath A horizon
2.	314	30	V	Beneath Ab horizon
3.	310A (1.06)	50	V	Between prisms in argillic
4.	314	75	V	At base of argillic horizon
5.	310A (1.02)	126	V	25 cm below water table

Appendix E2. Moisture/Temperature Cell Placement in Fall Creek Falls Soils

Cell No.	Cell Type	Depth (cm)	Orientation	Comments
Upland Pit 1				
1.	310A (1.05)	3	V	A horizon
2.	314	37	V	Between argillic prisms
3.	314	50	V	Upper contact of Cr horizon
4.	310A (1.08)	50	H	Upper contact of Cr horizon
5.	310A (1.08)	91	H	Top of R contact
Upland Pit 2				
1.	310A (1.07)	6	V	A12 horizon
2.	314	36	V	Between argillic prisms
3.	310A (1.07)	50	V	Top of fragipan
4.	314	50	H	Top of fragipan
5.	310A (0.92)	77	V	Inside polygon in pan
6.	314	76	V	Upper gray streak
7.	310A (0.91)	120	V	Lower gray streak
8.	314	198	V	A1g in paleosol
9.	310A (1.08)	270	V	Top of water table
Bottom Pit 1				
1.	310A (1.06)	3	V	A horizon
2.	314	17	V	Top of Ab horizon
3.	314	32	V	Lower 1/3 of Ab horizon
4.	310A (1.05)	50	V	Between argillic prisms
5.	310A (1.06)	81	V	Between argillic prisms
6.	314	108	V	Inside argillic prisms
7.	314	172	V	At lithologic discontinuity
8.	310A (1.07)	235	V	At Cr horizon
Slope Pit 1				
1.	310A (1.07)	12	V	In A_{12} horizon
2.	314	35	V	Above argillic horizon
3.	310A (1.03)	50	V	Between prisms in argillic
4.	314	88	V	Between prisms below discontinuity
5.	314	125	V	In yellow band in B & C
6.	310A (1.09)	150	V	In white band in B & C
7.	310A (1.09)	235	V	Above Cr
Slope Pit 2				
1.	310A (1.08)	15	V	Below A horizon
2.	310A (1.09)	50	V	Between prisms in argillic
3.	314	30	V	At top of argillic
4.	314	85	H	Above the restrictive horizon
5.	314	130	V	In gleyed zone in B & C
6.	310A (1.00)	145	H	Above bedrock

Cell No.	Cell Type	Depth (cm)	Orientation	Comments
Bottom Pit 2				
1.	310A (1.08)	4	V	In A$_1$ horizon
2.	314	19	V	In Bt just above 2Ab
3.	314	30	V	Inside 2Ab
4.	310A (1.02)	50	V	In 2Bt$_1$
5.	314	84	V	Between argillic prisms
6.	310A (1.09)	126	V	Inside argillic prism
7.	310A (1.08)	158	V	Discontinuity above paleosol
8.	310A (1.07)	262	V	In Cr boundary
Slope Pit 1				
1.	310A (0.93)	6	V	A horizon
2.	314	23	V	Top of argillic
3.	310A (1.09)	50	V	Prism face in argillic
4.	310A (1.02)	105	V	Above restrictive layer
5.	314	133	V	Inside restrictive layer
6.	310A (1.06)	173	V	In Bt & C
7.	310A (0.98)	189	V	In Cr boundary
Slope Pit 2				
1.	310A (1.02)	8	V	A$_{11}$ horizon
2.	310A (1.07)	50	V	Prism face in argillic
3.	314	70	V	Inside prism
4.	310A (0.97)	104	V	Above lithologic discontinuity
5.	310A (1.07)	134	V	Between prisms in 2Bt
6.	314	160	H	Top of 2Bt & C
7.	314	210	H	Lower boundary 2Bt & C (red)
8.	314	242	H	In gleyed horizon above Cr
9.	310A (1.09)	261	H	In Cr boundary

Appendix E3. Moisture Cell Readings for Catoosa and Fall Creek Falls Soils

SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE	DATE	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5	DEPTH6	DEPTH7	DEPTH8	DEPTH9
CU1	OCT82	370.0	118.0	25.0	230.0	.	.	.	.	.
CU1	DEC82	5.0	19.5	4.5	1.0	.	.	.	.	.
CU1	JAN83	12.0	24.0	6.5	2.0	.	.	.	.	.
CU1	FEB83	17.0	22.0	5.5	2.5	.	.	.	.	.
CU1	MAR83	10.0	18.5	5.0	2.5	.	.	.	.	.
CU1	APR83	11.0	11.0	3.5	2.0	.	.	.	.	.
CU1	MAY83	14.0	14.0	4.0	2.0	.	.	.	.	.
CU1	JUN83	88.0	39.0	7.0	7.0	.	.	.	.	.
CU1	JUL83	2000.0	500.0	400.0	250.0	.	.	.	.	.
CU1	AUG83	1900.0	1000.0	750.0	1000.0	.	.	.	.	.
CU1	SEP83	2500.0	1000.0	1000.0	1000.0	.	.	.	.	.
CU1	OCT83	1200.0	800.0	520.0	1000.0	.	.	.	.	.
CU1	NOV83	11.0	23.0	4.5	2.0	.	.	.	.	.
CU1	JAN84	18.0	35.0	7.5	6.0	.	.	.	.	.
CU1	FEB84	10.5	29.5	6.0	3.0	.	.	.	.	.
CU1	MAR84	11.0	31.0	7.0	5.0	.	.	.	.	.
CU1	MAY84	11.0	18.0	6.0	7.5	.	.	.	.	.
CU1	JUN84	46.0	40.0	13.0	38.0	.	.	.	.	.
CU1	JUN84	260.0	280.0	220.0	240.0	.	.	.	.	.
CU1	JUL84	18.0	24.0	4.5	8.5	.	.	.	.	.
CU1	AUG84	39.0	36.0	83.0	20.0	.	.	.	.	.
CU1	SEP84	2000.0	380.0	260.0	205.0	.	.	.	.	.
CU1	OCT84	8.0	41.0	38.0	345.0	.	.	.	.	.
CU1	DEC84	11.0	29.0	7.5	3.2	.	.	.	.	.
CU2	OCT82	129.0	41.0	26.0	129.0	102.0	112.0	113.0	.	.
CU2	DEC82	34.5	20.0	6.0	11.0	8.0	2.0	2.0	.	.
CU2	JAN83	750.0	29.0	8.0	29.5	13.0	5.0	2.5	.	.
CU2	FEB83	100.0	29.0	9.0	31.0	10.5	6.0	4.0	.	.
CU2	MAR83	79.0	24.5	8.0	27.0	11.0	5.0	1.5	.	.
CU2	APR83	82.0	23.0	7.0	230.0	8.0	5.0	3.5	.	.
CU2	MAY83	79.0	21.5	7.0	25.0	9.0	5.0	3.0	.	.
CU2	JUN83	165.0	46.0	15.0	43.0	24.0	24.0	13.5	.	.
CU2	JUL83	450.0	900.0	600.0	600.0	950.0	950.0	500.0	.	.
CU2	AUG83	330.0	800.0	750.0	1300.0	2000.0	2000.0	2000.0	.	.
CU2	SEP83	900.0	2000.0	2000.0	1900.0	2000.0	2000.0	2000.0	.	.
CU2	OCT83	108.0	73.0	58.0	900.0	2000.0	2000.0	2000.0	.	.
CU2	NOV83	105.0	28.0	16.5	40.0	12.0	5.0	3.0	.	.
CU2	JAN84	120.0	46.0	22.5	60.0	24.5	8.5	4.5	.	.
CU2	FEB84	89.0	45.0	22.0	46.0	17.0	4.5	4.5	.	.
CU2	MAR84	75.0	46.0	25.0	44.0	18.5	8.0	4.5	.	.
CU2	MAY84	68.0	26.0	8.0	31.0	12.0	6.0	4.0	.	.
CU2	JUN84	110.0	50.0	16.0	45.0	28.0	38.0	20.5	.	.
CU2	JUN84	109.0	68.0	45.0	160.0	141.0	290.0	195.0	.	.
CU2	JUL84	64.0	22.5	32.0	10.5	18.0	17.5	4.0	.	.
CU2	AUG84	100.0	39.0	15.0	36.5	27.0	34.5	20.0	.	.
CU2	SEP84	490.0	3000.0	350.0	300.0	800.0	500.0	300.0	.	.

SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE	DATE	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5	DEPTH6	DEPTH7	DEPTH8	DEPTH9
CU2	OCT84	40.0	25.5	12.5	90.0	100.0	900.0	700.0	.	.
CU2	DEC84	2000.0	40.0	12.0	34.5	12.5	6.0	4.0	.	.
CS1	OCT82	69.0	220.0	138.0	1500.0	8.0	450.0	49.0	.	.
CS1	DEC82	30.5	10.5	19.5	9.0	2.0	2.5	1.5	.	.
CS1	JAN83	34.5	11.0	28.0	19.0	3.5	3.0	2.5	.	.
CS1	FEB83	41.5	10.5	19.0	16.0	7.0	3.0	3.5	.	.
CS1	MAR83	21.5	8.0	15.5	20.5	7.0	3.0	3.0	.	.
CS1	APR83	38.5	8.5	12.0	11.0	7.0	2.5	3.0	.	.
CS1	MAY83	51.0	8.5	10.0	11.0	7.0	2.5	3.0	.	.
CS1	JUN83	103.0	21.0	35.0	24.5	6.5	3.0	2.5	.	.
CS1	JUL83	300.0	1900.0	500.0	2000.0	190.0	44.0	18.0	.	.
CS1	AUG83	58.0	140.0	380.0	2500.0	1800.0	600.0	480.0	.	.
CS1	SEP83	300.0	2000.0	950.0	2000.0	1900.0	750.0	500.0	.	.
CS1	OCT83	43.0	30.5	165.0	2000.0	1100.0	750.0	500.0	.	.
CS1	NOV83	44.5	10.0	10.0	30.0	5.0	125.0	6.0	.	.
CS1	JAN84	400.0	18.0	50.0	26.0	9.0	5.5	7.0	.	.
CS1	FEB84	42.5	8.0	12.0	12.5	7.0	2.5	6.5	.	.
CS1	MAR84	37.0	10.0	29.5	19.5	6.5	5.0	12.0	.	.
CS1	MAY84	26.5	10.0	17.5	12.5	3.0	7.0	6.0	.	.
CS1	JUN84	98.0	60.0	75.0	73.0	7.0	25.5	21.0	.	.
CS1	JUN84	72.0	33.0	1500.0	82.0	520.0	240.0	180.0	.	.
CS1	JUL84	58.0	30.0	35.0	19.0	8.5	19.5	16.0	.	.
CS1	AUG84	95.0	72.0	100.0	1000.0	400.0	120.0	150.0	.	.
CS1	SEP84	380.0	1100.0	480.0	1800.0	950.0	700.0	500.0	.	.
CS1	OCT84	19.0	11.5	36.0	19.5	350.0	750.0	520.0	.	.
CS1	DEC84	24.5	12.0	39.5	10.0	6.5	4.5	2.5	.	.
CS2	OCT82	102.0	96.0	250.0	26.0	12.0	500.0	.	.	.
CS2	DEC82	25.0	16.0	9.0	1.0	1.0	1.5	.	.	.
CS2	JAN83	20.0	22.5	15.5	1.5	4.0	1.0	.	.	.
CS2	FEB83	18.5	34.5	22.0	2.5	6.0	1.0	.	.	.
CS2	MAR83	15.5	21.0	15.5	4.5	5.0	1.5	.	.	.
CS2	APR83	19.1	29.0	13.0	2.5	4.5	1.5	.	.	.
CS2	MAY83	19.0	24.0	12.0	2.5	4.0	1.5	.	.	.
CS2	JUN83	30.0	39.0	17.5	6.0	1.0	1.5	.	.	.
CS2	JUL83	300.0	500.0	160.0	180.0	11.5	30.0	.	.	.
CS2	AUG83	19.5	59.0	36.0	500.0	200.0	450.0	.	.	.
CS2	SEP83	250.0	1000.0	500.0	950.0	380.0	900.0	.	.	.
CS2	OCT83	30.0	36.0	53.0	400.0	400.0	1900.0	.	.	.
CS2	NOV83	25.5	24.0	16.0	2.5	2.5	1.5	.	.	.
CS2	JAN84	10.0	32.0	29.5	5.0	4.5	2.5	.	.	.
CS2	FEB84	18.5	19.0	20.0	2.5	4.5	3.0	.	.	.
CS2	MAR84	17.5	22.0	18.0	3.0	5.0	2.5	.	.	.
CS2	MAY84	14.0	20.0	14.0	2.5	3.5	2.0	.	.	.
CS2	JUN84	52.0	35.0	35.0	32.0	3.5	2.0	.	.	.
CS2	JUN84	41.5	21.0	25.5	19.5	4.0	2.0	.	.	.
CS2	JUL84	24.0	16.0	19.0	1.0	0.5	1.0	.	.	.

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                           SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE    DATE     DEPTH1    DEPTH2    DEPTH3    DEPTH4    DEPTH5    DEPTH6    DEPTH7    DEPTH8    DEPTH9

CS2     AUG84      49.0      20.0      25.0       1.5       0.5       0.0         .         .         .
CS2     SEP84     600.0     205.0     420.0      46.0       7.0      12.0         .         .         .
CS2     OCT84      12.0      10.0      12.0      68.0      19.5       1.0         .         .         .
CS2     DEC84      11.5      18.0      13.0       1.0       2.0       1.5         .         .         .
CB1     OCT82     108.0      28.0      39.0       5.0       6.0         .         .         .         .
CB1     DEC82      59.5      19.5      59.0       1.0       2.0         .         .         .         .
CB1     JAN83      88.0      13.0       4.5       1.5       2.0         .         .         .         .
CB1     FEB83      98.0      12.0       3.5       1.0       2.0         .         .         .         .
CB1     MAR83      71.0      11.0       5.0       1.0       1.5         .         .         .         .
CB1     APR83      68.0      10.0       3.0       1.0       1.0         .         .         .         .
CB1     MAY83      70.0      10.0       4.0       1.0       1.0         .         .         .         .
CB1     JUN83      82.0      11.0       7.0       1.0       1.0         .         .         .         .
CB1     JUL83     120.0      19.5      16.0       1.0       1.5         .         .         .         .
CB1     AUG83     120.0      40.0      50.0       2.0       0.5         .         .         .         .
CB1     SEP83     600.0     180.0     100.0      25.0       1.5         .         .         .         .
CB1     OCT83     115.0      50.0      70.0       4.5       3.5         .         .         .         .
CB1     NOV83      42.5      31.0       4.0       1.0       0.5         .         .         .         .
CB1     JAN84     164.0      11.5       1.5       1.0       1.0         .         .         .         .
CB1     FEB84      37.0      12.5       1.5       1.5       1.0         .         .         .         .
CB1     MAR84       6.0      13.5       1.5       0.0       0.0         .         .         .         .
CB1     MAY84      60.5       7.0       1.5       1.5       1.0         .         .         .         .
CB1     JUN84      95.0       1.5       1.0       1.5       1.0         .         .         .         .
CB1     JUN84      85.0      19.0       0.5       0.5       1.0         .         .         .         .
CB1     JUL84      75.0      11.0       2.0       1.0       1.0         .         .         .         .
CB1     AUG84     105.0       6.0       0.5       0.5       1.0         .         .         .         .
CB1     SEP84     240.0      18.0       4.0       1.4       1.0         .         .         .         .
CB1     OCT84      40.0      12.0         .       0.5       0.5         .         .         .         .
CB1     DEC84      68.0       9.0         .       1.0       1.0         .         .         .         .
CB2     OCT82      82.0      22.0      46.0       3.0       5.5         .         .         .         .
CB2     DEC82      32.0       4.0       2.5       1.5       5.0         .         .         .         .
CB2     JAN83      52.0      10.0       0.0       1.5       2.0         .         .         .         .
CB2     FEB83      69.0      11.0      11.0       1.5       1.0         .         .         .         .
CB2     MAR83      51.0      10.0      29.5       1.0       1.0         .         .         .         .
CB2     APR83      44.0       8.0       5.0       1.0       1.0         .         .         .         .
CB2     MAY83      40.0       9.0       2.0       1.0       1.0         .         .         .         .
CB2     JUN83      65.0      15.0      24.5       1.5       1.0         .         .         .         .
CB2     JUL83     160.0      33.0      75.0       3.0       1.5         .         .         .         .
CB2     AUG83     450.0     700.0    1500.0     300.0       1.5         .         .         .         .
CB2     SEP83    1100.0    1200.0    2000.0     160.0      90.0         .         .         .         .
CB2     OCT83     450.0     160.0    2000.0      37.0     135.0         .         .         .         .
CB2     NOV83      41.0      10.5      19.5       1.0       1.5         .         .         .         .
CB2     JAN84     190.0      11.0       1.0       1.5       2.0         .         .         .         .
CB2     FEB84      46.0      10.0       4.0       1.5       2.0         .         .         .         .
CB2     MAR84      60.0      11.0      11.0       1.5       2.0         .         .         .         .
CB2     MAY84      44.0      10.0      10.0       2.0       1.5         .         .         .         .
CB2     JUN84      64.0      24.0      43.0       1.5       1.5         .         .         .         .
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SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE	DATE	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5	DEPTH6	DEPTH7	DEPTH8	DEPTH9
CB2	JUN84	72.0	28.0	58.0	3.0	0.5	.	.	.	.
CB2	JUL84	59.0	18.0	30.0	1.0	1.1	.	.	.	.
CB2	AUG84	112.0	25.0	42.0	0.5	1.5	.	.	.	.
CB2	SEP84	600.0	108.0	140.0	5.5	0.5	.	.	.	.
CB2	OCT84	40.0	14.0	25.5	0.5	1.0	.	.	.	.
CB2	DEC84	60.5	11.0	6.5	1.0	1.5	.	.	.	.
FCU1	OCT82	140.0	70.0	2.0	58.0	220.0	.	.	.	.
FCU1	DEC82	8.5	3.0	2.0	1.5	3.0	.	.	.	.
FCU1	JAN83	50.5	11.0	21.0	19.5	1.0	.	.	.	.
FCU1	FEB83	70.0	11.0	15.5	17.5	9.0	.	.	.	.
FCU1	MAR83	44.5	11.0	15.5	14.0	4.0	.	.	.	.
FCU1	APR83	52.0	7.5	25.0	21.5	9.0	.	.	.	.
FCU1	MAY83	46.0	8.0	12.5	13.0	11.0	.	.	.	.
FCU1	JUN83	500.0	30.0	37.5	39.0	72.0	.	.	.	.
FCU1	JUL83	1500.0	1900.0	120.0	150.0	300.0	.	.	.	.
FCU1	AUG83	2000.0	2000.0	260.0	750.0	1500.0	.	.	.	.
FCU1	SEP83	2500.0	1000.0	1000.0	1000.0	1100.0	.	.	.	.
FCU1	OCT83	100.0	80.0	145.0	800.0	1800.0	.	.	.	.
FCU1	NOV83	50.5	14.0	14.0	21.5	2.5	.	.	.	.
FCU1	JAN84	52.0	20.0	24.0	31.0	6.0	.	.	.	.
FCU1	FEB84	9.0	25.0	34.0	48.0	25.0	.	.	.	.
FCU1	MAR84	29.0	16.0	24.0	16.0	22.0	.	.	.	.
FCU1	MAY84	88.0	12.0	30.5	34.0	46.0	.	.	.	.
FCU1	JUN84	13.0	24.5	42.0	39.0	71.0	.	.	.	.
FCU1	JUN84	130.0	63.0	90.0	70.0	350.0	.	.	.	.
FCU1	JUL84	190.0	90.0	110.0	78.0	450.0	.	.	.	.
FCU1	AUG84	58.0	14.5	38.0	29.0	120.0	.	.	.	.
FCU1	SEP84	600.0	950.0	400.0	250.0	950.0	.	.	.	.
FCU1	OCT84	66.0	14.0	32.5	31.0	100.0	.	.	.	.
FCU1	DEC84	89.0	14.5	12.0	20.0	6.0	.	.	.	.
FCU2	OCT82	49.0	150.0	8.5	40.0	22.0	34.0	21.0	.	900.0
FCU2	DEC82	11.0	7.0	3.0	2.0	1.0	850.0	0.5	.	1.4
FCU2	JAN83	46.0	11.0	1.0	3.0	2.5	2.5	32.5	.	1.3
FCU2	FEB83	62.0	11.0	1.0	3.0	2.5	1.5	2.5	.	1.5
FCU2	MAR83	19.5	10.0	1.5	2.5	1.0	1.5	1.0	.	2.0
FCU2	APR83	46.0	8.0	1.5	3.0	1.5	1.5	0.0	.	200.0
FCU2	MAY83	44.0	11.0	3.0	2.5	0.5	1.5	2.0	.	2.0
FCU2	JUN83	350.0	65.0	24.0	7.0	2.5	11.5	2.0	.	1.0
FCU2	JUL83	900.0	490.0	145.0	250.0	26.0	130.0	13.5	.	32.0
FCU2	AUG83	1000.0	500.0	900.0	1600.0	100.0	350.0	105.0	900.0	100.0
FCU2	SEP83	2000.0	1000.0	1300.0	2000.0	160.0	420.0	170.0	1500.0	1000.0
FCU2	OCT83	650.0	160.0	350.0	180.0	83.0	300.0	190.0	2000.0	1000.0
FCU2	NOV83	68.0	26.0	14.5	4.5	1.5	3.0	2.5	4.5	1.5
FCU2	JAN84	34.5	12.0	4.0	2.0	3.0	2.0	2.0	3.0	1.5
FCU2	FEB84	62.0	22.5	7.0	5.0	3.0	2.5	2.5	63.0	2.0
FCU2	MAR84	29.5	9.0	4.0	4.0	4.0	4.5	3.0	2.0	2.5

SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE	DATE	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5	DEPTH6	DEPTH7	DEPTH8	DEPTH9
FCU2	MAY84	118.0	27.5	7.0	4.0	3.0	2.5	255.0	2.0	2.5
FCU2	JUN84	140.0	63.0	31.0	9.0	9.0	12.0	11.0	175.0	2.0
FCU2	JUN84	490.0	195.0	210.0	67.0	46.0	145.0	46.0	62.0	35.0
FCU2	JUL84	450.0	390.0	500.0	250.0	120.0	200.0	72.0	210.0	95.0
FCU2	AUG84	150.0	29.5	47.0	195.0	9.0	10.5	70.0	300.0	180.0
FCU2	SEP84	1900.0	510.0	950.0	750.0	245.0	500.0	160.0	510.0	300.0
FCU2	OCT84	110.0	85.0	30.0	6.0	98.0	59.0	34.5	190.0	280.0
FCU2	DEC84	10.5	11.0	2.5	3.0	4.5	2.5	2.5	2.0	1.5
FCS1	OCT82	2.4	45.0	230.0	49.0	.	189.0	46.0	.	.
FCS1	DEC82	3.3	4.5	22.5	0.5	.	2.0	1.0	.	.
FCS1	JAN83	1.0	2.0	3.5	0.0	.	2.0	1.5	.	.
FCS1	FEB83	10.0	19.0	40.0	0.0	.	2.5	1.0	.	.
FCS1	MAR83	4.0	10.5	26.0	0.0	.	2.0	1.0	.	.
FCS1	APR83	9.5	13.0	29.5	6.5	.	2.0	1.0	.	.
FCS1	MAY83	11.0	13.5	26.0	0.0	.	1.5	1.0	.	.
FCS1	JUN83	160.0	68.0	65.0	11.0	.	5.0	0.5	.	.
FCS1	JUL83	250.0	1000.0	1000.0	95.0	.	34.0	4.0	.	.
FCS1	AUG83	400.0	1500.0	1500.0	1000.0	.	390.0	82.0	.	.
FCS1	SEP83	500.0	1900.0	1900.0	90.0	.	600.0	120.0	.	.
FCS1	OCT83	11.0	58.0	1000.0	0.0	.	250.0	140.0	.	.
FCS1	NOV83	2.5	25.0	61.0	0.0	.	4.0	5.0	.	.
FCS1	JAN84	15.5	39.0	93.0	0.0	.	4.0	2.0	.	.
FCS1	FEB84	18.0	44.0	200.0	0.0	.	3.5	2.0	.	.
FCS1	MAR84	5.5	21.0	35.5	1.0	.	11.5	2.5	.	.
FCS1	MAY84	58.0	38.0	36.0	9.0	.	10.0	3.0	.	.
FCS1	JUN84	61.5	62.0	80.0	0.0	.	18.5	11.0	.	.
FCS1	JUN84	45.0	1000.0	1200.0	130.0	.	89.0	25.0	.	.
FCS1	JUL84	103.0	400.0	750.0	300.0	.	200.0	90.0	.	.
FCS1	AUG84	59.0	40.0	550.0	230.0	.	90.0	100.0	.	.
FCS1	SEP84	300.0	1000.0	1000.0	250.0	.	140.0	49.0	.	.
FCS1	OCT84	9.0	12.0	60.5	13.0	.	69.5	4.0	.	.
FCS1	DEC84	12.0	19.5	68.0	7.0	.	4.5	2.5	.	.
FCS2	OCT82	25.0	10.0	23.0	37.0	12.0	43.0	.	108.0	11.0
FCS2	DEC82	9.0	4.0	2.0	9.0	11.0	19.5	.	109.0	5.0
FCS2	JAN83	24.5	6.0	6.5	22.0	3.5	4.5	.	2.0	2.0
FCS2	FEB83	22.0	6.5	8.0	24.0	5.5	6.0	.	7.0	1.5
FCS2	MAR83	14.5	7.0	8.0	0.5	6.5	7.0	.	0.5	1.0
FCS2	APR83	21.0	17.5	16.5	24.0	4.0	6.0	.	6.0	2.0
FCS2	MAY83	16.5	14.0	16.5	18.5	3.0	4.5	.	3.5	1.0
FCS2	JUN83	60.0	28.0	19.5	28.0	5.0	5.0	.	5.0	1.0
FCS2	JUL83	230.0	100.0	79.0	53.0	9.0	12.0	.	29.0	8.0
FCS2	AUG83	550.0	600.0	500.0	300.0	58.0	45.0	.	370.0	160.0
FCS2	SEP83	950.0	1000.0	1000.0	300.0	75.0	145.0	.	700.0	400.0
FCS2	OCT83	26.0	1000.0	900.0	400.0	73.0	170.0	.	900.0	500.0
FCS2	NOV83	28.0	340.0	9.5	11.5	44.0	170.0	.	750.0	90.0
FCS2	JAN84	24.0	24.5	11.0	16.5	5.0	28.0	.	4.0	2.0

SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE	DATE	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5	DEPTH6	DEPTH7	DEPTH8	DEPTH9
FCS2	FEB84	30.5	28.0	16.0	23.0	5.0	14.0	.	3.5	2.5
FCS2	MAR84	10.0	16.0	16.0	29.0	7.0	3.0	.	5.5	3.0
FCS2	MAY84	40.5	18.0	11.0	24.0	5.0	2.0	.	9.0	3.0
FCS2	JUN84	34.0	25.0	19.5	40.0	7.0	3.5	.	1.5	0.5
FCS2	JUN84	59.5	63.0	145.0	110.0	11.0	10.0	.	57.0	17.0
FCS2	JUL84	47.0	59.0	100.0	161.0	25.0	27.0	.	105.0	38.0
FCS2	AUG84	13.5	32.5	27.0	108.0	20.5	46.0	.	200.0	80.0
FCS2	SEP84	350.0	37.0	51.0	100.0	50.0	49.0	.	260.0	120.0
FCS2	OCT84	20.0	75.0	11.8	21.0	22.0	72.0	.	350.0	220.0
FCS2	DEC84	35.0	11.0	24.0	12.0	4.0	25.0	.	3.0	2.5
FCB1	OCT82	6.0	30.0	21.5	79.0	62.0	6.5	.	19.0	.
FCB1	DEC82	8.0	3.0	1.5	1.0	1.0	4.0	.	1.0	.
FCB1	JAN83	59.0	28.0	2.0	2.0	0.5	3.0	.	1.0	.
FCB1	FEB83	58.0	34.0	2.0	2.0	1.0	3.5	.	1.5	.
FCB1	MAR83	18.0	10.0	2.0	2.0	1.0	2.5	.	1.5	.
FCB1	APR83	60.0	26.0	2.0	2.5	1.5	3.0	.	2.0	.
FCB1	MAY83	46.0	21.0	1.5	2.0	2.0	3.0	.	2.0	.
FCB1	JUN83	88.0	25,0	0.5	11.0	1.5	3.0	.	2.0	.
FCB1	JUL83	260.0	185.0	60.0	59.0	10.0	1.0	.	2.0	.
FCB1	AUG83	500.0	400.0	300.0	750.0	230.0	28.0	.	11.0	.
FCB1	SEP83	800.0	500.0	350.0	900.0	300.0	52.0	.	65.0	.
FCB1	OCT83	200.0	220.0	120.0	400.0	180.0	58.0	.	200.0	.
FCB1	NOV83	30.0	18.0	8.0	19.0	1.5	1.5	.	1.0	.
FCB1	JAN84	26.0	7.0	2.0	2.5	1.5	1.5	.	1.5	.
FCB1	FEB84	41.0	17.0	3.0	1.5	1.5	2.0	.	1.5	.
FCB1	MAR84	17.5	2.0	1.5	1.5	1.0	1.5	.	2.0	.
FCB1	MAY84	26.0	12.0	1.0	1.0	1.5	0.5	.	2.0	.
FCB1	JUN84	26.0	18.0	2.0	2.0	2.0	1.0	.	2.0	.
FCB1	JUN84	38.0	39.0	6.0	9.0	5.0	0.5	.	2.0	.
FCB1	JUL84	550.0	400.0	69.0	9.0	4.0	0.5	.	1.5	.
FCB1	AUG84	22.0	25.0	6.0	4.0	0.0	0.5	.	2.0	.
FCB1	SEP84	100.0	120.0	18.0	240.0	49.5	0.5	.	2.0	.
FCB1	OCT84	20.0	10.0	1.0	1.0	0.5	0.5	.	1.2	.
FCB1	DEC84	32.0	12.0	1.0	1.0	1.0	1.0	.	2.0	.
FCB2	OCT82	19.5	9.5	26.0	34.5	10.0	37.5	.	1.1	.
FCB2	DEC82	11.0	2.0	2.5	1.5	2.0	1.0	.	0.5	.
FCB2	JAN83	60.0	7.5	3.5	2.0	1.5	1.0	.	0.4	.
FCB2	FEB83	44.0	6.0	4.0	1.5	2.0	1.0	.	0.5	.
FCB2	MAR83	23.5	6.0	6.0	0.5	2.0	1.0	.	0.5	.
FCB2	APR83	59.0	6.5	4.5	1.5	1.5	1.0	.	0.5	.
FCB2	MAY83	58.0	8.0	3.5	1.5	2.5	1.0	.	0.5	.
FCB2	JUN83	185.0	37.0	34.5	4.0	0.0	1.5	.	0.0	.
FCB2	JUL83	350.0	250.0	260.0	50.0	1.0	3.0	.	0.5	.
FCB2	AUG83	450.0	750.0	900.0	300.0	38.0	165.0	.	1.0	.
FCB2	SEP83	750.0	950.0	1000.0	2000.0	400.0	58.0	.	9.5	.
FCB2	OCT83	50.0	20.0	60.0	118.0	24.0	300.0	.	24.0	.

SOIL MOISTURE CELL RESISTANCES (OHMS)

SITE	DATE	DEPTH1	DEPTH2	DEPTH3	DEPTH4	DEPTH5	DEPTH6	DEPTH7	DEPTH8	DEPTH9
FCB2	NOV83	24	5.5	3.5	1.0	1.0	1.5	.	0.5	.
FCB2	JAN84	13	6.0	4.0	2.0	2.0	2.0	1.0	1.0	.
FCB2	FEB84	25	7.5	4.0	2.5	2.0	2.5	0.5	1.0	.
FCB2	MAR84	18	6.0	4.0	2.0	2.0	2.0	1.0	1.0	.
FCB2	MAY84	51	11.5	9.5	0.0	0.0	1.0	2.0	1.0	.
FCB2	JUN84	65	27.5	26.0	3.0	2.5	1.0	1.5	1.0	.
FCB2	JUN84	70	45.0	60.0	28.0	1.5	1.0	1.5	1.0	.
FCB2	JUL84	205	85.0	85.0	37.0	2.0	1.0	0.0	1.2	.
FCB2	AUG84	30	9.0	11.0	49.0	0.0	0.5	1.5	1.0	.
FCB2	SEP84	500	310.0	145.0	70.0	1.0	0.5	0.0	1.0	.
FCB2	OCT84	46	12.5	9.0	1.5	1.0	0.5	0.5	1.0	.
FCB2	DEC84	36	7.5	4.0	1.5	1.0	0.5	1.5	1.0	.

APPENDIX F

DATA FOR SOIL CHEMICAL AND PHYSICAL PROPERTIES MEASURED BY GRID SAMPLING

Appendix F1. Chemical Data for Grid A Horizons

CHEMICAL DATA FOR GRID A HORIZONS

ORGMAT	K	CA	MG	NA	WATPH	KCLPH	SITE
5.34	97.33	281.61	23.97	21.93	4.50031	3.89997	FCU
4.32	99.84	312.49	29.26	22.32	4.40012	3.79997	FCU
4.18	98.85	159.93	26.78	10.82	4.30016	3.70006	FCU
4.15	78.37	49.60	13.93	11.24	3.89997	3.40001	FCU
4.61	70.16	60.34	14.44	13.23	3.89997	3.40001	FCU
4.71	95.99	89.95	25.85	14.05	3.79997	3.29999	FCU
5.05	117.25	35.15	25.96	16.70	3.59998	3.29999	FCU
5.48	79.38	168.58	24.20	20.33	3.19997	2.90001	FCU
4.64	93.66	97.32	15.06	24.37	3.59998	3.40001	FCU
4.61	129.92	72.32	19.44	20.37	3.70006	3.29999	FCU
3.56	89.26	69.19	22.40	15.28	3.79997	3.50004	FCU
4.62	100.46	53.21	22.30	16.81	3.59998	3.29999	FCU
4.11	129.69	262.14	21.58	25.15	4.00000	3.70006	FCU
4.18	106.96	200.25	12.55	12.61	3.70006	3.40001	FCU
4.42	119.73	92.70	22.51	19.85	3.89997	3.59998	FCU
6.03	162.17	392.94	61.76	23.22	3.89997	3.50004	FCU
5.19	91.71	158.80	20.28	19.13	3.59998	3.19997	FCU
3.93	95.35	196.47	27.84	18.10	3.89997	3.66514	FCU
4.67	205.36	2045.75	177.05	23.47	5.79588	5.30103	CS
5.11	253.98	1974.73	160.57	29.13	5.69897	5.30103	CS
5.19	210.53	2285.42	337.91	18.95	6.00000	5.39794	CS
4.49	221.70	1625.58	220.16	15.98	5.69897	5.10237	CS
5.03	210.62	1632.47	270.88	19.39	5.69897	5.00000	CS
5.27	172.62	1252.21	351.54	22.05	5.79588	5.20066	CS
5.35	195.87	1975.29	313.30	18.46	5.88606	5.39794	CS
5.39	191.05	2293.32	180.03	22.90	5.88606	5.39794	CS
4.74	264.68	1977.69	242.50	18.22	5.88606	5.30103	CS
4.42	150.00	1791.52	186.98	19.26	5.88606	4.89963	CS
4.79	183.78	1230.75	190.62	10.82	5.88606	5.20066	CS
4.38	205.26	1726.48	244.37	18.06	6.09691	4.69897	CS
4.73	163.06	1237.17	186.38	15.08	5.49485	4.69897	CS
3.64	222.95	1439.42	106.82	16.52	6.00000	5.20066	CS
4.62	258.59	1442.94	219.45	18.16	5.88606	5.10237	CS
5.15	229.55	1699.43	221.35	15.71	5.88606	5.10237	CS
3.61	140.33	974.87	188.27	22.91	5.79588	5.00000	CS
4.81	216.38	826.12	179.73	18.43	5.39794	4.60033	CS
4.26	269.20	1532.90	228.71	17.61	5.60206	5.10237	FCS
5.37	262.44	2071.10	321.45	14.48	5.79588	5.20066	FCS
7.54	281.19	2701.79	533.43	22.97	5.88606	5.39794	FCS
4.89	246.91	1586.48	301.89	24.31	5.79588	5.10237	FCS
5.04	198.30	615.37	138.00	22.96	4.89963	5.00000	FCS
6.10	250.23	2039.13	319.34	11.96	5.49485	6.00000	FCS
4.82	266.68	2278.64	271.19	17.97	5.88606	5.30103	FCS
7.14	339.32	2816.40	390.04	20.53	5.79588	5.30103	FCS
5.79	319.91	2839.21	362.94	19.27	5.49485	5.10237	FCS
7.85	292.68	3726.00	494.83	18.39	6.00000	5.49485	FCS

CHEMICAL DATA FOR GRID A HORIZONS

ORGMAT	k	CA	MG	NA	WATPH	KCLPH	SITE
4.20	106.56	83.63	15.85	10.49	3.89997	3.40001	CU
3.77	79.79	175.50	21.40	13.38	4.30016	3.79997	CU
5.30	113.16	342.00	32.59	12.21	4.19997	3.59998	CU
4.88	105.18	1278.28	74.51	18.94	4.80134	4.40012	CU
3.30	93.27	285.54	32.13	14.10	4.40012	3.89997	CU
5.16	89.87	154.76	27.78	11.00	4.19997	3.59998	CU
3.04	84.60	128.15	20.44	14.12	4.30016	3.79997	CU
4.98	90.73	288.96	28.69	13.74	4.30016	3.70006	CU
3.43	94.41	762.75	47.69	14.30	4.80134	4.30016	CU
5.42	97.35	198.19	32.85	13.02	4.19997	3.50004	CU
5.33	118.63	363.08	39.56	12.92	4.30016	3.79997	CU
2.47	52.24	38.59	5.16	9.55	4.30016	3.89997	CU
4.45	70.45	234.32	30.20	9.50	4.60033	4.00000	CU
4.77	87.98	448.39	59.42	11.46	4.69897	4.19997	CU
4.03	83.00	395.42	37.22	13.86	4.69897	4.10018	CU
3.39	70.76	282.04	25.11	8.65	4.69897	4.10018	CU
7.61	96.15	391.29	33.53	11.94	4.69897	4.00000	CU
4.83	91.39	376.35	26.98	11.91	4.50031	4.00000	CU
3.02	78.42	448.61	29.56	14.51	4.80134	4.19997	CU
3.71	81.64	102.14	18.55	9.71	4.60033	4.10018	CU
3.19	75.25	255.18	25.34	12.56	4.40012	3.89997	CU
6.33	123.92	347.68	35.60	13.59	4.50031	3.89997	CU
5.81	82.36	57.83	12.32	8.57	4.30016	3.79997	CU
4.06	90.66	212.99	30.50	9.64	4.19997	3.70006	CU
4.94	82.10	299.03	28.77	16.25	4.40012	3.89997	CU
3.87	60.46	68.57	12.15	7.13	4.19997	3.79997	CU
3.94	107.44	209.84	18.27	11.86	4.50031	4.00000	CU
3.21	65.41	87.21	15.37	9.17	4.30016	3.79997	CU
3.35	120.39	1182.42	105.53	9.86	4.00000	4.50031	CU
4.72	107.79	205.75	28.10	9.54	4.60033	4.00000	CU
2.85	74.72	355.07	34.13	8.71	4.80134	4.19997	CU
4.62	71.18	127.09	19.70	9.07	4.40012	3.89997	CU
3.85	67.49	46.30	16.28	14.33	3.89997	3.40001	FCU
5.00	80.31	72.25	17.19	13.07	3.89997	3.40001	FCU
3.94	77.22	83.83	21.28	13.67	4.10018	3.59998	FCU
1.97	54.23	81.45	19.19	16.31	4.10018	3.70006	FCU
4.91	71.43	82.65	21.58	19.01	3.79997	3.19997	FCU
4.29	62.94	83.64	23.14	7.82	4.00000	3.50004	FCU
4.07	94.78	73.73	15.93	16.63	3.89997	3.50004	FCU
4.61	107.33	105.60	20.90	21.72	4.00000	3.40001	FCU
3.61	75.72	66.80	12.94	15.31	4.40012	4.00000	FCU
5.22	136.55	233.59	31.35	16.52	4.50031	3.89997	FCU
3.43	65.12	85.13	12.52	11.46	4.19997	3.70006	FCU
6.11	94.70	124.62	24.42	11.64	3.79997	3.29999	FCU
5.42	114.38	90.80	21.92	11.30	3.89997	3.29999	FCU
4.61	105.11	190.47	41.08	16.56	4.10018	3.50004	FCU

CHEMICAL DATA FOR GRID A HORIZONS

ORGMAT	K	CA	MG	NA	WATPH	KCLPH	SITE
4.68	261.34	1637.54	243.11	19.10	5.79588	5.10237	FCS
6.04	311.06	2324.54	369.44	18.97	6.00000	5.39794	FCS
9.86	317.08	2877.88	556.78	16.59	5.79588	5.39794	FCS
5.87	315.86	2194.36	393.89	14.28	6.00000	5.49485	FCS
7.80	255.43	2195.27	339.38	18.11	6.09691	5.39794	FCS
5.91	324.43	1969.76	335.38	14.05	6.09691	5.39794	FCS
5.86	233.05	2012.07	348.17	17.47	6.00000	5.30103	FCS
6.33	293.13	2571.54	419.98	15.60	6.09691	5.49485	FCS
3.25	68.37	139.13	16.46	17.34	4.19997	3.70006	CB
3.89	91.81	232.37	35.81	20.22	4.19997	3.79997	CB
3.08	70.14	152.31	22.19	15.88	4.00000	3.50004	CB
3.67	84.41	135.82	24.87	22.02	4.19997	3.70006	CB
4.03	117.24	87.48	26.38	26.12	3.89997	3.50004	CB
3.29	79.25	137.14	23.10	15.72	4.19997	3.79997	CB
3.35	96.58	119.37	20.72	18.97	4.10018	3.70006	CB
3.60	97.99	89.61	21.33	27.18	4.10018	3.70006	CB
8.60	185.44	317.80	74.04	30.50	3.89997	3.50004	CB
3.68	66.46	116.96	19.61	21.07	4.10018	3.59998	CB
3.66	87.94	179.40	29.33	31.65	4.00000	3.59998	CB
3.78	91.70	67.86	21.85	21.16	4.10018	3.70006	CB
5.03	124.97	253.46	52.94	26.74	4.10018	3.59998	CB
2.83	46.82	88.14	11.93	16.14	4.00000	3.50004	CB
2.45	69.31	48.76	12.73	14.97	4.19997	3.70006	CB
4.56	97.12	70.54	26.78	25.49	4.30016	3.79997	CB
3.97	94.64	95.48	26.60	17.78	4.19997	3.59998	CB
2.72	66.54	33.91	12.13	15.48	4.19997	3.79997	CB
3.58	93.68	313.84	128.35	14.62	4.00000	3.79997	FCB
7.30	194.11	1015.62	364.14	16.09	4.89963	4.00000	FCB
5.00	121.80	862.65	231.71	15.35	4.80134	3.89997	FCB
4.48	86.96	230.47	87.80	10.91	4.30016	3.29999	FCB
3.85	78.68	301.32	117.04	12.13	4.40012	3.59998	FCB
8.02	124.54	1231.99	382.28	19.29	4.80134	4.00000	FCB
6.57	278.43	928.04	167.73	24.83	4.50031	3.59998	FCB
4.63	103.00	382.11	125.51	19.81	4.30016	3.40001	FCB
6.91	143.34	1085.53	215.54	17.27	4.60033	3.70006	FCB
5.81	148.93	873.13	282.90	14.63	4.69897	3.79997	FCB
4.84	122.65	783.87	264.32	10.28	4.69897	3.79997	FCB
6.13	143.14	1079.20	335.40	17.98	4.80134	4.00000	FCB
6.75	159.57	1020.92	371.30	20.74	4.89963	4.00000	FCB
6.03	303.32	2811.61	376.95	14.90	4.89963	4.00000	FCB

Appendix F2. Chemical Data for Grid AB Horizons

CHEMICAL DATA FOR GRID AB HORIZONS

WATPH	KCLPH	CA	MG	NA	K	SITE
4.62	3.71	16.83	8.91	20.79	35.37	CU
4.92	3.79	89.82	29.97	12.33	42.03	CU
4.93	3.77	41.70	33.47	15.31	45.28	CU
4.68	3.70	26.51	10.41	12.04	29.86	CU
4.80	3.76	121.56	72.59	15.12	44.48	CU
4.75	3.76	31.50	20.52	11.25	37.44	CU
4.92	3.80	42.42	30.61	13.52	33.03	CU
4.72	3.76	40.54	26.61	15.76	35.66	CU
4.82	3.99	73.80	24.47	14.92	42.30	CU
4.90	3.83	92.43	61.65	15.53	33.03	CU
4.87	3.80	119.66	31.03	20.42	43.87	CU
4.78	3.63	84.43	55.84	13.40	44.98	CU
4.82	3.75	103.09	61.05	15.29	52.52	CU
4.70	3.71	60.72	29.87	14.93	38.19	CU
4.86	3.85	152.28	54.81	12.78	45.09	CU
4.60	3.78	20.07	6.48	16.02	45.00	CU
4.55	3.64	32.05	17.46	15.94	52.63	CU
4.65	3.70	46.96	15.56	14.11	59.88	CU
4.90	4.00	217.89	48.87	14.67	49.23	CU
4.72	3.86	86.71	42.49	13.74	52.98	CU
4.90	3.98	128.88	49.85	15.31	43.23	CU
4.83	3.90	36.97	9.40	14.23	42.59	CU
4.92	3.94	71.91	41.31	10.89	62.73	CU
4.79	3.84	75.60	28.26	13.50	62.55	CU
4.92	3.93	41.91	20.97	12.42	54.89	CU
4.75	3.96	32.22	18.93	13.65	49.87	CU
4.77	3.93	61.28	23.58	11.14	79.65	CU
4.74	3.89	36.34	12.44	12.97	39.11	CU
4.71	3.97	68.70	14.57	18.72	67.94	CU
4.64	3.86	29.50	20.48	15.74	56.15	CU
4.78	3.96	54.41	29.02	8.03	50.70	CU
4.75	3.98	30.69	14.94	15.75	51.57	CU
4.80	3.87	47.89	44.36	17.03	28.17	FCU
4.85	3.90	34.56	52.09	15.53	48.19	FCU
4.83	3.79	11.41	34.11	10.73	22.77	FCU
4.73	3.75	7.44	35.53	11.74	23.27	FCU
4.76	3.81	24.17	24.89	14.31	32.41	FCU
4.78	3.63	7.01	85.45	15.20	60.61	FCU
4.76	3.58	11.25	75.51	13.41	37.80	FCU
4.77	3.49	17.90	75.83	20.81	63.17	FCU
4.75	3.63	18.18	63.72	14.76	74.25	FCU
4.77	3.58	69.93	69.93	16.37	45.51	FCU
4.81	3.57	67.05	77.76	14.04	90.81	FCU
4.82	3.60	53.88	67.67	10.38	105.44	FCU
4.78	3.77	63.89	29.51	18.47	61.28	FCU
4.77	3.75	24.32	60.00	14.59	55.73	FCU

CHEMICAL DATA FOR GRID AB HORIZONS

WATPH	KCLPH	CA	MG	NA	K	SITE
4.71	3.71	23.04	14.85	18.09	49.68	FCU
4.78	3.71	6.59	51.80	15.93	56.16	FCU
4.63	3.66	2.52	41.94	19.35	40.95	FCU
4.64	3.68	34.02	48.06	14.31	59.75	FCU
4.76	3.70	15.76	41.27	17.36	48.24	FCU
4.69	3.69	13.95	45.27	25.83	46.53	FCU
4.79	3.72	24.16	69.23	19.46	63.99	FCU
4.76	3.71	44.19	27.99	19.53	31.41	FCU
4.76	3.71	22.42	36.42	22.45	56.66	FCU
4.64	3.71	18.85	65.58	26.88	46.05	FCU
4.81	3.67	0.00	82.97	18.09	45.47	FCU
4.71	3.69	0.00	45.89	18.28	49.96	FCU
4.69	3.68	26.76	41.98	17.34	39.95	FCU
4.77	3.65	17.82	46.71	14.40	50.40	FCU
4.70	3.66	5.31	52.50	21.00	46.37	FCU
4.66	3.68	1.86	45.58	15.30	39.47	FCU
4.63	3.66	45.71	48.60	14.06	59.79	FCU
4.71	3.71	20.72	47.96	14.77	64.26	FCU
5.31	4.56	616.41	139.41	10.98	106.02	CS
5.21	4.39	757.85	122.54	11.82	132.90	CS
5.45	4.63	849.06	148.55	10.24	136.26	CS
5.16	4.30	436.05	92.88	11.34	106.56	CS
5.12	4.23	398.51	86.99	10.11	122.34	CS
5.11	4.26	508.86	128.16	9.09	97.83	CS
5.31	4.39	624.78	206.01	10.71	155.61	CS
5.16	4.29	519.82	88.17	11.35	100.44	CS
5.69	4.87	1306.62	204.84	13.77	208.44	CS
5.49	4.61	751.57	87.35	9.04	84.61	CS
4.81	4.05	138.69	40.95	7.83	60.84	CS
5.28	4.42	579.98	123.34	13.58	148.36	CS
5.17	4.27	510.03	106.52	19.51	232.22	CS
5.66	4.65	628.47	115.65	11.16	128.88	CS
5.10	4.15	455.58	94.50	8.82	108.72	CS
4.90	4.03	166.26	33.95	8.56	86.09	CS
5.01	4.10	330.39	103.14	13.32	76.50	CS
5.19	4.27	498.04	106.34	10.05	85.53	CS
4.77	3.74	101.31	52.09	10.57	44.57	FCS
4.90	3.70	105.92	70.55	14.47	67.84	FCS
4.64	3.55	114.37	94.16	19.85	83.58	FCS
4.79	3.63	88.38	109.92	15.04	51.98	FCS
4.78	3.66	47.08	55.53	17.34	56.85	FCS
4.84	3.66	77.15	56.30	16.92	74.92	FCS
4.87	3.66	89.05	76.00	11.65	69.22	FCS
4.81	3.63	85.80	85.35	13.75	57.61	FCS
4.82	3.76	75.10	31.87	14.51	49.59	FCS
4.76	3.76	184.13	52.59	8.64	55.52	FCS

CHEMICAL DATA FOR GRID AB HORIZONS

WATPH	KCLPH	CA	MG	NA	K	SITE
4.92	3.80	104.40	129.96	9.45	48.15	FCS
4.87	3.64	53.39	89.23	11.22	75.56	FCS
4.83	3.79	72.63	75.87	9.45	70.74	FCS
4.70	3.73	41.48	62.93	12.46	71.82	FCS
4.74	3.74	34.20	47.26	8.86	50.22	FCS
4.63	3.62	92.53	82.78	11.37	53.88	FCS
4.93	3.87	155.07	110.90	11.50	54.78	FCS
4.85	3.63	71.69	80.37	10.77	71.84	FCS
4.43	3.93	0.00	6.84	17.64	27.81	CB
4.61	3.82	24.47	15.28	18.31	28.52	CB
4.64	3.83	2.96	6.35	14.06	40.64	CB
4.56	3.91	10.22	3.92	20.56	19.54	CB
4.38	3.89	18.10	9.13	20.20	52.14	CB
4.60	3.94	30.86	4.27	19.14	26.44	CB
4.61	4.04	14.02	2.08	22.28	16.84	CB
4.60	4.09	12.15	3.78	19.35	30.42	CB
4.64	4.00	22.67	9.08	21.41	56.76	CB
4.70	3.80	58.16	19.20	20.76	36.33	CB
4.71	3.84	54.69	12.71	18.62	26.14	CB
4.65	3.94	18.51	4.57	24.72	20.59	CB
4.58	3.97	15.40	6.01	16.68	21.76	CB
4.58	3.73	17.19	5.13	19.80	26.19	CB
4.53	3.82	2.38	1.81	4.07	11.53	CB
4.57	3.90	27.58	13.26	9.86	45.20	CB
4.60	3.80	30.82	8.56	13.71	24.75	CB
4.64	3.67	28.99	16.56	5.40	22.50	CB
4.88	3.58	65.24	58.53	7.70	24.61	FCB
4.57	3.54	30.44	26.10	9.43	23.41	FCB
4.55	3.61	58.90	27.30	9.14	34.82	FCB
4.66	3.62	45.84	42.10	11.48	23.94	FCB
4.45	3.55	28.69	35.38	10.92	27.90	FCB
4.53	3.55	39.56	26.64	5.14	21.95	FCB
4.31	3.57	27.14	9.52	7.74	72.45	FCB
4.35	3.56	31.23	12.99	9.08	59.89	FCB
4.52	3.52	42.96	42.25	7.97	27.57	FCB
4.48	3.51	39.56	34.02	9.13	28.46	FCB
4.92	3.68	130.68	102.24	8.10	41.76	FCB
4.52	3.52	70.19	39.47	12.93	33.01	FCB
4.51	3.55	32.59	36.70	12.81	39.21	FCB
4.90	3.67	139.02	110.99	11.13	46.72	FCB

Appendix F3. Chemical Data for Grid Bt Horizons

CHEMICAL DATA FOR GRID BT HORIZONS

WATPH	KCLPH	CA	MG	NA	K	SITE
5.70	5.70	39.99	22.74	15.41	45.92	CU
5.50	5.30	77.52	30.63	12.44	51.42	CU
5.40	5.40	77.00	100.74	14.79	49.90	CU
5.40	5.10	76.14	55.35	14.67	38.25	CU
5.50	5.20	90.00	52.02	14.91	40.86	CU
5.30	5.30	53.66	57.23	15.39	51.05	CU
5.50	5.60	97.77	75.02	13.19	37.07	CU
5.20	5.40	83.96	48.49	10.62	49.72	CU
5.70	5.50	64.71	67.84	11.39	48.43	CU
5.40	5.30	78.57	68.91	19.21	35.69	CU
5.50	4.00	92.69	60.43	11.90	47.41	CU
5.40	5.00	69.93	56.70	24.12	42.39	CU
5.60	5.70	136.84	82.02	12.06	57.47	CU
5.20	5.40	52.01	46.73	7.83	36.70	CU
5.80	5.80	182.79	61.38	13.23	51.12	CU
5.70	5.30	27.18	9.54	11.97	46.71	CU
5.40	5.30	35.82	20.68	10.21	52.01	CU
5.50	5.30	52.37	19.12	14.85	59.81	CU
4.60	5.50	176.77	65.41	16.62	47.25	CU
5.10	5.20	83.64	43.60	16.02	51.35	CU
5.60	5.40	109.11	51.28	14.44	48.92	CU
5.50	5.20	61.20	34.47	13.05	45.72	CU
5.50	5.20	53.68	49.77	14.01	61.60	CU
5.30	5.30	49.76	36.20	11.30	51.32	CU
5.70	5.10	22.13	47.26	18.72	49.38	CU
5.50	5.20	15.02	34.65	15.04	54.73	CU
5.50	5.00	9.71	25.82	12.18	63.83	CU
5.70	5.20	9.86	25.43	13.30	43.44	CU
5.80	5.10	16.11	20.25	10.35	54.00	CU
5.70	5.40	5.17	27.25	12.39	45.05	CU
5.80	5.20	26.78	41.58	17.70	52.29	CU
5.70	5.40	28.75	61.29	13.86	50.67	CU
4.10	3.74	35.15	28.45	10.96	39.76	FCU
4.02	3.69	21.67	17.66	14.88	48.64	FCU
4.11	3.69	37.96	50.36	12.06	41.61	FCU
4.05	3.62	32.54	28.97	15.32	52.20	FCU
4.10	3.66	33.10	13.89	9.55	51.32	FCU
4.25	3.62	14.60	53.32	12.37	50.08	FCU
4.19	3.58	27.02	38.19	13.05	48.49	FCU
4.35	3.57	63.55	70.00	12.01	52.72	FCU
4.30	3.56	28.89	31.24	18.88	59.25	FCU
4.26	3.57	29.29	28.06	17.34	57.50	FCU
4.38	3.53	51.39	36.74	10.50	75.12	FCU
4.31	3.54	27.84	22.34	11.49	53.85	FCU
4.38	3.55	26.95	58.36	20.70	65.55	FCU
4.39	3.56	59.56	49.56	22.80	79.11	FCU

CHEMICAL DATA FOR GRID BT HORIZONS

WATPH	KCLPH	CA	MG	NA	K	SITE
4.35	3.48	11.61	44.37	14.53	42.57	FCU
4.45	3.60	52.39	53.72	18.28	65.03	FCU
4.32	3.57	26.29	47.94	16.53	58.63	FCU
4.23	3.47	45.51	20.36	11.75	75.16	FCU
4.48	3.61	65.45	71.98	19.42	66.21	FCU
4.50	3.56	51.24	74.21	26.44	72.56	FCU
4.40	3.59	36.28	76.13	20.19	79.00	FCU
4.63	3.63	235.79	39.88	12.71	58.13	FCU
4.45	3.55	106.75	58.73	19.32	67.95	FCU
4.36	3.59	30.46	80.02	17.45	63.19	FCU
4.49	3.59	18.85	48.22	15.35	56.92	FCU
4.42	3.54	29.17	52.89	13.20	65.81	FCU
4.36	3.60	72.38	32.90	20.89	59.13	FCU
3.91	3.57	47.22	24.60	18.22	59.08	FCU
4.46	3.54	48.98	57.69	19.75	66.91	FCU
4.47	3.52	52.33	57.87	14.36	62.54	FCU
4.50	3.54	234.56	52.35	13.69	83.56	FCU
4.43	3.45	9.31	66.21	25.13	46.89	FCU
5.03	4.27	543.72	199.93	19.54	85.91	CS
5.17	4.34	571.22	162.92	13.34	123.11	CS
5.36	4.63	1388.52	245.17	15.05	196.36	CS
4.96	4.12	552.89	127.64	18.31	150.69	CS
4.66	3.80	334.61	89.18	28.02	118.23	CS
4.90	4.05	752.90	117.97	21.58	109.10	CS
5.13	4.26	817.81	182.57	17.79	126.36	CS
5.03	4.18	711.70	113.99	10.96	98.14	CS
5.60	4.87	1668.14	231.25	17.23	188.18	CS
5.00	3.99	522.53	71.50	18.74	66.03	CS
4.70	3.88	428.08	84.74	16.36	89.44	CS
5.10	4.07	690.61	137.31	17.40	133.11	CS
4.90	3.88	465.87	130.68	13.20	132.26	CS
5.26	4.34	918.89	229.90	16.97	132.94	CS
5.00	4.09	616.48	108.75	14.01	112.14	CS
4.76	3.88	340.45	68.90	13.76	96.48	CS
4.85	3.85	476.46	156.60	12.33	84.96	CS
4.80	3.94	336.95	100.52	13.49	100.23	CS
4.58	3.70	282.72	94.16	25.12	86.09	FCS
4.84	3.84	269.52	96.73	22.49	85.15	FCS
4.67	3.70	375.23	117.63	11.49	91.96	FCS
4.73	3.74	172.96	119.14	18.56	78.31	FCS
4.68	3.85	97.01	81.44	18.97	106.14	FCS
4.80	3.86	310.87	92.35	34.17	98.49	FCS
4.75	3.80	254.34	94.41	18.18	99.09	FCS
4.86	3.91	371.14	83.96	26.36	147.55	FCS
4.80	3.86	214.36	55.46	23.98	90.99	FCS
4.81	3.85	221.80	96.63	27.03	101.41	FCS

CHEMICAL DATA FOR GRID BT HORIZONS

WATPH	KCLPH	CA	MG	NA	K	SITE
4.78	3.84	252.75	100.72	36.47	100.21	FCS
4.82	3.79	170.35	93.01	32.53	139.38	FCS
4.78	3.85	172.26	88.74	15.31	89.70	FCS
4.72	3.87	155.60	61.12	17.80	131.13	FCS
4.79	3.84	202.75	102.74	21.70	94.13	FCS
4.74	3.73	194.98	86.93	22.06	59.72	FCS
4.80	3.90	197.25	115.80	19.06	61.60	FCS
4.90	3.89	221.24	143.64	21.32	92.92	FCS
4.43	3.93	113.90	4.52	9.04	26.89	CB
4.61	3.82	32.50	5.40	9.05	30.02	CB
4.64	3.83	39.53	9.30	6.96	35.20	CB
4.56	3.91	16.36	4.09	8.09	18.62	CB
4.38	3.89	50.36	11.54	8.61	36.73	CB
4.60	3.94	58.92	9.12	8.15	33.79	CB
4.61	4.04	24.80	7.57	13.05	32.54	CB
4.60	4.09	19.58	13.66	13.66	55.07	CB
4.64	4.00	44.77	15.31	14.18	35.52	CB
4.70	3.80	16.63	5.48	9.94	38.59	CB
4.79	3.84	23.22	7.32	14.10	30.02	CB
4.65	3.94	15.40	4.88	17.75	31.41	CB
4.58	3.97	34.04	14.61	22.12	61.70	CB
4.58	3.73	10.79	4.61	8.70	33.15	CB
4.53	3.82	13.18	6.46	14.95	41.62	CB
4.57	3.90	53.68	21.84	21.85	75.91	CB
4.60	3.80	26.28	11.75	17.92	61.94	CB
4.64	3.67	9.74	4.60	10.42	28.30	CB
4.78	3.84	39.74	24.86	6.13	39.91	FCB
4.57	3.62	117.71	61.17	8.70	61.17	FCB
4.55	3.52	130.66	60.81	6.93	85.96	FCB
4.37	3.51	30.06	15.58	5.86	40.15	FCB
4.40	3.55	29.60	18.46	5.02	43.69	FCB
4.45	3.54	71.86	41.55	5.80	43.97	FCB
4.30	3.48	45.63	21.53	8.58	134.31	FCB
4.40	3.51	56.12	29.94	10.68	76.85	FCB
4.46	3.50	57.96	34.76	9.16	60.68	FCB
4.32	3.47	33.35	43.94	5.70	63.53	FCB
4.81	3.85	439.04	211.18	12.45	110.80	FCB
4.68	3.55	73.02	65.42	8.78	56.55	FCB
4.52	3.49	111.01	60.99	9.14	68.91	FCB
4.72	3.66	170.42	101.76	11.20	61.50	FCB

Appendix F4. Particle Size and Extractable Acidity Data for Grid A Horizons

A HORIZON PARTICLE SIZE AND EXTACTABLE ACIDITY DATA

OBS	ACSILT	AFSILT	ACLAY	AEXACID	AVFS	AFS
1	22.1	25.8	9.8	19.28	12.09	10.2
2	20.4	26.9	12.1	15.33	17.94	12.0
3	21.0	24.4	14.4	18.09	15.80	10.4
4	20.8	26.1	11.8	16.12	12.09	11.9
5	17.2	28.2	12.8	16.12	12.87	11.9
6	20.2	27.2	11.9	17.30	16.19	10.9
7	21.3	27.1	10.0	16.12	11.70	11.5
8	18.6	27.5	11.3	15.72	12.87	9.2
9	15.6	28.2	12.0	15.92	11.31	9.3
10	24.8	16.3	18.4	21.65	12.48	9.0
11	21.1	26.9	14.9	33.50	12.48	10.4
12	13.6	28.6	17.0	17.70	15.99	12.5
13	15.3	28.5	19.8	20.86	16.77	10.9
14	15.7	25.9	19.6	18.09	15.99	10.9
15	14.1	27.8	14.6	21.45	15.97	10.4
16	18.5	27.6	13.6	19.28	13.65	8.8
17	20.5	27.6	15.9	25.20	14.43	7.3
18	11.8	26.6	20.5	17.53	15.21	9.9
19	12.9	26.4	20.7	14.37	9.36	10.9
20	21.6	29.4	11.0	17.13	12.09	9.3
21	19.4	27.3	16.2	15.55	10.53	11.7
22	19.5	28.7	14.9	19.50	9.75	9.2
23	12.6	30.5	21.8	21.87	12.48	7.9
24	16.8	26.6	20.1	17.13	10.34	11.7
25	15.8	28.7	20.3	17.53	9.36	7.1
26	12.1	31.2	22.6	19.50	12.48	7.9
27	11.8	31.0	23.2	17.53	12.09	7.8
28	19.1	28.4	14.6	17.53	10.53	10.0
29	18.0	28.5	14.4	10.81	10.92	9.0
30	18.2	29.3	17.2	20.29	9.75	8.8
31	17.7	30.8	14.1	11.60	10.14	9.0
32	20.0	28.8	13.6	21.08	7.80	8.2
33	18.7	31.8	12.4	12.56	10.53	11.1
34	17.4	31.6	15.7	15.33	10.53	11.1
35	19.5	32.2	12.7	11.57	9.95	10.6
36	19.6	34.6	11.4	9.80	10.53	10.2
37	22.7	32.4	13.3	14.93	10.14	8.4
38	18.1	32.8	13.6	11.57	9.17	10.0
39	16.4	31.0	15.2	13.75	9.36	11.3
40	20.2	32.1	15.1	13.75	12.09	9.8
41	18.8	33.9	15.8	11.97	11.90	8.9
42	23.4	30.3	15.2	14.54	10.92	9.0
43	16.2	32.3	14.2	14.14	10.53	9.7
44	20.9	39.1	15.7	18.09	10.14	6.2
45	20.5	37.0	17.2	17.70	8.97	7.0
46	21.5	36.2	14.7	15.33	10.53	7.8

A HORIZON PARTICLE SIZE AND EXTACTABLE ACIDITY DATA

OBS	ACSILT	AFSILT	ACLAY	AEXACID	AVFS	AFS
47	22.7	34.3	15.3	13.94	11.31	8.1
48	16.4	38.7	17.4	12.96	10.14	8.3
49	16.0	39.0	19.2	14.14	9.75	8.0
50	21.2	38.4	12.7	15.92	10.53	8.6
51	20.6	38.9	15.5	12.17	9.36	7.7
52	17.8	39.9	18.3	13.08	10.14	6.9
53	24.2	39.5	12.6	15.72	10.73	7.2
54	23.7	37.6	15.8	20.86	9.36	6.8
55	18.1	40.2	17.0	13.35	10.14	7.5
56	19.4	39.6	17.0	10.59	10.14	7.5
57	20.0	41.3	16.5	10.98	8.58	7.5
58	21.5	41.4	14.7	13.75	10.92	7.2
59	15.9	42.5	20.6	13.15	15.41	6.7
60	24.6	34.6	17.4	13.75	11.70	7.7
61	23.7	37.5	16.0	15.72	10.92	6.8
62	24.1	41.0	17.2	14.14	10.53	6.0
63	24.6	41.7	16.4	15.72	11.31	5.6
64	16.0	43.6	20.5	12.96	12.41	7.0
65	24.0	32.7	26.6	15.33	20.27	5.4
66	23.1	34.5	25.4	11.38	20.28	4.8
67	24.3	30.9	26.9	11.38	19.11	5.9
68	19.2	30.0	25.0	12.17	19.89	7.2
69	22.9	33.6	24.8	12.96	20.28	5.2
70	22.8	30.3	31.0	12.76	21.26	4.6
71	28.0	29.7	25.5	12.17	20.28	4.4
72	18.5	32.1	29.9	11.77	18.33	6.1
73	21.2	35.5	22.9	11.18	23.40	5.7
74	21.0	33.0	24.5	10.59	20.28	6.8
75	21.5	31.9	26.2	14.54	21.84	6.5
76	21.5	32.6	24.8	11.18	21.26	6.2
77	24.6	31.2	24.6	13.35	19.89	6.5
78	17.6	33.6	27.7	17.30	21.84	6.7
79	17.9	32.1	29.6	15.32	22.82	6.2
80	24.0	31.6	22.0	12.57	21.45	6.8
81	17.9	32.9	26.1	13.35	18.72	7.3
82	23.3	32.8	22.1	12.17	22.43	5.9
83	21.8	34.0	24.2	12.17	10.14	10.4
84	27.8	31.5	21.4	11.77	10.92	9.1
85	24.6	29.1	29.8	10.59	11.51	8.0
86	28.1	28.1	22.4	7.82	9.36	10.2
87	23.7	35.0	24.1	19.28	10.92	8.8
88	25.4	31.6	24.4	13.35	14.82	9.3
89	30.0	29.3	21.5	11.38	7.80	9.8
90	28.0	31.5	22.4	12.56	8.19	10.1
91	27.6	27.5	23.9	11.97	8.97	11.1
92	30.3	27.2	23.9	11.97	8.97	10.0

A HORIZON PARTICLE SIZE AND EXTACTABLE ACIDITY DATA

OBS	ACSILT	AFSILT	ACLAY	AEXACID	AVFS	AFS
93	25.2	31.5	22.3	13.35	11.12	10.5
94	25.7	33.0	20.3	15.13	12.48	11.1
95	28.8	29.9	23.3	14.93	15.21	9.7
96	24.8	32.1	21.4	11.77	14.04	11.4
97	27.7	27.9	24.7	14.73	16.77	10.1
98	26.3	29.3	22.8	12.57	12.09	12.1
99	26.8	28.8	21.8	13.75	8.58	12.0
100	27.7	31.4	20.8	11.77	9.36	11.2
101	13.5	21.7	15.9	20.86	23.01	3.3
102	12.1	15.6	15.4	17.30	20.67	3.5
103	10.1	12.1	14.4	19.67	18.53	4.0
104	13.5	22.7	18.2	17.30	21.46	4.7
105	10.7	21.5	17.1	19.67	23.79	2.6
106	16.4	32.7	16.9	15.52	20.28	4.4
107	19.8	32.8	15.9	16.91	19.50	3.7
108	10.4	24.5	18.2	18.49	18.75	3.4
109	27.1	28.4	14.4	28.95	21.26	2.5
110	13.0	14.4	13.2	16.91	21.84	3.6
111	15.5	19.6	15.7	17.30	20.67	5.4
112	17.4	25.7	13.8	17.50	22.62	3.5
113	23.0	23.4	13.6	16.90	23.79	3.0
114	13.0	19.2	15.7	13.75	21.26	5.1
115	15.3	26.7	18.1	13.55	20.67	2.5
116	19.6	25.8	16.6	22.04	26.59	3.9
117	21.5	23.0	14.1	16.91	25.74	2.7
118	18.7	21.6	15.2	15.72	23.60	3.3
119	22.2	31.8	24.7	17.30	10.92	12.4
120	27.0	37.8	25.5	20.86	15.60	5.6
121	25.1	43.6	24.6	17.30	16.38	4.1
122	31.5	36.3	23.1	22.04	10.14	6.1
123	37.0	24.5	27.5	14.54	10.14	17.6
124	30.3	35.7	24.6	22.63	9.95	5.7
125	24.4	40.1	29.1	28.76	12.87	3.8
126	20.5	43.6	29.5	20.86	12.09	3.1
127	25.8	39.0	27.9	24.81	14.04	3.5
128	22.7	41.4	29.4	20.86	14.43	3.7
129	25.7	38.0	27.4	22.04	13.26	4.7
130	29.4	32.0	26.7	20.86	16.38	6.4
131	25.5	35.6	28.9	22.83	17.16	5.1
132	21.1	36.1	22.7	18.09	18.72	6.2

Appendix F5. Particle Size and Extractable Acidity Data for Grid Bt Horizons

BT HORIZON PARTICLE SIZE AND EXTRACTABLE ACIDITY DATA

OBS	BTCSILT	BTFSILT	BTCLAY	BTEXACID	BTVFS	BTFS
1	14.2	25.6	18.7	9.01	28.6	10.9
2	15.0	24.7	21.9	8.29	27.1	12.6
3	13.7	19.7	28.5	9.99	28.2	11.1
4	12.2	21.8	20.9	10.96	27.6	12.0
5	11.9	25.9	17.9	7.84	27.7	15.4
6	15.6	20.5	29.2	5.55	27.5	13.3
7	13.3	22.8	17.6	14.08	27.3	10.9
8	9.2	23.3	19.5	5.55	28.2	9.7
9	9.1	18.7	17.5	8.23	31.6	10.1
10	11.8	20.5	20.5	9.40	28.3	10.2
11	15.5	24.6	23.1	7.90	23.2	12.5
12	18.7	22.0	29.4	10.90	25.5	11.1
13	17.4	25.5	17.9	10.24	22.4	13.4
14	16.1	21.1	25.8	10.24	24.8	14.2
15	13.7	13.2	26.0	8.17	30.8	10.9
16	10.3	24.7	16.1	11.02	28.9	9.0
17	8.7	25.4	22.6	14.53	25.9	8.3
18	11.7	25.2	22.6	10.34	28.1	9.3
19	11.1	24.2	20.4	7.31	26.9	13.4
20	12.3	25.1	22.5	11.02	26.5	12.7
21	9.4	28.9	22.7	7.90	23.5	12.4
22	14.6	28.4	16.0	7.51	24.1	10.9
23	16.1	31.0	19.0	7.31	23.7	7.7
24	13.3	29.6	19.6	7.90	22.2	9.4
25	10.6	31.4	20.0	6.73	22.7	8.8
26	11.8	32.2	11.8	9.90	23.4	7.5
27	14.4	30.5	19.6	8.73	24.0	8.6
28	11.4	29.5	21.7	9.90	25.3	10.2
29	17.7	22.5	14.2	7.56	27.6	10.4
30	15.0	22.0	17.4	8.93	25.3	11.2
31	13.4	26.2	18.4	7.76	26.3	9.3
32	13.4	26.2	16.4	5.81	25.8	9.3
33	10.6	29.8	17.8	6.75	24.3	9.2
34	11.6	28.2	18.8	9.65	21.5	10.6
35	15.1	28.3	20.0	5.85	23.3	9.4
36	12.9	35.6	26.8	7.88	22.5	7.0
37	13.4	24.9	19.3	8.10	21.2	8.0
38	11.1	27.6	18.6	11.03	22.4	11.1
39	11.0	27.8	24.4	11.03	23.3	10.7
40	14.2	31.5	26.6	20.25	21.1	7.7
41	16.0	37.5	19.9	14.63	19.3	7.4
42	17.0	33.9	19.9	12.38	19.4	8.2
43	12.0	34.3	26.8	15.75	12.8	6.6
44	16.3	29.5	21.9	15.33	14.7	7.0
45	16.5	33.5	19.8	8.10	16.5	8.2
46	15.7	36.5	21.2	9.75	17.6	7.7

BT HORIZON PARTICLE SIZE AND EXTRACTABLE ACIDITY DATA

OBS	BTCSILT	BTFSILT	BTCLAY	BTEXACID	BTVFS	BTFS
47	16.5	31.6	17.6	11.25	17.7	10.6
48	15.5	34.7	21.4	8.33	16.7	8.7
49	17.7	36.6	19.6	8.55	16.2	8.0
50	22.5	35.2	20.6	9.45	16.6	6.5
51	21.1	35.7	17.4	7.20	14.9	8.6
52	15.2	37.0	20.7	7.65	14.7	8.3
53	22.4	29.3	24.5	10.13	14.3	6.8
54	17.8	38.7	19.5	9.00	13.6	7.5
55	15.9	39.7	22.8	8.55	14.7	7.4
56	13.1	42.7	23.5	9.00	14.0	6.6
57	28.6	29.6	23.2	9.00	12.8	6.4
58	28.3	38.3	16.4	5.63	12.6	6.0
59	21.0	37.7	21.0	7.65	12.3	7.0
60	15.5	40.6	21.7	7.88	13.2	7.5
61	16.8	40.3	22.7	7.43	13.1	6.4
62	14.5	47.9	22.7	8.78	9.9	5.1
63	18.6	41.3	21.8	9.23	10.2	6.1
64	17.5	38.2	22.1	9.68	11.1	8.0
65	19.3	44.8	19.6	13.26	6.0	3.5
66	20.0	36.4	19.4	16.38	6.0	5.5
67	17.6	43.0	19.8	15.80	6.9	5.6
68	19.3	41.0	20.3	15.21	12.7	5.8
69	18.0	40.2	21.2	15.60	5.8	6.0
70	17.0	39.4	22.8	16.77	5.5	5.0
71	11.1	39.4	23.3	10.92	5.8	4.4
72	17.3	40.0	22.6	12.09	7.7	5.6
73	24.9	30.5	27.0	10.04	7.5	4.6
74	17.1	38.8	20.6	9.95	8.6	6.6
75	19.8	38.5	20.3	9.56	8.1	5.8
76	22.1	38.3	20.0	8.78	7.7	5.7
77	14.1	38.7	26.7	10.14	7.2	6.2
78	20.0	37.6	20.2	6.63	8.2	6.5
79	20.5	37.7	18.2	9.85	8.8	7.2
80	20.8	38.5	19.8	12.48	10.2	5.8
81	20.1	32.2	20.7	7.80	10.6	6.7
82	16.5	38.5	19.4	9.36	7.9	6.7
83	21.8	38.6	21.2	7.61	5.1	9.9
84	17.7	37.3	25.3	8.97	5.1	9.5
85	18.6	38.5	31.0	17.04	5.2	3.7
86	16.9	31.9	28.9	10.73	6.1	11.4
87	18.1	38.0	24.7	12.87	4.8	9.6
88	15.7	41.4	24.2	11.51	4.9	10.3
89	15.6	40.1	24.2	5.46	5.6	10.4
90	14.1	36.2	23.4	6.05	5.4	11.2
91	17.9	32.3	23.7	5.07	6.4	11.9
92	17.9	32.3	23.7	5.07	5.7	11.1

BT HORIZON PARTICLE SIZE AND EXTRACTABLE ACIDITY DATA

OBS	BTCSILT	BTFSILT	BTCLAY	BTEXACID	BTVFS	BTFS
93	17.6	32.6	27.3	8.39	5.9	10.1
94	16.7	40.5	22.0	5.85	5.8	11.5
95	17.5	41.7	14.5	6.83	5.7	10.6
96	20.1	38.6	19.4	6.24	6.4	11.0
97	15.4	36.9	22.9	6.24	6.2	9.2
98	18.5	36.4	27.0	9.54	6.6	15.0
99	16.6	33.5	21.3	8.76	6.8	11.9
100	17.6	36.6	21.8	9.01	5.8	4.6
101	9.9	17.6	15.0	5.90	31.7	4.4
102	5.7	24.1	17.6	7.06	28.5	10.4
103	12.4	19.6	17.0	8.62	31.7	4.9
104	9.2	22.4	11.8	5.90	25.7	4.0
105	9.0	26.5	11.3	5.50	33.1	4.7
106	6.5	20.8	12.6	13.30	21.5	3.8
107	5.4	18.9	13.9	7.45	18.5	4.6
108	5.5	20.7	12.3	7.06	30.1	4.2
109	7.6	23.5	22.1	11.99	19.2	4.8
110	14.0	16.5	16.4	14.08	30.6	4.1
111	8.2	16.9	18.0	6.09	28.7	5.1
112	3.4	20.3	15.6	8.04	26.3	3.6
113	7.6	22.6	11.8	10.57	23.4	5.4
114	4.7	18.9	16.5	6.48	31.3	4.7
115	6.6	18.6	12.4	5.50	19.6	6.4
116	12.0	22.7	10.8	10.77	27.3	5.3
117	12.8	28.2	11.8	7.84	23.4	3.7
118	7.9	21.8	17.5	9.21	29.2	2.0
119	23.0	26.7	17.2	9.04	7.2	7.5
120	20.0	45.9	20.0	7.09	2.2	4.5
121	15.0	50.6	26.0	9.24	1.4	6.8
122	29.2	39.1	22.6	5.73	2.1	5.2
123	17.7	49.0	23.8	6.49	11.9	5.0
124	24.0	47.6	19.1	8.69	2.5	3.8
125	23.8	47.0	21.8	8.19	1.4	6.5
126	24.1	40.2	20.1	11.31	1.5	7.0
127	22.6	29.7	24.4	11.90	1.7	3.2
128	24.2	52.4	17.5	8.19	1.7	9.1
129	23.0	38.0	13.6	10.96	2.6	10.0
130	27.8	26.5	20.6	12.02	3.1	9.3
131	27.8	29.0	19.0	11.35	2.8	8.7
132	23.3	40.0	18.4	8.62	2.8	9.9

Appendix F6. Horizon Thicknesses and Coded Color Values for A, AB, and Bt Horizons

HORIZON THICKNESSES AND COLORS

ATHICK	ABTHICK	BTTHICK	ACOLOR	ABCOLOR	BTCOLOR	SITE
1.25	15.0	10.0	9.0	12	12	CB
7.50	20.0	7.5	12.0	12	12	CB
1.25	12.5	10.0	7.5	9	15	CB
2.50	20.0	25.0	9.0	12	18	CB
7.50	7.5	17.5	9.0	12	12	CB
1.25	17.5	17.5	7.5	12	15	CB
2.50	12.5	45.0	9.0	9	12	CB
2.50	7.5	5.0	6.0	12	12	CB
2.50	15.0	5.0	7.5	12	12	CB
2.50	10.0	42.5	9.0	12	15	CB
1.25	12.5	12.5	9.0	12	15	CB
5.00	12.5	12.5	9.0	12	15	CB
3.75	17.5	12.5	6.0	9	12	CB
5.00	15.0	12.5	6.0	12	12	CB
3.75	10.0	12.5	9.0	9	9	CB
5.00	20.0	12.5	9.0	9	9	CB
3.75	30.0	7.5	9.0	12	9	CB
5.00	20.0	10.0	9.0	12	12	CB
5.00	15.0	12.5	9.0	12	15	CB
5.00	17.5	17.5	9.0	12	12	CB
1.25	22.5	22.5	7.5	9	12	CB
2.50	10.0	10.0	6.0	9	12	CB
6.25	15.0	15.0	6.0	12	12	CB
5.00	15.0	15.0	9.0	12	12	CB
6.25	20.0	20.0	9.0	9	9	CB
5.00	20.0	20.0	9.0	9	9	CB
7.50	25.0	25.0	9.0	9	12	CB
3.75	20.0	20.0	7.5	12	12	CB
6.25	22.5	22.5	7.5	12	12	CB
7.50	20.0	20.0	7.5	9	12	CB
7.50	20.0	20.0	7.5	9	12	CB
6.25	25.0	25.0	7.5	9	12	CB
5.00	15.0	20.0	6.0	18	18	CB
7.50	12.5	32.5	6.0	18	18	CB
5.00	25.0	40.0	6.0	18	18	CB
5.00	27.5	32.5	6.0	18	18	CB
3.75	22.5	27.5	6.0	18	18	CB
5.00	20.0	37.5	6.0	21	18	CB
7.50	17.5	37.5	6.0	18	15	CB
7.50	12.5	55.0	6.0	18	15	CB
5.00	20.0	35.0	6.0	21	15	CB
7.50	20.0	27.5	6.0	18	15	CB
5.00	37.5	17.5	6.0	18	15	CB
5.00	22.5	32.5	6.0	18	15	CB
6.25	17.5	35.0	6.0	12	15	CB
3.75	22.5	27.5	6.0	12	12	CB

HORIZON THICKNESSES AND COLORS

ATHICK	ABTHICK	BTTHICK	ACOLOR	ABCOLOR	BTCOLOR	SITE
5.00	22.5	22.5	6	12	15	CB
5.00	25.0	30.0	6	15	15	CB
5.00	20.0	30.0	6	12	15	CB
3.75	17.5	27.5	6	12	15	CB
5.00	17.5	42.5	6	12	15	CB
6.25	17.5	35.0	6	12	18	CB
7.50	20.0	27.5	6	12	18	CB
5.00	20.0	47.5	6	12	15	CB
5.00	20.0	27.5	6	12	15	CB
3.75	17.5	27.5	6	18	18	CB
3.75	25.0	30.0	6	12	15	CB
3.75	30.0	32.5	6	12	15	CB
6.25	25.0	32.5	6	18	15	CB
8.75	20.0	40.0	6	18	15	CB
6.25	25.0	40.0	6	15	15	CB
2.50	22.5	22.5	6	12	15	CB
3.75	27.5	17.5	6	12	15	CB
6.25	25.0	17.5	6	12	15	CB
20.00	25.0	30.0	9	12	12	CB
20.00	20.0	35.0	6	9	12	CB
12.50	17.5	45.0	6	12	9	CB
20.00	35.0	20.0	6	12	9	CB
15.00	25.0	37.5	6	9	12	CB
10.00	20.0	80.0	6	9	12	CB
10.00	17.5	67.5	9	9	12	CB
7.50	22.5	57.5	6	9	12	CB
20.00	20.0	40.0	6	9	9	CB
12.50	17.5	45.0	6	12	12	CB
10.00	15.0	92.5	9	12	9	CB
12.50	15.0	97.5	9	9	12	CB
7.50	10.0	92.5	9	12	12	CB
15.00	12.5	77.5	9	12	12	CB
17.50	15.0	50.0	6	9	12	CB
12.50	17.5	45.0	6	12	12	CB
10.00	17.5	27.5	9	9	12	CB
12.50	17.5	20.0	9	12	18	CB
25.00	20.0	35.0	6	8	12	CB
27.50	22.5	87.5	6	12	18	CB
11.25	22.5	67.5	9	12	18	CB
12.50	22.5	77.5	9	8	12	CB
15.00	30.0	75.0	6	12	18	CB
12.50	22.5	80.0	6	12	18	CB
20.00	20.0	72.5	6	12	18	CB
15.00	25.0	35.0	6	8	18	CB
15.00	22.5	75.0	6	12	18	CB
10.00	20.0	45.0	6	12	12	CB

HORIZON THICKNESSES AND COLORS

ATHICK	ABTHICK	BTTHICK	ACOLOR	ABCOLOR	BTCOLOR	SITE
15.00	20.0	85.0	6	12	18	CB
12.50	30.0	77.5	6	8	12	CB
15.00	30.0	42.5	6	8	18	CB
17.50	22.5	42.5	6	8	18	CB
17.50	17.5	55.0	6	8	18	CB
15.00	17.5	35.0	6	8	18	CB
15.00	25.0	35.0	6	12	18	CB
17.50	22.5	35.0	6	8	8	CB
12.50	25.0	80.0	6	8	8	CB
10.00	22.5	82.5	6	8	8	CB
5.00	30.0	80.0	6	8	4	CB
5.00	22.5	77.5	6	4	8	CB
2.50	10.0	97.5	9	4	6	CB
5.00	17.5	95.0	9	6	4	CB
5.00	15.0	97.5	9	6	6	CB
5.00	10.0	75.0	6	8	6	CB
2.50	17.5	97.5	6	8	6	CB
5.00	22.5	92.5	6	10	10	CB
5.00	12.5	97.5	6	8	8	CB
3.75	12.5	97.5	6	8	4	CB
2.50	15.0	92.5	6	2	4	CB
6.25	12.5	90.0	9	2	8	CB
7.50	15.0	92.5	9	8	4	CB
12.50	15.0	87.5	6	6	4	CB
7.50	15.0	90.0	6	8	2	CB
2.50	12.5	90.0	6	8	8	CB
5.00	17.5	95.0	9	8	8	FCB
3.75	17.5	90.0	6	6	5	FCB
5.00	30.0	85.0	9	4	8	FCB
3.75	22.5	92.5	9	4	8	FCB
3.75	25.0	90.0	9	4	6	FCB
3.75	15.0	97.5	6	4	8	FCB
3.75	20.0	95.0	9	4	8	FCB
3.75	15.0	97.5	9	6	10	FCB
2.50	25.0	92.5	6	8	12	FCB
3.75	20.0	67.5	9	4	8	FCB
1.25	17.5	65.0	9	6	8	FCB
1.25	15.0	95.0	9	8	12	FCB
2.50	15.0	97.5	9	8	12	FCB
1.25	22.5	95.0	9	6	8	FCB

VITA

Richard D. Hammer was raised in rural central Illinois, where his father, Richard F. Hammer of Princeville, Illinois, and his mother, the former Dorothy Cooper, of Bemis, Tennessee, managed grain elevators and worked as a nurse, respectively.

After graduating from Warrensburg High School, he attended the U.S. Naval Academy, where he received his B.S. in mechanical engineering. While at the Academy, Dr. Hammer lettered in varsity gymnastics and was Chairman of the Brigade Honor Committee. He also served on the committee which wrote the honor code currently used at the Academy. He accepted a commission in the U.S. Marine Corps and was assigned to The Basic School at Quantico, Virginia, where he received six months of infantry officers' training, during which he was selected Company Commander of the class of 242 officers. Subsequent to graduation from TBS he entered the Naval Aviation Training Command, from which he graduated with honors with the designation of fixed wing (jet) aviator. His six years with the Marine Corps included an overseas tour in which he flew 80 combat missions in Viet Nam. He was assigned aide-de-campe to the Commanding General, 4th Marine Aircraft Wing during his final tour.

Dr. Hammer received his M.S. in forestry with a major in soil science from the University of Illinois. He worked in Washington state as a forest soils specialist for the State Department of Natural Resources, then worked for the U.S. Forest Service as a soil scientist before coming to the University of Tennessee, Knoxville, as a research associate in soil genesis and classification.

Dr. Hammer accepted a position as Assistant Professor of Soil Science at the University of Missouri, Columbia, subsequent to completing his program at Tennessee.

He and his wife, Jennifer, have a daughter, Meredith.