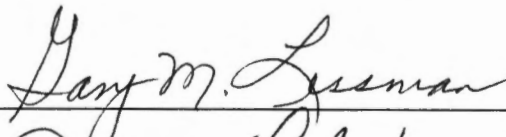
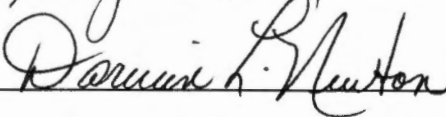


To the Graduate Council:

I am submitting herewith a thesis written by Janice L. Branson entitled "Spatial Variability of Soil Solution Nitrates and Soil Morphology as Effected by Long Term Management on a Highland Rim Site." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.


John T. Ammons, Major Professor

We have read this thesis and
recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor and
Dean of the Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at The University of Tennessee, Knoxville, I agree that the library shall make it available to borrowers under the rules of the library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made.

Permission for extensive quotation or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of the Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Janece L. Branson
Date July 29, 1992

SPATIAL VARIABILITY OF SOIL SOLUTION NITRATES
AND SOIL MORPHOLOGY AS EFFECTED BY LONG TERM
MANAGEMENT ON A HIGHLAND RIM SITE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Janice L. Branson

August, 1992

AO-VET-MED.

THESIS
92
B725

DEDICATION

This work is dedicated to my parents, Beulah and James H. Branson, Jr., my sister, Sharon Beeler, and my best friend, Tom Willis, without whose love, support, and patience it would not have been possible.

ACKNOWLEDGMENTS

The author wishes to thank the Institute of Agriculture and the Department of Plant and Soil Science for their support in providing the opportunity to pursue graduate studies.

A special thanks is given to Dr. John T. Ammons for serving as the major professor and for providing direction and moral support to the author throughout all phases of this research.

Thanks is offered to the members of the author's graduate committee, Dr. Gary Lessman and Mr. Darwin Newton, for guidance, advice, and encouragement through the research process.

The author would also like to thank Mike Timpson, Mike Morris, Nathan Hargrove, Anthony Khiel, Rick Livingston, Andy Gallagher, and Sonja Entrekin for their friendship and assistance in the field and laboratory.

ABSTRACT

A study of the effects of long term management and soil morphology on distribution of soil solution nitrates and chlorides was conducted at the Highland Rim Experiment Station in Robertson County, Tennessee.

The site area was a soil fertilization study which had been under continuous corn for 28 years. Two sites were fertilized annually with 336 kg ha⁻¹ nitrogen, 112 kg ha⁻¹ phosphorus, 336 kg ha⁻¹ potassium, and 56 kg ha⁻¹ of a minor element supplement. Two other sites received this same treatment plus 10 tons/acres of manure. Two control sites were sampled in undisturbed native soils on the same landscape.

Six pedons were sampled to study spatial variability of the soil taxon. The effect of manuring and long term management on measured soil chemical properties was determined. Fourteen points in each of two plots were randomly sampled to determine distribution and quantity of soil solution nitrates and chlorides.

Field morphology included horizon designations, depth, boundary distinctness, texture, color, consistence, and structure. Observations of concretions, fossils, and other soil components were noted.

Laboratory data included total carbon analysis, cation exchange capacity, percent base saturation, pH, particle size analysis, KCl total acidity, hydroxylamine-hydrochloride

manganese, citrate-bicarbonate-dithionite iron, and Mehlich I extraction of eighteen elements.

The soils in pedons 1 and 2 were classified as fine-silty, siliceous, thermic Fragic Paleudults. Pedons 3 and 8 were classified as fine-silty, siliceous, thermic Typic Paleudults. Pedons 4 and 7 were classified as fine-silty, siliceous, thermic Typic Hapludults.

Parent material generally was loess over alluvium over residuum. Movement of soil solution nitrates and chlorides was influenced by soil texture, structure, chemical composition, and the presence of pans or discontinuities. Nitrates were concentrated in the horizons above a plow pan at approximately 28 centimeters and above a paleosol at approximately 85 centimeters. The nitrates were moving laterally downslope over the paleosol.

Additions of high amounts of nitrogen had no direct correlation with soil solution nitrates. Long term additions of manure and fertilizer amendments influenced the chemical and physical composition of the soil. Total carbon was a good indicator of total nitrogen. A similar relationship was exhibited between Mehlich I extracted manganese and hydroxylamine hydrochloride extracted manganese.

Long term management did influence soil morphology. Both management and morphology had an effect on concentration and distribution of nitrates as well as other chemical components in the soil.

	Sand, silt, and clay distribution in the soil profile at site 3.	137
	Sand, silt, and clay distribution in the soil profile at site 4.	138
	Sand, silt, and clay distribution in the soil profile at site 7.	139
	Sand, silt, and clay distribution in the soil profile at site 8.	140
VITA		141

LIST OF FIGURES

Figure 1. Location map of the study area.	10
Figure 2. Layout of the eight plots in the study area.	11
Figure 3. Ratio of fine sand to total sand plus silt plotted by depth in the soil profile at site 2. .	30
Figure 4. Ratio of medium sand to total sand plus silt plotted by depth in the soil profile at site 3. .	32
Figure 5. Ratio of medium sand to total sand plus silt plotted by depth in the soil profile at site 4. .	36
Figure 6. Ratio of medium sand to total sand plus silt plotted by depth in the soil profile at site 7. .	40
Figure 7. Ratio of medium sand to total sand plus silt by depth in the soil profile at site 8.	42
Figure 8. Citrate-bicarbonate-dithionite free iron distribution by depth in the soil profiles at sites 3 and 7.	43
Figure 9. Citrate-bicarbonate-dithionite free iron distribution by depth in the soil profiles at sites 4 and 8.	44
Figure 10. Citrate-bicarbonate-dithionite free iron distribution by depth in the soil profiles at sites 1 and 2.	46
Figure 11. Total carbon distribution by depth in the soil profiles at sites 1, 2, and 3.	47
Figure 12. Total carbon distribution by depth in the soil profiles at sites 4, 7, and 8.	48
Figure 13. Grid for randomly sampling plots 3 and 4 for nitrates.	59
Figure 14. Nitrate distribution by depth in the soil profile of high fertilization plot no. 3.	61
Figure 15. Nitrate distribution by depth in the soil profile of the high fertilization plus manure plot no. 4.	63
Figure 16. Chloride and nitrate distribution by depth in the soil profile of high fertilization plot no. 3.	65
Figure 17. Chloride and nitrate distribution by depth in the soil profile of high fertilization plot no. 4.	66
Figure 18. Comparison of nitrate and total nitrogen distribution by depth in the soil profile of high fertilization plot no. 3.	67
Figure 19. Comparison of nitrate and total nitrogen distribution by depth in high fertilization plus manure plot no. 4.	68
Figure 20. Regression correlation between nitrates and total nitrogen.	70
Figure 21. Regression correlation between total carbon and total nitrogen.	93

Figure 22. Regression correlation between the Mehlich I and hydroxylamine-hydrochloride methods of manganese extraction.	108
Figure 23. Regression correlation between Mehlich I extracted silica and total clay determined by particle size analysis.	111

LIST OF TABLES

Table 1. Coarse silt, fine silt, and coarse fragment content of the six soil profiles of the study area.	18
Table 2. Classification of the six study sites according to Soil Taxonomy.	21
Table 3. Soil morphological data for site 1.	22
Table 4. Citrate-bicarbonate-dithionite extracted iron and hydroxylamine-hydrochloric extracted manganese concentration for sites 1, 2, 3, 4, 7, and 8. . .	23
Table 5. Soil morphological data for site 2.	25
Table 6. Total sand, silt, and clay distribution in sites 1 and 2.	27
Table 7. Mehlich I concentrations of aluminum, arsenic, boron, potassium, strontium, and zinc in the soil profile at site 2.	29
Table 8. Soil morphological data for site 3.	31
Table 9. Soil morphological data for site 4.	34
Table 10. Total sand, silt, and clay distribution in sites 3 and 4.	35
Table 11. Soil morphological data for site 7.	37
Table 12. Total sand, silt, and clay distribution in sites 7 and 8.	38
Table 13. Soil morphological data for site 8.	41
Table 14. KCl total acidity and pH of soil pedons 3 and 4.	71
Table 15. Cation exchange capacity, exchangeable bases, base saturation, and pH in the soil profiles at sites 3 and 4.	73
Table 16. Total carbon and calcium carbonate equivalent in the soil profiles at sites 1, 2, 3, 4, 7, and 8. . .	84
Table 17. Cation exchange capacity, exchangeable bases, and pH in the soil profiles at sites 1, 2, 3, 4, 7, and 8.	87
Table 18. Total nitrogen, total carbon, and C:N ratios in the soil profiles for sites 1, 2, 3, 4, 7, and 8.	91
Table 19. KCl total acidity and pH of soil pedons 1, 2, 3, 4, 7, and 8.	95
Table 20. Mehlich I concentrations of aluminum, arsenic, boron, calcium, cadmium, chromium, copper, and iron, potassium, magnesium, manganese, sodium, nickel, phosphorus, lead, silica, strontium, and zinc in sites 1, 2, 3, 4, 7, and 8.	97
Table 21. Mehlich I concentrations of potassium, magnesium, manganese, sodium, nickel, phosphorus, lead, and silica in sites 1, 2, 3, 4, 7, and 8. .	100
Table 22. Mehlich I concentrations of strontium and zinc in sites 1, 2, 3, 4, 7, and 8.	103

CHAPTER 1
SPATIAL VARIABILITY OF THE SOIL TAXON
ON A HIGHLAND RIM UPLAND SITE

INTRODUCTION

A major problem in describing the taxonomy of a soil is spatial variability. Soil is an open system continually changing chemically, physically, and biologically. From previous experience, the north face of a backhoe pit can vary greatly from the south face. The soil is a dynamic system involving additions, removals, transfers, and transformation (Simonson, 1967).

With such a variety of factors involved, classification of a soil taxon is difficult. The objective of this study was to examine the spatial variability of a Dickson silt loam (fine-silty, siliceous, thermic Glossic Fragiudult) by observing changes of the taxon over a short linear distance.

LITERATURE REVIEW

Soil development can follow a variety of paths. Variation depends on the five soil forming factors: climate, time, parent material, topography, and biotic factors (Jenny, 1941). All five work simultaneously and to varying degrees to influence the direction of soil development.

Climate is often the most dominating factor in soil formation. Temperature and precipitation greatly affect the

chemical and physical weathering processes. Generally, each ten degree rise in temperature, doubles the rate of chemical processes. Climate is the controlling factor for vegetation (Brady, 1984).

Climate may be subdivided into several components. The major parts are: temperature, precipitation, rainfall intensity, wind, humidity, water balance, and microclimate (Springer and Elder, 1980).

Plants and animals influence soil properties by stirring or mixing the soil, recycling nutrients, increasing organic matter, and increasing structural stability. Vegetation increases the organic matter content by the addition of roots and root exudates and the decay of plant residues (Springer and Elder, 1980).

The type of vegetation has a strong influence. Different types of elements are contained in the leaves and limbs. Most soils developed in forest environments are acidic, where as, grassland soils have a higher cation exchange capacity than forest soils. Vegetation has a major role in erosion control. Erosion affects soil depth and exposes the soil to the weathering processes (Brady, 1984).

Microorganisms decompose organic matter releasing nutrients and acids. Some, such as the genus *Rhizobium*, supply nitrogen for plant growth. Human activities, also, have a major influence on soil development. Agricultural practices

can destroy aggregate stability, mix horizons, alter CEC, and create traffic pans (Brady, 1984).

Topography involves the size, shape, and position of the land surface(Webster, 1988). It can increase or decrease the speed of development of a soil. Referring to spatial variability, microtopography is more influential than overall topography. Two different soils may develop within a few meters of each other because of microtopographical differences (Buol, 1989).

The mineral composition of the parent material determines its resistance to weathering. Texture and the type of clay found in soil are dependant on the parent material. Texture influences the movement of water through the soil and the erodibility of the soil (Birkeland, 1984).

In soils having limestone parent material, acidification processes are slowed by the high base content resulting from weathering of the limestone. The weathering of parent material releases nutrients for vegetative growth (Brady, 1984).

Time is based on the amount of time that has passed since the parent material was first exposed to the soil forming factors. "Time-zero" usually occurs after a major event, such as a land slide, flood, volcanic eruption, earthquake, or other catastrophic occurrence(Brady, 1984). Differences in horizon development, depth, aggregation, and vegetative cover are all affected by the amount of time that has passed since

"time-zero". Upland soils may have been developing for thousands of years, while soil on a floodplain may have just recently been deposited (Springer and Elder, 1980).

The geologic structure of the Western Highland Rim is directly related to that of the Central Basin. The area of the basin was originally a structural dome (Nashville Dome). In weakened areas, sediments were detached and transported downstream by erosional forces. Subsequently, a topographical basin was formed.

The Highland Rim is the portion of the Nashville Dome remaining relatively intact. Evidence of uplift is indicated by the prevailing dip of the geological beds (Safford, 1869).

The rim has been dissected by streams leaving some areas at an elevation of 234 meters mean sea level and valleys at 122 meters mean sea level. Most of the exposed rocks are of Devonian and Mississippian age (Hershey and Maher, 1963).

In most areas, the overburden is chert gravel, silt, and clay resulting from the weathering of the underlying formations, but some areas contain terraces deposits developed from the transportation of sediments (Hershey and Maher, 1963).

Most of the soils in Robertson County formed from limestone parent material, loess, or alluvium. Residuum parent material consists of St. Louis limestone over Warsaw limestone (Hardeman, 1966). There are, also, outcrops of Fort Payne chert.

The youngest of the marine sediments of north-central Tennessee, the St. Louis limestone averages 55-61 meters thick. Karst topography is common (Hershey and Maher, 1963). This formation is generally a massive or medium-bedded, fine-grained, bluish-gray limestone containing nodular and cellular chert. It weathers to a bright-red soil containing clay, rounded fragments of chert, and silicified colonies and fragments of fossils. Massive colonial corals, especially *Lithostrotion basaltiforme*, are common (Piper, 1932)

The Warsaw geological formation is widely distributed over the Highland Rim with average thickness ranging 24 to 30 meters. The lithology is similar to the Fort Payne, except that limestone facies are more extensive (Hershey and Maher, 1963).

Beneath the St. Louis, the Warsaw formation is highly fossiliferous, especially in the middle and upper parts. The remains are very fragmented and difficult to classify because they generally decompose with the surrounding rock material.

The lower part resembles the Fort Payne and can be difficult to distinguish. On upland tracts, it weathers to a brick-red clayey soil containing many fragments of chert (Piper, 1932)

The Fort Payne is exposed extensively in the Western Highland Rim. This formation is the most siliceous of the Lower Mississippian formations. Composition includes siltstone, bedded chert, limy siltstone, silty limestone, to

coarse-grained crinoidal limestone (small amounts). The presence of biothermal reefs is possible. Quartz geodes are common (Hershey and Maher, 1963)

The Fort Payne lies under the Warsaw limestone. Essentially non-fossiliferous in north-central Tennessee, the opposite is true of Fort Payne in other areas. The formation is deeply weathered in upland areas producing a reddish or yellowish-buff soil containing much dense chert in subangular fragments (Piper, 1932)

Many soils developed in the cherty clay resulting from weathering of residuum. After a period of time, a layer of loess was deposited over these profiles. Loess is basically windblown silt with a small percentage of clay (Buol, 1989).

Loess has been geologically linked to periods of glaciation. When outwash from glacial meltwater dried, westerly winds would blow a blanket of silt particles eastward (Ritter, 1986).

Percent base saturation is characteristically high in loess due to the presence of 2:1 clays (Buol et al, 1989). The primary mineral found in loess is quartz. Feldspars, mica, hornblende, and augite are also common (Brady, 1984).

Loess material has a variable thickness due to topographical differences. Windblown silts tend to smooth over topography rather than accumulate in dunes (Ritter, 1986). Soils in upland positions on the Highland Rim have developed in the loessial parent material.

Alluvial soils can also form in upland positions in the sediments deposited by water erosion. In Robertson County, some alluvial soils developed in material resulting from the weathering of small mountains which were thinly scattered through the county at one time (Soil Survey Staff, 1968).

Soils formed in contrasting parent material commonly develop fragipans. Material from both parent materials are commonly mixed in this transitional area (Soil Survey Staff, 1968).

Soils, classified in the Dickson soil series, formed in loess over clay developed from either the residuum limestone or old alluvium. These are moderately well drained soils which have a fragipan at the contact point of the two parent materials.

Dickson soils are commonly adjacent to Mountview (fine-silty, siliceous, thermic Typic Paleudult) and Sango (coarse-silty, siliceous, thermic Glossic Fragiudult) soils. Mountview soils have no fragipan, but do contain fragic properties. Sango soils are in deeper loess, have a fragipan, and are less well drained than the Dickson soils (Soil Survey Staff, 1968).

Spatial variability can be systematic and/or random. Systematic variation is a gradual or marked change in soil properties as the result of landform, geomorphic processes, soil forming factors, and management. Random variation involves soil properties with an unknown cause (Wilding and Drees, 1983).

Age is also a factor in soil variability. With time, some soil properties reach an equilibrium. Younger soils tend to have greater variability than more mature soils (Harradine, 1949).

When a soil unit is mapped, inclusions of other soils are common. Powell and Springer (1965) checked the precision of classification of several mapping units in Walton County, Ga. After 518 soil observations, they found three soil series units examined contained from 17 to 40% inclusions of other soils.

Soils can vary within the space of a few centimeters (Soil Survey Staff, 1981). The differences can involve numerous variables. In a comparison of selected physical and chemical properties, Mausbach et al (1980) studied four parent materials: loess, glacial drift, residuum, and alluvium.

The lowest coefficients of variation (CV's) were found in loess (9-18%). The highest were in residuum and alluvial soils (26-47%). A and B horizons had CV's of 5%, while C horizons showed greater variation. As clay content increased, CV's for clay decreased (Mausbach et al, 1980).

Chemically, pH was the least variable with a CV of 9%. Base saturation and extractable acidity had CV's of 25% and 59%, respectively. The highest CV's were for organic carbon (> 100%). Ap horizons tended to have larger CV's due to cultivation (Mausbach et al, 1980).

Loess had the lowest CV's for both physical and chemical properties.

MATERIALS AND METHODS

FIELD SAMPLING

In 1962, a soil fertility study was initiated in field 46 at the Highland Rim Experiment Station in Springfield, Tennessee (Fig. 1). The plots were located on a Dickson silt loam (fine-silty, siliceous, thermic Glossic Fragiudult) (Soil Survey Staff, 1968). This study was maintained for 28 years. These plots were located at approximately 36° 49' 30" N and 86° 28' 40" W on the Greenbrier Quadrangle topographic sheet (U. S. Geological Survey, 1980). Elevation was 280 meters above mean sea level.

Eight plots (Fig. 2) of continuous corn (*Zea mays* L.) were developed to evaluate the effects of different fertilizer rates and manure additions on crop yields and soil properties. The four fertilizer rates were: no fertilizer (control), fertilization as recommended by soil test results, high fertilization rates, and manure plus high fertilization rates. There were two replications of each treatment (Parks and Safley, 1977; Parks and Safley, 1982).

The high fertilization plots received 336 kg ha⁻¹ nitrogen, 112 kg ha⁻¹ phosphorus, 336 kg ha⁻¹ potassium, and 56 kg ha⁻¹ minor elements each year. Minor elements were supplied in applications of Es-min-el, a commercial micronutrient supplement. Ten tons acre⁻¹ year⁻¹ of manure were applied to the high fertilizer plus manure plots.

Nutrients were applied to the soil test plots as recommended by results of laboratory data from the Soil Test

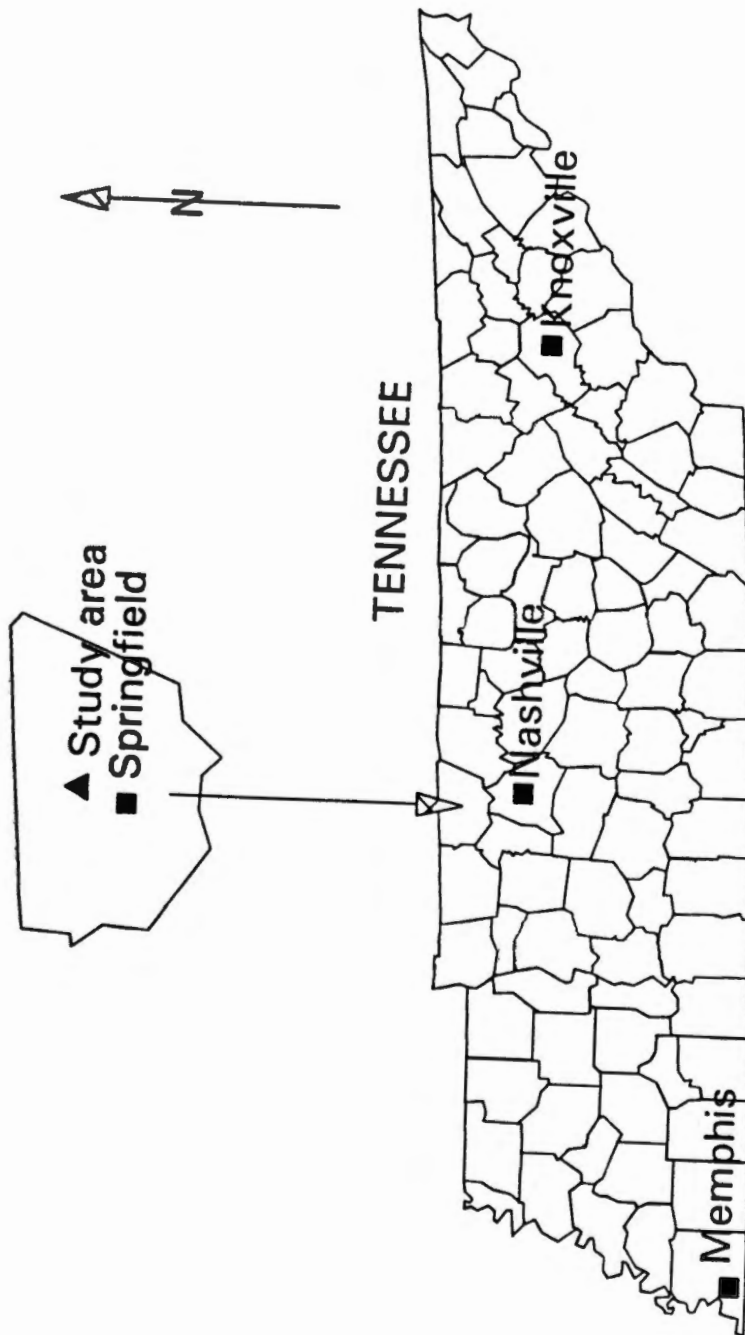


Figure 1. Location map of the study area.

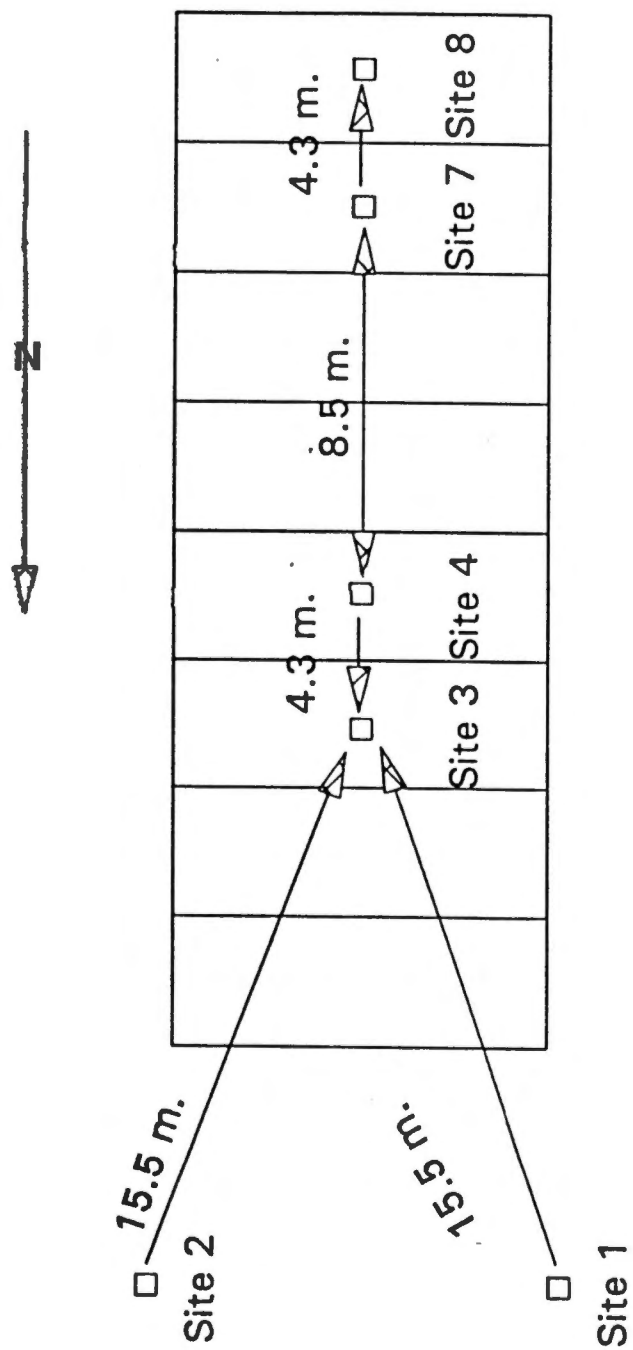


Figure 2. Layout of the eight plots in the study area.

Lab in Nashville each year. Nitrogen was added at a rate of 134 kg ha⁻¹. No potassium or phosphorus was added the first three years (Parks and Safley, 1982).

The two plots receiving high fertilization and the two receiving high fertilization plus manure were sampled for this research. Since all the fertility plots were adjacent, the control plots and soil fertilization plots were not sampled in this investigation. There was a high probability these plots had been affected by lateral movement of soil solution and cultivation of the more highly fertilized plots.

Two control sites were chosen at random for comparison. These sites were approximately 7 meters from the fertility plots on the same landscape. There was little likelihood of these sites being affected by the management practices on the fertility plots.

A total of six soil cores were removed for characterization: two from the high fertilization plots, two from the high fertilization plus manure plots, and two from the control sites.

The four fertility plots were sampled in May, 1990. The two control sites were sampled in January, 1991. Cores, 7.62 centimeters in diameter, were extracted with a Giddings GSRP-S-M hydraulic probe.

Soil morphology was completed according to National Cooperative Soil Survey Standards (Soil Survey Staff, 1981). Field notes included: horizon designation, depth, boundary distinctness, texture, color, consistence, and structure.

The presence of cutans, manganese concretions, fossils, and other observations were noted. Elevation, aspect, vegetation, slope, and other site characteristics were also recorded.

The external rind of the cores were peeled prior to sampling to avoid contamination.

LABORATORY ANALYSIS

Each sample was air dried and sieved through a 2mm screen. The coarse fragments were removed, weighed, and bagged separately. The <2mm fraction was mixed thoroughly and one-fourth of it was ground to 60 mesh.

Total carbon analysis was determined on 60 mesh samples with a Leco CR-12 Carbon System. The Orion Research Ionalyzer model 399A was used to read pH. Two replications of each sample were mixed with water in a 1:1 ratio as recommended by Olsen and Ellis (1982).

The pipette method was used to determine percent sand, silt, and clay for particle size analysis (Kilmer and Alexander, 1949). Hydrogen peroxide was used to eliminate interference from organic matter in horizons with high carbon contents. The sands were fractionated into very coarse sand (vcs), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs) (Gee and Bauder, 1986).

Percent base saturation was determined by the ammonium acetate saturation method and the extract was analyzed on the Perkin-Elmer 5000 Atomic Absorption Spectrophotometer

(Jackson, 1958). The ammonium saturated samples were then extracted with a solution of 10% NaCl. This extract was distilled with a Lab Conco distillation unit to determine cmol (+) kg⁻¹ for cation exchange capacity (Chapman, 1965).

Manganese oxides were extracted with hydroxylamine hydrochloride (Gambrell and Patrick, 1982). The citrate-bicarbonate-dithionite method was used to extract iron oxides (Olsen and Ellis, 1982).

Dilute double acid nutrient extraction (Mehlich I) was analyzed using the inductively coupled argon plasma-optical emission spectrophotometer (ICAP-OES) (Mehlich, 1953). The elements measured included aluminum, arsenic, boron, calcium, cadmium, chromium, copper, iron, lead, magnesium, manganese, nickel, phosphorus, potassium, silica, sodium, strontium, and zinc.

Soil morphology and the results of the laboratory analysis were used to classify each pedon according to accepted soil survey techniques (Soil Survey Staff, 1975) (Soil Survey Staff, 1990).

Spatial variability was determined with the results of the laboratory analysis. All sites were compared for differences in soil chemical and physical properties over a linear distance of approximately 39 meters. The methods employed in this research project were the standard field and laboratory methods used in the University of Tennessee's Soil Characterization Laboratory.

RESULTS AND DISCUSSION

GEOLOGY

The topographic map of the Greenbrier Quadrangle (U. S. Geological Survey, 1980) shows the study site was on the Western Highland Rim approximately seven miles northwest of the drainage divide between the Central Basin and the Highland Rim. The divide enters southwestern Robertson County at the convergence of Robertson, Sumner, and Davidson Counties.

The area is highly dissected indicating continuing erosion of the Nashville Dome. The highest elevation in this area is 273.6 meters mean sea level. The elevation rapidly drops to 243.2 meters mean sea level. In the area of the study sites, only individual remnants remain at the 243.2 meter level. One such remnant is directly adjacent to the study site, which is at an elevation of 237 meters above mean sea level.

In the field adjacent to the study area, elevation rapidly dropped to 219 meters with the drainageway terminating in a large depression. Large depressions are an important component of the landscapes on the Highland Rim.

According to the West-Central Tennessee geological map (Hardeman, 1966), the study sites were in a region underlain by the Fort Payne Formation. However, Safford and Killebrew (1867) specifically stated the city of Springfield was built on the St. Louis limestone.

They described this formation as being fossiliferous. A common fossil was the *Lithostrotion canadense*, which was a large coral. Chert nodules were common. Another characteristic of the St. Louis is karst topography produced by the presence of depressions, underground streams, and caves.

Examination of the surrounding locale indicated Safford and Killebrew were correct. In close proximity to the study location, approximately 12 meters of St. Louis limestone was exposed in a road cut on Greenbrier Pike. The residual parent material for the investigation site was St. Louis limestone.

The parent material for the surface horizons of the site was loess. The primary sources of loess in this region of Tennessee were the rivers carrying glacial melt water (Wascher et al, 1947). A little may have come from the area of the Western Ohio River, but most came from the Mississippi to the west. The colors of the loess in the study area corresponded to the yellowish browns of the Peorian deposition.

Frazer et al (1970) found depth of loess deposition decreases with distance from the source. Also, particle size distribution changes over distance. Coarser silts are deposited near the source area. As distance increases fine silts and clay become the predominant particle size.

The deposition at the study site is 0.3-0.6 meters thick. Generally, fine silts made up 60-70% of the total silt content (Table 1). The thinness of the deposition and dominance of

Table 1. Coarse silt, fine silt, and coarse fragment content of the six soil profiles of the study area.

HORIZON	DEPTH (cm)	%COARSE SILT	%FINE SILT	%COARSE FRAGMENTS (volume)
Site 1				
A1	0-6	25.9	48.3	0
A2	6-26	42.1	34.9	0
Bt1	26-47	45.1	23.9	0
Bt2	47-61	24.8	39.4	2
2Bt3	61-81	25.9	38.7	4
2Bt4	81-102	40.6	23.5	13
2BT5	102-120	21.4	34.5	14
3Bt6	120-130	17.1	27.1	20
3Bt7	130-158	14.3	31.5	13
3Bt8	158-185+	13.3	23.3	14
Site 2				
A	0-38	42.4	35.6	0
Bt1	38-62	52.9	19.4	0
2Bt2	62-93	26.8	40.1	0
2Bt3	93-120	16.5	40.8	1
3Bt4	120-185	18.4	30.9	2
Site 3				
Ap1	10-13	21.6	55.9	0
Ap2	13-28	20.0	54.1	0
Bt1	28-51	14.5	52.8	1
2Bt2	51-83	24.5	44.5	3
3Bt3	83-110	13.6	41.8	0
3Bt4	110-123	9.9	44.4	0
3Bt5	123-150+	26.9	26.7	0

Table 1 (continued)

HORIZON	DEPTH (cm)	%COARSE SILT	% FINE SILT	% COARSE FRAGMENTS (volume)
Site 4				
Ap1	0-18	27.9	47.2	0
Ap2	18-29	19.7	56.0	0
Bt1	29-46	4.4	64.3	0
Bt2	46-64	22.6	46.5	2
2Bt3	64-85	18.2	51.1	1
2Bt4	85-99	19.7	45.1	0
2Bt5	99-110+	15.8	47.4	0
Site 7				
Ap1	0-16	25.6	54.0	0
Ap2	16-33	21.2	59.1	0
Bt1	33-61	15.2	53.2	1
Bt2	61-82	62.0	8.7	7
2Bt3	82-111	18.9	50.5	10
2Bt4	111-128	17.3	46.8	7
2Bt5	128-158	29.0	25.6	14
Site 8				
Ap1	0-19	18.8	64.2	0
Ap2	19-36	21.1	60.5	0
Bt1	36-71	16.6	58.2	0
Bt2	71-96	18.4	48.7	1
Bt3	96-120	21.1	49.5	5
2Bt4	120-148	16.1	41.5	4
2Bt5	148-186	21.9	26.7	2
2Bt6	186-206	15.6	32.5	3

fine silts indicate the source of the loess was distant rather than local. As a Peorian deposition, this would make this soil approximately 10,000 years in age.

Positioned between the loess and residual horizons was a thin alluvial layer. This morphologic layer was often hard to differentiate. In some instances, coarse fragment volume increased (Table 1). However, some of the chert included in the coarse fragment totals had weathered in place from the residuum. Observation of rounded sand sized particles under a microscope was often necessary to confirm the presence of alluvium.

Two fossils were found in the alluvial material. One was a horned coral. The other was unidentifiable. These fossils probably were imbedded in residual limestone upslope from the study position. Erosional forces detached the fossils and surrounding sediments. Eventually, alluvial action transported the fossils and sediments to the tract where they were unearthed.

The alluvial layer is high in silt content. Some of the original parent material probably came from accumulations of loessial material prior to the Peorian deposition. The sediments of these highly erodible surfaces were detached and transported by water along with some of the more resistant underlying residual materials.

SOIL MORPHOLOGY AND CLASSIFICATION BY SITE

Site 1 was classified as a fine silty, siliceous, thermic Fragic Paleudult (Table 2). This pedon 1 was described to a depth of 185 centimeters (Table 3). This site had 40% brittleness between 102 and 130 centimeters. The few observed roots at this depth were following the light gray (10 YR 7/1) prism faces.

At 61 centimeters, a lithologic discontinuity between the loess and underlying alluvium was present. Another lithologic discontinuity between the alluvium and residuum occurred at 120 centimeters. At 120 centimeters, the matrix color abruptly changed from yellowish brown (10YR 5/8) to red (2.5YR 4/6).

Manganese concentration was much greater in the surface horizons in site 1 than in the lower portion of the profile. Percent CBD iron increased with soil depth with the highest levels occurring in the paleosol (Table 4).

Site 2 was also classified as a fine-silty, siliceous, thermic Fragic Paleudult (Table 2). This pedon was described to a depth of 185 centimeters (Table 5). Manganese concentration was highest in the surface and decreased with depth (Table 4).

While this soil profile did not have a well defined fragipan, the horizon between 93 and 120 centimeters had fragic properties. As in site 1, roots were observed following

Table 2. Classification of the six study sites according to Soil Taxonomy.

Site Number	Classification
1	fine-silty, siliceous, thermic Fragic Paleudult
2	fine-silty, siliceous, thermic Fragic Paleudult
3	fine-silty, siliceous, thermic Typic Paleudult
4	fine-silty, siliceous, thermic Typic Hapludult
7	fine-silty, siliceous, thermic Typic Hapludult
8	fine-silty, siliceous, thermic Typic Paleudult

Table 3. Soil morphological data for site 1.*

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCY
A1	0-6	10YR 4/3 (DARK BROWN)	SiL	2,F,GR	FR
A2	6-26	10YR 4/4 (DARK YELLOWISH BROWN)	SiL	1,F,SBK	FR
Bt1	26-47	10YR 5/6 (YELLOWISH BROWN)	SiL	1,F,SBK	FR
Bt2	47-61	10YR 5/6 (YELLOWISH BROWN)	SiCL	1,M,SBK	FR
2Bt3	61-81	10YR 5/6 (YELLOWISH BROWN)	SiL	2,M,SBK	FR
2Bt4	81-102	10YR 5/4 (YELLOWISH BROWN)	SiCL	2,M,SBK	FR
2Bt5	102-120	10YR 5/8 (YELLOWISH BROWN)	SiCL	2,M,SBK	FI
3Bt6	120-130	2.5YR 4/6 (RED)	GRSiC	2,M,ABK	FI
3Bt7	130-150	2.5YR 4/6 (RED)	SiC	2,M,ABK	FI
3Bt8	158-185+	2.5YR 4/6 (RED)	C	3,M,ABK	FI

*Abbreviations defined in Appendix A.

Table 4. Citrate-bicarbonate-dithionite extracted iron and hydroxylamine-hydrochloric extracted manganese concentration for sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	MN++ mg kg ⁻¹	Fe %	Fe ₂ O ₃ %
Site 1				
A1	0-6	205.86	0.97	1.39
A2	6-26	185.77	0.86	1.22
Bt1	26-47	34.52	1.35	1.93
Bt2	47-61	3.99	1.87	2.68
2Bt3	61-81	2.93	1.76	2.51
2Bt4	81-102	2.67	1.77	2.53
2Bt5	102-120	0.98	3.51	5.01
3Bt6	120-130	1.15	4.23	6.05
3Bt7	130-158	1.39	4.04	5.77
3Bt8	158-185+	1.29	4.90	7.00
Site 2				
A	0-38	234.60	0.90	1.29
Bt1	38-62	20.02	1.48	2.12
2Bt2	62-93	10.63	1.75	2.51
2Bt3	93-120	2.15	1.64	2.34
3Bt4	120-185	2.51	3.28	4.69
Site 3				
Ap1	0-13	111.56	1.28	1.82
Ap2	13-28	89.22	1.32	1.89
Bt1	28-51	3.44	1.94	2.78
2Bt2	51-83	2.04	1.55	2.22
3Bt3	83-110	1.84	2.83	4.05
3Bt4	110-123	1.65	2.77	3.96
3Bt5	123-150+	2.07	3.39	4.85

Table 4. (continued)

HORIZON	DEPTH (cm)	MN++ mg kg ⁻¹	Fe %	Fe ₂ O ₃ %
Site 4				
Ap1	0-18	108.36	1.17	1.67
Ap2	18-29	103.57	1.30	1.85
Bt1	29-46	7.10	1.76	2.52
Bt2	46-64	3.72	1.76	2.52
Bt3	64-85	3.33	1.39	1.98
2Bt4	85-99	2.80	1.66	2.38
2Bt5	99-110+	2.04	2.13	3.05
Site 7				
Ap1	0-16	130.50	0.85	1.21
Ap2	16-33	143.06	0.87	1.25
Bt1	33-61	5.28	1.65	2.36
2Bt2	61-82	6.83	1.35	1.93
2Bt3	82-111	3.62	1.00	1.42
2Bt4	111-128	2.24	1.61	2.31
3Bt5	128-158	3.06	2.66	3.81
Site 8				
Ap1	0-19	165.58	0.73	1.04
Ap2	19-36	157.92	0.75	1.08
Bt1	36-71	31.99	1.33	1.90
2Bt2	71-96	5.54	1.42	2.03
2Bt3	96-120	3.50	0.95	1.36
3Bt4	120-148	3.28	2.78	3.98
3Bt5	148-186	2.82	3.21	4.59
3Bt6	186-206	3.45	4.09	5.85

Table 5. Soil morphological data for site 2.*

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCY
A1	0-38	10YR 4/3 (DARK BROWN)	SiL	1,F,SBK	FR
Bt1	38-62	10YR 5/6 (YELLOWISH BROWN)	SiL	1,F,SBK	FR
2Bt2	62-93	10YR 5/6 (YELLOWISH BROWN)	SiL	1,M,SBK	FR
2Bt3	93-120	10YR 5/6 (YELLOWISH BROWN)	SiL	1,F,ABK	FI
3Bt4	120-185+	2.5YR 4/8 (RED)	SiC	2,M,ABK	FI

*Abbreviations defined in Appendix A.

prism faces in this horizon and there was approximately 40% brittleness.

The parent material sequence of site 2 was loess over alluvium over residuum. The first lithologic discontinuity (loess/alluvium) occurred at 62 centimeters. Indications of a change in parent material included changes in coarse fragment content (Table 1), percent total sand (Table 6), and Mehlich I extraction of aluminum, arsenic, boron, potassium, strontium, and zinc (Table 7).

A second discontinuity (alluvium/residuum) occurred at 120 centimeters in site 2. Clay content increased (Table 6). Mehlich I boron, strontium, and zinc levels showed strong changes at this depth (Table 7). The matrix color changed from yellowish brown (10YR 5/6) to red (2.5YR 4/8).

The fine sand to total sand plus silt ratio also showed the change at 120 centimeters (Fig. 3). While CBD iron increased with depth, the highest measurement was in the paleosol at 120 centimeters (Table 4).

Site 3 was described to a depth of 150 centimeters (Table 8). This soil was classified as a fine-silty, siliceous, thermic Typic Paleudult (Table 2). Pedon 3 had two lithological discontinuities. The first discontinuity occurred between the loess and alluvium at 51 centimeters. The ratio of medium sand to total sand plus silt showed inflections at these depths (Fig. 4).

Table 6. Total sand, silt, and clay distribution in sites 1 and 2. Sand fractions included very coarse sand (vcos), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs).

HORIZON	DEPTH (cm)	VCOS	COS	MS	FS	VFS	TOTAL SAND	TOTAL SILT	TOTAL CLAY
-----PERCENT-----									
Site 1									
A1	0-6	0.3	1.1	1.1	3.4	2.6	8.4	74.3	17.3
A2	6-26	0.6	1.1	1.2	3.1	1.7	7.8	77.0	15.2
Bt1	26-47	0.5	1.0	1.1	2.4	1.6	6.5	69.1	24.4
Bt2	47-61	1.9	1.0	0.8	2.3	1.7	7.5	64.3	28.1
2Bt3	61-81	1.3	0.9	1.0	2.9	2.3	8.5	64.7	26.7
2Bt4	81-102	1.4	0.6	0.2	3.0	2.0	7.2	64.2	28.5
2Bt5	102-120	0.8	0.5	0.5	2.5	2.4	6.7	56.0	37.3
3Bt6	120-130	0.8	0.8	0.8	2.3	2.4	7.6	44.3	48.2
3Bt7	130-158	1.7	1.3	0.7	2.4	2.6	9.3	45.8	44.9
3Bt8	158-185	1.4	1.0	0.6	1.7	2.7	8.8	36.7	54.5

Table 6. (continued)

HORIZON	DEPTH (cm)	VCOS	COS	MS	FS	VFS	TOTAL SAND	TOTAL SILT	TOTAL CLAY
-----PERCENT-----									
Site 2									
A	0-38	0.8	0.9	1.3	2.5	1.7	7.8	78.1	14.2
Bt1	38-62	0.1	1.2	1.0	2.3	1.3	6.4	72.4	21.3
2Bt2	62-93	0.9	1.1	1.5	2.8	2.2	8.6	67.0	24.4
2Bt3	93-120	0.8	0.7	0.7	3.2	2.0	15.9	57.4	26.7
3Bt4	120-185	0.3	0.5	0.8	3.8	3.2	8.6	49.4	42.0

Table 7. Mehlich I concentrations of aluminum, arsenic, boron, potassium, strontium, and zinc in the soil profile at site 2.

HORIZON	DEPTH (cm)	AL	As	B	K	Sr	Zn
-----mg kg ⁻¹ -----							
A	0-38	326	0.05	4.4	60	2.25	1.26
Bt1	38-62	287	0.07	4.7	80	3.79	1.26
2Bt2	62-93	436	0.20	3.4	54	2.27	0.47
2Bt3	93-120	505	0.32	3.7	24	1.33	0.56
3Bt4	120-185	551	0.42	5.1	21	3.80	1.46

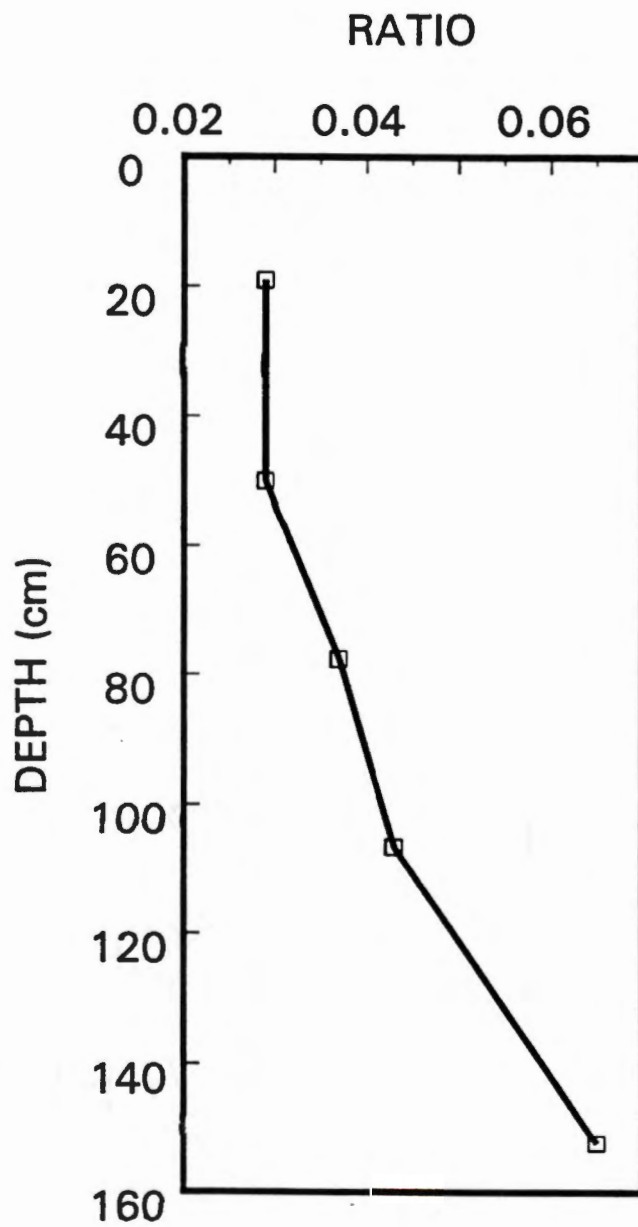


Figure 3. Ratio of fine sand to total sand plus silt plotted by depth in the soil profile at site 2.

Table 8. Soil morphological data for site 3.*

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCY
Ap1	0-13	10YR 4/4 (DARK YELLOWISH BROWN)	SiL	1,M,SBK 1,M,GR	FR
Ap2	13-28	10YR 4/3 (DARK BROWN)	SiL	1,M,SBK	FR
Bt1	28-51	10YR 4/6 (DARK YELLOWISH BROWN)	SiL	1,M,SBK	FR
2Bt2	51-83	2.5YR 5/4 (REDDISH BROWN)	SiL	2,M,SBK	FR
3Bt3	83-110	2.5YR 3/6 (DARK RED)	SiCL	2,M,SBK	FR
3Bt4	110-123	5YR 4/6 (YELLOWISH RED)	SiCL	2,M,SBK	FR
3Bt5	123-150+	5YR 4/6 (YELLOWISH RED)	SiCL	2,M,SBK	FR/FI

*Abbreviations defined in Appendix A.

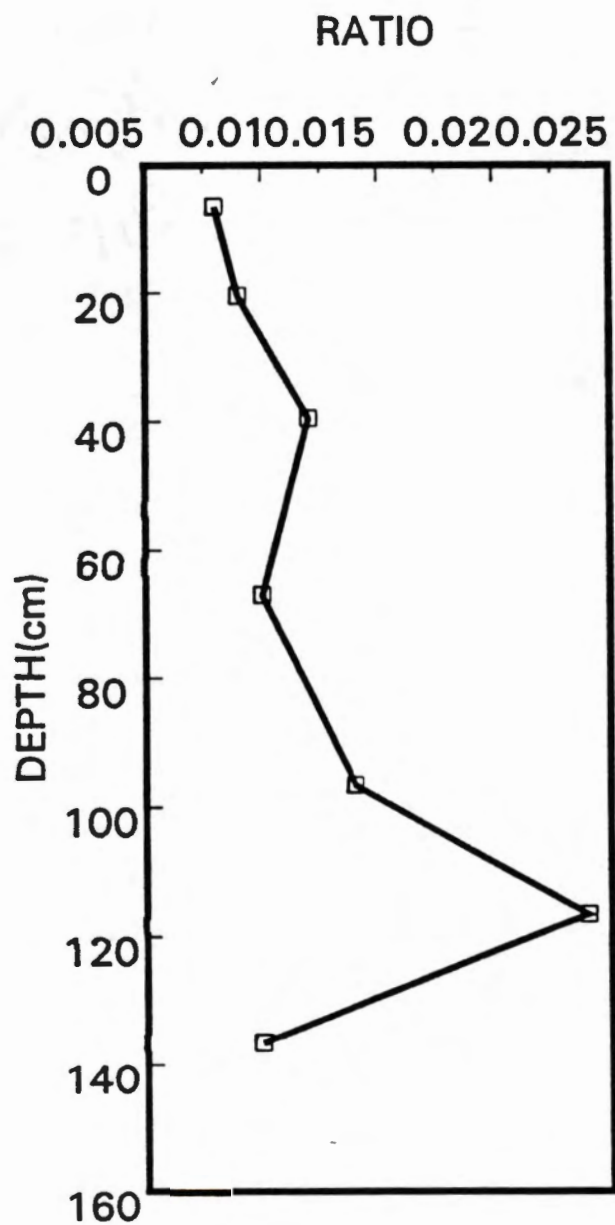


Figure 4. Ratio of medium sand to total sand plus silt plotted by depth in the soil profile at site 3.

Data revealed a second lithologic discontinuity between the alluvium and residuum at 83 centimeters. Microscopic examination of the quartz grains in pedon 3 revealed a shift from predominately rounded quartz beginning at 51 centimeters to predominately angular grains at 83 centimeters.

Major fluctuations in total sand, silt, and clay at 83 centimeters (Table 9) support this observation. Higher levels of CBD iron denoted the presence of a paleosol beginning at 83 centimeters (Table 4).

Site 4 was classified as a fine-silty, siliceous, thermic Typic Hapludult (Table 2). This pedon was described to a depth of 110 centimeters (Table 9). A lithologic discontinuity occurred between the loess and residuum at 85 centimeters in site 4.

The amount of total sand, coarse sand, and medium sand decreased at this depth (Table 10). The matrix color changed from light yellowish brown (10YR 6/4) to strong brown (7.5YR 5/6). The discontinuity was noted in the medium sand/total sand plus silt ratio (Fig. 5).

Described to a depth of 158 centimeters (Table 11), site 7 was classified as a fine-silty, mixed, thermic Typic Hapludult (Table 2). Particle size data indicated a lithologic discontinuity between loess and alluvium at 61 centimeters. Total sand increased, while clay decreased by more than 20% from the overlying horizon (Table 12). The medium sand to

Table 9. Soil morphological data for site 4.*

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCY
Ap1	0-18	10YR 5/3 (BROWN)	SiL	2,F,SBK/ 2,M,GR	FR
Ap2	18-29	10YR 5/4 (YELLOWISH BROWN)	SiL	1,M,SBK/ 2,F,GR	FR
Bt1	29-46	10YR 5/6 (YELLOWISH BROWN)	SiL	1,M,SBK	FR
Bt2	46-64	10YR 5/6 (YELLOWISH BROWN)	SiL	2,M,SBK	FR
Bt3	64-85	10YR 6/4 (LIGHT YELLOWISH BROWN)	SiL	2,M,SBK	FR
2Bt4	85-99	7.5YR 5/6 (STRONG BROWN)	SiCL	2,M,SBK	FR
2Bt5	99-110+	5YR 4/6 (YELLOWISH RED)	SiCL	2,M,SBK	FI

*Abbreviations defined in Appendix A.

Table 10. Total sand, silt, and clay distribution in sites 3 and 4. Sand fractions included very coarse sand (vcos), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs).

Site 3									
HORIZON	DEPTH (cm)	VCOS	COS	MS	FS	VFS	TOTAL SAND	TOTAL SILT	TOTAL CLAY
-----PERCENT-----									
Ap1	0-13	0.7	0.8	0.7	2.7	1.6	6.6	77.6	15.8
Ap2	13-28	0.4	0.9	0.7	2.7	1.9	6.6	74.2	19.1
Bt1	28-51	1.2	0.7	0.9	3.1	1.9	7.7	67.4	24.9
2Bt2	51-83	1.2	0.5	0.8	3.8	2.3	8.5	69.1	22.4
3Bt3	83-110	0.7	0.5	0.9	3.4	2.1	7.5	55.5	37.0
3Bt4	123-150	0.3	0.7	1.5	2.9	2.3	7.7	54.4	37.9
3Bt5	150+	0.4	0.5	0.6	3.4	2.3	7.2	53.7	39.1
Site 4									
Ap1	0-18	0.3	0.9	0.8	3.0	2.1	6.9	75.2	17.9
Ap2	18-29	0.4	0.8	0.8	3.0	2.0	7.2	75.8	17.0
Bt1	29-46	1.0	0.7	0.9	2.9	1.9	7.5	68.8	23.7
Bt2	46-64	0.4	0.5	0.9	3.3	1.9	7.9	69.2	22.9
Bt3	64-85	1.0	0.6	0.8	3.4	2.3	8.1	69.5	22.5
2Bt4	85-99	0.8	0.1	0.4	2.6	2.0	5.9	64.9	29.1
2Bt5	99-110+	0.5	0.6	0.9	3.0	1.2	6.8	63.3	30.0

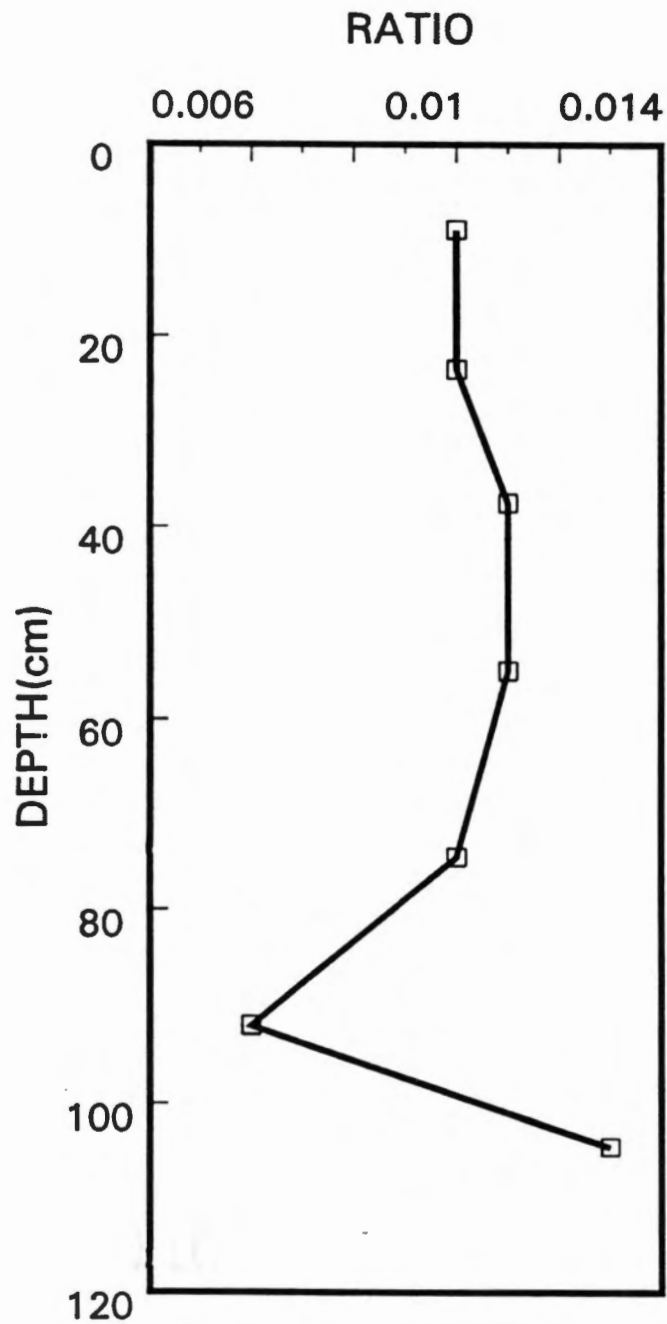


Figure 5. Ratio of medium sand to total sand plus silt plotted by depth in the soil profile at site 4.

Table 11. Soil morphological data for site 7.*

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCY
Ap1	0-16	10YR 4/3 (DARK BROWN)	SiL	1,M,SBK/ 1,M,GR	FR
Ap2	16-33	10YR 4/4 (DARK YELLOWISH BROWN)	SiL	1,M,SBK	FR
Bt1	33-61	10YR 4/6 (DARK YELLOWISH BROWN)	SiL	2,M,SBK	FR
2Bt2	61-82	10YR 5/6 (YELLOWISH BROWN)	SiL	2,M,SBK	FR
2Bt3	82-111	10YR 5/4 (YELLOWISH BROWN)	SiL	1,M,SBK	FR
2Bt4	111-128	10YR 4/6 (DARK YELLOWISH BROWN)	SiL	2,F,SBK	FR
3Bt5	128-158+	5YR 4/6 (YELLOWISH RED)	SiCL	2,F,SBK	FR

*Abbreviations explained in Appendix A.

Table 12. Total sand, silt, and clay distribution in sites 7 and 8. Sand fractions included very coarse sand (vcos), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs).

Site 7									
HORIZON	DEPTH (cm)	VCOS	COS	MS	FS	VFS	TOTAL SAND	TOTAL SILT	TOTAL CLAY
-----PERCENT-----									
Ap1	0-16	0.5	0.9	0.6	2.2	1.2	5.8	79.6	14.6
Ap2	16-33	0.4	0.7	0.9	2.4	1.2	5.6	80.4	14.0
Bt1	33-61	0.5	0.7	0.1	3.2	1.9	7.0	68.6	24.5
2Bt2	61-82	1.3	1.1	1.2	4.5	2.6	10.7	70.8	18.5
2Bt3	82-111	1.6	0.7	0.1	3.9	2.4	9.3	69.4	21.3
2Bt4	111-128	1.9	0.8	0.8	3.6	2.1	9.1	64.2	26.7
3Bt5	128-158	2.1	0.9	1.0	4.1	3.0	11.0	54.6	34.4
Site 8									
Ap1	0-19	0.5	0.8	0.9	2.1	1.2	5.8	83.1	11.2
Ap2	19-36	0.6	0.8	0.8	2.4	1.4	6.2	81.8	12.1
Bt1	36-71	0.3	1.1	0.8	2.4	1.5	6.2	74.9	18.9
2Bt2	71-96	1.2	0.9	1.6	3.7	1.8	9.2	67.2	23.6
2Bt3	96-120	0.9	0.3	1.0	4.0	2.4	8.5	70.7	20.8
3Bt4	120-148	0.9	0.7	0.9	3.0	2.6	8.2	57.7	34.1
3Bt5	148-186	0.4	0.6	1.3	4.2	3.1	9.7	48.7	41.6
3Bt6	186-206	0.9	0.7	0.8	3.7	2.4	8.6	48.2	43.3

total sand plus silt ratio illustrated the change at 61 centimeters (Fig. 6).

At 128 centimeters, a second lithologic discontinuity was present between the alluvium and residuum. Laboratory data revealed changes in CBD iron (Table 4), total clay, and total sand (Table 12) at 128 centimeters. Also, the matrix color of dark yellowish brown (10YR 4/6) was replaced by a yellowish red (5YR 4/6) color.

The soil classification for site 8 was a fine-silty, mixed, thermic Typic Paleudult (Table 2). This pedon was described to a depth of 206 centimeters (Table 13).

The medium sand/total sand plus silt ratio showed evidence of lithologic discontinuities at 71 and 128 centimeters (Fig. 7). The parent material was loess over alluvium over residuum.

Total clay content increased at both 71 and 128 centimeters (Table 12). At 120 centimeters, the soil color changed from yellowish brown (10YR 5/6) to red (2.5YR 4/6) (Table 13). The highest levels of CBD iron were measured in the paleosol beginning in the 3Bt4 horizon (Table 4).

Examination of CBD iron data indicated the pedons that were paired exhibited similar weathering patterns. Sites 3 and 7 (Fig. 8) had sharp peaks between 40 to 50 centimeters. A sharp drop occurred between 70 and 90 centimeters, followed by an increase in the lower depths. Sites 4 and 8 (Fig. 9) had a bulge where iron increased in the upper part of the Bt

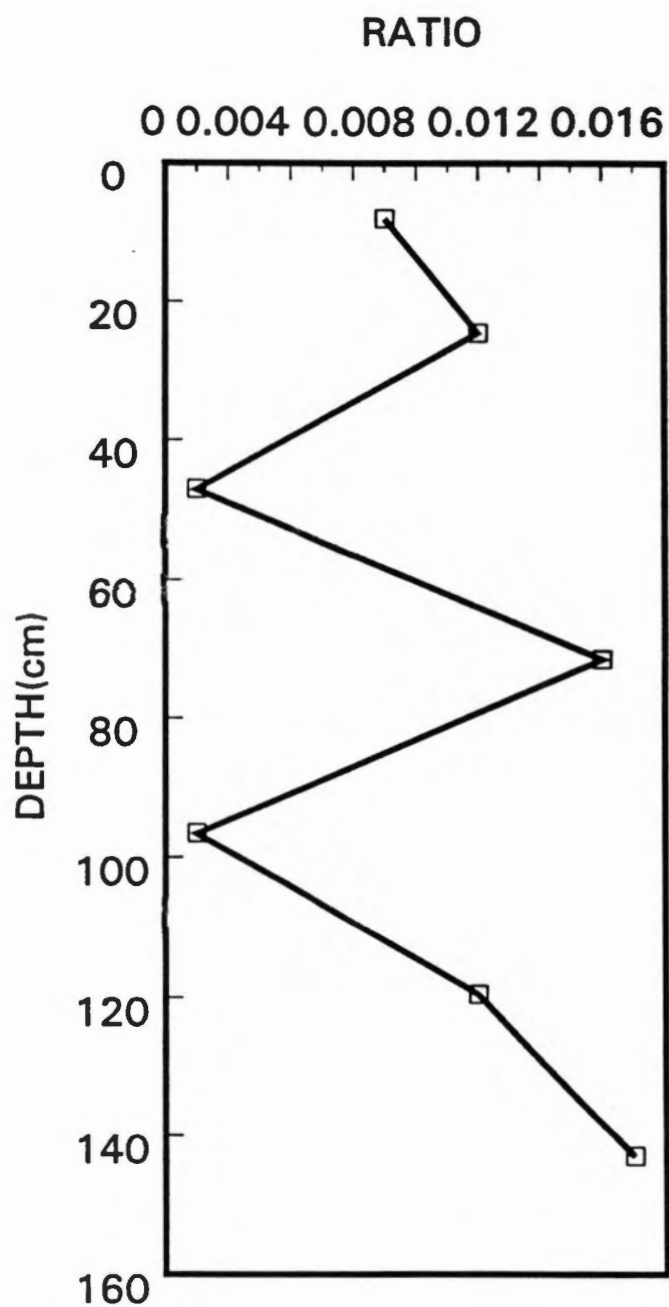


Figure 6. Ratio of medium sand to total sand plus silt plotted by depth in the soil profile at site 7.

Table 13. Soil morphological data for site 8.*

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCY
Ap1	0-19	10YR 5/3 (BROWN)	Si	1,M,SBK/ 1,M,GR	FR
Ap2	19-36	10YR 5/3 (BROWN)	SiL	1,F,SBK/ 1,M,SBK	FR
Bt1	36-71	10YR 5/8 (YELLOWISH BROWN)	SiL	2,M,SBK	FR
2Bt2	71-96	10YR 5/6 (YELLOWISH BROWN)	SiL	2,F,SBK/ 2,M,SBK	FR
2Bt3	96-120	10YR 5/6 (YELLOWISH BROWN)	SiL	1,F,SBK	FR
3Bt4	120-148	2.5YR 4/6 (RED)	SiCL	2,F,SBK	FR
3Bt5	148-186	2.5YR 4/6 (RED)	SiC	2,F,SBK	FR
3Bt6	186-206+	2.5YR 3/6 (DARK RED)	SiC	2,F,SBK	FR

*Abbreviations explained in Appendix A.

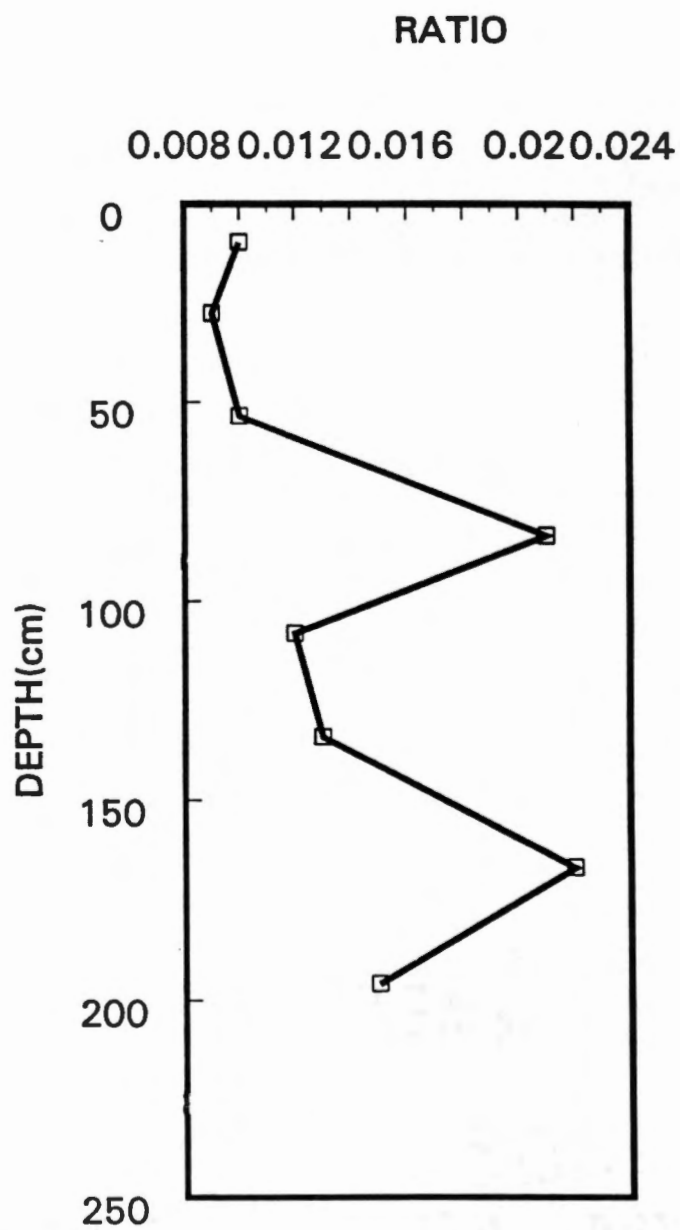


Figure 7. Ratio of medium sand to total sand plus silt by depth in the soil profile at site 8.

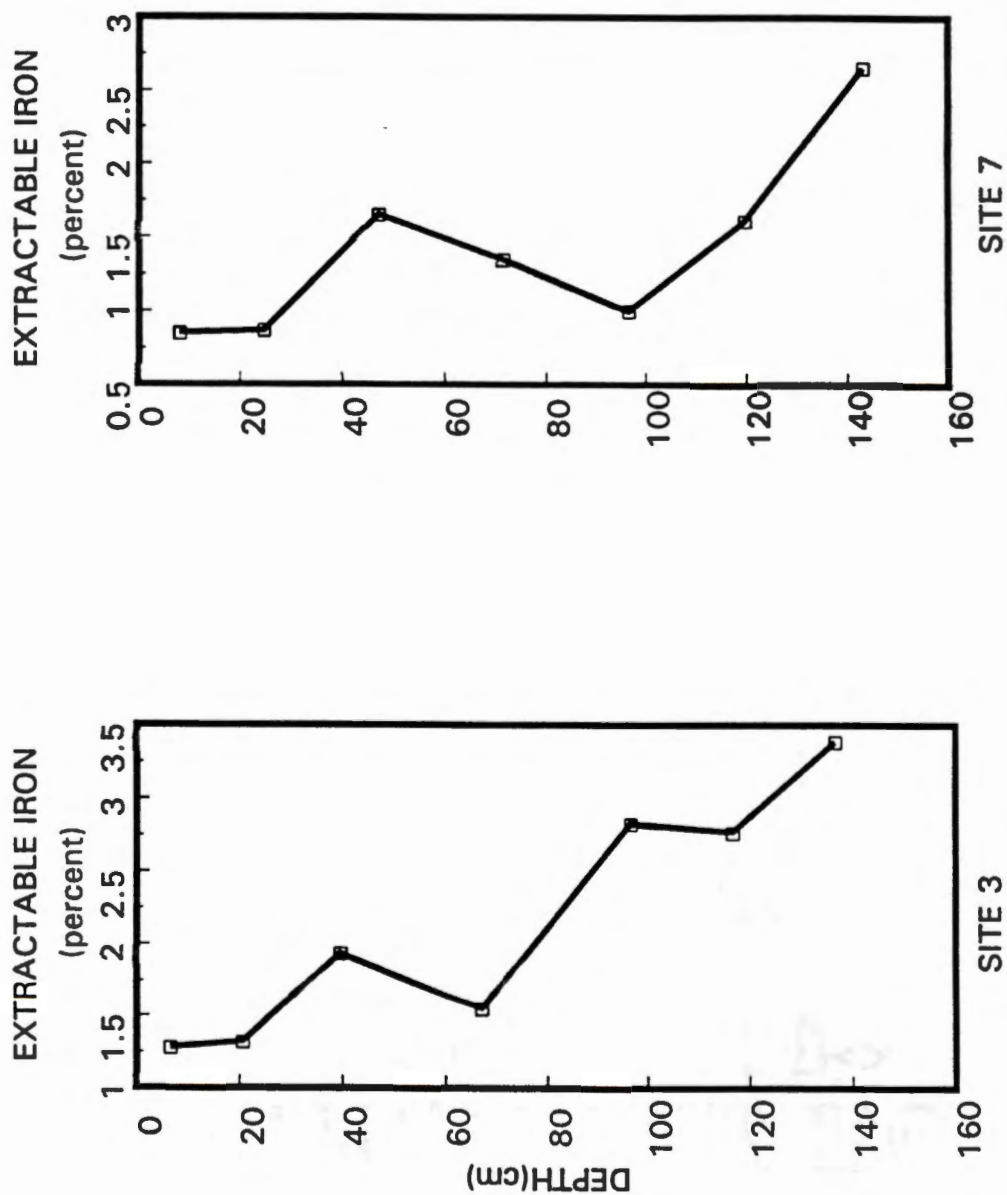


Figure 8. Citrate-bicarbonate-dithionite free iron distribution by depth in the soil profiles at sites 3 and 7.

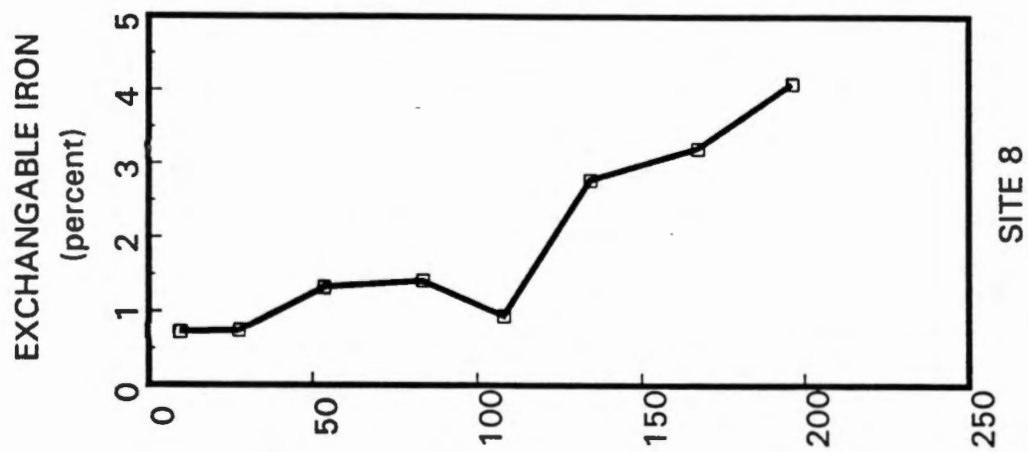
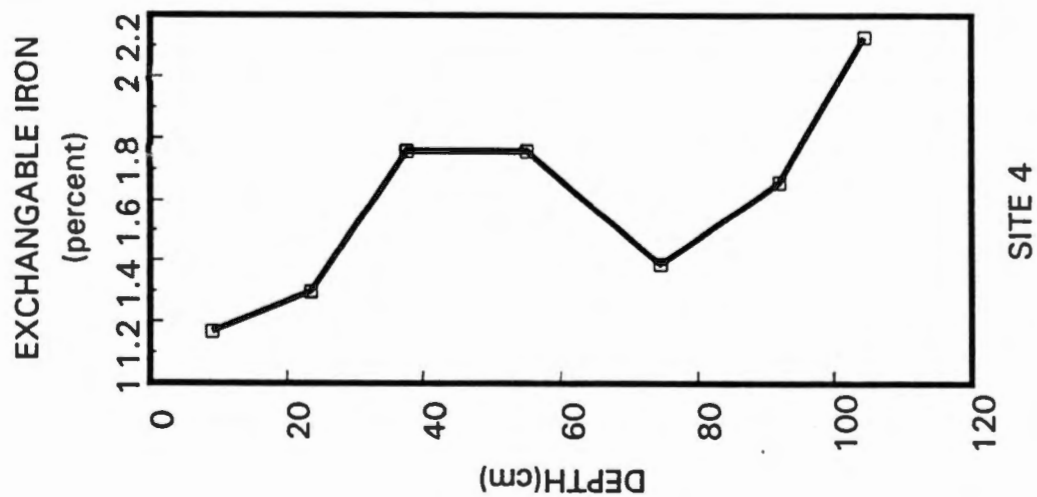


Figure 9. Citrate-bicarbonate-dithionite free iron distribution by depth in the soil profiles at sites 4 and 8.

followed by a relatively sharp drop. Sites 1 and 2 (Fig. 10) had a subtle increase followed by a gentle decrease in iron content.

While every pedon described had at least one discontinuity, old surfaces had been truncated. Total carbon analysis gave no evidence of the existence of buried A horizons in any of the sites (Figures 11 and 12).

All six pedons were within a linear distance of 39 meters (Fig. 1). Three different taxons were described. Sites 3 and 4 had different classifications within a distance of 4.25 meters. The same is true of sites 7 and 8. Sites 1 and 2, which were approximately 15.5 meters from site 3, were also classified differently from the other four sites.

HISTORY OF SOIL CLASSIFICATION AT THE STUDY SITE

The soils in the study area were mapped in the Robertson County Soil Survey (1968) as Dickson silt loams. At that time, these soils were classified as fine-silty, mixed, thermic Ochreptic Fragiudults. Presently, Dickson soils are classified as fine-silty, siliceous, thermic Glossic Fragiudults.

These were moderately well drained soils developed in 2-3 feet of loess over cherty limestone or old alluvium. They also had a fragipan.

None of the sites sampled met the Dickson classification and did not display strong fragic properties. Control sites 1 and 2 both had distinguishable fragic properties and

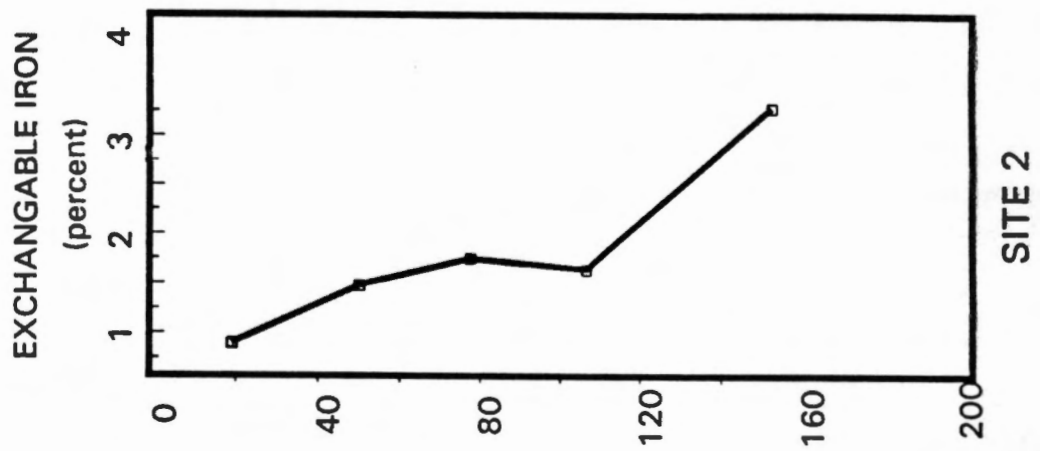
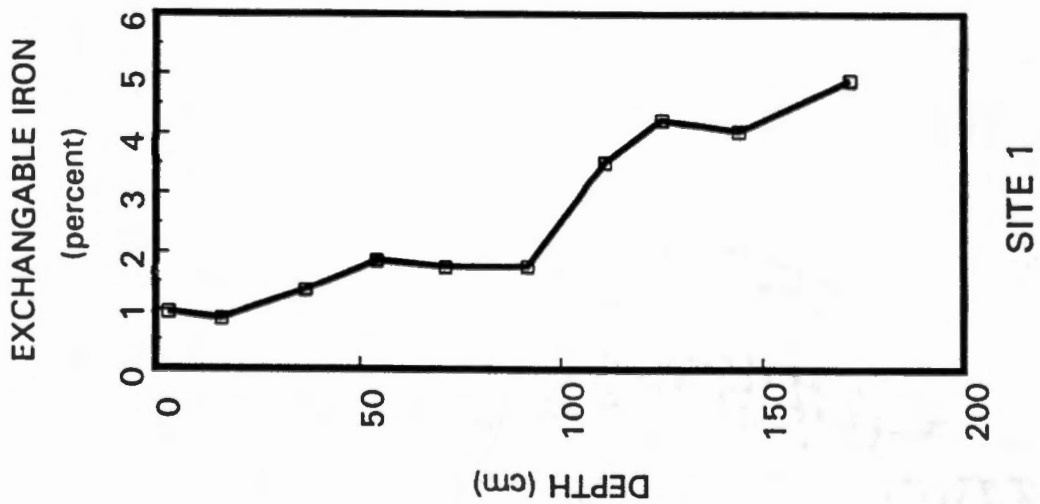


Figure 10. Citrate-bicarbonate-dithionite free iron distribution by depth in the soil profiles at sites 1 and 2.

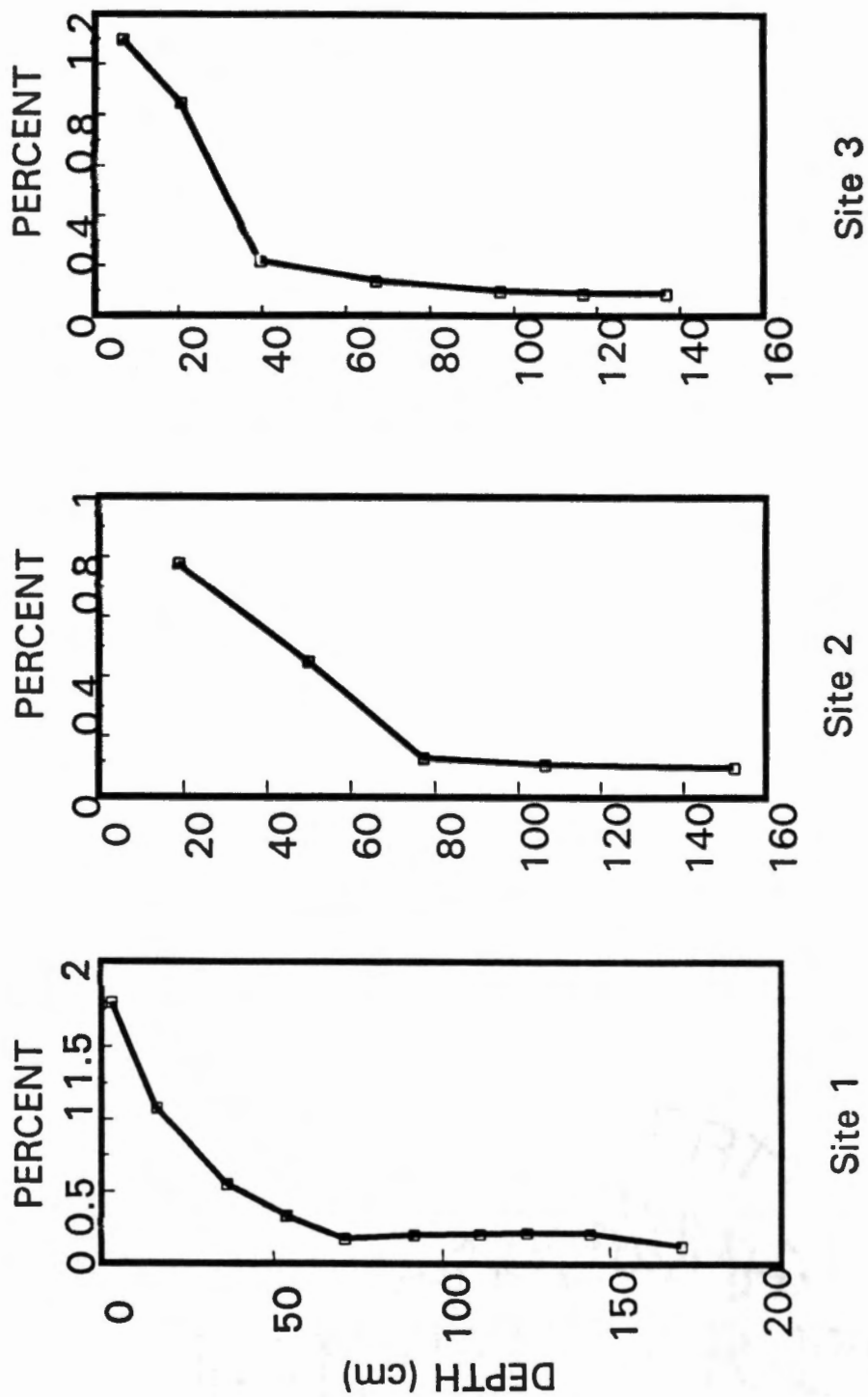


Figure 11. Total carbon distribution by depth in the soil profiles at sites 1, 2, and 3.

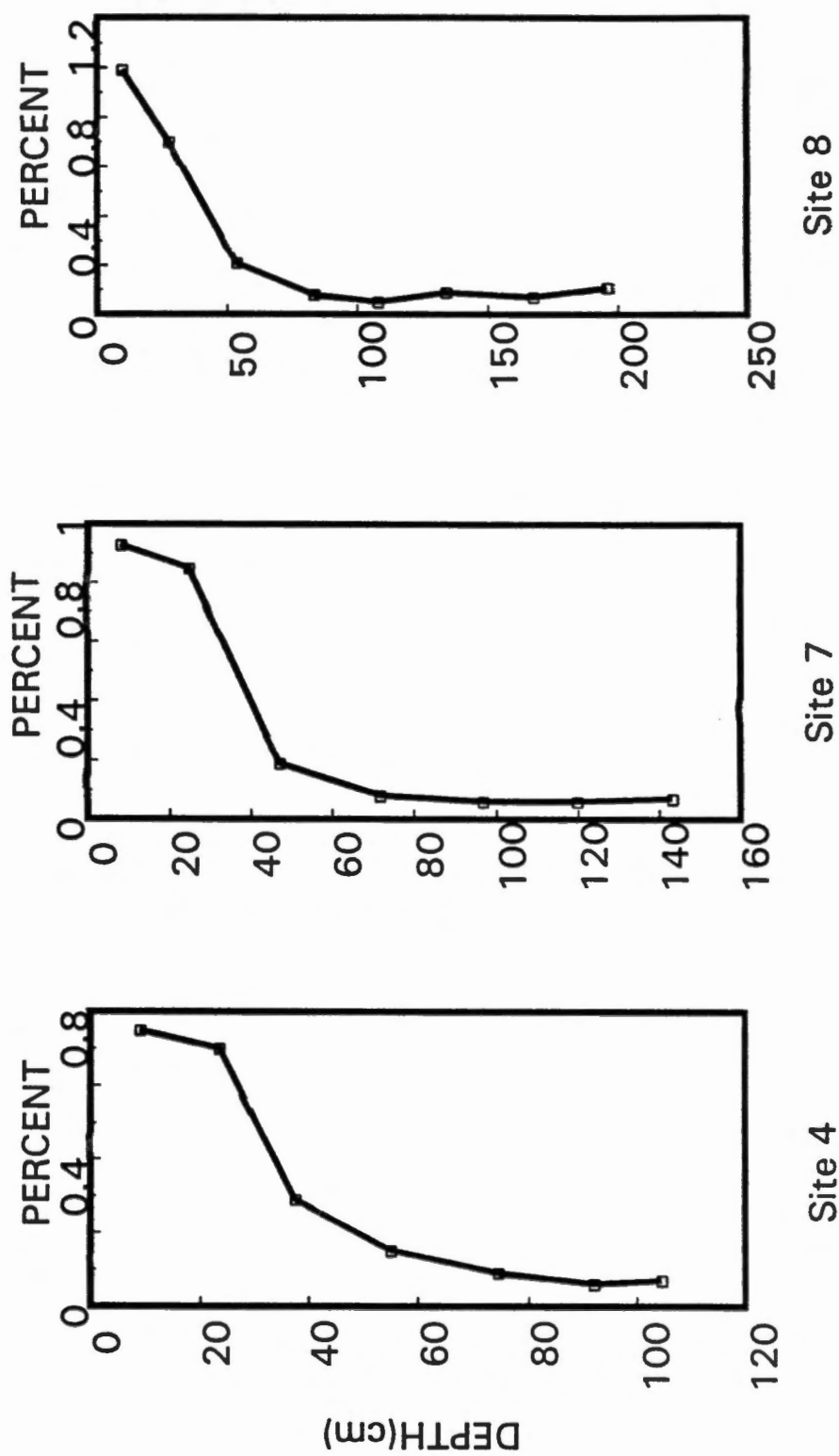


Figure 12. Total carbon distribution by depth in the soil profiles at sites 4, 7, and 8.

brittleness, but no definite fragipan. The parent material was very similar to that described for the Dickson series.

The Mountview soil series has commonly been found adjacent to Dickson soils. These were deep, well-drained soils developing on a 2-3 feet thickness of loess over a red or cherty clay. These soils also exhibit some fragic properties.

Mountview is classified as a fine-silty, siliceous, thermic Typic Paleudult. Sites 1 and 2 were more closely related to the old Dickson classification, while Sites 3, 4, 7, and 8 were more like the Mountview series. None of these soils resemble the present classification of Dickson. Actually, these soils are probably in transition between the two taxon.

CONCLUSIONS

1. The soil in the study area was Pleistocene in age. The loess deposition was approximately 10,000 years in age. The paleosol was estimated to be 500,000 years old.
2. The parent material was loess over alluvium over St. Louis limestone residuum in all pedons except site 4, which was loess over residuum.
3. Site 4 had no discernible alluvial layer. Most of the alluvial material that had been deposited was eroded off this site. Any remnants were blended with the loess and residual materials making detection extremely difficult.

4. Sites 1 and 2 were classified as fine-silty, siliceous, thermic Fragic Paleudults.
5. Sites 3 and 8 were classified as fine-silty, siliceous, thermic Typic Paleudults.
6. Sites 4 and 7 were classified as fine-silty, siliceous, thermic Typic Hapludults.
7. Classification of each site indicated spatial variability occurred within a short linear distance. Three different taxons were described with 39 meters.
8. There were no buried A horizons. All former surfaces had been truncated.
9. None of the study pedons met the criteria to be classified in the Dickson soil series. Mountview would be the more appropriate classification.

CHAPTER 2

THE INFLUENCE OF SOIL MORPHOLOGY ON SPATIAL VARIABILITY OF SOIL SOLUTION NITRATES AND CHLORIDES

INTRODUCTION

The potentially harmful environmental impact from the intensive use of fertilizers has become a major concern. Nitrogen is often the nutrient added in greatest quantity in fertilizers and it is the most mobile nutrient.

The relationship between ground water contaminated with nitrates and methemoglobinemia or blue-baby syndrome has been documented in several cases (Shuval and Gruener, 1974). Because of the danger to public health, the maximum contaminant level for nitrate in drinking water is 10 mg l⁻¹ (U.S.E.P.A., 1991).

To decrease groundwater contamination from agriculture, an understanding of how nitrogen in the form of nitrates moves from the area of application to groundwater. Chloride has been shown to be a good tracer of nitrate (Tisdale, 1985). Also, soil properties can either enhance or deter the movement of nitrates. A greater understanding of soil morphological influences will result in better management decisions concerning nitrogen application.

The objective of this study was to examine the spatial variability of soil solution nitrates in respect to the influence of soil morphology by depth.

LITERATURE REVIEW

Nitrates and chlorides move through the soil profile as constituents of the soil solution. Soil particle size is a major factor in the movement of ions and soil water through the soil. Cation exchange capacity, soil porosity, and water volume are a few properties influenced by particle size.

In sandy soils, nitrate movement with the soil solution is greater than in finer textured soils. On a Plainfield sand (Typic Udipsamment), 30 centimeters of rain plus irrigation over a five week period, resulted in movement of nitrates to a depth of 75 to 150 centimeters after an NH_4NO_3 application (Olsen et al, 1970).

In contrast, nitrates from NH_4NO_3 applications moved through the profile of corn plots on a Plano silt loam (Typic Argiudoll) at a rate of 30 to 40 centimeters per year over a period of three years (Olsen et al, 1970).

Soils with high clay contents have a significant influence on the amount of nitrate available as well as nitrate movement. As clay content increases, nitrate concentrations decrease (Lund et al, 1974).

Hydraulic conductivity refers to the rate water moves through the soil. Soil properties influence the rate of water movement. Saturated hydraulic conductivity occurs when more than 95 percent total pore space is filled with water and hydraulic gradient is positive. Pore geometry, pore

distribution, total porosity, and clay mineralogy are factors in saturated hydraulic conductivity.

Hydraulic conductivity is variable in the soil. There can be a 10 fold difference between soil samples only a few centimeters apart (Soil Survey Staff, 1981).

The primary sources of soil nitrogen are atmospheric nitrogen, plant and animal residues, and applications of fertilizers containing nitrogen. In mineral soils, nitrogen is primarily found as ammonium nitrogen associated with certain clay minerals, organic nitrogen in the humus fraction, and soluble inorganic ammonium and nitrate compounds (Brady, 1984).

The nitrification process involves several steps. The first phase is a natural soil acidification process involving the enzymatic oxidation of ammonium into nitrite by Nitrosomas bacteria. The nitrite is rapidly utilized by another bacteria genus (Nitrobater) and converted to nitrate (Foth and Ellis, 1988) .



Fixation of ammonium by certain clay minerals, especially vermiculite and illite, can prevent the ion from being converted to nitrate. Organic matter has also been shown to have an affinity to fix ammonium.

The presence of potassium will often restrict ammonium fixation. Both are monovalent and of similar size. The

dehydrated ionic radii of potassium is 0.133 nm and ammonium is 0.143 nm (Ross, 1989).

After ammonium fertilizer application, ammonium is rapidly fixed in clay molecules. High levels of divalent and trivalent cations depress ammonium fixation. As pH increases, trivalent cations become less of a problem. In soils high in potassium, ammonium fixation is inhibited since potassium ions are fixed in the clay lattices and on the exchange sites. In soils not already having a high potassium content, an increase in potassium ions will interfere with the defixation of ammonium ions (Ross, 1989).

The type of clay present in the soil profile not only can reduce the amount of ammonium available for conversion to nitrate, but also can reduce the amount of exchangeable potassium (Tisdale et al, 1985).

Early experiments at Rothamsted found the nitrifying organisms were present primarily in that part of the soil subject to cultivation. At depths greater than 23 centimeters, the organisms become fewer and less effective in inducing nitrification (Hall, 1917).

The nitrogen source for nitrate production can be lost in ways other than fixation. Increases in moisture and temperature can cause loss of nitrogen as ammonia from manure through volatilization immediately after application (Adriano, et al, 1974).

Denitrification is another process dependent on soil morphology. In this process, nitrates are converted to nitrogen gases capable of escaping to the atmosphere. Specific soil conditions are necessary for the metabolism of denitrifying organisms to become active. Soil moisture content, aeration, pH, organic matter, temperature, and available nitrates are major factors in denitrification (Foth and Ellis, 1988).

For denitrification to proceed, an energy source is required for the soil microorganisms. Organic amendments, such as manure, greatly increase the amount of soluble carbon in the soil solution. In the lower part of the soil profile, the soluble organic carbon becomes an important factor in developing reducing zones (Meek et al, 1974).

Below the rooting zone, the concentration of nitrates decreases primarily by dilution with water. Soil microorganisms and energy sources decrease rapidly with depth lessening the possibility of nitrate levels decreasing through denitrification (Olsen et al, 1970).

Nitrate concentration is influenced by the presence of pans and textural discontinuities in the soil profile, which affect not only nitrification and denitrification, but also drainage volume (Lund et al, 1974). The presence of a restricting layer, such as a fragipan, results in lower concentrations of nitrates below this layer.

Denitrification proceeds more readily in the layer directly above the pan after a heavy rainfall due to the resulting anaerobic conditions. Also, under a fixed water volume, a high clay content in soil allows for the possible creation of anaerobic conditions (Lund et al, 1974).

Nitrate accumulation at depths below the area of maximum root activity, indicates the rate of nitrate movement into the sublayers is higher than the rate of denitrification (Hahne et al, 1977). Nitrate accumulation and movement is also affected by cultivation practices. Tillage can greatly damage the soil's structural stability by decreasing the size of aggregates (Troeh et al, 1980) and promoting more rapid oxidation of organic matter (Blevins et al, 1977).

In an investigation of seven different sizes of soil aggregates ranging from <0.25 to 20mm in diameter, Seech et al (1988) found an inverse relationship between rate of denitrification and aggregate size. The smaller the aggregate, the greater the rate of denitrification. The availability of a carbon energy source was also a major factor limiting denitrification rates.

Destruction of the soil macropore system by conventional tillage, has a significant impact on soil hydrology. Continuity is disrupted due to the blockage of macropore pathways. This increases run-off and leaching of the resident soil solution. With a loss of the macropores, rainwater moves

down the profile through smaller pores displacing the soil solution (Chan and Mead, 1989).

Soil organic matter is the main natural source of nitrogen. Nitrogen content in a soil increases with the amount of humus. Humus is a very effective cation exchanger and stores many elements against leaching (Tisdale, 1985).

Denitrification and manganese reduction occur at approximately the same redox potential (Eh) of about 300-350 mV. Manganese in soil solution is an indication of reducing conditions conducive to denitrification (Meek et al, 1974).

Soils classified as Dickson (fine-silty, siliceous, thermic Glossic Fragiudult), are moderately well drained and contain a fragipan. While the upper horizons above the fragipan are easily penetrated by air, moisture, and roots, the fragipan is impenetrable to most roots and moisture moves through the pan at an extremely slow rate. This part of the profile is often saturated during periods of continuous wet weather (Soil Survey Staff, 1968).

MATERIALS AND METHODS

FIELD METHODS

Soil fertility plots were established at the Highland Rim Experiment Station in Springfield, TN in 1962. The fertility groups consisted of no fertilization (control), soil test fertilization, high fertilization (336 kg ha⁻¹ nitrogen, 112 kg ha⁻¹ phosphorus, 336 kg ha⁻¹ potassium, and 56 kg ha⁻¹ minor

elements), and high fertilization plus manure (ten tons acre⁻¹ year⁻¹). These plots were discussed in detail in the materials and methods section of chapter one.

To determine the distribution of nitrates, only the two high fertilization and two high fertilization plus manure plots were of interest. The samples had to be extracted under the same moisture conditions.

One plot of high fertilization and one plot of high fertilization plus manure were sampled. However, the other two replicated plots were not sampled due to heavy rainfall immediately following sampling of plots 3 and 4. The increased moisture altered the sampling conditions.

Plots 3 and 4 were sampled for nitrates according to a randomized split block design (Fig. 13). Fourteen cores were removed from high fertilization plot 3. Maximum depth was 78 centimeters. A total of 56 samples were analyzed for soil solution nitrates and chlorides from plot 3.

Fourteen cores were, also, extracted from high fertilization plus manure plot 4. Maximum depth was 89 cm. Soil solution nitrates and chlorides were analyzed on 59 samples from plot 4.

Cores, 7.62 centimeters in diameter, were extracted with a Giddings GSRP-S-M hydraulic probe. The exterior rind was removed and discarded. The cores were immediately sampled by horizon, labeled, and placed in ice chests. Ice packs were placed around the samples curb loss of nitrogen through volatilization.

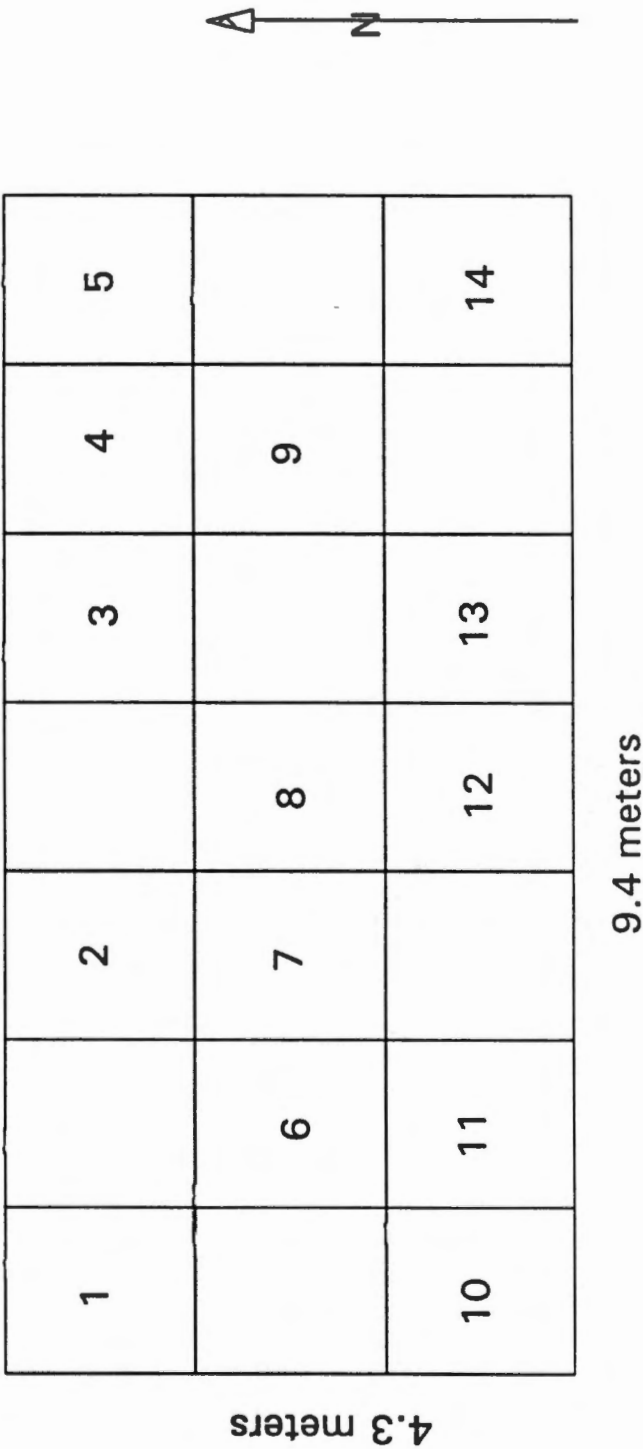


Figure 13. Grid for randomly sampling plots 3 and 4 for nitrates.

LABORATORY ANALYSIS

Soil solution nitrates and chlorides were determined by ion chromatography (Pfaff et al, 1989). The Dumas method was used to determine total nitrogen on the Carlo Erba Nitrogen Analyzer 1500 (Stewart et al, 1964).

Total acidity, pH, particle size, base saturation, cation exchange capacity, and total carbon analyses were determined using methods discussed in the materials and methods section of chapter one.

RESULTS AND DISCUSSION

Morphology of site 3 (Table 8) and site 4 (Table 9) confirmed the presence of lithologic discontinuities. The parent material of site 3 was loess over alluvium over limestone residuum. Site 4 had loess over limestone residuum. Although some alluvial material may have been present, mixing made detection difficult.

Both chlorides and nitrates generally are mobile with the soil water (Bohn et al, 1985). Any obstacle to water movement limits chloride and nitrate movement. In site 2, the discontinuity at 51 centimeters created no discernible hinderance to soil solution movement. Soil water movement was augmented by an increase in total sand and decrease in total clay in the 2Bt2 horizon (Table 10).

The presence of a paleosol in site 3 and site 4 acted as a barrier to soil solution movement. Figure 14 illustrates an increase in nitrate concentration above the lithologic

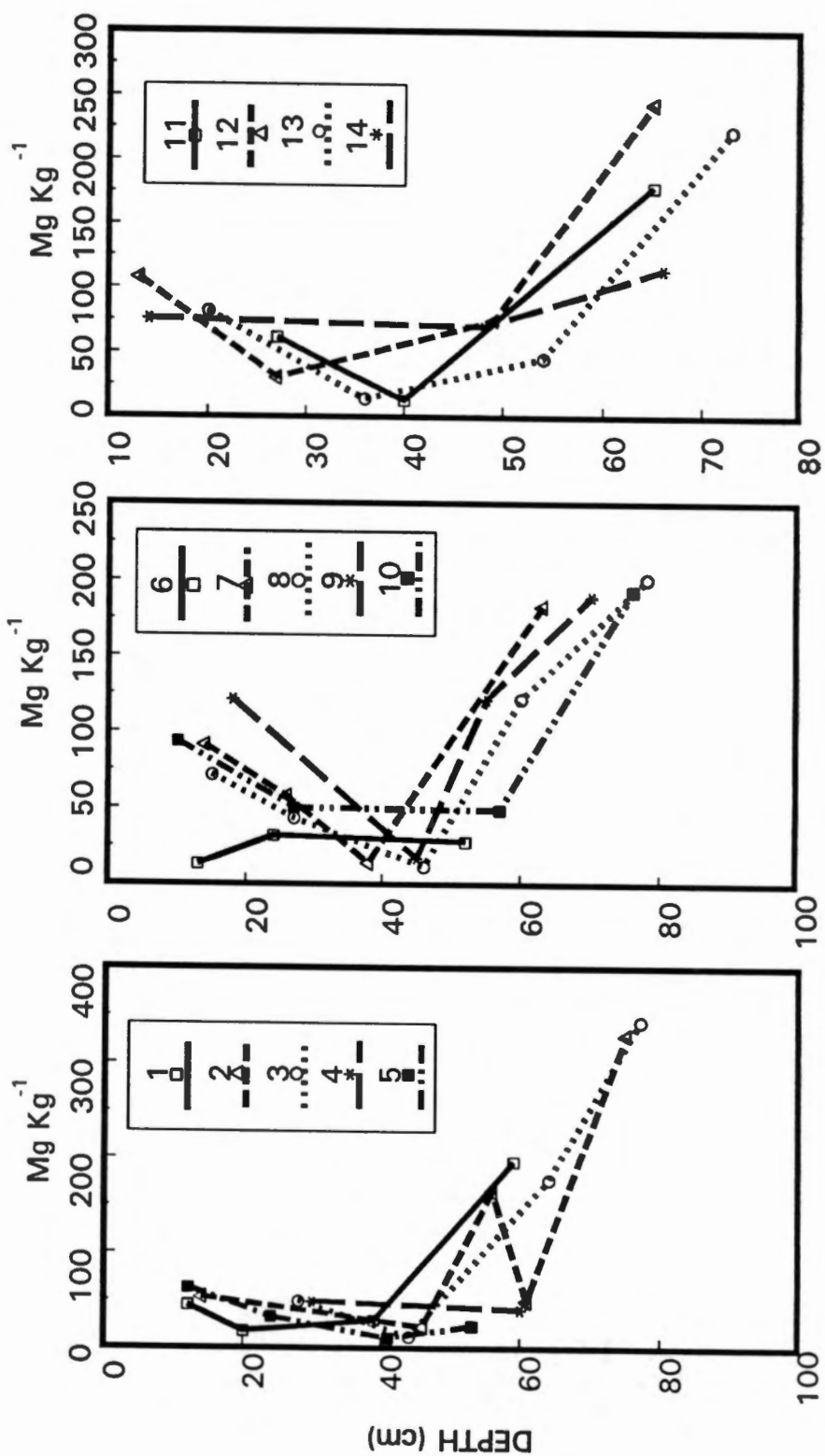


Figure 14. Nitrate distribution by depth in the soil profile of high fertilization plot no. 3.

discontinuity at 85 centimeters. Low chroma mottles were evident in this region of both profiles indicating impeded drainage.

An increase in total clay content in the paleosols of both pedon 3 and pedon 4 probably contributed to the perching of soil water (Table 10). The 3Bt3 of site 3 had a 65% relative increase in clay from the overlying 2Bt2 horizon. The 2Bt4 in site 4 had a 29% relative clay increase from the Bt3 horizon (Table 10). Soil texture and structure appeared to affect the leaching of nitrates. Fine materials impeded the movement of soil solution nitrates to a greater degree than coarser material. Strong structure facilitates greater movement of the soil solution. In site 3 (Table 8) and site 4 (Table 9), structure generally ranged from weak to moderate with depth.

Soil solution movement was also restricted between the Ap2 and Bt1 in both sites 3 and 4. Compaction after 28 years of continuous row cropping had produced a plow pan that impeded the movement of soil water.

Generally, the distance between sampling points for nitrates was 0.5 to 0.8 meters. Nitrate distribution was similar in both site 3 (Fig. 14) and site 4 (Fig. 15). Nitrates were concentrated in the plow zone. Downward movement of nitrates was hindered by the presence of the plow pan. After entering the argillic, the nitrates in soil solution

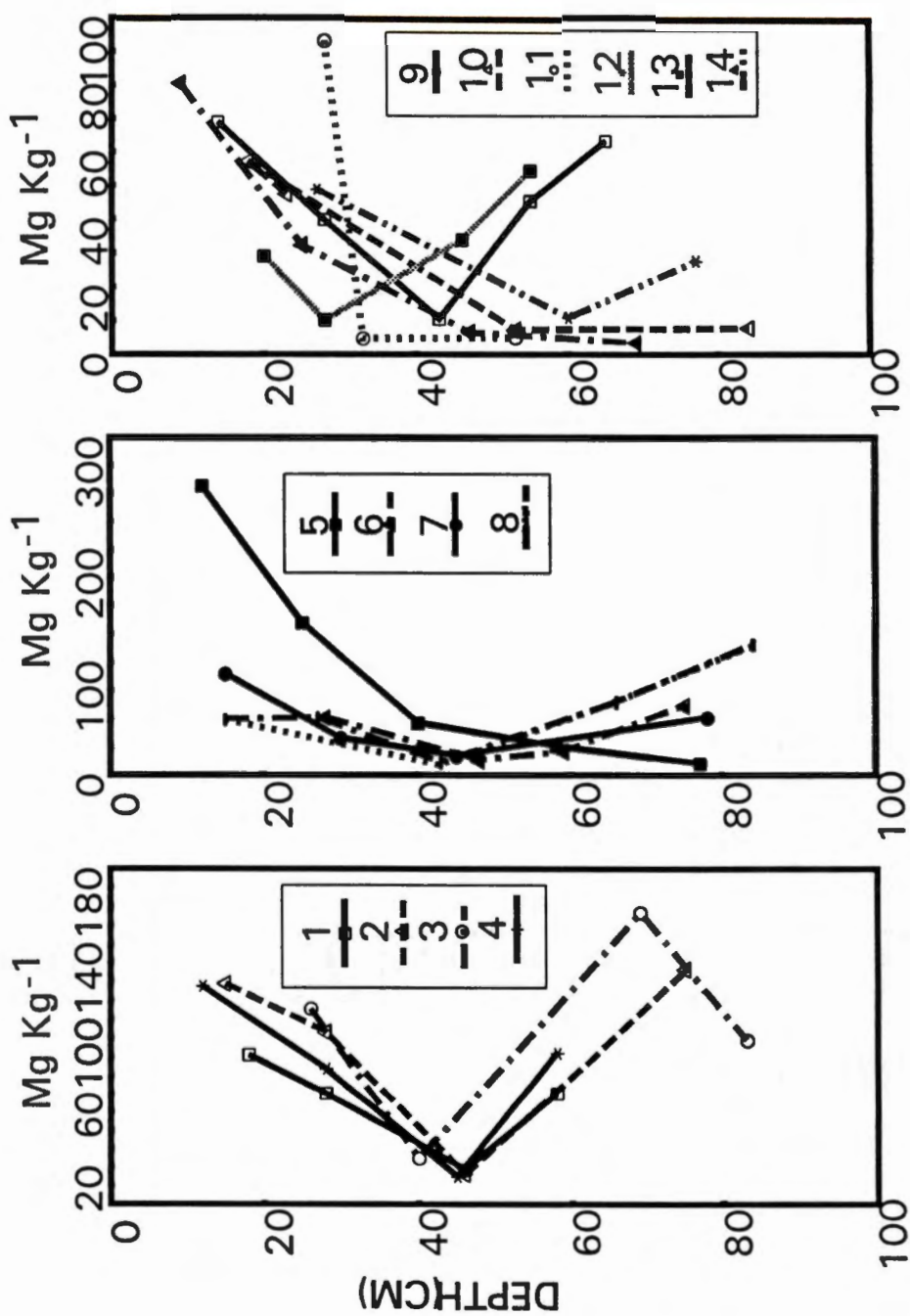


Figure 15. Nitrate distribution by depth in the soil profile of the high fertilization plus manure plot no. 4.

moved unhindered down to the lithologic discontinuity occurring at roughly 85 centimeters.

While there was a higher concentration of nitrates in both plots just above the contact with the paleosol (85 centimeters), plot 3 generally had higher levels of nitrates than plot 4 (Fig. 14 and 15). Laboratory data indicated soil solution nitrates were moving laterally over the paleosol from plot 4 into plot 3. The most probable point for the nitrates to enter into groundwater was in a depression below the study area.

Chloride distribution in sites 3 (Fig. 16) and site 4 (Fig. 17) was similar to that of the nitrates but in lower concentration. Chlorides were concentrated in the Ap1 and Ap2 above the plow pan. However, between the Ap2 and the paleosol at approximately 85 centimeters, the levels of chloride differed from nitrates in that they exhibited a random pattern rather than being concentrated just above the paleosol.

A comparison of nitrate with total nitrogen in the pedons characterized for plot 3 (Fig. 18) and plot 4 (Fig. 19) showed definite differences. Total nitrogen was highest in the surface and decreased with depth. Nitrates showed an elevated level in the surface. Levels dropped to almost zero in the upper argillic and rose to the highest levels at the approximately 80 centimeter depth.

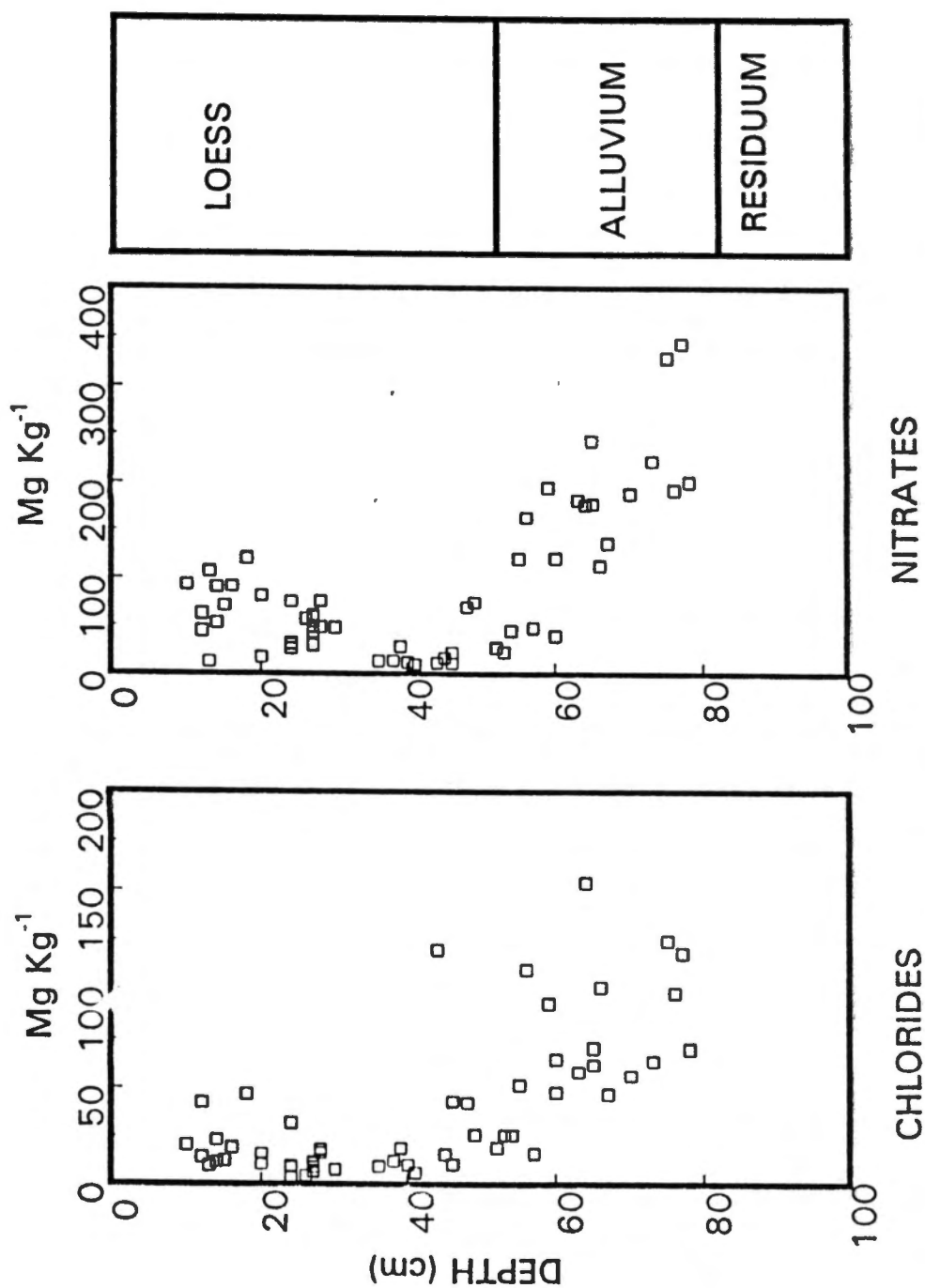


Figure 16. Chloride and nitrate distribution by depth in the soil profile of high fertilization plot no. 3. The position of the different parent materials is shown for reference.

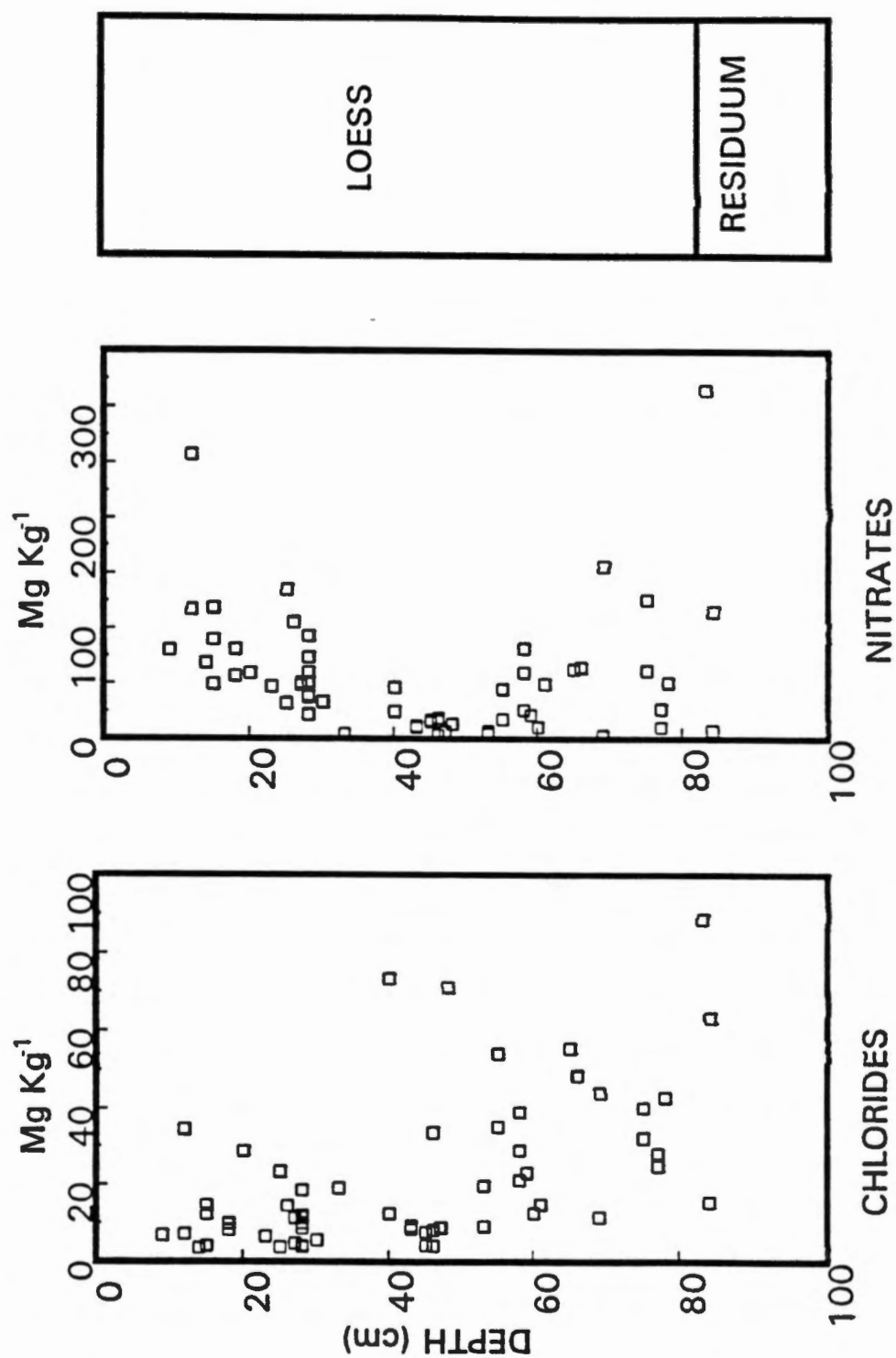


Figure 17. Chloride and nitrate distribution by depth in the soil profile of high fertilization plot no. 4. The position of the different parent materials is shown for reference.

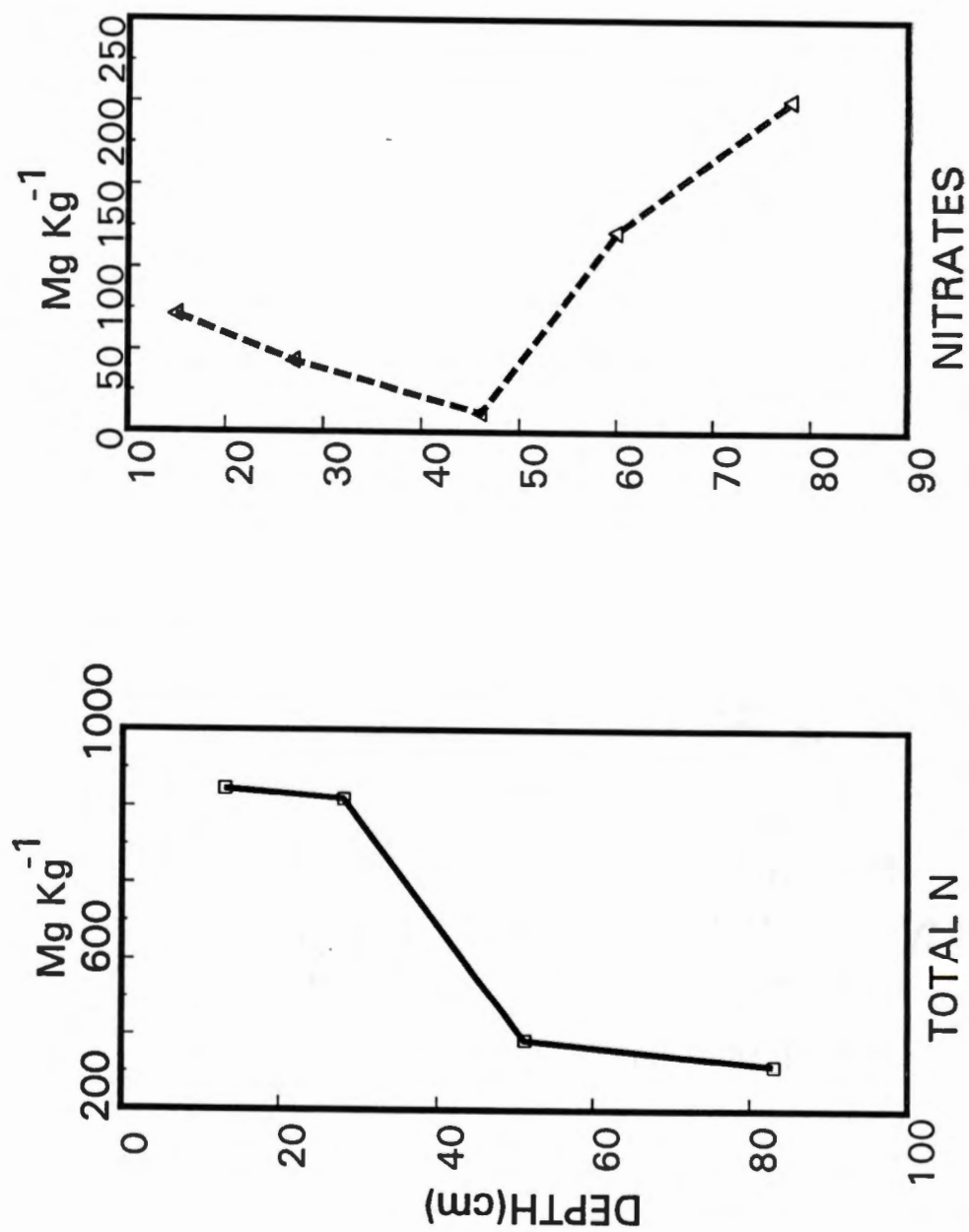


Figure 18. Comparison of nitrate and total nitrogen distribution by depth in the soil profile of high fertilization plot no. 3.

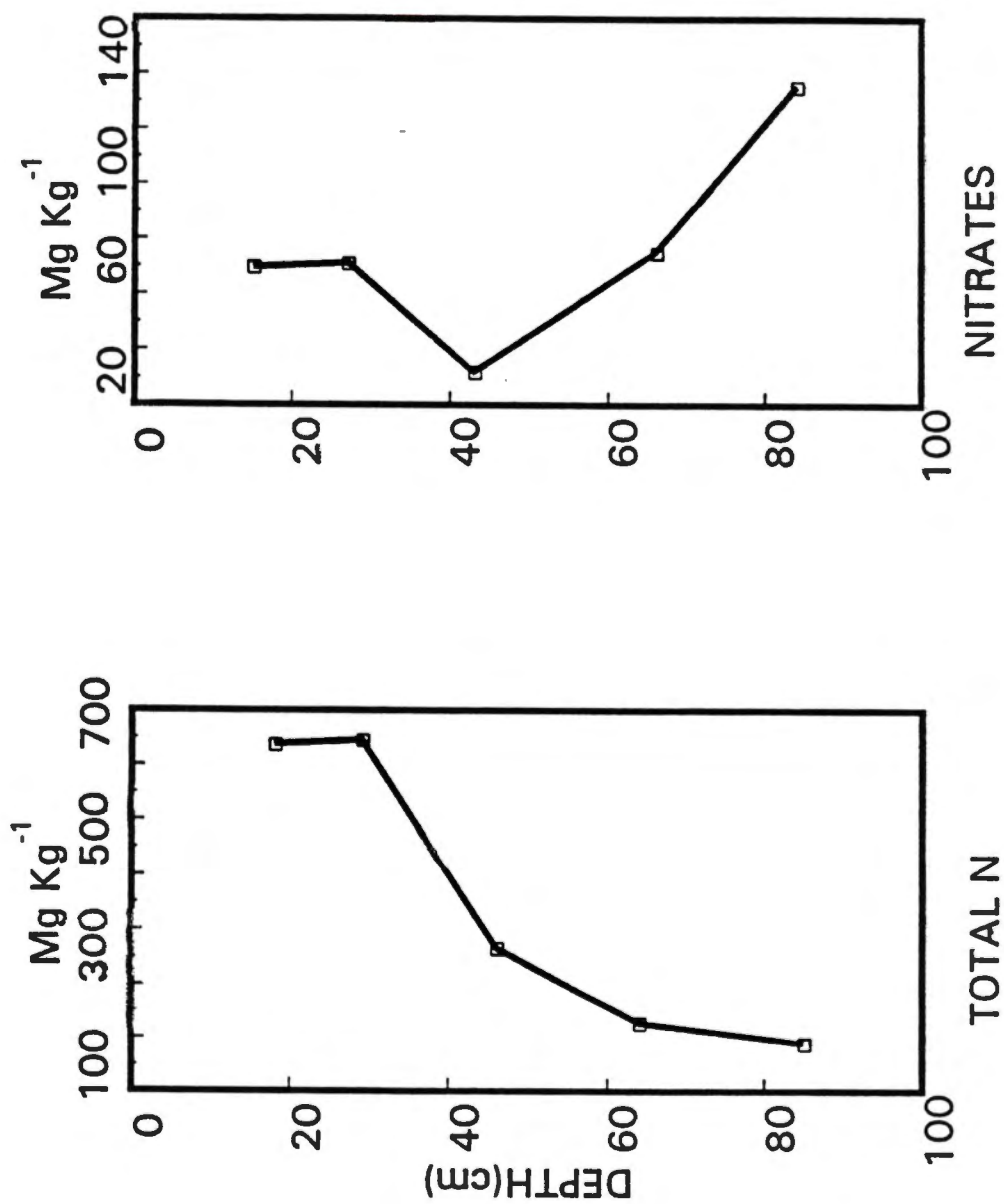


Figure 19. Comparison of nitrate and total nitrogen distribution by depth in high fertilization plus manure plot no. 4.

Regression correlation showed no apparent relationship between total nitrogen and nitrates. An r factor of .0514 was produced using 64 samples (Fig. 20).

The amount of nitrates in a soil depends on the factors controlling the activity of nitrifying bacteria. These include the availability of ammonium, soil reaction, soil aeration, soil moisture, soil temperature, and the population size of the microbes (Tisdale et al, 1985).

Annual applications of 336 kg ha⁻¹ of nitrogen insured an adequate supply of this element. The incorporation of crop stubble and manure by cultivation generally increases soil mineral nitrogen. This introduces more carbon for microbial activity. Crops grown after drilling rather than cultivation generally require more fertilizer nitrogen (Russell, 1988).

Both site 3 (Fig. 11) and site 4 (Fig. 12) had the greatest concentrations of total carbon in the surface. Total acidity was very low in the plow zone and pH ranged between 5.6 and 6.5 over both plots (Table 14). Nitrification generally occurs in a pH range between 5.5 and 10, although other studies have shown the process to occur at lower pH's (Tisdale et al, 1985).

The bacteria involved in the nitrification process are obligate autotrophic aerobes and must have an oxygen supply. Strong soil structure provides pathways both for infiltration of air and downward movement of nitrate carrying soil water. The fine granular structure of topsoils allows thorough

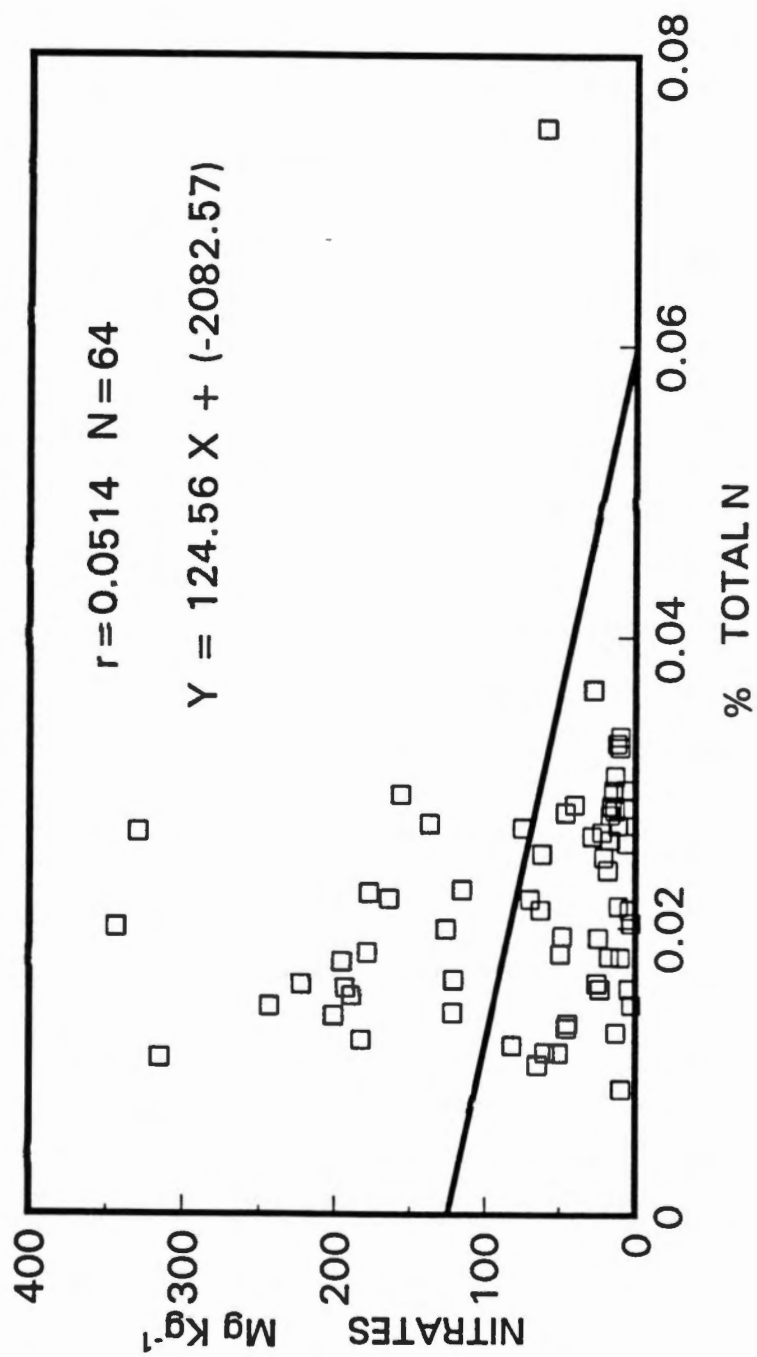


Figure 20. Regression correlation between nitrates and total nitrogen.

Table 14. KCl total acidity and pH of soil pedons 3 and 4.

HORIZON	DEPTH (cm)	TOTAL ACIDITY	AL+++	H+	pH
-----mg kg ⁻¹ -----					
Site 3					
Ap1	10-13	0.0	0.0	0.0	5.6
Ap2	13-28	0.4	0.0	0.4	6.4
Bt1	28-51	1.6	1.7	0.0	4.8
2Bt2	51-83	3.5	3.5	0.1	4.3
3Bt3	83-110	6.3	6.5	0.0	3.9
3Bt4	110-123	7.0	7.2	0.0	3.9
3Bt5	123-150+	7.0	7.0	0.0	3.9
Site 4					
Ap1	0-18	0.0	0.0	0.0	6.2
Ap2	18-29	0.0	0.0	0.0	6.5
Bt1	29-46	0.4	0.3	0.1	5.3
Bt2	46-64	2.4	2.3	0.0	4.6
Bt3	64-85	3.9	3.8	0.1	4.2
2Bt4	85-99	4.7	5.0	0.0	4.0
2Bt5	99-110+	5.6	5.6	0.0	4.0

mixing of water with soil and diffusion of nitrate into the soil solution (Haigh and White, 1986).

Potassium ions interfere with the defixation of ammonium ions from clay lattices. In both plots, exchangeable base extraction indicated a higher amount of potassium on the exchange sites in the upper part of the profile (Table 15). Organic matter in the Ap1 and Ap2 horizons also provides exchange sites for ammonium.

From the differences in total nitrogen and nitrate nitrogen, it is apparent that not all of the nitrogen being added annually is being converted to nitrates. Much of it is being fixed by the clays, taken up by crops, or consumed by microbes.

Some nitrogen may be lost through volatilization in the open surface after cultivation. Other nitrogen may be lost due to denitrification during seasons of heavy rainfall.

CONCLUSIONS

1. The plow pan impeded movement of soil solution nitrates and chlorides at the surface.
2. The lithologic discontinuity between the residuum and loess and/or alluvium impeded soil solution nitrate and chloride movement at a depth of approximately 85 centimeters.
3. The lithologic discontinuity between the loess and alluvium at 51 centimeters did not impede movement of soil solution nitrates and chlorides.

Table 15. Cation exchange capacity, exchangeable bases, base saturation, and pH in the soil profiles at sites 3 and 4.

HORIZON	DEPTH	pH	%BASE	CEC SAT.	Ca++	Mg++	K+ -----cmol (+)	Na+ kg ⁻¹ soil-----
Site 3								
Ap1	0-13	5.6	66	9.76	4.234	0.820	1.183	0.063
Ap2	13-28	6.4	72	9.99	5.520	0.681	0.950	0.073
Bt1	28-51	4.8	52	10.89	4.137	0.676	0.780	0.074
2Bt2	51-83	4.3	35	9.33	2.186	0.729	0.314	0.063
3Bt3	83-110	3.9	23	14.57	1.419	1.635	0.216	0.058
3Bt4	110-123	3.9	20	15.50	1.019	1.922	0.171	0.058
3Bt5	123-150+	3.9	19	17.64	1.140	2.004	0.172	0.058
Site 4								
Ap1	0-18	6.2	42	7.72	2.562	0.291	0.340	0.034
Ap2	18-29	6.5	44	7.62	2.641	0.285	0.386	0.034
Bt1	29-46	5.3	37	9.47	2.781	0.291	0.358	0.055
Bt2	46-64	4.6	22	8.28	1.411	0.249	0.108	0.026
Bt3	64-85	4.2	34	9.94	2.195	0.973	0.166	0.074
2Bt4	85-99	4.0	35	10.36	1.737	1.665	0.121	0.070
2Bt5	99-110+	4.0	31	12.71	1.488	2.225	0.108	0.080

4. The annual addition of fertilizer containing 336 kg ha^{-1} nitrogen did not produce a corresponding increase in nitrate levels in the soil. This indicates the N in the fertilizer was not all converted to nitrates.
5. Total soil nitrogen did not correlate well to predict nitrate levels for determining depth of leaching.
6. Chlorides and nitrates move in a similar pattern in the soil profile.
7. Fine soil texture and weak soil structure inhibit nitrate movement.
8. Nitrates appeared to be moving laterally over the paleosol and may eventually enter the groundwater through surface runoff into the adjacent sinkhole.

CHAPTER 3

THE EFFECT OF MANURING AND LONG-TERM MANAGEMENT ON MEASURED SOIL CHEMICAL PROPERTIES

INTRODUCTION

The depletion of one of our most vital resources, soil, has been a major concern in the United States during this century. In the early 1900's, virgin farmland began to rapidly disappear. The American farmer began to look more seriously at the practices being used in agriculture. Soil deterioration and loss of fertility were serious problems resulting from intensive use of row crops (Troeh et al, 1980).

Because of its availability, animal manures have a long history of use as a soil amendment. Manures not only supply nutrients such as nitrogen, phosphorus, and potassium, but may improve soil physical properties as well (Sweeten and Mathers, 1985). Synthetic fertilizers came into prominent use after the development of the Haber-Bosch process in 1910 (Tisdale et al, 1985).

The effects of manure and/or fertilizers on crops and soils during short term management have been widely investigated (Hahne et al, 1977; Mathers and Stewart, 1974; and Blevins et al, 1977).

The objective of this study was to evaluate the soil chemical effects of 28 years of soil fertility management of continuous corn (*Zea mays* L.). Changes in soil chemical properties with reference to nitrogen have been assessed as to possible environmental consequences. Since nitrogen is the nutrient most often added in agricultural practices, emphasis will be given to this element.

LITERATURE REVIEW

Both economical and public health concerns have caused an interest in soil chemical changes resulting from the additions of soil amendments, especially those containing nitrogen.

The availability of nutrients, metals, and potential pollutants depends greatly on the chemical properties of the soil. Whether an ion is held on an exchange site, is immobilized by soil microorganisms, or becomes soluble, may depend on factors such as pH, cation exchange capacity, or available carbon. Soil management practices utilizing manures and fertilizers influences these factors.

Soil acidity is influenced by the decomposition of organic materials and the use of nitrogen fertilizers.

During the nitrification process, two protons are released into the soil solution. Long-term fertilization with nitrogen will result in a decreasing effect on soil pH (Kay, 1990). Conversely, Sowden and Atkinson (1968) found additions of manure have little effect on pH.

A high correlation exists between soil pH and the ability of the soil to exchange ions with those in the soil solution. Both cations and anions may be exchanged. As pH increases, cation exchange capacity increases in soils with pH dependent charge. A pH increase has the opposite effect on anion exchange.

Cation exchange is of greater interest than anion exchange. The cations of primary interest include calcium, magnesium, sodium, potassium, aluminum, and hydrogen. Cations are attracted to negative surfaces. There are two types of charges associated with clays. Negative surfaces arise from unsatisfied oxygen atoms on the edges of clay crystals and through isomorphic substitution of one atom for another of similar size (Tisdale et al, 1985).

Manure additions result in an increase in exchange capacity, especially calcium, magnesium, and potassium (Halstead and Sowden, 1968). Higher nitrate concentrations in the soil solution are often accompanied by higher calcium and magnesium concentrations in soil (Lutz, et al, 1977).

In soils with a high pH, anions are not usually retained. Nitrates, chlorides, phosphates, and sulfates are the anions of major interest. Anions are negatively charged, and therefore, attracted to positively charged sites. Anion exchange sites occur in broken bonds of clays exposing OH groups and with the displacement of OH ions from hydrous iron and aluminum oxides (Tisdale et al, 1985).

Tillage has many different effects on soil. Thicker Ap horizons result from the mixing effect of tillage practices as compared to untilled soils, faunal activity is reduced, and there is a greater translocation of silt, organic matter, and clay to subsurface horizons. In addition, clay skins are more abundant on the ped faces in Bt horizons of cultivated soils. Tillage results in a loss of structure and porosity in the surface horizon (Thompson et al, 1990).

A rapid increase in mineralization of organic nitrogen occurs immediately after plowing. If cultivation continues without a return of residues, carbon content declines (Tisdale et al, 1985).

Tillage can decrease aggregate size and influence soil chemistry. An examination of seven sizes of soil aggregates ranging from <0.25 to 20mm in diameter, Seech et al (1988) found an inverse relationship between rate of denitrification and aggregate size. The smaller the aggregate, the greater the rate of denitrification. Lower availability of a carbon energy source was also a major factor in decreasing denitrification rates of larger aggregates (Seech et al, 1988).

Results of a three year study in Iowa showed an increase of 720 kg ha⁻¹ nitrogen below the corn rooting zone in plots fertilized with 448 kg ha⁻¹ nitrogen. Similar plots fertilized according to soil test recommendations with 168 kg ha⁻¹ nitrogen, did not increase nitrate concentrations below the

rooting zone, although some leaching did occur (Schuman et al, 1975).

High rates of fertilizer produce both positive and negative results in the soil chemistry. Nitrogen fertilizers have a profound effect on soil pH. The release of hydrogen ions during nitrification produces an acidifying effect (Tisdale et al, 1985). Lutz et al (1977) observed that an increase of nitrate in the absorbed state was accompanied by a decrease in soil solution pH in examining a Davidson clay loam.

Soil pH influences ion activities that affect the toxicity of elements such as aluminum and manganese. Exchangeable aluminum increases at lower pH. At a pH of 6 or more, aluminum exists in the soil as a precipitate. The hydrolysis of aluminum compounds results in the release of hydrogen ions at a lower pH. If a source of OH⁻ ions is not available to neutralize the liberated hydrogen ions, pH will decrease. Aluminum interferes with the availability of phosphorus, calcium, and magnesium (Tisdale et al, 1985).

Manganese in the soil solution is a useful indication of reducing conditions conducive to denitrification. Denitrification and manganese reduction occur at approximately the same redox potential (Eh) of about 300-350 mV (Meek et al, 1974). Fertilization with high levels of nitrogen produces an increase in exchangeable Mn (Blevins et al, 1977).

Nitrogen fertilizers can adversely effect cation exchange capacity. Due to the influence of nitrate anions, calcium becomes susceptible to leaching. Exchangeable calcium decreases due to leaching (Blevins et al, 1977).

Soil organic matter is the main natural source of nitrogen. The nitrogen content in a soil increases with its amount of humus. An effective cation exchanger, organic matter stores many elements against leaching.

Livestock manure contains both organic matter and nutrients. Manure, not only provides nutrients for plant growth, but is valuable in improving and conditioning the soil. Halstead and Sowden (1968) found manure improved the stability of soil aggregates in a clay soil.

Uneven spreading of manure can lead to differences in the carbon:nitrogen ratio. There are also differences in C:N ratio due to volatilization when manure is spread on top of the soil instead of being incorporated. This is important because the C:N ratio determines whether the nitrogen will be mineralized or immobilized (Flaig et al, 1977).

The method of incorporation does not affect total organic matter content or total nitrogen. It does affect distribution in the upper part of the profile (Sommerfeldt et al, 1988).

Below the rooting zone, the concentration of nitrates decreases primarily by dilution with water. Soil microorganisms and energy sources decrease rapidly with depth

lessening the possibility of nitrate decreases through denitrification and immobilization (Olsen et al, 1970).

Manure greatly increases the amount of soluble organic carbon in the soil solution. Denitrification has a greater probability of occurring at lower depths after manure applications (Meek et al, 1974). The amounts of organic matter and total nitrogen are highly correlated with each other (Sommerfeldt et al, 1988).

The rate of accumulation of organic matter and total nitrogen decreases exponentially with time until the annual increase becomes small, usually after two or three decades of annual application (Sommerfeldt et al, 1988).

Sowden and Atkinson (1968) found manure additions to a clay soil and a sandy soil, increased carbon content more during the first ten years of their study, while carbon content for the second ten years decreased slightly.

In another study, manure applied at the rate of 45 tons ha⁻¹ or less resulted in a fairly constant level of nitrate over a three year period. Higher rates caused large accumulations of nitrate (Mathers and Stewart, 1974).

Nitrate accumulations are usually small the first year of application, but increase in each succeeding year due to an accumulation effect. Not all of the nitrogen in the manure is mineralized during the first year. In the following years, nitrate is produced from prior applications as well as with

the new application resulting in a larger concentration (Mathers and Stewart, 1974).

Meek et al (1974) found nitrate leaching was less when manure was applied annually than when only applied one year. More leaching of nitrates occurs in plots fertilized with inorganic N than in those receiving manure. Manure associated nitrates are more susceptible to denitrification (Kimble, et al, 1972).

MATERIALS AND METHODS

FIELD SAMPLING

A description of the study area and field sampling methods were discussed in depth in the materials and methods section of chapter one.

LABORATORY ANALYSIS

Total acidity, pH, particle size, base saturation, cation exchange capacity, and total carbon analyses were determined using methods discussed in the materials and methods section of chapter one. Total nitrogen analysis was discussed in the materials and methods section of chapter two.

Dilute double acid nutrient extraction (Mehlich I) was analyzed using the ICAP-OES (Mehlich, 1953). The elements measured included aluminum, arsenic, boron, calcium, cadmium, chromium, copper, iron, lead, magnesium, manganese, nickel, phosphorus, potassium, silica, sodium, strontium, and zinc.

Calcium carbonate equivalents were determined using a procedure based on Jackson (1958), which has been modified by Sobek et al (1978).

RESULTS AND DISCUSSION

The study area was divided into plots according to treatment (Fig.1). Sites 1 and 2 were control sites. Sites 3 and 7 received fertilization at high rates. Sites 4 and 8 also received fertilization at high rates plus applications of manure. Sites 3, 4, 7, and 8 will also be referred to as the agricultural plots.

Using field morphology and laboratory data, the author came to the conclusion the manure was incorrectly incorporated. The manured plots (sites 4 and 8) had a color value of five (Tables 10 and 13). The no manure plots (sites 3 and 7) were darker with a color value of four (Tables 8 and 11). On average, the Ap1 and Ap2 of the no manure plots (3 and 7) had higher total carbon content than the manured plots (4 and 8) (Table 16).

The plots were plowed along the long axis of the study area rather than across each individual plot. Therefore, material from sites 3 and 4 were plowed into each other. The same was true of sites 7 and 8.

Control site 1 actually had a higher total carbon content than any of the other pedons, while control site 2 had a lower total carbon content than the other sites.

Table 16. Total carbon and calcium carbonate equivalent in the soil profiles at sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	CALCIUM CARBONATE EQUIVALENT -----PERCENT-----	TOTAL CARBON
Site 1			
A1	0-6	-3.21	1.80
A2	6-26	-3.14	1.08
Bt1	26-47	-0.01	0.54
Bt2	47-61	-0.01	0.32
2Bt3	61-81	-0.01	0.15
2Bt4	81-102	-0.05	0.17
2Bt5	102-120	-0.06	0.17
3Bt6	120-130	-0.06	0.17
3Bt7	130-158	-0.32	0.16
3Bt8	158-185	-0.52	0.06
Site 2			
A	0-38	-0.03	0.78
Bt1	38-62	0.01	0.45
2Bt2	62-93	0.03	0.13
2Bt3	93-120	-0.01	0.11
3Bt4	120-185	-0.05	0.10
Site 3			
Ap1	0-13	-0.04	1.10
Ap2	13-28	-0.03	0.85
Bt1	28-51	3.10	0.22
2Bt2	51-83	3.08	0.14
3Bt3	83-110	-0.05	0.10
3Bt4	110-123	-0.07	0.09
3Bt5	123-150+	-0.13	0.09

Table 16. (continued)

HORIZON	DEPTH (cm)	CALCIUM CARBONATE EQUIVALENT -----PERCENT-----	TOTAL CARBON
Site 4			
Ap1	0-18	0.04	0.75
Ap2	18-29	-0.01	0.70
Bt1	29-46	-0.03	0.29
Bt2	46-64	-0.01	0.15
Bt3	64-85	0.03	0.09
2Bt4	85-99	-0.05	0.06
2Bt5	99-110+	0.02	0.07
Site 7			
Ap1	0-16	0.03	0.93
Ap2	16-33	0.01	0.85
Bt1	33-61	-0.01	0.19
2Bt2	61-82	-0.02	0.08
2Bt3	82-111	-0.04	0.06
2Bt4	111-128	-0.01	0.06
3Bt5	128-158	-0.05	0.07
Site 8			
Ap1	0-19	-0.02	0.99
Ap2	19-36	0.00	0.70
Bt1	36-71	0.00	0.21
2Bt2	71-96	-0.02	0.08
2Bt3	96-120	-0.03	0.05
3Bt4	120-148	0.01	0.09
3Bt5	148-186	-0.03	0.07
3Bt6	186-206	-0.03	0.11

All sites had a higher silt content in the surface that decreased with depth. The reverse is true of clay content, which increased with depth. Fine sand was the fraction with the highest values. The medium, fine, and very fine sands were dominated by quartz. The coarse and very coarse sands consisted mainly of manganese and iron concretions. The total sand content fluctuated in areas of discontinuities (Tables 7, 9, and 12) .

Sites 3 and 7 show a sharp increase in pH in the Ap₂ followed by decreasing pH with depth (Table 17). In sites 4 and 8, pH was similar to sites 3 and 7, but the increase is not as sharp. In the control sites, pH continuously decreases from the surface with depth.

Cation exchange capacity was higher in the lower part of each horizon (Table 17). Percent base saturation was higher in the surface horizons of all the sites. The highest values were in control sites 1 and 2 and agricultural site 3. The other three sites were approximately 20% lower. Base saturation decreased between the Bt₁ and Bt₂ in each site to 35% or less.

Calcium carbonate equivalents indicated little influence from liming (Table 16). Records indicated periodic liming in the first twelve years of this study (Parks and Safley, 1982). Records for the later portion were either not available or inconsistent.

Table 17. Cation exchange capacity, exchangeable bases, and pH in the soil profiles at sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	pH	%BASE SAT.	CEC -----	Ca++ -----cmol	Mg++ (+) kg ⁻¹ soil	K+ -----	Na+ -----
Site 1								
A1	0-6	5.5	69	8.07	4.72	0.47	0.35	0.04
A2	6-26	5.6	62	6.46	3.76	0.03	0.13	0.04
Bt1	26-47	5.5	66	7.87	4.58	0.34	0.17	0.05
Bt2	47-61	4.8	38	10.38	2.84	0.74	0.25	0.05
2Bt3	61-81	4.6	24	9.44	1.21	0.82	0.18	0.05
2Bt4	81-102	4.6	24	9.72	0.86	1.21	0.20	0.04
2Bt5	102-120	4.5	23	14.06	0.92	2.10	0.17	0.05
3Bt6	120-130	4.5	25	15.24	1.04	2.47	0.18	0.06
3Bt7	130-158	4.5	29	11.40	0.89	2.17	0.13	0.05
3Bt8	158-185	4.6	29	12.36	0.98	2.32	0.12	0.07
Site 2								
A	0-38	6.0	69	4.94	3.20	0.00	0.17	0.03
Bt1	38-62	5.5	60	7.78	4.40	0.00	0.20	0.04
2Bt2	62-93	4.7	29	9.25	1.53	0.95	0.16	0.04
2Bt3	93-120	4.6	22	9.38	0.20	1.70	0.09	0.05
3Bt4	120-185	4.6	19	12.77	0.29	1.97	0.07	0.07

Table 17. (continued)

HORIZON	DEPTH (cm)	pH	%BASE SAT.	CEC	Ca++ -----cmol	Mg++ (+) kg ⁻¹ soil	K+	Na+
Site 3								
Ap1	0-13	5.6	66	9.76	4.23	0.82	1.18	0.06
Ap2	13-28	6.4	72	9.99	5.52	0.68	0.95	0.07
Bt1	28-51	4.8	52	10.89	4.13	0.67	0.78	0.07
2Bt2	51-83	4.3	35	9.33	2.18	0.72	0.31	0.06
3Bt3	83-110	3.9	23	14.57	1.41	1.63	0.21	0.05
3Bt4	110-123	3.9	20	15.50	1.01	1.92	0.17	0.05
3Bt5	123-150+	3.9	19	17.64	1.14	2.00	0.17	0.05
Site 4								
Ap1	0-18	6.2	42	7.72	2.56	0.29	0.34	0.03
Ap2	18-29	6.5	44	7.62	2.64	0.28	0.38	0.03
Bt1	29-46	5.3	37	9.47	2.78	0.29	0.35	0.05
Bt2	46-64	4.6	22	8.28	1.41	0.24	0.10	0.02
Bt3	64-85	4.2	34	9.94	2.19	0.97	0.16	0.07
2Bt4	85-99	4.0	35	10.36	1.73	1.66	0.12	0.07
2Bt5	99-110+	4.0	31	12.71	1.48	2.22	0.10	0.08

Table 17. (continued)

HORIZON	DEPTH (cm)	pH	%BASE SAT.	CEC	Ca++ -----cmol	Mg++ (+) kg ⁻¹ soil	K+	Na+
Site 7								
Ap1	0-16	5.8	43	6.45	2.02	0.24	0.44	0.03
Ap2	16-33	6.5	52	6.45	2.59	0.26	0.46	0.04
Bt1	33-61	4.9	36	9.41	2.57	0.28	0.45	0.05
2Bt2	61-82	4.2	24	7.76	1.37	0.32	0.12	0.02
2Bt3	82-111	3.9	26	6.45	1.17	0.40	0.05	0.02
2Bt4	111-128	3.8	17	10.22	1.08	0.61	0.04	0.03
3Bt5	128-158	3.8	12	12.24	0.61	0.78	0.04	0.05
Site 8								
Ap1	0-19	5.8	43	6.53	2.18	0.27	0.34	0.03
Ap2	19-36	6.5	50	6.33	2.47	0.25	0.36	0.04
Bt1	36-71	6.1	54	5.99	2.51	0.26	0.40	0.03
2Bt2	71-96	4.4	25	8.98	1.77	0.27	0.20	0.03
2Bt3	96-120	4.3	23	8.31	1.39	0.41	0.10	0.03
3Bt4	120-148	4.1	20	12.33	1.56	0.76	0.11	0.05
3Bt5	148-186	4.0	18	12.85	1.32	0.89	0.08	0.04
3Bt6	186-206	4.0	18	12.50	1.33	0.80	0.08	0.03

Total nitrogen was highest in the surface horizons as a result of annual applications of nitrogen fertilizer (Table 18). Crop residue and manure amendments also contribute to the higher totals of surface nitrogen. There was a nitrogen decrease in the argillic horizons between 60 and 100 centimeters.

Plant roots may have taken up more nitrogen during periods of low moisture in upper horizons of the argillic. The increase in nitrogen at lower depths was probably a result of fewer roots and leaching.

Carbon to nitrogen ratios were much higher in the surface horizons of all six pedons. In the agricultural plots, the higher ratios extended into the upper portion of the argillic horizon. This may be due to the influence of manure applications. Compared with sites 3, 4, 7, and 8, the C:N ratios of control sites 1 and 2 were relatively higher except in the 3Bt8.

Regression correlation of total carbon and total nitrogen indicates a close association (Fig. 21). An r value of 0.966 was obtained using values of 44 samples.

In topsoils with pH greater than 5, carbon:nitrogen ratios normally range between 10 and 14. A C:N ratio greater than 14 indicates the presence of much decomposed plant material (Russell, 1988). C:N ratios for all the study sites ranged from 10 to 14 in the upper three horizons of the soil profiles.

Table 18. Total nitrogen, total carbon, and C:N ratios in the soil profiles for sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	%TOTAL CARBON	%TOTAL NITROGEN	C:N RATIO
SITE 1				
A1	0-6	1.80	0.134	13.40
A2	6-26	1.08	0.091	11.80
Bt1	26-47	0.54	0.048	11.19
Bt2	47-61	0.31	0.030	10.48
2Bt3	61-81	0.15	0.018	8.35
2Bt4	81-102	0.17	0.017	9.84
2BT5	102-120	0.17	0.020	8.56
3Bt6	120-130	0.17	0.022	7.87
3Bt7	130-158	0.16	0.021	7.45
3Bt8	158-185+	0.06	0.020	3.06
SITE 2				
A	0-38	0.78	0.066	11.84
Bt1	38-62	0.45	0.016	12.42
2Bt2	62-93	0.13	0.009	8.12
2Bt3	93-120	0.11	0.013	11.47
3Bt4	120-185	0.10	0.011	7.64
SITE 3				
Ap1	10-13	1.10	0.085	12.97
Ap2	13-28	0.85	0.082	10.35
Bt1	28-51	0.22	0.019	11.78
2Bt2	51-83	0.14	0.012	11.73
3Bt3	83-110	0.10	0.021	4.77
3Bt4	110-123	0.09	0.020	4.48
3Bt5	123-150+	0.09	0.021	4.33

Table 18. (continued)

HORIZON	DEPTH (cm)	%TOTAL CARBON	%TOTAL NITROGEN	C:N RATIO
SITE 4				
Ap1	0-18	0.75	0.064	11.75
Ap2	18-29	0.70	0.064	10.84
Bt1	29-46	0.29	0.027	10.83
Bt2	46-64	0.15	0.013	11.70
Bt3	64-85	0.09	0.009	9.91
2Bt4	85-99	0.06	0.011	5.45
2Bt5	99-110+	0.07	0.013	5.50
SITE 7				
Ap1	0-16	0.93	0.075	12.37
Ap2	16-33	0.85	0.075	11.34
Bt1	33-61	0.19	0.022	8.58
2Bt2	61-82	0.08	0.010	8.12
3Bt3	82-111	0.06	0.011	5.45
3Bt4	111-128	0.06	0.012	4.84
3Bt5	128-158	0.07	0.014	4.87
SITE 8				
Ap1	0-19	0.99	0.086	11.57
Ap2	19-36	0.70	0.059	11.84
Bt1	36-71	0.20	0.021	9.86
2Bt2	71-96	0.00	0.011	7.39
2Bt3	96-120	0.05	0.008	6.43
3Bt4	120-148	0.09	0.012	7.62
3Bt5	148-186	0.07	0.014	5.17
3Bt6	186-206	0.11	0.016	7.05

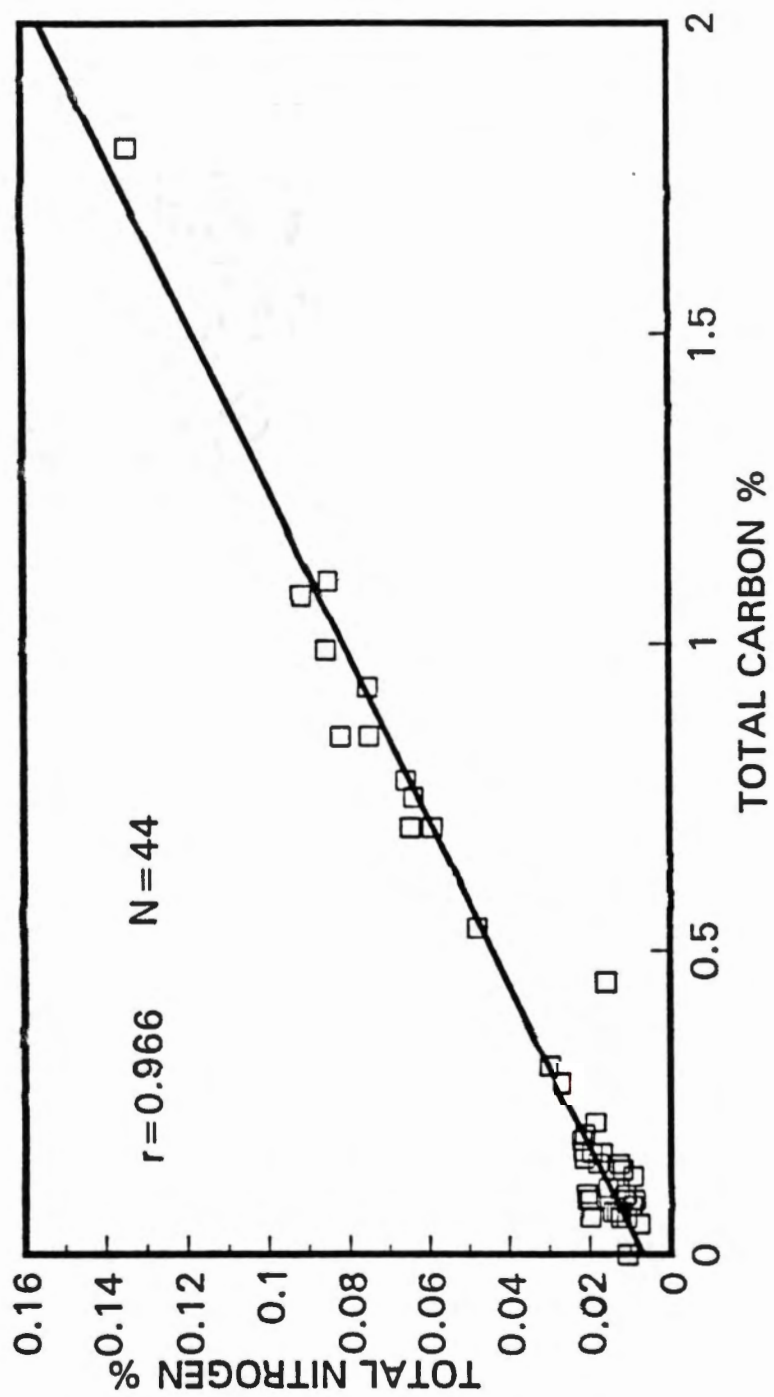


Figure 21. Regression correlation between total carbon and total nitrogen.

In the surface horizons, measurements of total acidity were zero (Table 19). This reflects the influence of liming. Measurable amounts increased with depth along with a corresponding decrease in pH. Most of the total acidity was due to an increase in exchangeable aluminum.

Mehlich I extractions of eighteen elements showed interesting trends (Tables 20, 21, and 22). Since phosphorus was added annually at a rate of 112 kg ha⁻¹, phosphorus was higher in the surface horizons of the agricultural sites (3, 4, 7, and 8) than in control sites 1 and 2. Generally, phosphorus does not move more than 5 centimeters from its originally point of placement (Tisdale et al, 1985). Any redistribution may be attributed to plant root activity, erosion, and plowing. Applications of nitrogen fertilizer enhance plant uptake of phosphorus.

Potassium was higher in the surface horizons. Annual fertilization, higher pH, and fixation by clays were contributing factors in this concentration.

Both calcium and magnesium can be easily leached from the soil. There was a major increase in calcium in the agricultural plots in the lower part of the plow layer. The same was not true of magnesium. The plow layer was lower in magnesium than the underlying subsoil. The logical conclusion was that lime that had been added was probably not dolomitic.

Leaching of calcium may have been slightly retarded by the formation of a weak plow pan or the increase in clay in

Table 19. KCl total acidity and pH of soil pedons 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	TOTAL ACIDITY	AL+++	H+	pH
-----mg kg ⁻¹ -----					
Site 1					
A1	0-6	0.00	0.00	0.00	5.5
A2	6-26	0.00	0.00	0.00	5.6
Bt1	26-47	0.39	0.29	0.09	5.5
Bt2	47-61	2.38	3.28	0.00	4.8
2Bt3	61-81	4.31	4.64	0.00	4.6
2Bt4	81-102	5.12	5.37	0.00	4.6
2BT5	102-120	7.25	7.59	0.00	4.5
3Bt6	120-130	8.47	8.78	0.00	4.5
3Bt7	130-158	5.60	6.28	0.00	4.5
3Bt8	158-185+	5.83	5.77	0.05	4.6
Site 2					
A	0-38	0.00	0.00	0.00	6.0
Bt1	38-62	0.39	0.21	0.17	5.5
2Bt2	62-93	3.57	3.71	0.00	4.7
2Bt3	93-120	4.37	4.94	0.00	4.6
3Bt4	120-185	6.81	7.51	0.00	4.6
Site 3					
Ap1	10-13	0.00	0.00	0.00	5.6
Ap2	13-28	0.39	0.00	0.38	6.4
Bt1	28-51	1.57	1.72	0.00	4.8
2Bt2	51-83	3.54	3.46	0.08	4.3
3Bt3	83-110	6.32	6.49	0.00	3.9
3Bt4	110-123	6.95	7.24	0.00	3.9
3Bt5	123-150+	7.03	7.01	0.02	3.9

Table 19. (continued)

HORIZON	DEPTH (cm)	TOTAL ACIDITY	AL+++ -----mg kg ⁻¹ -----	H+	pH
Site 4					
Ap1	0-18	0.00	0.00	0.00	6.2
Ap2	18-29	0.00	0.00	0.00	6.5
Bt1	29-46	0.39	0.32	0.07	5.3
Bt2	46-64	2.35	2.30	0.04	4.6
Bt3	64-85	3.86	3.78	0.07	4.2
2Bt4	85-99	4.71	5.02	0.00	4.0
2Bt5	99-110+	5.56	5.64	0.00	4.0
Site 7					
Ap1	0-16	0.00	0.00	0.00	5.8
Ap2	16-33	0.00	0.00	0.00	6.5
Bt1	33-61	0.78	1.08	0.00	4.9
2Bt2	61-82	3.42	3.65	0.00	4.2
2Bt3	82-111	3.96	4.26	0.00	3.9
2Bt4	111-128	5.44	5.75	0.00	3.8
3Bt5	128-158	6.37	7.24	0.00	3.8
Site 8					
Ap1	0-19	0.00	0.00	0.00	5.8
Ap2	19-36	0.00	0.00	0.00	6.5
Bt1	36-71	0.00	0.00	0.00	6.1
2Bt2	71-96	3.90	3.41	0.48	4.4
2Bt3	96-120	3.95	3.78	0.16	4.3
3Bt4	120-148	6.37	5.41	0.95	4.1
3Bt5	148-186	6.37	6.03	0.33	4.0
3Bt6	186-206	5.96	6.11	0.00	4.0

Table 20. Mehlich I concentrations of aluminum, arsenic, boron, calcium, cadmium, chromium, copper, and iron, potassium, magnesium, manganese, sodium, nickel, phosphorus, lead, silica, strontium, and zinc in sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	Al	As	B	Ca	Cd	Cr	Cu	Fe
-----mg kg ⁻¹ -----									
Site 1									
A1	0-6	416	0.27	4.3	847	0.02	0.02	2.0	210
A2	6-26	368	0.22	4.9	669	0.06	0.11	1.7	109
Bt1	26-47	370	0.03	4.7	789	0.00	0.01	1.4	32
Bt2	47-61	583	0.02	3.8	478	0.00	0.00	0.9	38
2Bt3	61-81	546	0.23	5.1	191	0.00	0.00	1.0	39
2Bt4	81-102	484	0.20	5.0	127	0.00	0.00	1.3	46
2Bt5	102-120	598	0.24	4.1	130	0.00	0.00	0.4	65
3Bt6	120-130	608	0.44	3.5	156	0.00	0.00	1.2	65
3Bt7	130-158	388	0.23	4.2	137	0.00	0.00	1.1	62
3Bt8	158-185	314	0.22	3.8	185	0.00	0.00	1.4	32
Site 2									
A	0-38	326	0.05	4.4	679	0.00	0.00	1.1	79
Bt1	38-62	287	0.07	4.7	809	0.01	0.00	0.7	23
2Bt2	62-93	436	0.20	3.4	309	0.03	0.00	1.1	30
2Bt3	93-120	505	0.32	3.7	50	0.00	0.00	0.9	38
3Bt4	120-185	551	0.42	5.1	590	0.00	0.00	1.3	42

Table 20. (continued)

HORIZON	DEPTH (cm)	Al	As	B	Ca	Cd mg kg ⁻¹	Cr	Cu	Fe
Site 3									
Ap1	0-13	422	0.10	4.3	851	0.00	0.00	5.5	61
Ap2	13-28	370	0.12	4.8	1174	0.00	0.00	4.7	46
Bt1	28-51	373	0.00	4.4	798	0.00	0.00	1.0	38
2Bt2	51-83	360	0.04	4.4	414	0.00	0.00	1.6	28
3Bt3	83-110	518	0.16	4.2	267	0.00	0.00	1.4	36
3Bt4	110-123	548	0.27	5.1	203	0.00	0.00	1.6	29
3Bt5	123-150+	532	0.20	4.9	216	0.00	0.00	2.4	33
Site 4									
Ap1	0-18	304	0.17	4.6	988	0.00	0.00	3.8	33
Ap2	18-29	379	0.05	5.9	1059	0.00	0.00	4.0	43
Bt1	29-46	377	0.00	5.4	996	0.00	0.00	1.1	29
Bt2	46-64	405	0.00	5.6	579	0.00	0.00	1.1	35
Bt3	64-85	415	0.08	5.0	323	0.00	0.00	1.3	34
2Bt4	85-99	480	0.02	4.2	165	0.00	0.00	1.1	39
2Bt5	99-110+	468	0.17	4.3	120	0.00	0.00	1.7	39

Table 20. (continued)

HORIZON	DEPTH (cm)	Al	As	B	Ca	Cd mg kg ⁻¹	Cr	Cu	Fe
Site 7									
Ap1	0-16	337	0.47	4.1	737	0.07	0.00	6.1	211
Ap2	16-33	612	0.49	4.3	955	0.06	0.00	5.1	76
Bt1	33-61	340	0.09	4.3	800	0.02	0.00	1.9	25
2Bt2	61-82	384	0.00	4.0	303	0.00	0.00	1.0	37
2Bt3	82-111	389	0.00	4.9	192	0.00	0.00	1.5	36
2Bt4	111-128	458	0.06	4.0	170	0.00	0.00	1.7	33
3Bt5	128-158	498	0.18	2.5	181	0.00	0.00	3.4	37
Site 8									
Ap1	0-19	331	0.30	4.3	766	0.11	0.00	7.2	234
Ap2	19-36	343	0.27	4.4	850	0.07	0.00	6.1	104
Bt1	36-71	315	0.07	4.0	776	0.03	0.00	1.4	31
2Bt2	71-96	423	0.47	3.9	487	0.01	0.00	1.0	34
2Bt3	96-120	398	0.49	4.8	268	0.02	0.00	1.9	32
3Bt4	120-148	423	0.09	3.9	335	0.03	0.00	1.9	33
3Bt5	148-186	475	0.00	3.6	245	0.02	0.00	1.6	41
3Bt6	186-206	411	0.00	3.4	296	0.02	0.00	1.3	38

Table 21. Mehlich I concentrations of potassium, magnesium, manganese, sodium, nickel, phosphorus, lead, and silica in sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	K	Mg	Mn	Na	Ni	P	Pb	Si
						mg kg ⁻¹			
Site 1									
A1	0-6	138	50	92.67	15	0.34	11.94	3.16	38
A2	6-26	56	81	58.17	19	0.34	7.89	2.87	36
Bt1	26-47	897	110	15.43	19	0.02	2.86	1.24	70
Bt2	47-61	114	100	2.63	17	0.00	2.90	1.20	108
2Bt3	61-81	79	135	0.83	16	0.02	1.16	0.83	107
2Bt4	81-102	61	243	0.57	18	0.07	1.58	0.77	99
2Bt5	102-120	51	315	0.27	17	0.16	0.80	0.49	222
3Bt6	120-130	47	263	0.32	20	0.20	1.00	0.45	206
3Bt7	130-158	32	317	0.37	19	0.22	0.85	0.61	156
3Bt8	158-185	30	25	0.56	20	0.37	0.53	0.62	205
Site 2									
A	0-38	60	50	51.43	14	0.15	8.20	2.07	41
Bt1	38-62	80	117	10.75	16	0.00	1.92	1.38	67
2Bt2	62-93	54	172	1.65	16	0.06	1.09	1.10	99
2Bt3	93-120	24	225	0.56	17	0.09	1.10	0.64	167
3Bt4	120-185	21	208	0.95	23	0.16	1.51	1.04	226

Table 21. (continued)

HORIZON	DEPTH (cm)	K	Mg	Mn	Na	Ni mg kg ⁻¹	P	Pb	Si
Site 3									
Ap1	0-13	388	41	70.02	20	0.17	130.90	1.87	68
Ap2	13-28	343	35	52.50	24	0.09	80.01	1.85	97
Bt1	28-51	227	45	2.56	22	0.00	2.01	2.12	99
2Bt2	51-83	113	177	1.50	20	0.00	1.11	1.21	78
3Bt3	83-110	73	220	1.52	22	0.11	0.96	0.67	196
3Bt4	110-123	59	221	1.25	21	0.15	0.79	0.59	186
3Bt5	123-150+	58	89	1.47	21	0.16	0.92	0.62	197
Site 4									
Ap1	0-18	231	42	52.94	71	0.09	45.26	0.94	77
Ap2	18-29	253	42	58.91	20	0.05	52.63	1.86	113
Bt1	29-46	235	47	4.78	25	0.00	2.45	1.74	136
Bt2	46-64	117	35	1.62	25	0.00	1.27	1.97	105
Bt3	64-85	53	199	1.34	23	0.07	0.74	1.12	112
2Bt4	85-99	35	239	1.21	23	0.15	0.88	0.68	179
2Bt5	99-110+	33	58	1.17	26	0.25	1.64	0.57	179

Table 21. (continued)

HORIZON	DEPTH (cm)	K	Mg	Mn	Na	Ni mg kg ⁻¹	P	Pb	Si
Site 7									
Ap1	0-16	294	31	88.07	63	0.18	108.48	2.31	51
Ap2	16-33	303	33	72.75	61	0.15	87.17	2.07	68
Bt1	33-61	268	36	2.12	69	0.00	2.26	1.99	93
2Bt2	61-82	90	48	1.49	65	0.01	1.20	1.64	92
2Bt3	82-111	48	82	1.62	76	0.05	1.47	0.74	99
2Bt4	111-128	33	138	1.12	79	0.06	1.01	0.43	132
3Bt5	128-158	31	173	1.04	70	0.09	0.89	0.34	176
Site 8									
Ap1	0-19	240	41	88.00	17	0.22	84.76	2.30	52
Ap2	19-36	239	30	70.81	20	0.16	60.49	2.22	79
Bt1	36-71	250	34	10.89	69	0.15	3.05	1.60	120
2Bt2	71-96	137	37	1.41	51	0.07	0.44	2.02	100
2Bt3	96-120	71	82	0.95	20	0.08	1.23	0.67	120
3Bt4	120-148	73	160	1.37	67	0.16	1.88	0.39	168
3Bt5	148-186	51	197	1.09	21	0.19	0.81	0.66	236
3Bt6	186-206	52	189	1.25	71	0.21	1.01	0.90	193

Table 22. Mehlich I concentrations of strontium and zinc in sites 1, 2, 3, 4, 7, and 8.

HORIZON	DEPTH (cm)	Sr -----mg kg ⁻¹ ----	Zn -----
Site 1			
A1	0-6	2.51	7.84
A2	6-26	2.24	4.42
Bt1	26-47	3.33	0.82
Bt2	47-61	2.39	5.19
2Bt3	61-81	1.48	0.47
2Bt4	81-102	1.48	0.55
2Bt5	102-120	2.32	0.81
3Bt6	120-130	2.90	0.99
3Bt7	130-158	2.48	1.15
3Bt8	158-185	2.92	1.57
Site 2			
A	0-38	2.25	1.26
Bt1	38-62	3.79	1.26
2Bt2	62-93	2.27	0.47
2Bt3	93-120	1.33	0.56
3Bt4	120-185	3.80	1.46

Table 22. (continued)

HORIZON	DEPTH (cm)	Sr -----mg kg ⁻¹ -----	Zn -----
Site 3			
Ap1	0-13	2.05	5.00
Ap2	13-28	2.19	2.40
Bt1	28-51	1.45	0.57
2Bt2	51-83	0.99	0.49
3Bt3	83-110	1.88	0.66
3Bt4	110-123	1.92	2.15
3Bt5	123-150+	1.85	2.85
Site 4			
Ap1	0-18	2.17	1.79
Ap2	18-29	2.23	5.78
Bt1	29-46	1.96	0.50
Bt2	46-64	1.21	0.49
Bt3	64-85	1.22	0.67
2Bt4	85-99	1.60	0.79
2Bt5	99-110+	1.90	1.43

Table 22. (continued)

HORIZON	DEPTH (cm)	Sr -----mg kg ⁻¹ -----	Zn -----
Site 7			
Ap1	0-16	1.77	3.59
Ap2	16-33	2.07	2.85
Bt1	33-61	1.41	0.68
2Bt2	61-82	0.88	0.44
2Bt3	82-111	1.07	0.79
2Bt4	111-128	1.52	1.08
3Bt5	128-158	1.82	1.55
Site 8			
Ap1	0-19	2.03	5.41
Ap2	19-36	2.01	3.11
Bt1	36-71	1.58	0.77
2Bt2	71-96	1.10	0.63
2Bt3	96-120	1.17	1.45
3Bt4	120-148	1.85	1.32
3Bt5	148-186	2.22	1.37
3Bt6	186-206	2.23	1.43

the argillic. Also, Tisdale et al (1985) suggests a high level of nitrate stimulates organic anion synthesis, resulting in an accumulation of cations, particularly calcium. Nitrate levels of the Ap₂ horizons in sites 3 (Fig. 14) and 4 (Fig. 15) were much greater than those of the underlying Bt₁ horizons.

Manganese was more highly concentrated in the A or Ap horizons in all six pedons. These horizons also had higher pH values than the underlying horizons. The maximum activity of soil microorganisms responsible for formation of organic manganese complexes occurs at pH 7. As pH increases toward this optimum, manganese becomes less available in the soil solution. Organic matter also contributes to the formation of chelated manganese compounds. High levels of copper, iron, and zinc interfere with plant uptake of manganese (Tisdale et al, 1985).

In all six pedons, both pH (Table 19) and total carbon (Table 18) overall were higher in the same horizons as the higher totals of manganese. This was also true of Mehlich I extractions of copper, iron, and zinc.

Results from Mehlich I extracted manganese in each horizon was less than that obtained using the hydroxylamine-hydrochloride method. Mehlich I was generally used to deduce elements available to plants. The hydroxylamine-hydrochloride method also extracts manganese that is tightly bound in hydrous manganese oxides (Gambrell and Patrick, 1982).

In the samples from these sites, there was a positive correlation between the Mehlich I and hydroxylamine-hydrochloride methods for determination of manganese. Using 44 samples, an r value of 0.866 was obtained (Figure 22).

Mehlich I iron was generally higher in the surface horizons with decreasing amounts with depth. The addition of organic materials supplied chelating agents that increased iron availability.

In nature, arsenic distribution is highly variable. Soil particles retain arsenic very strongly making it essentially unavailable at low concentrations. Except when highly concentrated, arsenic does not move easily through soils.

Arsenic was once a popular component in herbicide and pesticides. Native soils in Virginia contained arsenic levels between 0.2 and 40 $\mu\text{g g}^{-1}$. Applications of arsenicals increased arsenic levels to 550 $\mu\text{g g}^{-1}$ (Bohn et al, 1985).

Arsenic levels in all pedons were highly variable. There was a decrease in the upper part of the argillic horizon. Amounts above and below this area were higher. Total levels were generally low, indicating there was probably little application of arsenical pesticides to the agricultural plots.

Anthropogenic influence has contributed to increased levels of lead in the surface horizons of all six sites. The burning of fossil fuels probably has contributed to elevated atmospheric lead levels. Annual cultivation of the agricultural plots deposited lead residues from tractor emissions.

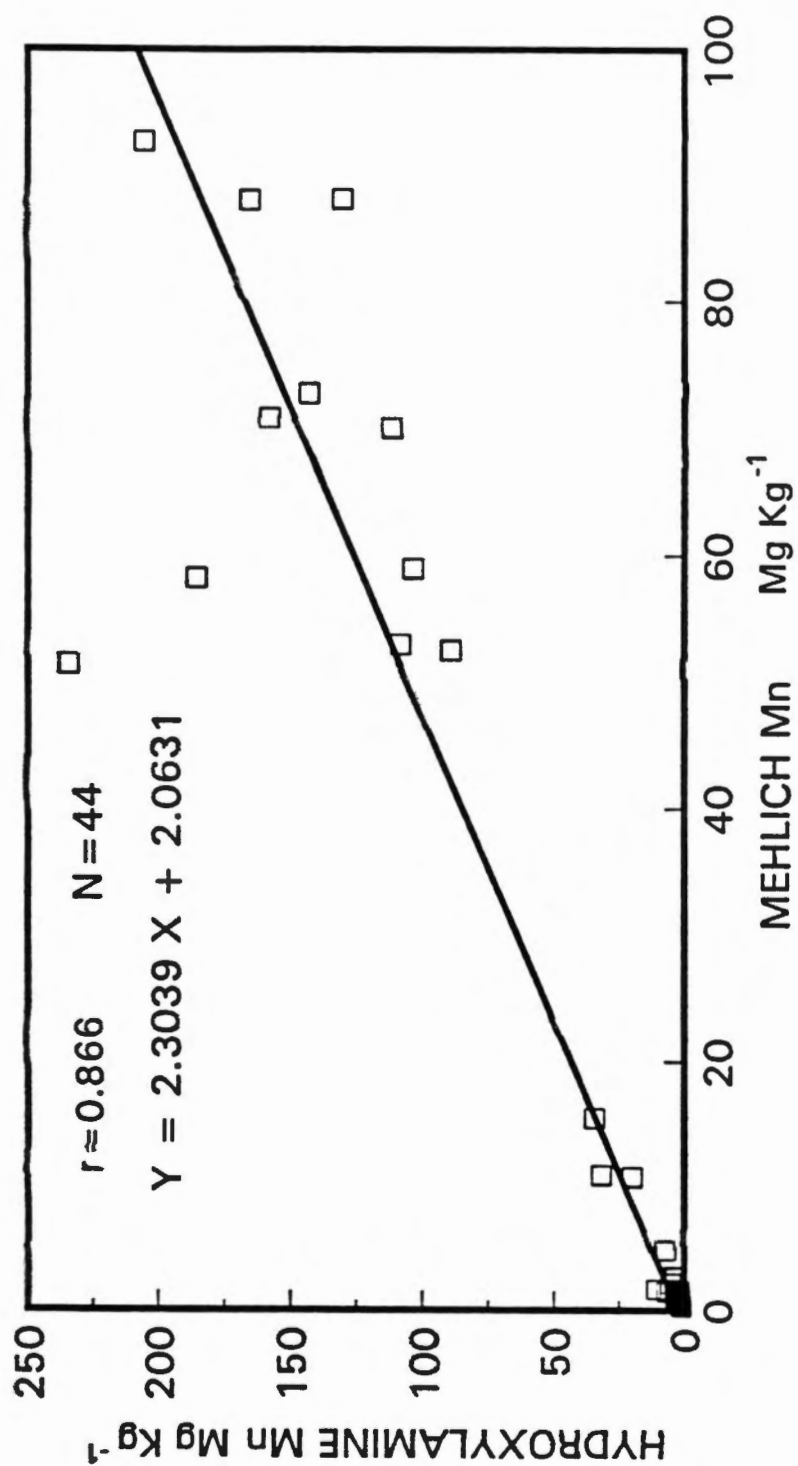


Figure 22. Regression correlation between the Mehlich I and hydroxylamine-hydrochloride methods of manganese extraction.

Chromium in soil is essentially chemically inert. Extraction releases forms bound with sesquioxides or organics (Reisenauer, 1982). The only measurable chromium was in the upper horizons of site 1. Since these horizons also had the highest content of total carbon (Table 19), the chromium may have been held in the humus fraction.

Copper, zinc, nickel, and cadmium are strongly bound in all but sandy soils. Levels of these elements are normally low and contamination during sampling can be a problem.

Copper was higher in the surface of the agricultural sites than the control sites. Copper was a common component in manure. It may have also been an element contained in the Es-min-el that was added as a micronutrient fertilizer. The control sites have an inconsistent pattern of copper by depth.

Zinc occurs in greater overall amounts in the A and Ap horizons. The pH in these horizons was also higher. As pH increases, zinc solubility decreases. The formation of insoluble zinc compounds, the complexing of zinc by humic acids in organic material, and the adsorption of zinc by clay and oxide minerals are pH dependent (Tisdale et al, 1985).

In all pedons, zinc decreased in the upper part of the argillic horizon. The element then increased in the lower depths. A major fluctuation of zinc was measured between 47 and 61 centimeters. Since zinc is relatively immobile in the soil (Tisdale et al, 1985), the parent material probably contained a high amount of zinc.

Cadmium contents were variable among the pedons. Sites 3 and 4 showed no cadmium at any depth. Sites 1 and 7 had low levels in the upper horizons. Site 2 had low cadmium levels in the upper part of the argillic horizon. Site 8 had variable amounts throughout the pedon. The greatest levels of cadmium were in the surface.

Nickel was higher in the surface and the lower horizons of each pedon. The nickel was probably a residue of the original parent material. The higher amounts in the surface may be due to plant cycling.

Silica content increased with depth. Surface totals were very low while higher levels in the bottom horizons indicated of the weathering of the residual parent material. Silica content and clay content have similar patterns. Correlation regression of 44 samples resulted in an r value of 0.768 which was significant at the 0.5 confidence level (Figure 23).

Strontium levels follow a pattern similar to that of nickel. These were probably naturally occurring levels due to parent material.

All sites had similar amounts of boron, however, distribution was very erratic. Since the control sites and cultivated sites have similar amounts in the surface, boron probably was not included in the micronutrient amendment. Also, as boron free glassware was not used, laboratory materials could have contributed to boron content.

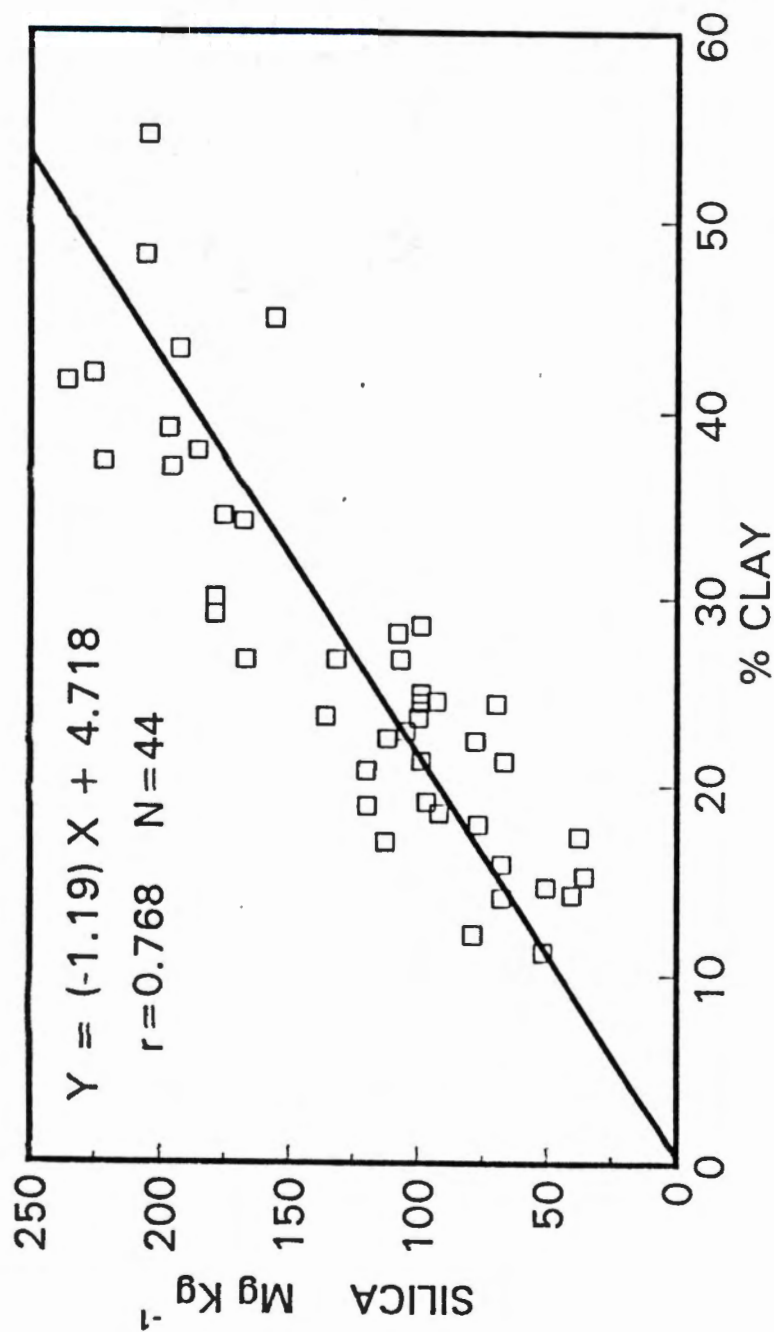


Figure 23. Regression correlation between Mehlich I extracted silica and total clay determined by particle size analysis.

CONCLUSIONS

1. Through amendments of manure and incorporation of crop residues, total carbon of agricultural soils was generally equivalent to levels in the control soils.
2. There was a positive correlation between total carbon and total nitrogen.
3. Percent base saturation was generally higher in the topsoil and first argillic horizon of the non-agricultural sites than the cultivated sites. Site 3 was the exception.
4. Percent base saturation had similar levels below the lithologic discontinuity at lower depths in all pedons.
5. Manganese concentrations are very high in surface horizons. They drop quickly to almost immeasurable levels in argillic horizons.
6. Mehlich I extraction of manganese correlates well with hydroxyl amine-hydrochloride extraction.
7. Few, if any, arsenical pesticides were applied to the study site.
8. Anthropogenic influences elevate lead levels in the soil surface.
9. Chromium and cadmium were barely detectable in these pedons.
10. Copper and zinc were probably added to the soil in the micronutrient amendment.
11. Total clay correlated well with Mehlich I extractable silica.

12. Increased totals of nitrogen, phosphorus, and potassium in the Ap1 and Ap2 resulted from annual additions of 336 kg ha⁻¹ nitrogen, 112 kg ha⁻¹ phosphorus, and 336 kg ha⁻¹ potassium in the agricultural plots (3, 4, 7, and 8).

13. There appeared to be no micronutrient deficiency in the soil.

14. Commercial fertilizer from long-term management had not significantly moved into the lower subsoil and was not a significant source for pollution.

LIST OF REFERENCES

LIST OF REFERENCES

- Adriano, D. C., A. C. Chang, and R. Sharpless. 1974. Nitrogen loss from manure as influenced by moisture and temperature. *J. Environ. Qual.* 3:258-262.
- Birkeland, P. W. 1984. *Soils and geomorphology*. Oxford Univ. Press. NY.
- Blevins, R. L., G. W. Thomas, and P. L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. *Agron. J.* 69:383-386.
- Bohn, H. I., B. L. McNeal, and G. A. O'Connor. 1985. *Soil chemistry*. John Wiley & Sons. New York.
- Brady, N. C. 1984. *The nature and properties of soils*. Macmillan Publishing Co., N. Y.
- Buol, S. W., F. D. Hole, and R. J. McCracken. 1989. *Soil genesis and classification*. 3th ed. Iowa State University Press. Ames, IA.
- Chan, K. Y. and J. A. Mead. 1989. Water movement and macroporosity of an Australian alfisol under different tillage and pasture conditions. *Soil & Till. Res.* 14:301-310.
- Chapman, H. D. 1965. Cation exchange capacity. p. 891-901. In C. A. Black et al. (ed.) *Methods of soil analysis*. Part 1. 1st ed. Agronomy Monogr. 9. ASA, Madison, WI.
- Flaig, W., B. Nagar, H. Sochtig, and C. Tietjen. 1977. *Organic materials and soil productivity*. FAO. 35. Rome, Italy.
- Foth, H. D. and B. G. Ellis. 1988. *Soil fertility*. John Wiley & Sons. New York.
- Frazee, C. J., J. B. Fehrenbacher, and W. C. Krumbein. 1970. Loess distribution from a source. *Soil Sci. Soc. Amer. Proc.* 34:296-301.
- Gambrell, R. P. and W. H. Patrick. 1982. Manganese. p. 313-322. In A. L. Page (ed.) *Methods of soil analysis*. Part 2. 2nd ed. Agronomy Monogr. 9. ASA, Madison, WI.

- Gee, G. W. and J. W. Bauder. 1986. Particle size analysis. p. 401. In *Methods of soil analysis. Part 1.* 2nd ed. Agronomy Monogr. 9. ASA, Madison, WI.
- Hahne, H. C. H., W. Kroontje, and J. A. Lutz, Jr. 1977. Nitrogen fertilization: I. Nitrate accumulation and losses under continuous corn cropping. *Soil Sci. Soc. Am. J.* 41:562-567.
- Haigh, R. A. and R. E. White. 1986. Nitrate leaching from a small, underdrained, grassland, clay catchment. *soil use and management.* Vol. 2. 65-70.
- Hall, A. D. 1917. *The book of the Rothamsted experiments.* E.P.Dutton and Company. New York.
- Halstead, R. L. and F. J. Sowden. 1968. Effect of long-term additions of organic matter on crop yields and soil properties. *Can. J. Soil Sci.* 48:341-348.
- Hardeman, W. D. 1966. *Geologic map of Tennessee. West-Central Sheet.* Department of Geology. Nashville, TN.
- Harradine, F. F. 1949. The variability of soil properties in relation to stage of profile development. *Soil Sci. Soc. Am Proc.* 14:302-311.
- Hershey, R. E. and S. W. Maher. 1963. *Limestone and dolomite resources of Tennessee.* Division of Geology. 65. Nashville, Tennessee.
- Jackson, M. L. 1958. *Soil chemistry: A first course.* 6th ed. Madison, WI.
- Jenny, H. 1941. *Factors of soil formation.* McGraw Hill, New York.
- Kay, B. D. 1990. Rates of change of soil structure under different cropping systems. p. 34. In Stewart (ed.) *Advances in soil science.* Vol 12.
- Kilmer, V. J. and L. T. Alexander. 1949. Methods of making mechanical analysis of soils. *Soil Science.* 68:1.
- Kimble, J. M., R. J. Bartlett, J. L. McIntosh, and K. E. Varney. 1972. Fate of nitrate from manure and inorganic nitrogen in a clay soil cropped to continuous corn. *J. Environ. Qual.* 1:413-415.

- Lund, L. J., D. C. Adriano, and P. F. Pratt. 1974. Nitrate concentrations in deep soil cores as related to soil profile characteristics. *J. Environ. Qual.* 3:78-82.
- Lutz, Jr., J. A., W. Kroontje, and H. C. H. Hahne. 1977. Nitrogen fertilization: II. Effect on the soil solution composition, acidity, and nitrate adsorption. *Soil Sci. Soc. Am. J.* 41:568-572.
- Mathers, A. C., and B. A. Stewart. 1974. Corn silage yield and soil chemical properties as affected by cattle feedlot manure. *J. Environ. Qual.* 3:143-147.
- Mausbach, M. J., B. R. Brasher, R. D. Yeck, and W. D. Nettleton. 1980. Variability of measured properties in morphologically matched pedons. *Soil Sci. Soc. Am. J.* 44:358-363.
- Meek, B. D., A. J. MacKenzie, T. J. Donovan, and W. F. Spencer. 1974. The effect of large applications of manure on movement of nitrate and carbon in an irrigated desert soil. *J. Environ. Qual.* 3:253-258.
- Mehlich, A. 1953. Determination of P, Ca, Mg, K, Na, and NH_4 . North Carolina Soil Test Division Mimeo.
- Olsen, R.V. and R. Ellis. 1982. Iron. p. 301-312. In A.L. Page (ed.) *Methods of soil analysis. Part 2.* 2nd ed. Agronomy Monogr. 9. ASA. Madison, WI.
- Olsen, R.V. and R. Ellis. 1982. Soil pH and lime requirement. p. 311-312. In A.L. Page (ed.) *Methods of soil analysis. Part 2.* 2nd ed. Agronomy Monogr. 9. ASA, Madison, WI.
- Olsen, R. J., R. F. Hensler, O. H. Attoe, S. A. Witzel, and L. A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. *Soil Sci. Soc. Am. Proc.* 34:448-452.
- Parks, W. L. and L. Safley. 1982. Corn yields with fertilizer rates from zero to high. *Better Crops with Plant Food.* 67:25-27.
- Parks, W. L. and L. Safley. 1977. No fertilizer, soil test fertilization, and heavy fertilization of corn-What happens with each case? *Tennessee Farm & Home Science.* 102.

Pfaff, J. D., C. A. Brockhoff, and J. W. O'Dell. 1989. The determination of inorganic anions in water by ion chromatography-method 300.0. USEPA 300.0-1. Cincinnati, OH.

Piper, A. M. 1932. Ground water in North-Central Tennessee. Division of Geology. 43. Nashville, Tennessee.

Powell, J. C. and M. E. Springer. 1965. Composition and precision of classification of several mapping units of the Appling, Cecil, and Lloyd series in Walton County, Georgia. Soil Sci. Soc. Am. Proc. 29:454-458.

Ritter, D.F. 1986. Process geomorphology. 2nd ed. W.C. Brown, Dubque, IA.

Ross, S. 1989. Soil processes: A systematic approach. Routledge, Chapman, and Hall, Inc. London.

Russell, E. W. 1988. Russell's soil conditions and plant growth. 10th ed. Alan Wild (ed). Bath Press. Avon, UK.

Safford, J. M. 1869. Geology of Tennessee. S. C. Mercer(printer). Nashville, TN.

Safford, J. M. and J. B. Killebrew. 1867. The elements of the geology of Tennessee. Ambrose Printing Co. Nashville, TN.

Schuman, G. E., T. M. McCalla, K. E. Saxton, and H. T. Knox. 1975. Nitrate movement and its distribution in the soil profile of differentially fertilized corn watersheds. Soil Sci. Soc. Am. Proc. 39:1192-1197.

Seech, A. G. and E. G. Beauchamp. 1988. Denitrification in soil aggregates of different sizes. Soil Sci. Soc. Am. J. 52:1616-1621.

Shuval, H. I. and N. Gruener. 1974. Effects on man and animals of ingesting nitrates and nitrites in water and food. In Effects of agricultural production on Nitrates in Food and Water with Particular Reference to Isotope Studies. IAEA. Vienna, Austria.

Simonson, R. W. 1967. Outline of a generalized theory of soil genesis. p.301-310. In J. V. Drew (ed.) Selected papers in soil formation and classification. Soil Sci. Soc. Am. Madison, WI.

- Sobek, A. A., W. A. Schuller, J. R. Freeman, and R. M. Smith. 1978. Field and laboratory methods applicable to overburdens and mine soils. USEPA 600/2-78-054. Cincinnati, OH.
- Soil Survey Staff. 1990. Keys to soil taxonomy. 4th ed. SMSS technical monograph no. 6. Blacksburg, VA.
- Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS. Agric. Handb. 436. U.S. Gov. Print. Office, Washington, D.C.
- Soil Survey Staff. 1981. Soil survey manual. Chapter 4. USDA Handb. 18. U.S. Gov. Print Office, Washington, D.C.
- Soil Survey Staff. 1968. Soil survey: Robertson County, Tennessee. USDA-SCS. U. S. Gov. Print. Office. Washington, D. C.
- Sommerfeldt, T. G., C. Chang, and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Sci. Soc. Am. J. 52:1668-1672.
- Sowden, F. J. and H. J. Atkinson. 1968. Effect of long-term additions of various organic amendments on the organic matter content of a clay and a sand. Can. J. Soil Sci. 48:323-330.
- Springer, M. E. and J. A. Elder. 1980. Soils of Tennessee. University of Tennessee Agri. Exper. Stat. Bull. 596. Knoxville, TN.
- Stewart, B. A., L. K. Porter, and W. E. Beard. 1964. Determination of total nitrogen and carbon in soils by a commercial Dumas apparatus. Soil Sci. Soc. Proc. 28:366-368.
- Sweeten, J. M. and A. C. Mathers. 1985. Improving soils with livestock manure. J. Soil and Water Cons. 206-210.
- Thompson, M. L., N. Fedoroff, and B. Fournier. 1990. Morphological features related to agriculture and faunal activity in three loess-derived soils in France. Geoderma. 46:329-349.
- Tisdale, S. L., W. L. Nelson, and J. D. Beaton. 1985. Soil fertility and fertilizers. New York.

- Troeh, F.R., J. A. Hobbs, and R. L. Donahue. 1980. Soil and water conservation for productivity and environmental protection. Prentice-Hall, Inc. Englewood Cliffs, N. J.
- U. S. Environmental Protection Agency. 1991. Phase II fact sheet: National primary drinking water regulations for 38 inorganic and synthetic organic chemicals. USEPA Rep 68-03-3432. U. S. Gov. Print. Office, Washington, DC.
- U. S. Geological Survey. 1980. Greenbrier quadrangle topographical map.
- Wascher, H. L., R. P. Humbert, and J. G. Cady. 1947. Loess in the Southern Mississippi valley: Identification and distribution of the loess sheets. Soil Sci. Soc. Amer. Proc. 12:389-399.
- Wilding, L. P. and L. R. Drees. 1983. Spatial variability and pedology. p. 83-166. In L. P. Wilding, N. E. Smeck, and G. F. Hall (eds.) Pedogenesis and soil taxonomy: I. Concepts and interactions. Elsevier. NY.

APPENDICES

APPENDIX A

EXPLANATION OF ABBREVIATIONS USED IN THE

MORPHOLOGY AND MEHLICH I TABLES

I. Soil Texture.

A. Modifiers of soil texture

gr = gravelly

B. Texture classes.

sil = silt loam

sicl = silty clay loam

sic = silty clay

II. Soil structure.

A. Grade of structure.

1 = weak

2 = moderate

B. Size of structure.

f = fine

m = medium

C. Type of structure.

gr = granular

sbk = subangular blocky

abk = angular blocky

III. Moist consistence.

fr = friable

fi = firm

IV. Mehlich I elements

Al=aluminum

As=arsenic

B=boron

Ca=calcium

Cd=cadmium

Cr=chromium

Cu=copper

Fe=iron

K=potassium

Mg=magnesium

Mn=manganese

Na=sodium

Ni=nickel

P=phosphorus

Pb=lead

Si=silica

Sr=strontium

Zn=zinc

APPENDIX B
SITE CHARACTERISTICS

Location: University of Tennessee
Highland Rim Experiment Station
Springfield, Tennessee

Latitude/Longitude: 86° 49' 30" N 36° 28' 40" W

Elevation: 280 meters above mean sea level

Aspect: East

Slope: 2-3 %

Vegetation: Agricultural plots 3, 4, 7, and 8 =
continuous corn
Control sites = grasses, fescue, orchard
grass

APPENDIX C
SOIL MORPHOLOGY

SITE 1

- A1 0-6 centimeters; dark brown (10 YR 4/3) silt loam; moderate, fine, granular structure; friable; strongly acid; clear, smooth boundary.
- A2 6-26 centimeters; dark yellowish brown (10 YR 4/4) silt loam; few, prominent yellowish red (5 YR 5/8) mottles; weak, fine, subangular blocky structure; friable; few iron concretions; medium acid; clear, smooth boundary.
- Bt1 26-47 centimeters; yellowish brown (10 YR 5/6) silt loam; weak, fine, subangular blocky structure; friable; strongly acid; clear, smooth boundary.
- Bt2 47-61 centimeters; yellowish brown (10 YR 5/6) silty clay loam; few, prominent yellowish red (5 YR 5/8) mottles; weak, medium, subangular blocky structure; friable; few iron concretions; 2% coarse fragments; very strong acid; clear, smooth boundary.
- 2Bt3 61-81 centimeters; yellowish brown (10 YR 5/6) silt loam; moderate, medium, subangular blocky structure; friable; horned coral fossil; 4% coarse fragments; very strong acid; clear, smooth boundary.
- 2Bt4 81-102 centimeters; yellowish brown (10 YR 5/4) silty clay loam; few, prominent gray (10 YR 6/1) and few, distinct yellowish red (5 YR 5/8) mottles; moderate, medium, subangular blocky structure; friable; 13% coarse fragments; very strong acid; clear, smooth boundary.
- 2Bt5 102-120 centimeters; yellowish brown (10 YR 5/8) silty clay loam; common, prominent yellowish red (5 YR 5/8) and common, distinct light gray (10 YR 7/2) mottles; moderate, medium, subangular blocky structure; firm; 14% chert fragments; fragic properties, 40% brittleness; very strong acid; clear, smooth boundary.
- 3Bt6 120-130 centimeters; red (2.5 YR 4/6) gravelly silty clay; common, prominent light gray (10 YR 7/2), and common, distinct yellowish red (5YR 5/8) mottles; moderate, medium, angular blocky structure; firm; 20% chert fragments; fragic properties, 40% brittleness; very strong acid; abrupt, smooth boundary.

3Bt7 130-158 centimeters; red (2.5 YR 4/6) silty clay; common, prominent yellowish brown (10 YR 5/6) and gray (10 YR 6/1) mottles; moderate, medium, angular blocky structure; firm; 13% chert fragments; very strong acid; clear, smooth boundary.

3Bt8 158-185+ centimeters; red (2.5 YR 4/6) clay; common, prominent strong brown (7.5 YR 5/8) and light gray (10 YR 7/1) mottles; strong, medium, angular blocky structure; firm; 14% chert fragments; very strong acid.

SITE 2

- A 0-38 centimeters; dark brown (10 YR 4/3) silt loam; few, prominent yellowish red (5 YR 4/6) mottles; weak, fine, subangular blocky structure; friable; medium acid; clear, smooth boundary.
- Bt1 38-62 centimeters; yellowish brown (10 YR 5/6) silt loam; weak, fine, subangular blocky structure; friable; strongly acid; clear, smooth boundary.
- 2Bt2 62-93 centimeters; yellowish brown (10 YR 5/6) silt loam; common, faint light brownish gray (10 YR 6/2) mottles; weak, medium, subangular blocky structure; friable; few iron concretions; very strong acid; gradual, smooth boundary.
- 2Bt3 93-120 centimeters; yellowish brown (10 YR 5/6) silt loam; few, prominent yellowish red (5 YR 5/8) and common, distinct light brownish gray (10 YR 6/2) mottles; weak, fine, angular blocky structure; firm; few iron concretions; fragile properties, 20% brittleness; very strong acid; clear, smooth boundary.
- 3Bt4 120-185+ centimeters; red (2.5 YR 4/8) silty clay; few, prominent yellowish brown (10 YR 5/8) and light gray (10 YR 7/1) mottles, common, prominent very pale brown (10 YR 7/4) mottles; moderate, medium, angular blocky structure; firm; 2% coarse fragments; very strong acid; a yellowish brown (10 YR 6/6) tongue of silt loam material came in at 143 centimeters.

SITE 3

- Ap1 0-13 centimeters; dark yellowish brown (10 YR 4/4) silt loam; weak, medium, subangular blocky and weak, medium granular structure; friable; medium acid; clear, smooth boundary.
- Ap2 13-28 centimeters; dark brown (10 YR 4/3) silt loam; few, faint dark yellowish brown (10 YR 4/6) mottles; weak, medium, subangular blocky structure; friable; slightly acid; abrupt, smooth boundary.
- Bt1 28-51 centimeters; dark yellowish brown (10 YR 4/6) silt loam; common, distinct yellowish brown (10 YR 5/8) and light brownish gray (10 YR 6/2) mottles; weak, medium, subangular blocky structure; friable; very strong acid; clear, smooth boundary.
- 2Bt2 51-83 centimeters; reddish brown (2.5 YR 5/4) silt loam; common, distinct dark brown (7.5 YR 4/4) and light brownish gray (10 YR 6/2) mottles; moderate, medium, subangular blocky structure; friable; 2% coarse fragments; extremely acid; clear, smooth boundary.
- 3Bt3 83-110 centimeters; dark red (2.5 YR 3/6) silty clay loam; many, distinct yellowish brown (10 YR 5/6) and light brownish gray (10 YR 6/2) mottles; moderate, medium, subangular blocky structure; friable; extremely acid; clear, smooth boundary.
- 3Bt4 110-123 centimeters; yellowish red (5 YR 4/6) silty clay loam; many, distinct red (2.5 YR 4/6) and light brownish gray (10 YR 6/2) mottles; moderate, medium, subangular blocky structure; friable; extremely acid; clear, smooth boundary.
- 3Bt5 123-150+ centimeters; yellowish red (5 YR 4/6) silty clay loam; common, distinct gray (10 YR 6/1) mottles; moderate, medium, subangular blocky structure; friable to firm; extremely acid.

SITE 4

- Ap1 0-18 centimeters; brown (10 YR 5/3) silt loam; moderate, fine subangular blocky and moderate, medium granular structure; friable; slightly acid; clear, smooth boundary.
- Ap2 18-29 centimeters; yellowish brown (10 YR 5/4) silt loam; weak, medium, subangular blocky and moderate fine granular structure; friable; slightly acid; abrupt, smooth boundary.
- Bt1 29-46 centimeters; yellowish brown (10 YR 5/6) silt loam; weak, medium, subangular blocky structure; friable; thin, discontinuous clay films; strongly acid; clear, smooth boundary.
- Bt2 46-64 centimeters; yellowish brown (10YR 5/6) silt loam; moderate, medium, subangular blocky structure; friable; few manganese concretions; 2% coarse fragments; very strong acid; clear, smooth boundary.
- Bt3 64-85 centimeters; light yellowish brown (10 YR 6/4) silt loam; few, distinct pinkish gray (7.5 YR 6/2) mottles; moderate, medium, subangular blocky structure; friable; extremely acid; clear, smooth boundary.
- 2Bt4 85-99 centimeters; strong brown (7.5 YR 5/6) silty clay loam; common, distinct grayish brown (10 YR 5/2) mottles; moderate, medium, subangular blocky structure; friable; extremely acid; clear, smooth boundary.
- 2Bt5 99-110+ centimeters; yellowish red (5 YR 4/6) silty clay loam; common, distinct yellowish brown (10 YR 5/6) and grayish brown (10 YR 5/2) mottles; moderate, medium, subangular blocky and moderate, medium platy structure; firm; extremely acid.

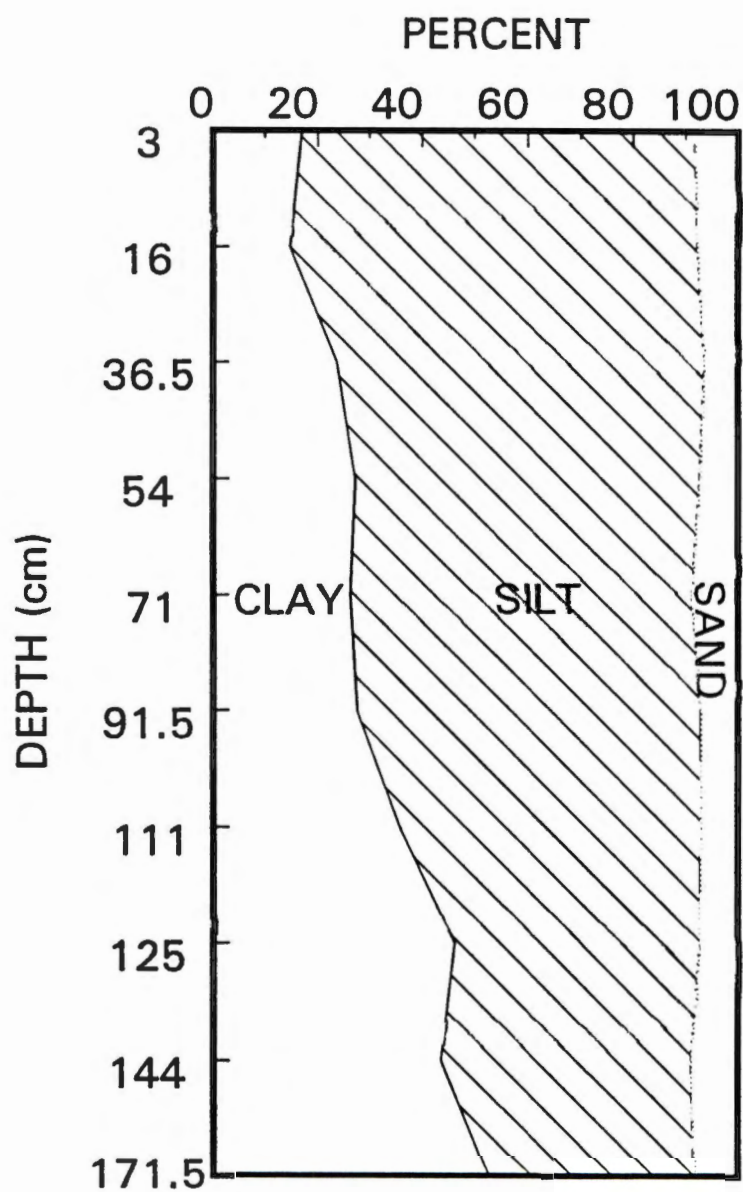
SITE 7

- Ap1 0-16 centimeters; dark brown (10 YR 4/3) silt loam; few, prominent yellowish red (5 YR 4/6) mottles; weak, medium, subangular blocky and weak, medium granular structure; friable; medium acid; clear, smooth boundary.
- Ap2 16-33 centimeters; dark yellowish brown (10 YR 4/4) silt loam; few, prominent yellowish red (5 YR 4/6) mottles; weak, medium, subangular blocky structure; friable; slightly acid; abrupt, smooth boundary.
- Bt1 33-61 centimeters; dark yellowish brown (10 YR 4/6) silt loam; moderate, medium, subangular blocky structure; friable; very strong acid; clear, smooth boundary.
- 2Bt2 61-82 centimeters; yellowish brown (10 YR 5/6) silt loam; many, prominent yellowish red (5 YR 4/6) and light brownish gray (2.5 Y 6/2) mottles; moderate, medium, subangular blocky structure; friable; 7% coarse fragments; extremely acid; clear, smooth boundary.
- 2Bt3 82-111 centimeters; yellowish brown (10 YR 5/4) silt loam; common, distinct yellowish red (5 YR 4/6) and light brownish gray (2.5 Y 6/2) mottles; weak, medium, subangular blocky structure; friable; 10% coarse fragments; extremely acid; clear, smooth boundary.
- 2Bt4 111-128 centimeters; dark yellowish brown (10 YR 4/6) silt loam; many, prominent light brownish gray (2.5 Y 6/2) and yellowish red (5 YR 4/6) mottles; moderate, fine, subangular blocky structure; friable; 7% coarse fragments; extremely acid; clear, smooth boundary.
- 3Bt5 128-158+ centimeters; yellowish red (5 YR 4/6) silty clay loam; common, distinct dark yellowish brown (10 YR 4/6) mottles; moderate, fine, subangular blocky structure; friable; 14% coarse fragments; extremely acid.

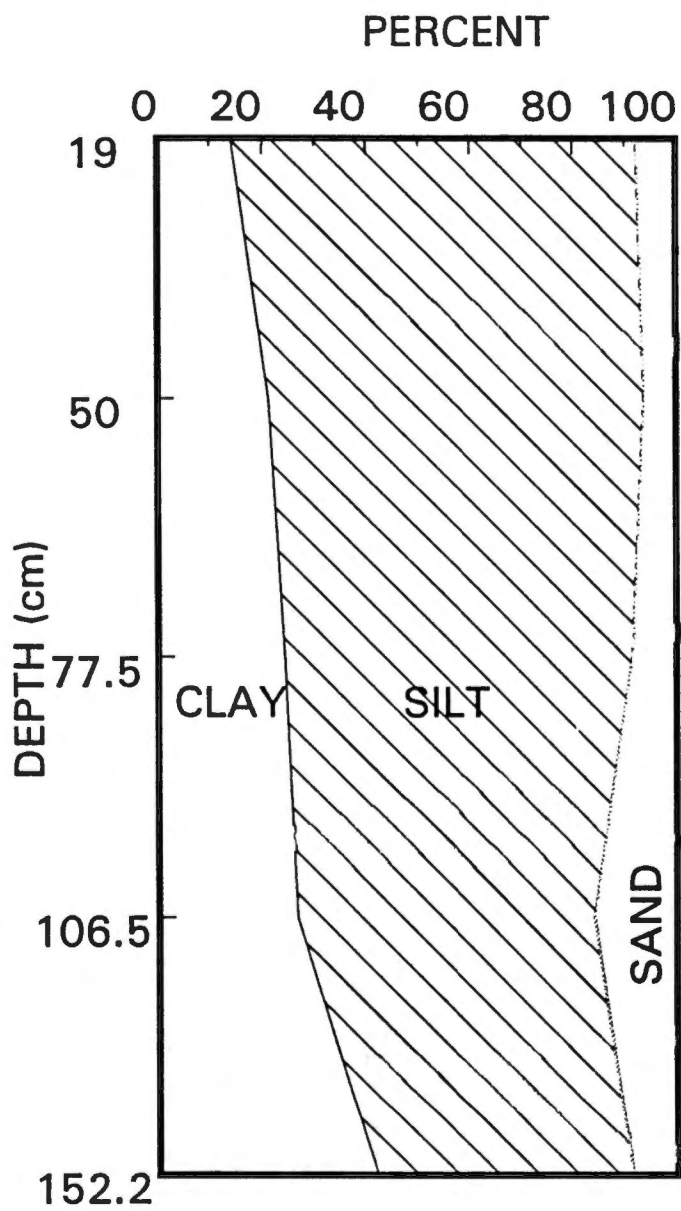
SITE 8

- Ap1 0-19 centimeters; brown (10 YR 5/3) silt; weak, medium, subangular blocky and weak, medium granular structure; friable; medium acid; clear, smooth boundary.
- Ap2 19-36 centimeters; brown (10 YR 5/3) silt loam; common, distinct strong brown (7.5 YR 4/6) mottles; weak, fine to medium, subangular blocky structure; friable; slightly acid; clear, smooth boundary.
- Bt1 36-71 centimeters; yellowish brown (10 YR 5/8) silt loam; moderate, medium, subangular blocky structure; friable; slightly acid; clear, smooth boundary.
- 2Bt2 71-96 centimeters; yellowish brown (10 YR 5/6) silt loam; few, distinct strong brown (7.5 YR 5/8) and common, faint light brownish gray (10 YR 6/2) mottles; moderate, fine to medium, subangular blocky structure; friable; fossil; extremely acid; clear, smooth boundary.
- 2Bt3 96-120 centimeters; yellowish brown (10 YR 5/6) silt loam; common, faint light brownish gray (10 YR 6/2) and strong brown (7.5 YR 5/8) mottles; weak, fine, subangular blocky structure; friable; few iron and manganese concretions; 5% coarse fragments; extremely acid; clear, smooth boundary.
- 3Bt4 120-148 centimeters; red (2.5 YR 4/6) silty clay loam; common, prominent brown (7.5 YR 5/4) and light gray (10 YR 7/2) mottles; moderate, fine, subangular blocky structure; friable; 4% coarse fragments; extremely acid; gradual, smooth boundary.
- 3Bt5 148-186 centimeters; red (2.5 YR 4/6) silty clay; common, prominent light brown (7.5 YR 6/4) and light gray (10 YR 7/2) mottles; moderate, fine, subangular blocky structure; friable; 2% coarse fragments; extremely acid; gradual, smooth boundary.
- 3Bt6 186-206+ centimeters; dark red (2.5 YR 3/6) silty clay; common, prominent light brown (7.5 YR 6/4) and light gray (10 YR 7/2) mottles; moderate, fine, subangular blocky structure; friable; 3% coarse fragments; extremely acid.

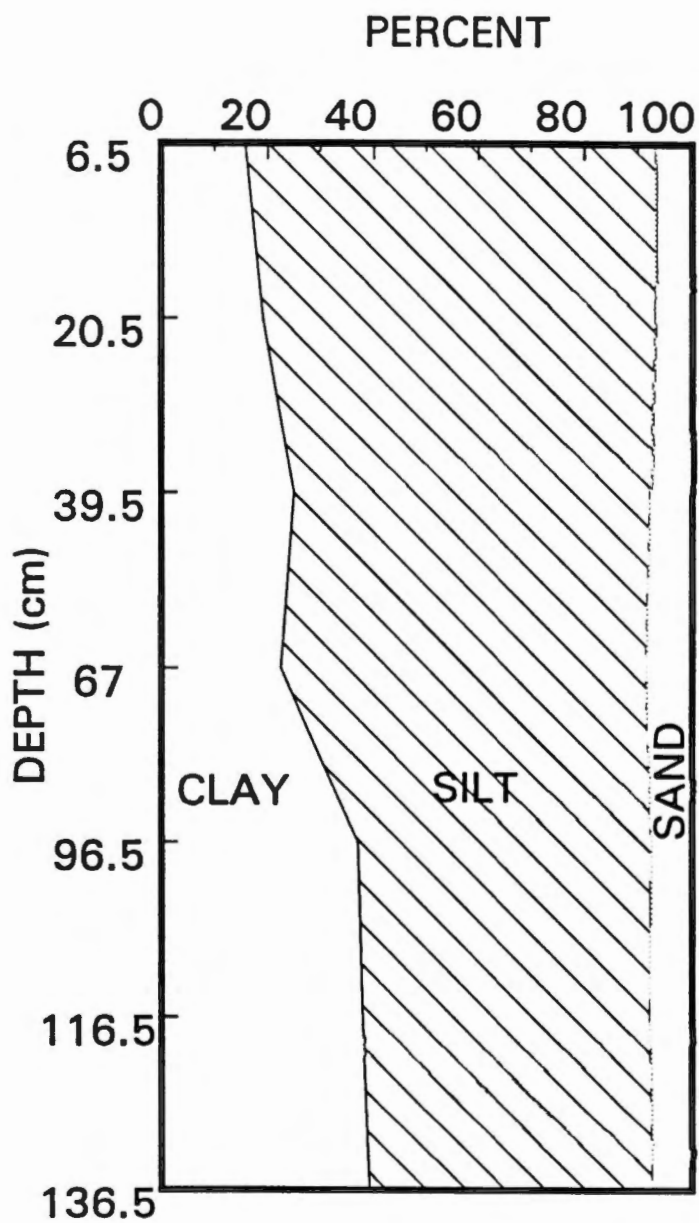
APPENDIX D
GRAPHS OF PARTICLE SIZE DATA



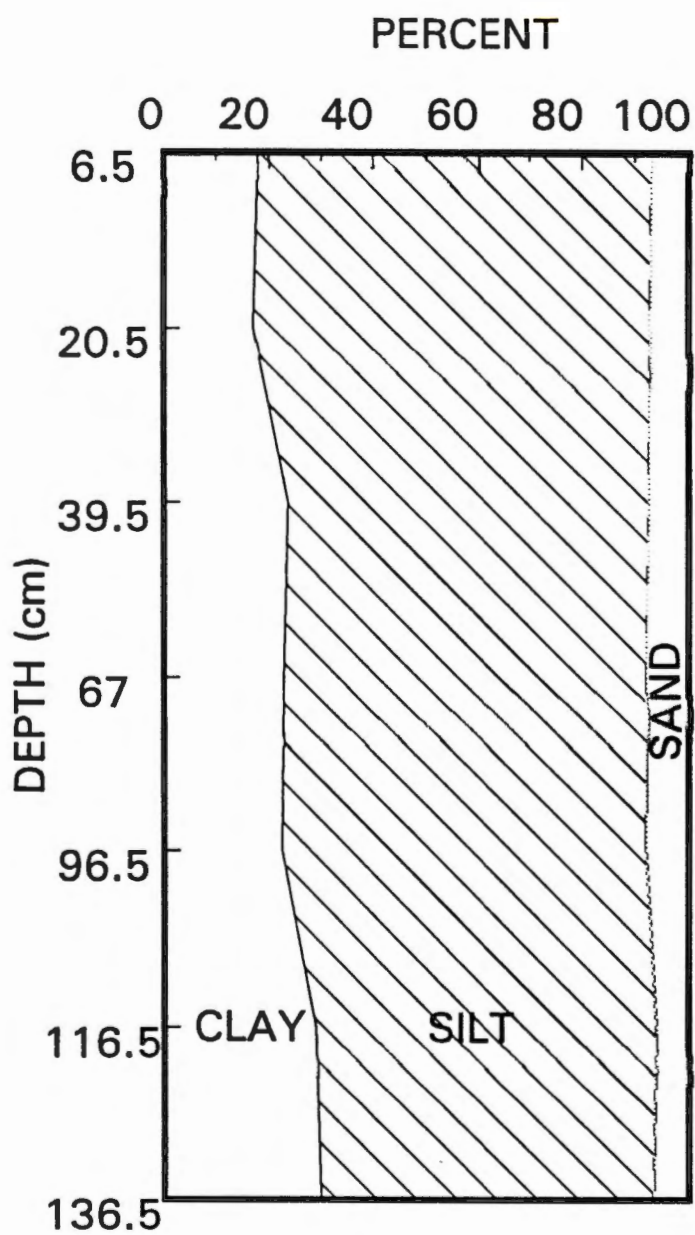
Sand, silt, and clay distribution in the soil profile at site 1.



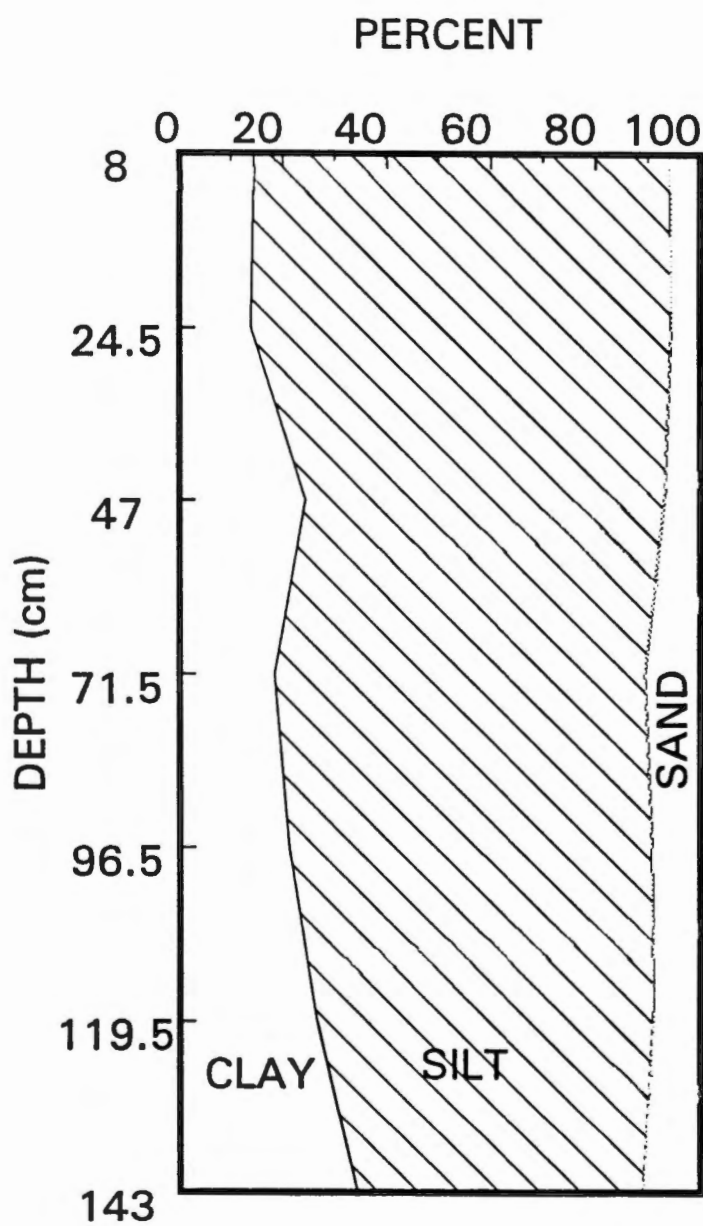
Sand, silt, and clay distribution in the soil profile at site 2.



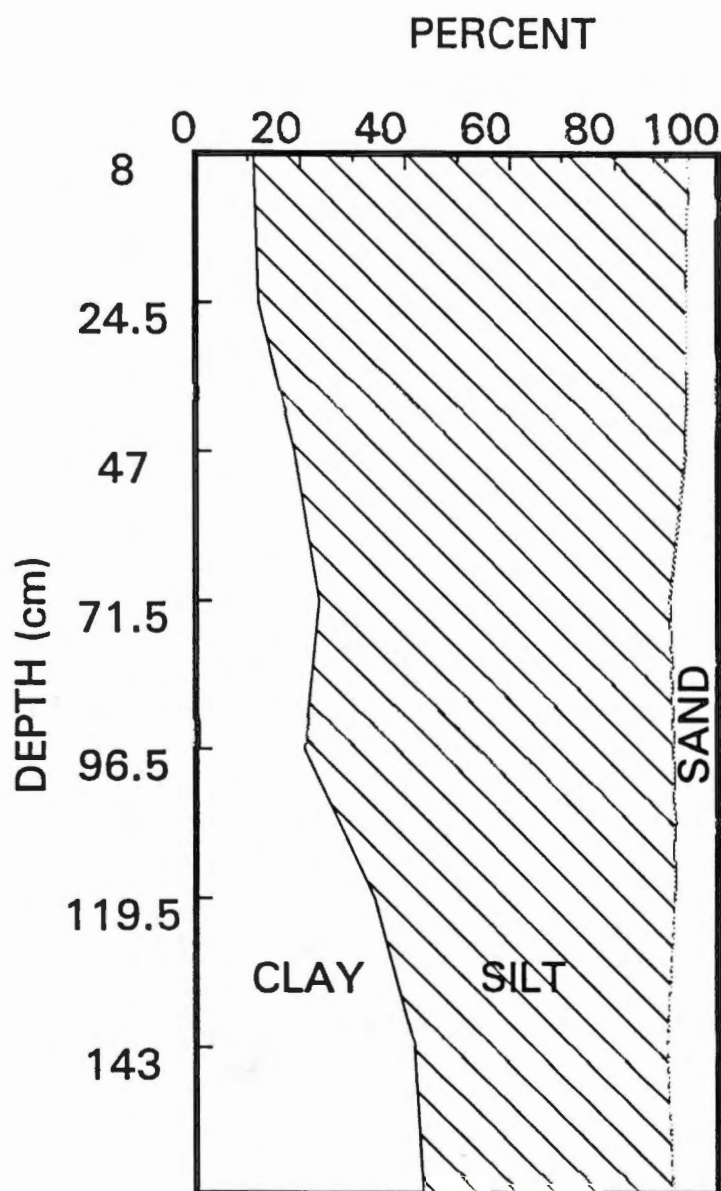
Sand, silt, and clay distribution in the soil profile at site 3.



Sand, silt, and clay distribution in the soil profile at site 4.



Sand, silt, and clay distribution in the soil profile at site 7.



Sand, silt, and clay distribution in the soil profile at site 8.

VITA

Janice Lee Branson was born on June 30, 1954 in Knoxville, Tennessee to Mr. and Mrs. James H. Branson, Jr.. She completed elementary, middle, and high school in the Knox County School System. Upon graduation from Gibbs High School in 1972, she entered Carson-Newman College. She was a member of Epsilon Alpha Gamma and the softball team. She was very active in all intermural sports. In 1976, she graduated with a B. S. in Physical Education and Health.

While at Carson-Newman, she realized teaching physical education was not the career she desired. She entered the University of Tennessee in fall of 1977 as an animal science major in the College of Agriculture.

With the onset of financial problems, Janice began working in the Redraw Department at Robertshaw Controls in Knoxville. In thirteen years, she worked almost every job available in the department, including two years as assistant foreman. During this time, she realized, there was more to life than she was getting.

She re-enrolled in the University of Tennessee in the College of Agriculture as a full-time student, while continuing to work full-time at Robertshaw Controls. During this time, she participated in soil judging for two years and became interested in soils as a career. She was also a member of the Plant and Soil Science Club, the Soil and Water

Conservation Society, and Alpha Zeta fraternity. She graduated with a B. S. in Agriculture with a major in plant and soil science in 1990.

In August, 1990, she entered the Institute of Agriculture and the University of Tennessee to pursue a Master of Science degree in plant and soil science. She is presently a member of Gamma Sigma Delta honor society, a student member of the American Society of Agronomy, and a member of the Soil and Water Conservation Society.

Upon completion of the M. S. degree, she has been hired to work on a background soils study on a grant received by the University of Tennessee through Oak Ridge National Laboratory.