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Soil water movement along a loess and alluvium interface in West Tennessee

Holly Ann Carter

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To the Graduate Council:

I am submitting herewith a thesis written by Holly Ann Carter entitled "Soil water movement along a loess and alluvium interface in West Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

John T. Ammons, Major Professor

We have read this thesis and recommend its acceptance:

Ron Yoder, Michael Essington, Vernon Reich

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Dr. John T. Ammons, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

CW Minkel

Associate Vice Chancellor
and Dean of the Graduate School

SOIL WATER MOVEMENT ALONG A LOESS AND ALLUVIUM INTERFACE IN WEST TENNESSEE

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

Holly Ann Carter
December, 1996

DEDICATION

This thesis is dedicated to: my parents, Robert and Linda Carter; my sister, Kimberly Carter; my grandparents, Hubert and Jessie Arnold, and Farmer and Marjorie Carter; and my dearest friends, Elizabeth Abel, Dana Andrzejewski, the Bentley family, Daniel Guzynski, Shannon Shaw, Marcy Storck, and Nathan Storck. The love and support of these people, through my achievements and frustrations, has made the success of my education possible.

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Thank-you foremost to my major professor Dr. John T. Ammons, for not only providing me with an invaluble opportunity to learn, but also for helping me to make the most of it with immeasurable patience and guidance. Much appreciation is given to Dr. Ron Yoder, for his involvement in both field and laboratory aspects of this thesis. I also wish to thank the other members of my committee, Dr. Michael Essington and Dr. Vernon Reich, for their helpful comments and suggestions throughout the thesis writing process. The assistance of my co-workers was irreplaceable; Janice Branson, Kristy Brooks, Alex Brown, Luis Donado, Shane Gaither, Sonja Gaither, Anthony Khiel, Melissa Oliver, Richard Roy, and Nathan Storck. I would also like to extend sincere thanks Daniel Smith for all of his contributions at the Ames Plantation Experiment Station, and to the rest of the staff at the Ames Plantation for their assistance and co-operation.

ABSTRACT

Ongoing water quality research at the University of Tennessee Ames Plantation Agricultural Experiment Station in west Tennessee, has provided opportunity to examine the factors affecting soil water movement, for applications in determining the fate of agricultural chemicals. This research was to create a high intensity, order one soil survey map of the research plot, and to examine the effects of soil morphology on the direction of soil water movement.

In order to establish general morphology of the research area, four soil cores equally spaced in a 15.24 meter linear transect were taken with a Giddings-S-M hydraulic probe using a 7.62 cm sampling tube. Morphology of each core was recorded in the field. Individual horizons of each core were sampled and taken to the laboratory for determination of: total carbon, particle size, citrate-dithionite extractable iron oxides, KCl exchangeable acidity, hydroxylamine-hydrochloride extractable manganese, exchangeable bases, cation exchange capacity, free carbonates, and pH. Moist sub-samples of each horizon were refrigerated for determination of background chloride levels. Based on field morphology notes and laboratory data, the four transect cores were classified to the family level, as fine-silty, mixed, thermic Typic Hapludalfs.

The soil morphology for 32 cores surrounding a 0.05 hectare release area on the research plot were recorded. Alluvium was found underlying the surface loessial layer across the entire plot. Based on the depth to this alluvial paleosol and soil morphology, a high intensity, order one soil survey map was created. Surface and paleosurface topography and 3-dimensional surface maps were also made based on measured elevations and depths.

Shallow sampling wells were set to the depth of the alluvium in each of the 32 holes where the cores were taken. A prediction as to which wells would receive water based on their topographic position on the alluvial surface, and also a prediction of the general expected direction of movement across the plot were made. A 527 m^2 tracer release area was established in the center of the previously designated release area. A calcium chloride tracer solution was applied to the release area and allowed to move into and through the soil, after which wells that yielded water were sampled. A total of two background and three post-release sampling events occurred. Ion-chromatography results reflecting background and post-release chloride levels were statistically inconclusive, and could not be used to prove or disprove the validity of the prediction. Instead, the presence of water samples in a well on all three sampling dates was considered to make that well a consistent receptor. While individual wells were not very successfully predicted, the general direction of soil water movement was quite accurately forecasted.

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CHAPTER ONE

SOIL GENESIS AND MAPPING OF A SOIL WATER RESEARCH PLOT

Introduction

Research was conducted on the University of Tennessee Ames Plantation Agricultural Experiment Station in southwest Tennessee, located on the border of Fayette and Hardeman Counties (Figure 1). The Ames Plantation experiment station of approximately 7422 hectares has a rich history. A generous arrangement was made by Julia Ames after her husband Hobart Ames died in 1945, to make the plantation a University of Tennessee research facility in 1950. Hobart Ames had purchased the plantation land in 1901. The Ames' love for bird dog hunting and past of old south plantation farming were preserved in several locations. Buildings and activities, such as the beautiful horse stables and the annual bird dog trials, were maintained on the experiment station.

Since becoming a University of Tennessee facility, the experiment station has been used for research in many different areas of agriculture and natural resource studies. The Animal Science, Veterinary Medicine, Forestry, Wildlife, Plant and Soil Science, and Agricultural Engineering departments are prominent users of the land for research on topics ranging from dairy and beef cattle grazing to agricultural water quality (Livingston, 1993).

Opportunity for this thesis came about via the water quality research

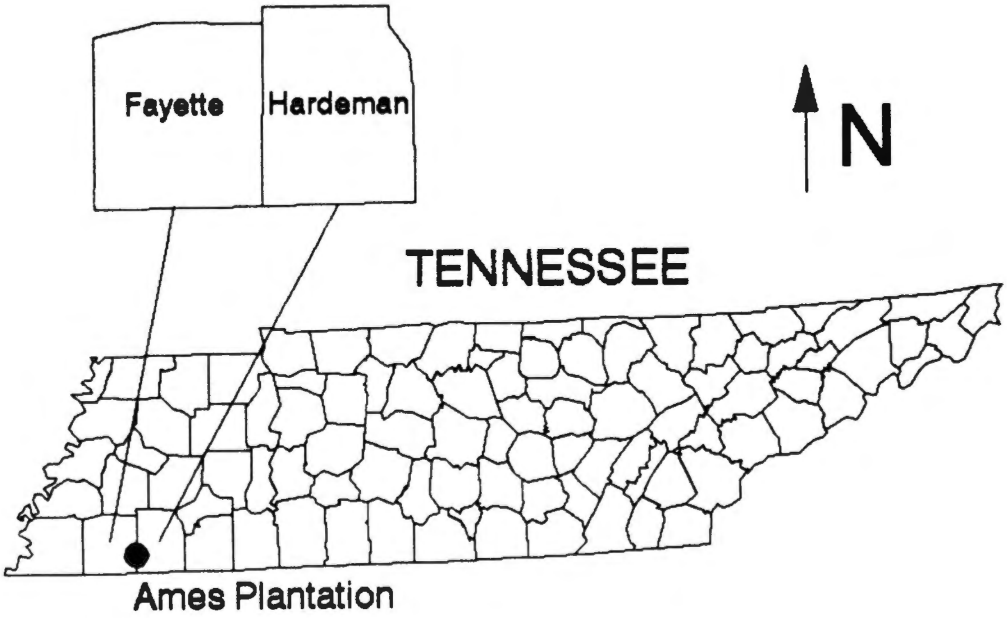


Figure 1. General location map of the Ames Plantation in Tennessee.

already being conducted at the station. Livingston (1993) concluded that soil morphology played a pertinent role in soil water movement, and determined it to be a very important factor in predicting transport and fate of agricultural chemicals.

On the surface, water moves from higher elevations to lower ones. Following this line of thought, it was proposed that water being perched in a soil profile by a discontinuity would also move from higher to lower topographic points of that restrictive layer. The objectives of this study were to: 1) confirm genesis and morphology across the research plot 2) prepare surface and paleosol topography maps of the research plot, and 3) create an order 1, high intensity soil map of a research plot.

Literature Review

<u>Soil Genesis</u>

To thoroughly understand the morphology of any soil profile, we must consider its genesis. Jenny (1941) stated that one must consider climate, organic matter, relief, parent material, and time in a study of soil formation. Rode (1961) suggested soil was a dynamic system, and the soil forming process was part of a continuous cycle of matter and energy. Gravity and groundwater were suggested as factors in addition to those of Jenny (1941), although these are considered more obvious and often assumed. These soil forming factors were related to soil genesis in an equation where soil formation was a function of climate, organics, relief, and parent material over time (s = f [(cl,o,r,p)t]).

Many attempts have been made to "solve" the equation using simple statistical methods. Scientists such as Levine and Ciolkosz (1986) developed computer simulation models to simulate processes of soil formation, and their ultimate effects. This particular model provided a simplified simulation of leaching, acidification, and associated processes in humid, temperate climates.

Climate was determined to be the primary source of moisture and heat energy for soil, providing matter and energy from moving air (Rode, 1961; Paton, 1978; Duchaufor, 1982; Buol et al., 1989). Moisture was necessary to allow weathering, leaching, and new mineral formation. While heat, as in most chemical reactions, facilitated or even catalyzed these reactions.

Rabenhorst and Wilding (1986) concentrated on the effects of precipitation in calcareous soils in subhumid, semiarid, and arid regions, considering temperature only as it was related to evaporation. A definite difference was noted from dry to humid areas of the research. Soils of the dryer research location contained calcareous, calcic, and petrocalcic horizons. Non-calcareous sola were found in the humid area, with argillic horizons forming on stable landforms.

Griffin and Rabenhorst (1989) also noted the definite effects of post glacial climatic change on the formation of tidal marsh soils along the Atlantic coast of the United States. The climate change came with glacial recession, melting, and subsequent ocean warming. This climate change allowed new plant species to flourish.

Plant debris is the prime source of organic matter in soil, although many microorganisms, small animals, and even humans contribute significantly (Rode, 1961; Paton, 1978; Duchaufor, 1982; Buol et al., 1989). Physical remnants of small animals (e.g. burrowing) and human activity (e.g. compaction) affect the genesis of soil. A number of complex biochemical interactions (e.g. humification) also alter the material making up the soil.

Zhang et al. (1988) investigated the effects of vegetation with 120 years of cultivation on soils. The other soil forming factors were held as constant as possible. Prairie soils with mollic epipedons had higher organic carbon and total nitrogen than did ochric epipedons of forested soils. Cultivated soils had lower organic carbon and total nitrogen than uncultivated ones.

Griffin and Rabenhorst (1989) showed that organic matter content, iron availability, and several other factors all affect the microbial sulfate reduction of sulfate-sulfur to pyrite. Roberts et al. (1988b) showed that organic carbon content, accumulated by large manual additions of sewage sludge, was the dominating factor in the chemical make-up of weakly buffered minesoil reclamation attempts. Dissolution, leaching, oxidation, and organic matter accumulation/decomposition were also considered as factors over given periods of time.

Time was an extremely important factor in the formation of soil, because it controlled the extent to which the other factors contributed to soil formation. The soil forming factors themselves changed with time, as with a climatic change over time (Rode, 1961; Paton, 1978; Duchaufor, 1982; Buol et al., 1989). Changes in the factors over time affected the importance of each in soil formation over time.

Topography and relief were shown to be very important as major controls of climate and fluvial activity (Rode, 1961; Paton, 1978; Duchaufor, 1982; Buol et al., 1989). As local relief increases, and topography is more developed, it becomes a greater factor in soil formation.

Rebertus et al. (1989) showed that although loess thickness could not be predicted based on current landforms and relief in Delaware, it was controlled by the paleosurface topography on which it had been deposited. The loess was thicker where it filled lower points in the Coastal Plain paleosurface, and thinner at higher points giving a more level modern day landscape.

Stolt et al. (1993b) examined the relationship between landscape position and soil genesis in a reconstruction analysis of the Piedmont and Blue Ridge Highlands regions of Virginia. Reconstruction analysis is a quantitative determination of gains and losses of soil constituents via soil genesis. Summit and backslope positions were shown to be similar in morphology and clay distribution. Footslope positions showed bisequal soils with lower clay percentages in argillic horizons and less soil development in general.

Moore et al. (1993) studied the effects of water movement through and across a landscape on development of a catena of soils in Colorado. Terrain characteristics were shown to create pathways of flow, and hence affect soil characteristics indirectly. Terrain and soil characteristics were related, and these relationships were used to enhance knowledge of unknown relationships on existing soil maps.

In their study to evaluate the relationships between landscape position and soil genesis, Stolt et al. (1993a) considered the effects of soil variability caused not only by landscape position, but also by parent material. Total variability was shown to be caused by differences among the study sites, landscape positions within the sites, horizons within positions, and various types of random error. Landscape position contributed minimally to variance in this study. Regional climate, and most importantly parent material type were found to be the significant contributors to total variance in soil genesis.

Parent material, which would control the mineral portion of the soil that formed, was determined to be the most important factor of soil genesis. This starting point was where the initial material was exposed to the other soil forming factors. A wide variety of parent materials have been found throughout the world. The many parent materials allowed for the formation of different soil types with many different mineral constituents (Rode, 1961; Paton, 1978; Duchaufor, 1982; Buol et al., 1989).

Differences in parent volcanic ashes and soil temperature regimes were shown to control clay mineral formation in ustic soil moisture regimes in Hawaii (Wada et al., 1990). In a different study of the effects of parent material on soil formation, Roberts et al. (1988a) described how spoil type controlled initial soil texture in a surface mining study in southwest Virginia.

Wysocki et al. (1988) studied the effect of weathering of parent material before soil formation. In the southeastern United States Piedmont region, saprolite was found to be a common parent material. Extensive weathering of saprolite during its formation, stripped the material of its potential chemical and mineralogical influences in soil formation. Normally a soil landscape relationship reflects the parent material, but in this case there was difficulty in determining a soil-geologic pattern.

In the Mississippi River Valley, Quaternary loess has been found to be the surface parent material. Miller and Donahue (1990) defined loess as 60-90% silt, transported and deposited by wind. The silt fraction included those particles ranging in size from 0.05 mm to 0.002 mm. These windblown silts were derived from floodplains of glacial meltwaters or from arid to semi-arid lands (Buol et al., 1989). Even though eolian deposits were composed of both sand and silt, the finer particle size of silt allowed it to be transported further than the sands, hence creating a separate deposit (Scott, 1991).

At least three different aged loess deposits have been detected in the Mississippi River Valley. The loessial depositions originated periglacially, from meltwater of North American glacial activity of the Laurentide Ice Sheet (Forman et al., 1992). This ice sheet was composed of several lobes which extended down from Canada into the northern portions of the United States marked by terminal glacial features.

Different names have been used in the literature in reference to the same loess depositions. Using radiocarbon and thermoluminescence dating results, Norton et al. (1988) found the lowest and oldest deposit to be Loveland, in the Illinoian age group (about 125,000 years B.P.). The Farmdale loess was deposited between 22,000-28,000 years B.P. during the late Wisconsinan in the Farmdalian glacial substage. A thin layer at the bottom of some Farmdale loess was deposited >28,000 years B.P., in the Altonian glacial substage. This intermittent layer was called Roxana silt. The Peoria loess was the most recent deposition, dating about 12,500- 22,000 years B.P., also late Wisconsinan in age but from the Woodfordian glacial substage.

Forman et al. (1992) used both radiocarbon dating of snails and thermoluminescence procedures to determine the age of the three loess depositions. Peoria loess was Wisconsinan aged. Beneath the Peoria was an older Wisconsinan deposit called Roxana loess with a soil formed at the top from the Farmdalian glacial substage within the Wisconsinan. Next was a Sangamonian soil formed in the top of Illinoian aged Loveland loess at the bottom. Loess stratigraphy provides a helpful record of glacial activity, primarily of the Laurentide Ice Sheet in this region.

Norton and Bradford (1985) used a thermoluminescence dating procedure to date the three loess depositions. At that time, they determined this procedure to be only a relative indicator of age. Their work with radiocarbon dating had shown the top two depositions to be Wisconsinan and the bottom one to be Illinoian. The three loess depositions were named Peoria, Farmdale, and Loveland, respectively. Fehrenbacher et al. (1986) called the three layers Peoria, Roxana, and Loveland including Farmdalian only as a small layer above the Roxana. Wascher et al. (1947) described the three deposits as Peorian, Sangamon, and Loveland. Loveland was often referred to as third loess, because a definite correlation of properties could not be made at the time. A "fossil soil", or paleosol (possibly Roxana), was noted to be at the top of the third loess, hence separating it from Sangamon and Peoria.

The main discrepancy appeared to be the area between Peoria and Loveland loess. Figure 2 shows the scheme of Forman et al. (1992). These names will be used as reference for this thesis.

Another aspect of the loessial parent material concerned its thickness. Loess thickness can be predicted based on distance from its source using mathematical models (Frazee et al., 1970). Thickness decreases with distance from the source due to a decrease in particle load with deposition, and lower wind velocities. A more local effect is that finer particles can be transported further than the eolian sands, which will be quickly deposited closer to the source.

Putnam et al. (1988) confirmed that distance from source and strength of wind affected the loessial sedimentation system. Initial coarseness and abundance of the source material, along with width of the source area,

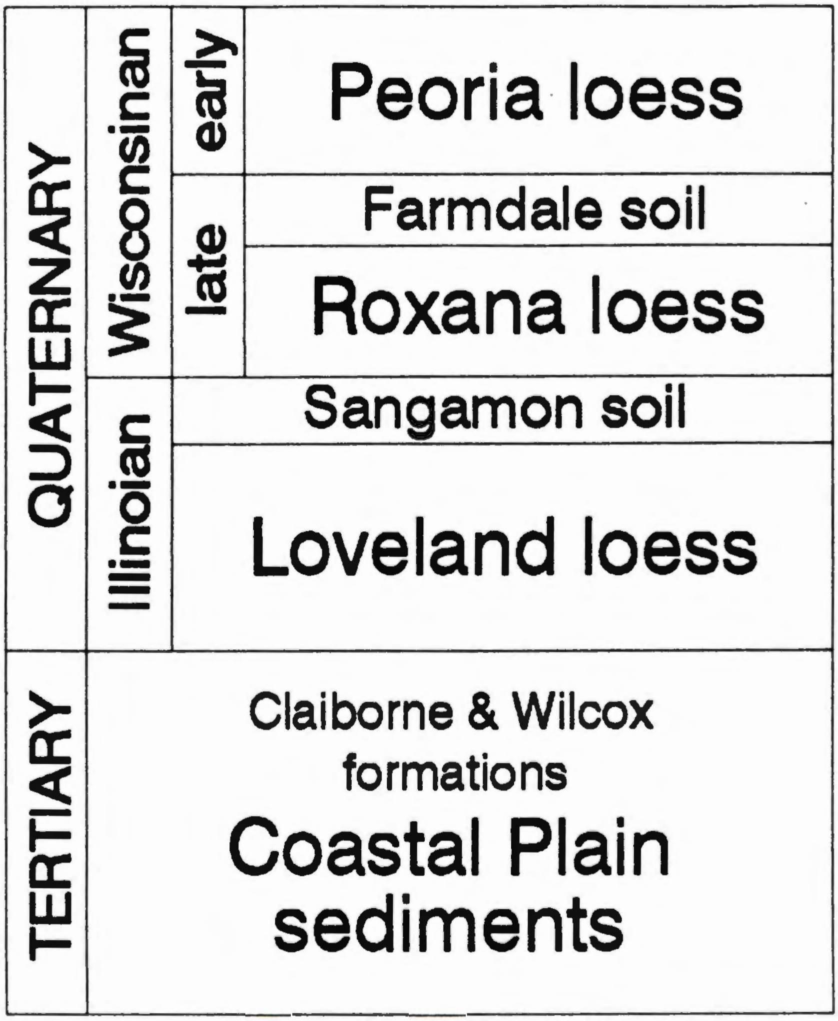


Figure 2. General scheme of parent materials in the lower Mississippi River Valley.

influenced thickness of deposition. Wide valleys associated with the Mississippi River contributed to thicker adjacent loess deposits.

The composition of loess, aside from silt requirements, has been described by Buol et al. (1989) as having an abundance of weatherable minerals. Loess can be calcareous, meaning it contains carbonates and effervesces upon addition of HCl (Soil Survey Staff, 1992). Base saturation may be high indicating the adsorption complex of a soil was highly saturated with exchangeable basic cations. Any clays present are primarily montmorillinite, with some illite and vermiculite. These soils have fairly large nutrient reserves, and hence good fertility (Buol et al., 1989).

In studying a transect of soils in Peoria loess north to south along the Mississippi River Valley, Ruhe (1984) described some compositional characteristics of loess. All soils had textural B horizons, and their bulk densities, cation exchange capacities, extractable iron, and moisture holding capacities were fairly consistent. He stated that these similarities were due to the loess sedimentation system and not climate.

Wascher et al. (1947) described the composition of the three loess deposits in the Mississippi River Valley. The Peoria loess was calcareous and unweathered, containing orthoclase feldspar, quartz, and small amounts of mica. Heavy minerals such as horneblende, epidote, and garnet were also found. The Roxana loess, or Sangamon as they called it, was shown to have much of the same mineral composition with a higher degree of weathering. The Loveland loess was more highly weathered with only the most resistant minerals remaining, such as epidote, zircon, and anatase.

Lewis et al. (1984) used a Coulter Counter TA II to determine a refined particle size distribution within the silt fraction. Samples were taken from Idaho, Montana, Nebraska, Mississippi, and Louisiana. Fifteen size fractions from 2 to 50 microns were separated. There was a gap in the distribution between 40 and 50 microns, indicating a possible break between the processes of saltation and suspension in loess transport. This separation indicated more about mixtures of loess with other materials, distance from source, and possible multiple sources, than the previous standard fine and coarse silt separations had. The process was also found to have potential applications in detecting mixing zones of loess with other materials.

Intermittent alluvial materials have been noted underlying the loess deposits in some areas associated with the lower Mississippi River Valley. An abrupt textural change occurred at the interface between the loess and alluvium. These alluvial depositions also affected the overlying loessial topography. Saucier (1987) identified four Quaternary aged terraces occurring in west Tennessee, where most are capped with loess (Figure 3). Using topographic maps and aerial photos, the terraces were identified over an area including the Obion, Forked Deer, Hatchie, Loosahatchie, and Wolf Rivers. The youngest terrace was the Finley, at about 3 to 7 meters above the current floodplain where the two have not merged. This terrace was flat, well preserved, and easiest to

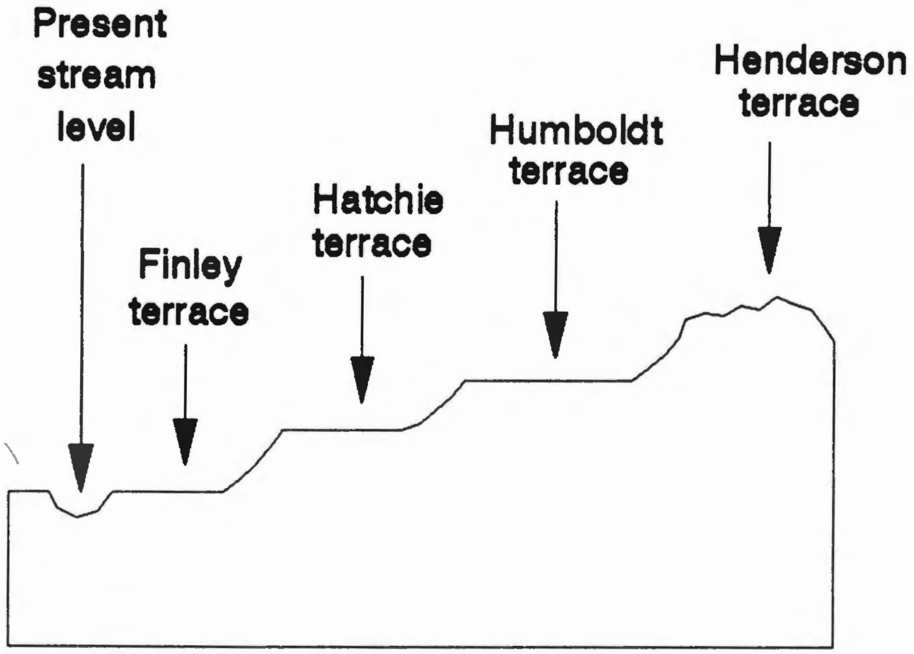


Figure 3. Four Quaternary alluvial terraces present in west Tennessee (Saucier, 1987).

identify. The Finley was composed of lacustrine materials. Lakes were formed as an effect of damming from rapid outwash deposition in the area during the early Wisconsinan.

The second level was the Hatchie terrace at 10 to 15 meters above the current floodplain levels. As the most well preserved, the Hatchie terrace was never a buried or merged feature. There was evidence in some places that this is a lacustrine deposit, while in other places it is a relict floodplain of the former rivers. The terrace formed in a long period of geomorphological stability and was thought to be from the Sangamonian substage.

The Humboldt terrace was the third, paralleling current streams intermittently at about 10-20 meters above the current floodplain. Due to more dissection, and smaller areas of occurrence it was difficult to identify. This terrace was a strictly fluvial deposition from the Yarmouthian substage.

There was difficulty in identification of the fourth due to complicated stream dissection. This oldest terrace was called the Henderson, and was thought to only be present on the Forked Deer River. However, Livingston (1993) found it at the Ames Plantation, associated with the Wolf River. Mapping difficulties with a highly dissected surface, or destruction of the terrace through erosional processes, may explain the lack of presence of the Henderson terrace. An age for this terrace has not been determined.

Tertiary coastal plain sediments of the Claiborne and Wilcox Formations were found as surface materials just east of the Ames Plantation (Hardeman, 1966). The Claiborne formation was comprised mainly of quartz sand and intermittent clay lenses and clay-balls. The sands were poorly to moderately well sorted, deposited by low-gradient streams running across the former low coastal area. Shades of pink, gray, and orange weathered to yellows, oranges, reds, and browns were reported as sand colors. Aside from quartz, mica and other heavy minerals were reported as smaller constituents of the material (Russel and Parks, 1975).

The Wilcox formation was reported to consist of a heterogeneous layer of sand, silt, and clay with a few beds of lignite, kaolin, and siderite. These sediments were not necessarily deposited in a marine environment, but rather in a fluvial one. Sawdust sand, fine-grained sand particles bound together by silt and clay and hence appearing coarse-grained, were characteristic of this formation. Sands showed cross-bedding or no bedding, and were comprised chiefly of quartz. Fossil clay balls were also noted in some places (Russel and Parks, 1975).

An abrupt change in particle size distribution occurred at the contact between the loess and coastal plain sediments where there was no alluvium (Wascher et.al., 1947). Loess sands were very fine, while those in the underlying coastal plain materials range up to gravel size. Laboratory data as well as field observations showed that a pedon had formed in this coastal plain material prior to deposition of the Loveland loess. Springer and Elder (1980) found the coastal plain materials formed a predominantly hilly landscape.

Coastal plain topography then influenced the topography of subsequent depositions.

Soil Mapping

Soil maps are used to delineate areas occupied by different types of soil. These different types of soil have unique sets of interrelated properties characteristic of their parent material, environment, and history (Soil Survey Division Staff, 1993). These properties can be interpreted from a general soil map. There are many specialized uses for soil maps, based mainly on specific soil properties. In many cases, soil maps containing only properties of interest are created for special use.

Transects are commonly used to estimate the composition of the map units in a given area (Soil Survey Division Staff, 1993). In using a transect, it is assumed that the points of the transect line are representative of areas on the land. The transect must cross all parts of the landscape to avoid bias.

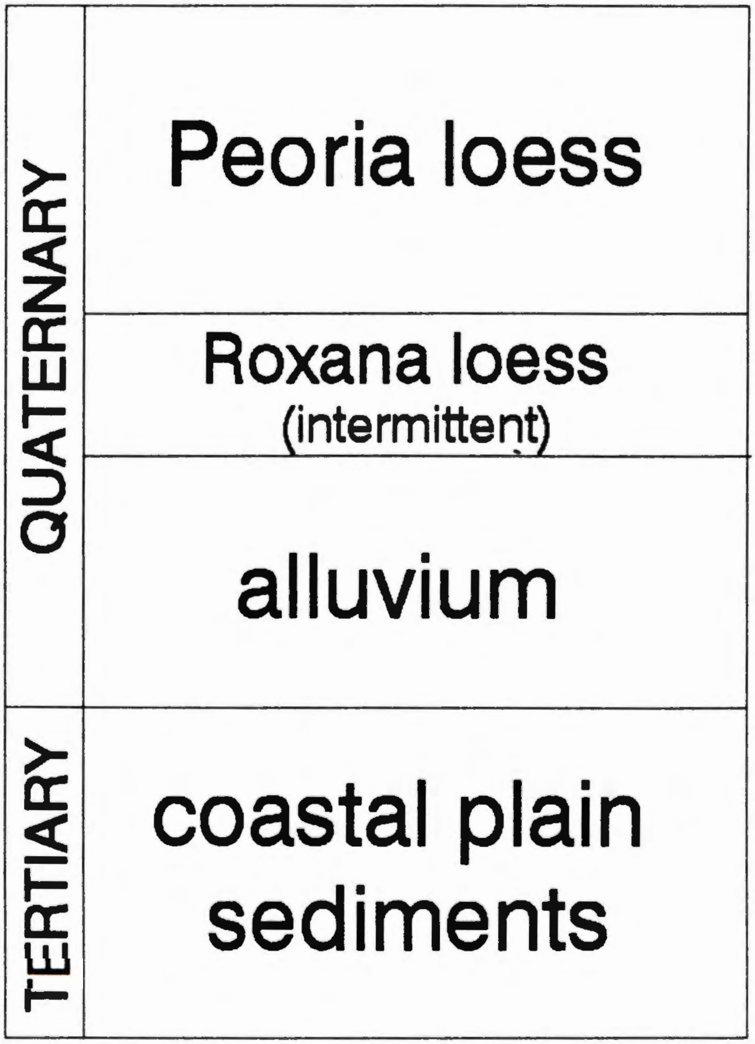
Materials and Methods

Site selection and characteristics

The climate of the region associated with the Ames Plantation was described as having hot summers and mild winters (Flowers, 1960). The annual precipitation was 134.92 cm, slightly higher than the statewide average of 128.27 centimeters.

The general geology of the area was Quaternary loess overlying Quaternary alluvium deposits and Tertiary coastal plain sediments (Figure 4) (Hardeman, 1966). Figure 5 shows the research site location in terms of topography, while Figure 1 showed the general location of the Ames Plantation within Tennessee. Livingston (1993) could not distinguish chemically or morphologically between Peoria and Roxana loess deposits where significant weathering had occurred. Total loess thickness ranged from 1.43 to 3.05 meters on selected research sites at Ames Plantation. Loveland loess was noted as the silt fraction in mixing zones that ranged from 1.44 to 1.52 meters thick. The West Pasture site was underlain by the Humboldt terrace defined by Saucier (1987), while the Henderson terrace was present at the Hancock tract (Livingston, 1993). These terrace levels were associated with the North Fork Wolf River at Ames plantation. Alluvial deposits were found 2.75 to 4.20 meters thick. Determinations from these sites were used as a general guide for parent material designation on the current Centennial Field research site.

The latitude/longitude coordinates of the research site are 35 degrees, 8 minutes, 30 seconds North; 89 degrees, 14 minutes West. This study site was chosen for its relatively level surface topography across a 0.05 hectare plot established for future release of chloride as a soil water tracer. The site was located on the Centennial field at Ames Plantation, and was being used for corn production under no-till cultivation.



QUATERNARY	Peoria loess
	Roxana loess (intermittent)
	alluvium
TERTIARY	coastal plain sediments

Figure 4. General geology at Ames Plantation (Hardeman, 1966).

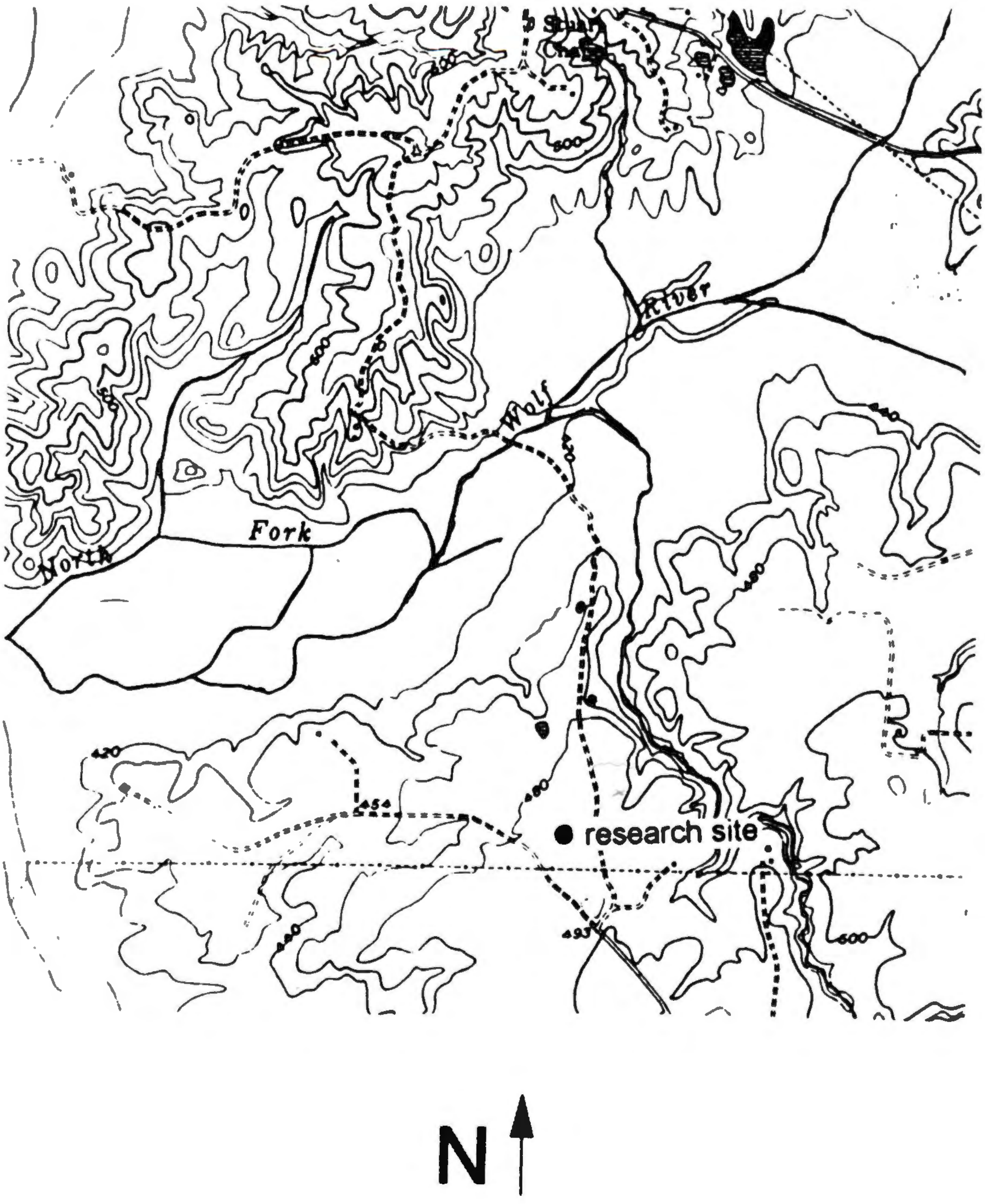


Figure 5. Topographic position of research site at 1:24000 scale, Hickory Valley, TN quadrangle (USGS, 1980).

Field Methods

Four soil cores, equally spaced in a 15.24 meter linear transect, were taken with a Giddings GSRP-S-M hydraulic probe with a 7.62 cm sample tube to determine the morphology of the 0.05 hectare release plot. Soil morphology was recorded for each core (Soil Survey Division Staff, 1993). A total of 47 soil samples were taken in the field. A sample was taken from each morphological layer in each of the 4 profiles.

Soil Mapping Methods

In this study, a high intensity, order 1, soil survey map of the entire research area was created (Soil Survey Division Staff, 1993). Map units were delineated based on field morphology and notes of physical characteristics recorded at each of 32 cores drilled for shallow well placement. The well placement design was set up on a grid that was 900 m^2, with a 506.25 m^2 release plot centrally located. Figure 6 shows the layout of the wells on the Centennial field. Using SURFER Version 4 (Golden Software, 1991), surface and paleosurface topography maps were created based on elevations of the surface with respect to a designated plot center and the morphological position of the alluvial paleosol. The paleosol map was used to predict the effect of the alluvial paleosurface topography on direction of soil water movement along the interface.

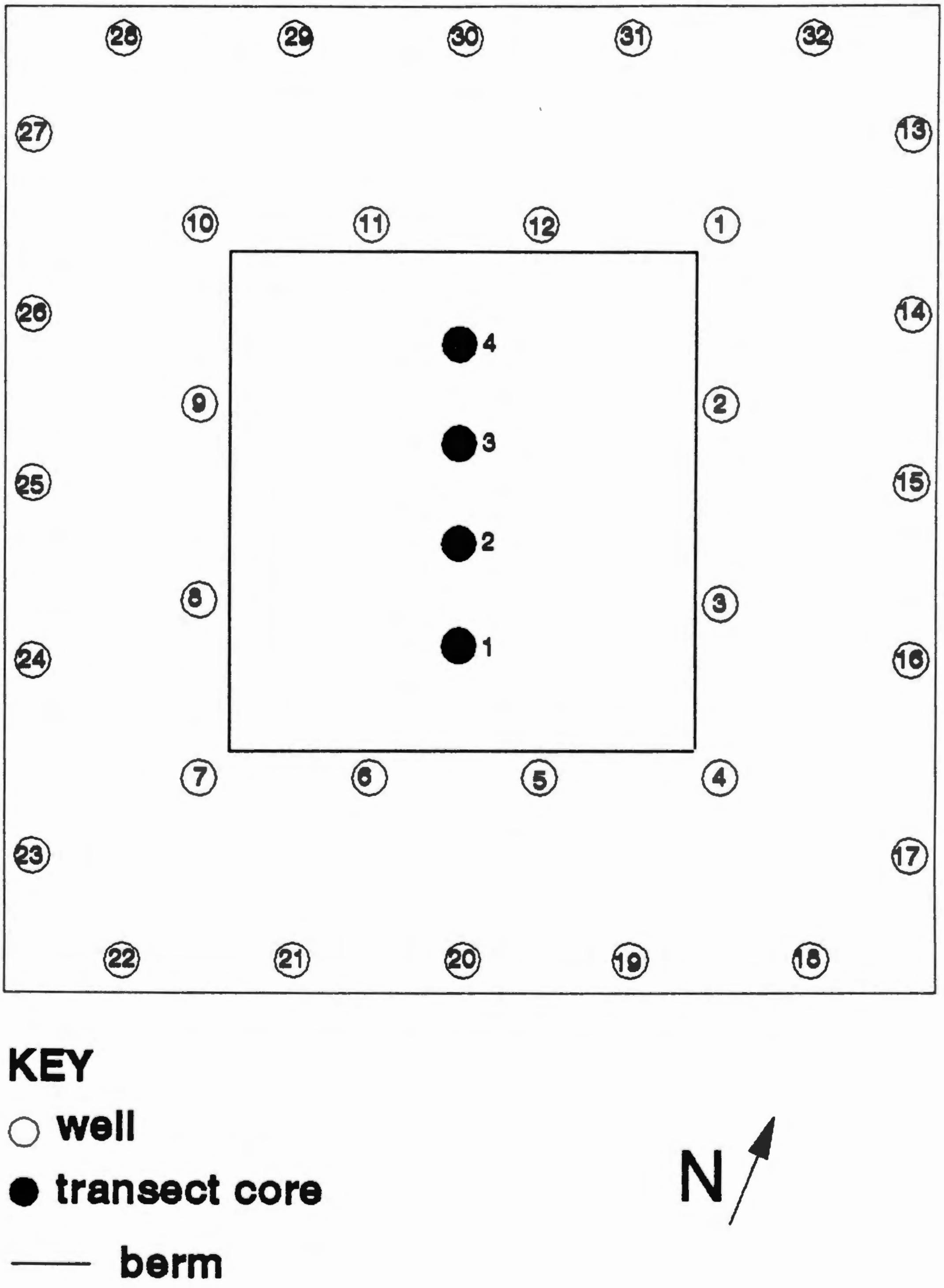


Figure 6. Well placement design on the Centennial field.

Laboratory Methods

The 47 samples from the 0.05 hectare release plot were air dried. Air dried samples were crushed to pass a 2 mm sieve. One-fourth was ground to pass a 60 mesh sieve (Soil Survey Staff, 1984). Total carbon analysis was determined on the 60 mesh samples with a Leco CR-12 carbon analyzer.

Particle size analyses were performed on all samples by the pipette method (Kilmer and Alexander, 1949). The particle size fractions determined included sand, silt, and clay as defined by the USDA system of soil textural classification. In addition, the sand was separated into very coarse, coarse, medium, fine, and very fine fractions (Gee and Bauder, 1986).

Iron oxides were extracted using the citrate-dithionite method (Olsen and Ellis, 1982). The KCl extraction method was used for total acidity, allowing for measurement of exchangeable aluminum (Thomas, 1982). Barium chloride-triethanolamine extractable acidity was also determined for the critical base saturation depth in each transect profile. Manganese was determined using the hydroxylamine hydrochloride method (Chao, 1972). A Perkin-Elmer Model 5000 Spectrophotometer was used to analyze the above extracts for iron, aluminum, and manganese by atomic absorption spectroscopy.

A 1:1 mixture of soil sample in deionized water, and 1:1 soil to 0.01M calcium chloride ratio were used with the Orion Research Ionalyzer model 339a to measure pH (Peech, 1965).

Exchangeable base cations (Na , K , Ca , Mg) were determined with the ammonium acetate pH 7 method (Soil Survey Laboratory Staff, 1992). The Perkin-Elmer 5000 Atomic Absorption Spectrophotometer was used to analyze the extract. To determine cation exchange capacity, acidified NaCl was used to displace the ammonium from the soil samples, and the extract was distilled with a Lab Conco distillation unit (Chapman, 1965). Base saturation was then calculated for each sample based on both the ammonium acetate pH 7 method, as well as the barium chloride-triethanolamine extractable acidity measurements.

Results and Discussion

In order to establish morphological uniformity of the release plot, laboratory data were coupled with notes taken in the field and analyzed. A topographically uniform release plot was desired so as to avoid bias on tracer movement upon the initial release. Some miscellaneous data tables for the transect profiles are located in Appendices A, B, C, and D for cores 1, 2, 3, and 4 respectively. Profiles were classified to the family level of taxonomy based on laboratory data and field descriptions (Soil Survey Staff, 1992).

Transect profiles

Morphology of the profiles included loess overlying a mixing zone of loess and alluvium (Tables 1, 2, 3, and 4). The loess portions of the profiles extended to depths ranging from 170 cm to 201 cm (Figure 7). As was suggested in the

Table 1. Transect core # 1 soil morphology and field descriptions.

sample #	horizon*	bottom depth (cm)	boundary**	color	texture*	structure	concretion	mottles	misc.
9512	Ap	9	A	10YR 4/4	SiL	1 f gr/pl	-	-	m fi roots
9513	Bt1	29	C	10YR 3/6	SiCL	1 m sbk	-	-	c fi roots
9514	Bt2	68	C	10YR 3/4	SiCL	2 m sbk	c, Mn	-	argillans
9515	Bt3	110	C	10YR 4/6	SiL	2 m sbk	c, Mn	-	-
9516	Bt4	148	C	7.5YR 4/6	SiL	1 m sbk	f, Mn	-	argillans, pores
9517	BC1	169	C	7.5YR 4/4	SiL	1 f sbk	f, Mn	c, 10YR 5/3	pref.flow, pores
9518	BC2	190	C	7.5YR 3/4	SiL	1 f sbk	f, Mn	f, 10YR 5/3	pref. flow
9519	2Bt1	230	C	5YR 4/6	SiCL	2 m sbk	f, Mn	f, 10YR 4/4	-
9520	2Bt2	262+	-	2.5YR 4/8	SiCL	2 m sbk	c, Mn	f, 10YR 6/4	-

* changed from field description on basis of laboratory data
** key to all abbreviations in APPENDIX E

Table 2. Transect core # 2 soil morphology and field descriptions.

sample #	horizon*	bottom depth (cm)	boundary**	color	texture*	structure	concretion	mottles	misc.
9521	Ap1	7	C	10YR 3/4	SiL	2 f gr	-	-	-
9522	Ap2	20	A	10YR 3/4	SiL	2 m gr	-	-	-
9523	Bt1	46	C	7.5YR 3/4	SiCL	1 m sbk	c, Mn	-	-
9524	Bt2	78	G	7.5YR 4/6	SiCL	2 m sbk	c, Mn	-	-
9525	Bt3	120	C	7.5YR 4/4	SiL	2 m sbk	-	f, 7.5YR 5/3	pref. flow
9526	Bt4	150	C	7.5YR 4/3	SiL	2 m sbk	-	c,7.5YR 6/3	pref. flow
9527	BC1	172	C	7.5YR 3/4	SiL	2 m sbk	-	c, 10YR 6/3	pref. flow
9528	B't1	201	G	7.5YR 3/3	SiL	2 m sbk	f, Mn	-	
9529	2B't2	219	C	5YR 3/4	SiCL	2 m sbk	-	c, 10YR 5/4	pref. flow
9530	2B't3	243	C	5YR 3/4	SiCL	2 m sbk	-	c, 10YR 6/4	-
9531	2B't4	260+	-	2.5YR 3/6	SiCL	2 m sbk	-	-	pref. flow

*changed from field description on basis of laboratory data
** key to all abbreviations in APPENDIX E

Table 3. Transect core # 3 soil morphology and field descriptions.

sample #	horizon*	bottom depth (cm)	boundary**	color	texture*	structure	concretion	mottles	misc.
9532	Ap1	4	A	10YR 3/4	SiL	2 f gr	-	-	m fi roots
9533	Ap2	13	A	10YR 3/4	SiL	2 m gr	-	-	onion
9534	Bt1	29	C	10YR 3/4	SiL	2 m sbk	f, Mn	-	f fi roots
9535	Bt2	52	G	10YR 3/6	SiCL	2 m sbk	c, Mn	-	-
9536	Bt3	95	C	7.5YR 3/4	SiCL	2 m sbk	f, Mn	-	argillans, pores
9537	BC1	128	C	7.5YR 3/3	SiL	2 m sbk	f, Mn	-	-
9538	BC2	158	C	7.5YR 2.5/3	SiL	2 m sbk	-	f, 10YR 6/8	-
9539	BC3	187	C	7.5YR 3/3	SiL	2 m sbk	f, Mn	f, 10YR 6/8	pores
9540	2BC4	207	G	5YR 3/4	SiL	2 m sbk	f, Mn	c, 10YR 6/3	free water present
9541	2BC5	218	C	5YR 3/4	SiL	2 m sbk	-	c 7.5YR 4/4	-
9542	2BC6	243	C	5YR 3/4	CL	2 m sbk	m, Mn	m 10YR 6/3	large pref. flow pores
9543	2BC7	259+	-	5YR 4/6	SiCL	2 m sbk	-	m, 7.5YR 4/4	pref. flow

*changed from field description on basis of laboratory data
** key to all abbreviations in APPENDIX E

Table 4. Transect core # 4 soil morphology and field descriptions.

sample #	horizon*	bottom depth (cm)	boundary**	color	texture*	structure	concretion	mottles	misc.
9544	Ap1	6	A	10YR 3/4	SiL	2 m gr	-	-	c fi roots
9545	Ap2	16	G	10YR 4/4	SiL	1 m sbk	-	-	f fi roots
9546	Bt1	43	C	7.5YR 4/6	SiL	2 m sbk	f, Mn	-	organic staining
9547	Bt2	70	G	10YR 4/4	SiCL	2 m sbk	c, Mn	-	argillans
9548	Bt3	96	C	7.5YR 4/6	SiL	2 m sbk	c, Mn	f, 10YR 6/3	argillans
9549	Bt4	116	C	7.5YR 4/6	SiL	1 m sbk	c, Mn	f, 10YR 6/3	-
9550	Bt5	134	G	10YR 3/6	SiL	2 m sbk	f, Mn	f, 10YR 6/3	-
9551	Bt6	170	C	7.5YR 3/4	SiL	1 f sbk	-	f, 10YR 6/3	-
9552	BC1	189	C	7.5YR 4/6	SiL	1 f sbk	-	c, 10YR 7/2	pref. flow
9553	BC2	205	G	7.5YR 4/6	SiL	1 f sbk	-	f, 10YR 7/3	-
9554	2Bt1	227	C	2.5YR 4/6	L	1 m sbk	f, Mn	c, 10YR 6/3	large pref. flow pores
9555	2Bt2	250	G	2.5YR 4/6	L	1 m sbk	-	c, 10YR 6/3	argillans

Table 4. (cont.)

sample #	horizon*	bottom depth (cm)	boundary**	color	texture*	structure	concretion	mottles	misc.
9556	2Bt3	261	G	5YR 4/6	L	2 m sbk	-	m, 10YR 8/3	large continuous argillans
9557	2Bt4	283	C	2.5YR 4/6	SiCL	2 m sbk	-	c, 10YR 8/3	large pref. flow pores
9558	2Bt5	328+	-	7.5YR 5/8	CL	1 m sbk	-	c, 10YR 6/4	pref. flow

*changed from field description on basis of laboratory data
** key to all abbreviations in APPENDIX E

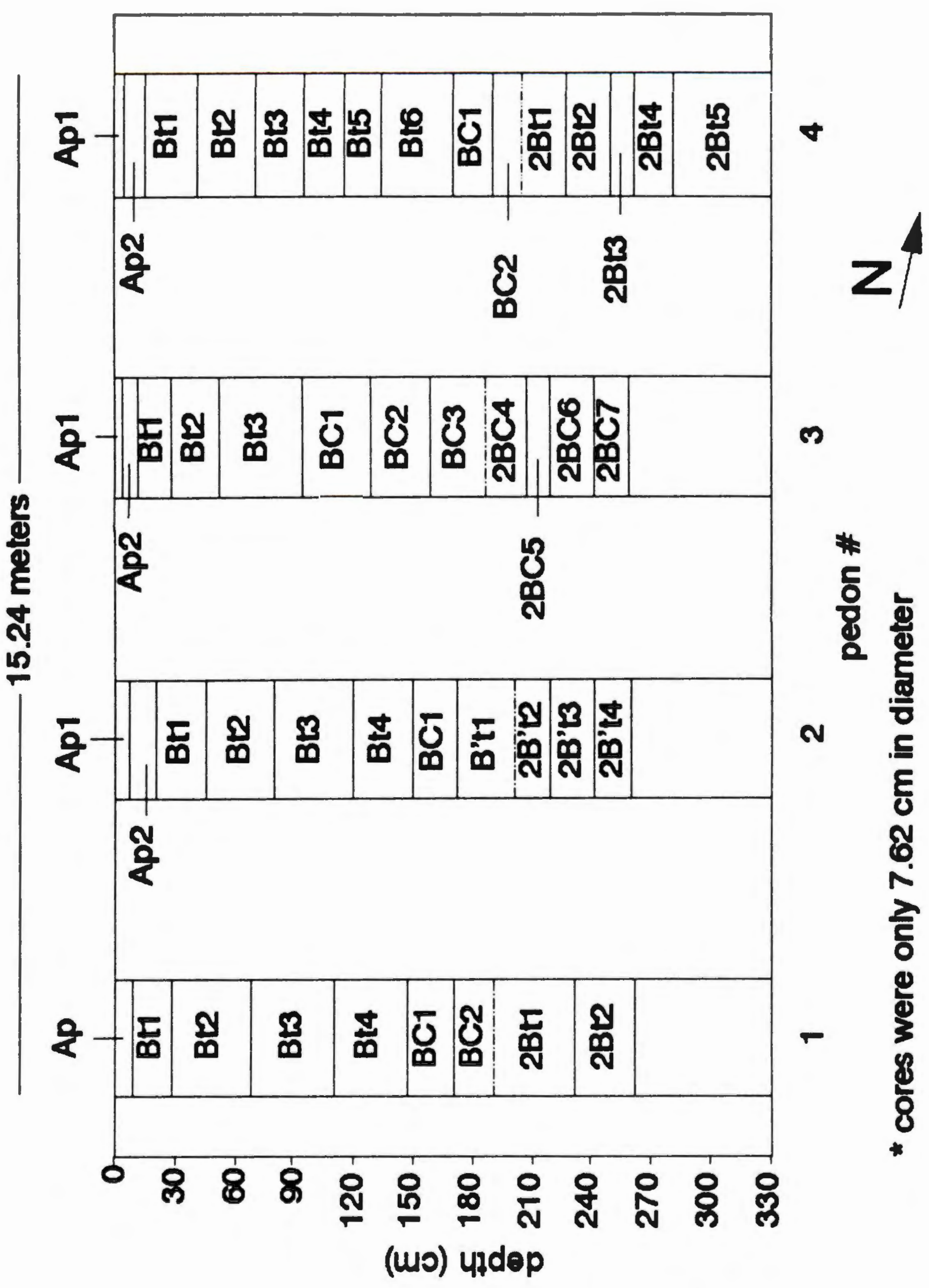


Figure 7. Cross-section view of the transect profile morphology.

literature, the surface loess was Peorian, and the second was most likely Roxana. These depositions were distinguished with laboratory particle size data which showed two distinct zones of high to low silt values (Table 5, 6, 7, and 8). The first zone , marking the Peorian loess, appeared to range in thickness from 68 cm to 95 cm. At this approximate depth, the Roxana loess began its extension down to the alluvial paleosol. The 5YR and 2.5YR colors in the paleosol, along with the moderate levels of silt content, suggested the possibility of a mixing zone between the Roxana, or even Loveland loess, with alluvium in that portion of each profile. Although slight variations occurred in loess thickness, the four profiles were much the same morphologically and genetically

Particle size data showed two distinct zones of clay increase in each profile (Tables 5, 6, 7, and 8). Clay content increased markedly from the surface horizons, peaking in the loess between 29 cm and 95 cm, with values of about 30 percent. The second inflection in clay content occured in the alluvium mix at depths from 219 cm to 283 cm, having values of approximately 30 percent once again (Figure 8). There was a little variation in depths, but the same two, 30% clay peak patterns were seen in all four profiles.

Silt values in the loess portions of the profiles, remained in the range of 65 to 82 percent. Sand content was consistently low in the loess material, ranging from 1 to 11 percent, where the higher values were at the top of the mixing zone. The presence of alluvial material was confirmed below the loess, across the transect (Figure 7, Tables 5, 6, 7, and 8).

Table 5. Particle size distribution for transect core #1.

sample #	horizon	bottom depth (cm)	**sand**	vcos	cos	ms	fs	vfs	**silt**	**clay**	**fine clay**
			% of <2mm fraction								
9512	Ap1	9	6	4.0	0.6	0.3	0.6	0.5	78	16	6
9513	Bt1	29	1	0.1	0.1	0.2	0.2	0.4	71	28	13
9514	Bt2	68	1	0.0	0.3	0.2	0.2	0.3	70	29	14
9515	Bt3	110	1	0.0	0.0	0.2	0.3	0.5	74	25	12
9516	Bt4	148	2	0.0	0.3	0.4	0.7	0.6	74	24	12
9517	BC1	169	6	0.3	1.3	1.6	2.0	0.8	72	22	10
9518	BC2	190	9	0.5	2.2	2.6	2.9	0.8	67	24	13
9519	2Bt1	230	11	1.0	3.2	3.4	3.4	1.0	60	29	16
9520	2Bt2	262+	12	0.7	3.3	3.4	3.8	0.8	58	30	16

Table 6. Particle size distribution for transect core #2.

sample #	horizon	bottom depth (cm)	**sand**	vcos	cos	ms	fs	vfs	**silt**	**clay**	**fine clay**
			% of <2mm fraction								
9521	Ap1	7	3	0.5	0.7	0.5	0.5	0.8	82	15	5
9522	Ap2	20	2	0.0	0.3	0.4	0.8	0.5	80	18	7
9523	Bt1	46	1	0.0	0.2	0.2	0.3	0.3	69	30	16
9524	Bt2	78	1	0.0	0.0	0.3	0.4	0.3	70	29	15
9525	Bt3	120	1	0.0	0.2	0.1	0.3	0.4	74	25	13
9526	Bt4	150	3	0.0	0.6	0.8	0.8	0.8	73	24	13
9527	BC1	172	6	0.0	1.2	1.7	2.1	1.0	74	20	16
9528	B't1	201	11	0.8	3.0	2.4	3.7	1.1	65	24	14
9529	2B't2	219	15	1.0	3.7	4.6	4.8	0.9	57	28	17
9530	2B't3	243	15	0.8	4.4	4.6	4.6	0.6	54	31	20
9531	2B't4	260+	19	1.3	4.7	5.8	6.0	1.2	51	30	19

Table 7. Particle size distribution for transect core #3.

sample #	horizon	bottom depth (cm)	**sand**	vcos	cos	ms	fs	vfs	**silt**	**clay**	**fine clay**
			% of <2mm fraction								
9532	Ap1	4	2	0.3	0.5	0.5	0.4	0.3	82	16	5
9533	Ap2	13	3	0.0	0.4	0.4	0.7	0.5	81	16	6
9534	Bt1	29	2	0.1	0.5	0.5	0.6	0.3	74	24	13
9535	Bt2	52	1	0.0	0.2	0.2	0.2	0.4	69	30	16
9536	Bt3	95	1	0.0	0.2	0.1	0.2	0.5	69	30	16
9537	BC1	128	2	0.0	0.4	0.5	0.6	0.5	76	22	11
9538	BC2	158	5	0.1	1.2	1.4	1.4	0.9	71	24	12
9539	BC3	187	11	0.5	3.1	3.2	3.3	0.9	67	22	11
9540	2BC4	207	18	0.8	5.0	5.7	5.5	1.0	58	24	14
9541	2BC5	218	21	1.0	5.7	6.7	6.6	1.0	53	26	17
9542	2BC6	243	30	1.7	8.0	9.4	9.5	1.4	43	27	18
9543	2BC7	259+	21	0.9	5.8	6.7	6.8	0.8	50	29	11

Table 8. Particle size distribution for transect core #4.

sample #	horizon	bottom depth (cm)	**sand**	vcos	cos	ms	fs	vfs	**silt**	**clay**	**fine clay**
			% of <2mm fraction								
9544	Ap1	6	2.7	0.4	0.8	0.7	0.6	0.8	82.4	15.0	5.2
9545	Ap2	16	2.3	0.0	0.5	0.7	0.6	0.6	82.0	15.8	6.5
9546	Bt1	43	1.3	0.0	0.3	0.2	0.2	0.4	72.6	26.2	18.8
9547	Bt2	70	1.1	0.0	0.2	0.0	0.4	0.4	69.3	29.6	15.0
9548	Bt3	96	1.2	0.0	0.3	0.2	0.4	0.4	73.6	25.1	12.1
9549	Bt4	116	2.9	0.0	0.4	0.5	0.7	0.6	73.4	23.7	11.8
9550	Bt5	134	4.6	0.1	1.2	1.4	1.5	0.8	72.1	23.2	12.5
9551	Bt6	170	9.1	0.2	2.8	3.1	3.0	0.1	68.6	22.3	10.9
9552	BC1	189	18.8	0.9	5.7	6.4	5.2	0.9	62.4	18.8	4.6
9553	BC2	205	23.6	1.2	6.4	7.9	6.9	1.0	58.5	18.0	8.8
9554	2Bt1	227	24.4	0.9	7.0	8.0	7.4	1.1	51.3	24.4	15.2
9555	2Bt2	250	27.3	1.4	8.4	9.0	7.7	0.7	45.9	26.8	17.8
9556	2Bt3	261	23.9	1.1	7.1	8.2	7.2	0.8	49.5	26.6	17.1
9557	2Bt4	283	17.2	0.8	5.0	6.2	5.4	0.6	51.2	31.6	19.8
9558	2Bt5	328+	29.81	0.7	6.7	10.6	10.6	1.3	42.82	27.37	14.51

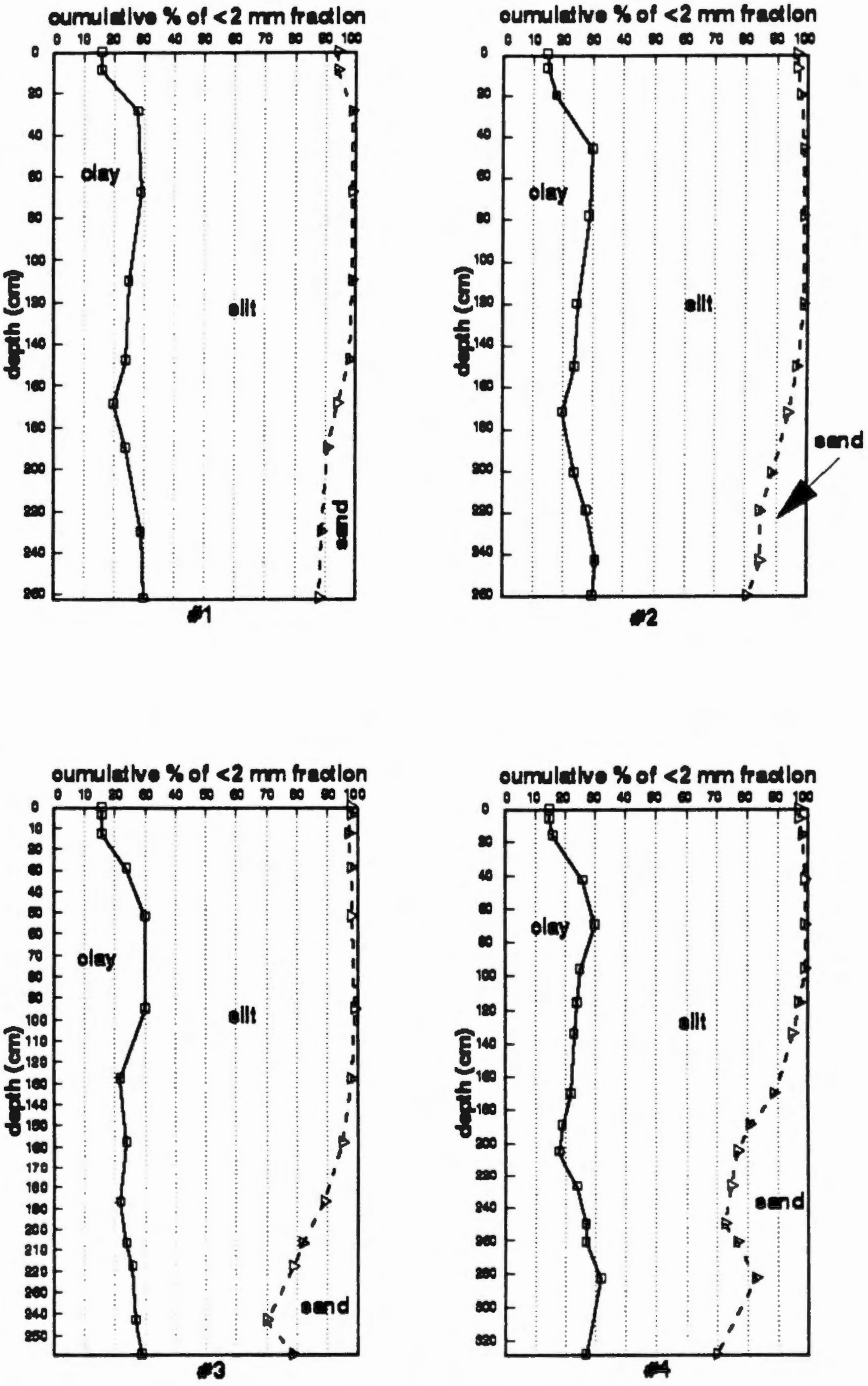


Figure 8. Particle size distribution of <2 mm fraction with depth for each transect profile.

Two distinct inflections in free iron oxides coincided with the noted clay increases (Tables 9, 10, 11, and 12). The first peak values, ranging from 1.12 to 1.62%, occurred somewhere between 29 cm and 110 cm (Figure 9). A second high iron content of about 0.86 to 1.36 %, occurred after the discontinuity between 190 cm and 283 cm. Trends in depth and value of the inflections from north to south were identified, with the shallower peaks, higher values in the north, to deeper, lower values in the south.

Evidence of a discontinuity at 190 cm was determined by changes in iron oxide levels, and distinct changes in particle size values (Figures 8 and 9) The increase in sand content coupled with a decrease in silt content from the loessial material, indicated the possible presence of alluvium or a mixing zone between loess and alluvium. A more obvious indicator of the discontinuity, was the presence of a sharp increase in manganese near the interface (Tables 9, 10, 11, and 12). Distinct peaks in manganese content were found ranging from 358.36 mg kg^{-1} soil to 1520.25 mg kg^{-1} soil, at depths between 190 cm and 230 cm (Figure 10). In the field these were seen abundantly as purple manganese concentrations (Tables 1, 2, 3, and 4). Once again a trend of high to low values was noted from north to south in the transect.

While exchangeable potassium and sodium values did not appear to vary much in any of the profiles, exchangeable calcium and magnesium did show differences above and below the discontinuity (Tables 13, 14, 15, and 16). In general, exchangeable calcium values were higher in the loess than in the

Table 9. Iron and manganese in transect core # 1.

sample #	horizon	depth (cm)	% free iron oxides	manganese (mg kg^{-1} soil)
9512	Ap1	9	0.89	1059.09
9513	Bt1	29	1.25	419.88
9514	Bt2	68	1.42	77.21
9515	Bt3	110	1.46	71.07
9516	Bt4	148	1.30	101.33
9517	BC1	169	1.08	316.85
9518	BC2	190	1.16	753.08
9519	2Bt1	230	1.36	1520.25
9520	2Bt2	262+	1.33	1139.93

Table 10. Iron and manganese in transect core # 2.

sample #	horizon	bottom depth (cm)	% free iron oxides	manganese (mg kg^{-1} soil)
9521	Ap1	7	0.84	869.37
9522	Ap2	20	0.95	878.03
9523	Bt1	46	0.96	266.26
9524	Bt2	78	1.62	91.55
9525	Bt3	120	1.32	85.36
9526	Bt4	150	1.14	142.32
9527	BC1	172	0.86	149.65
9528	B't1	201	0.86	753.28
9529	2B't2	219	1.23	1232.56
9530	2B't3	243	1.16	628.03
9531	2B't4	260+	1.22	419.20

Table 11. Iron and manganese in transect core # 3.

sample #	horizon	bottom depth (cm)	% free iron oxides	manganese (mg kg^{-1} soil)
9532	Ap1	4	0.53	862.94
9533	Ap2	13	0.56	793.43
9534	Bt1	29	1.02	622.39
9535	Bt2	52	1.25	524.20
9536	Bt3	95	1.09	274.02
9537	BC1	128	0.80	154.73
9538	BC2	158	0.78	144.88
9539	BC3	187	0.73	358.36
9540	2BC4	207	0.97	717.14
9541	2BC5	218	1.07	721.57
9542	2BC6	243	1.05	357.89
9543	2BC7	259+	1.15	114.57

Table 12. Iron and manganese in transect core # 4.

sample #	horizon	bottom depth (cm)	% free iron oxides	manganese (mg kg^{-1} soil)
9544	Ap1	6	0.39	774.80
9545	Ap2	16	0.53	870.38
9546	Bt1	43	0.94	302.30
9547	Bt2	70	0.89	188.11
9548	Bt3	96	1.12	75.67
9549	Bt4	116	1.01	127.54
9550	Bt5	134	0.80	119.88
9551	Bt6	170	0.63	147.56
9552	BC1	189	0.52	237.06
9553	BC2	205	0.46	357.72
9554	2Bt1	227	0.65	358.98
9555	2Bt2	250	0.73	189.41
9556	2Bt3	261	0.75	64.15
9557	2Bt4	283	0.86	31.94
9558	2Bt5	328+	0.82	29.00

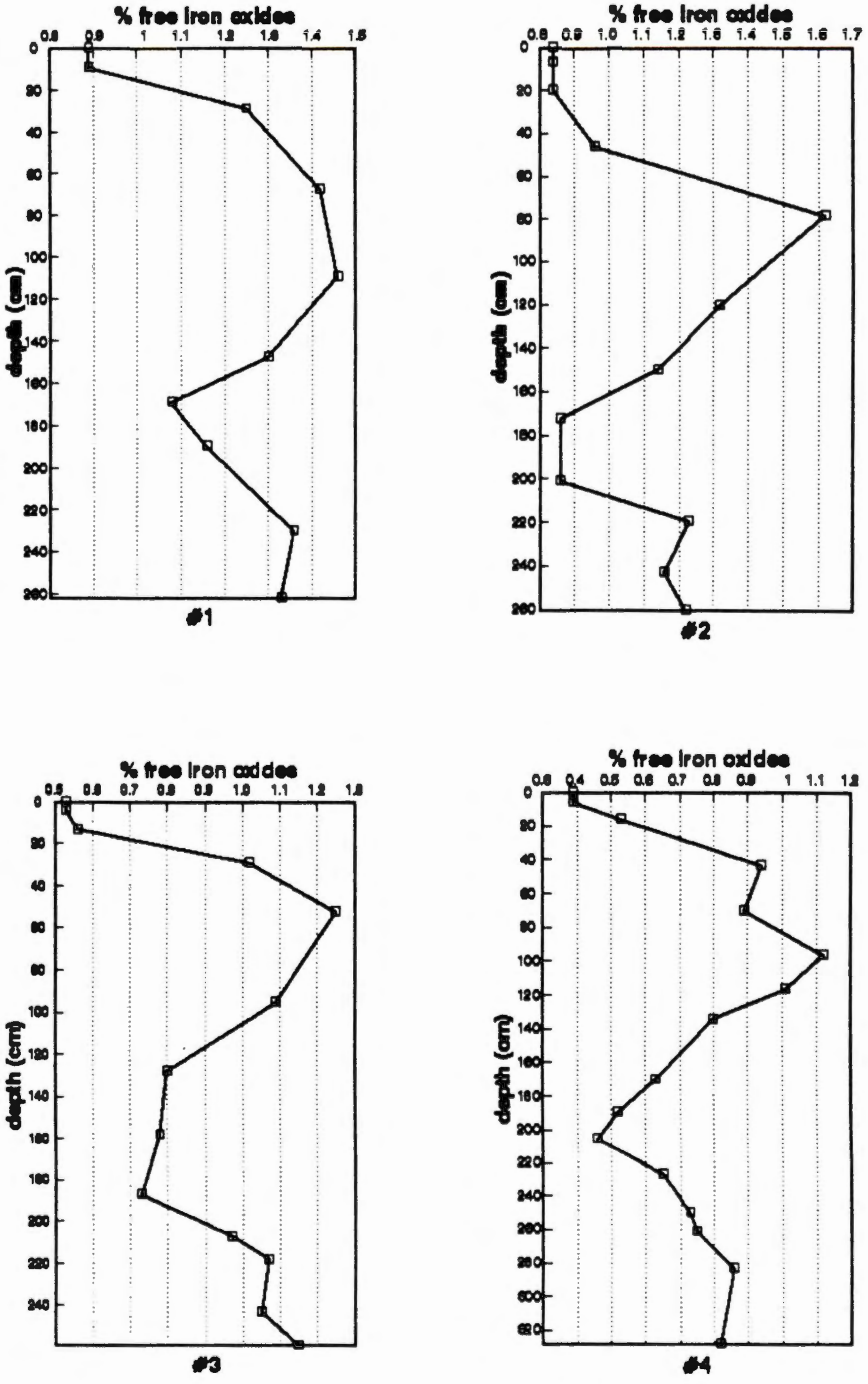


Figure 9. Percentage of free iron oxides with depth in each transect profile.

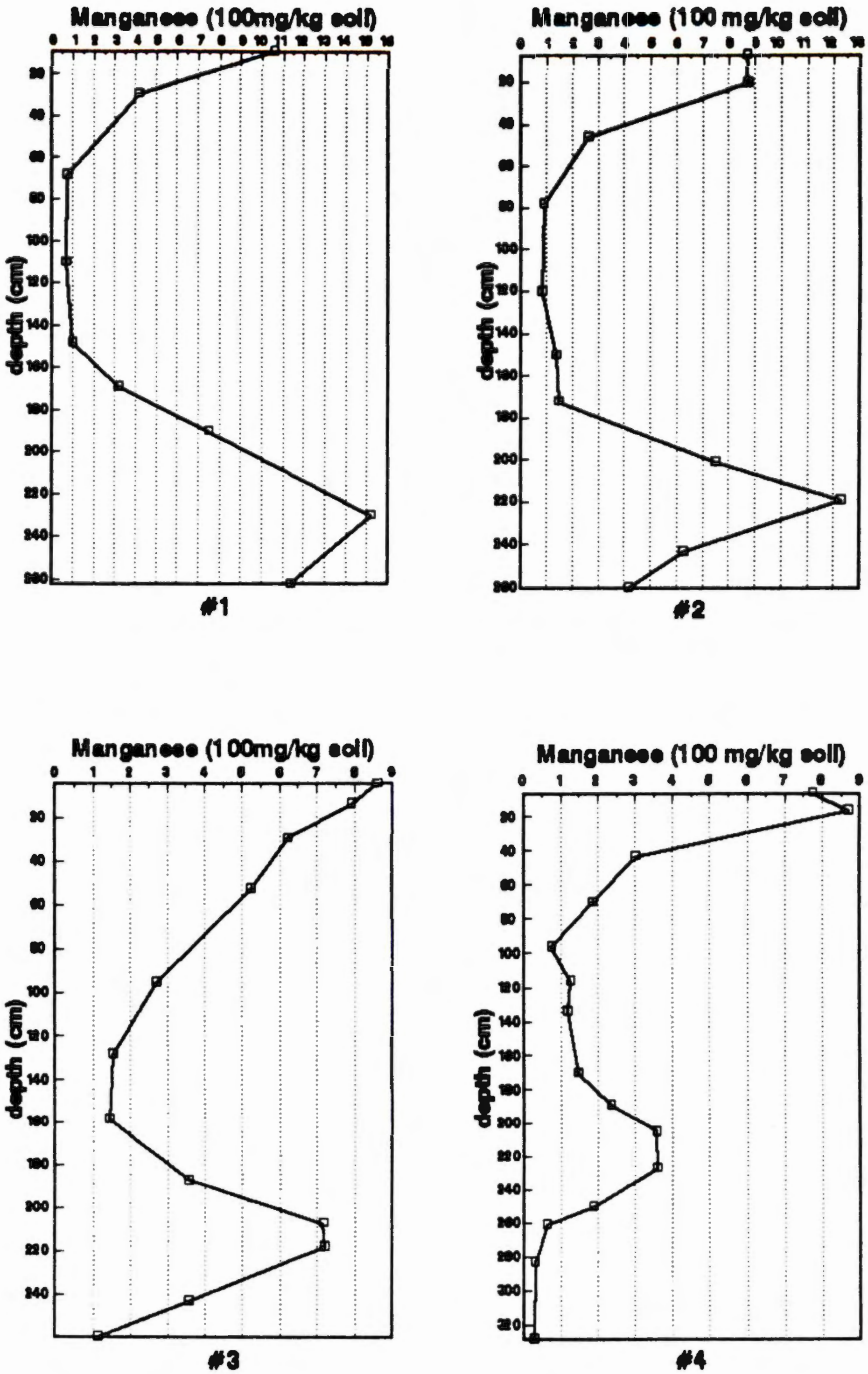


Figure 10. Hydroxylamine-HCl extracted manganese in transect profiles.

Table 13. Ammonium extractable bases, cation exchange capacity, and base saturation data for transect core # 1.

sample #	horizon	bottom depth (cm)	Ca	Mg	K	Na	CEC	% base saturation (NH$_4$OAc, pH 7)
			cmol kg^{-1} soil					
9512	Ap1	9	7.72	0.40	0.41	0.24	10.03	87.44
9513	Bt1	29	9.91	0.55	0.40	0.08	14.77	74.07
9514	Bt2	68	11.48	0.73	0.36	0.09	16.25	77.91
9515	Bt3	110	9.46	0.89	0.28	0.09	14.12	75.92
9516	Bt4	148	7.06	1.11	0.30	0.09	12.44	68.81
9517	BC1	169	4.18	1.02	0.30	0.08	9.00	62.00
9518	BC2	190	4.38	1.23	0.36	0.08	10.20	59.31
9519	2Bt1	230	4.13	1.24	0.40	0.06	9.72	59.98
9520	2Bt2	262+	4.13	1.18	0.38	0.08	9.76	59.12

Table 14. Ammonium extractable bases, cation exchange capacity, and base saturation data for transect core #2.

sample #	horizon	bottom depth (cm)	Ca	Mg	K	Na	CEC	% base saturation (NH$_4$OAc, pH 7)
			cmol kg^{-1} soil					
9521	Ap1	7	10.65	0.52	0.80	0.08	10.96	109.94
(repeat)			10.81	0.51	0.84	0.08	10.81	113.23
9522	Ap2	20	5.67	0.25	0.21	0.08	8.49	73.14
9523	Bt1	46	9.52	0.90	0.24	0.10	14.69	73.25
9524	Bt2	78	5.97	1.45	0.29	0.10	15.25	51.21
9525	Bt3	120	2.03	1.12	0.25	0.09	11.91	29.3
9526	Bt4	150	1.57	0.97	0.26	0.08	10.89	26.45
9527	BC1	172	1.62	0.88	0.24	0.07	8.77	32.04
9528	B't1	201	2.35	0.99	0.22	0.09	9.03	40.42
9529	2B't2	219	2.67	1.06	0.22	0.10	9.64	42.01
9530	2B't3	243	2.74	1.04	0.22	0.09	9.36	43.70
9531	2B't4	260+	2.73	1.05	0.22	0.09	9.26	44.17

Table 15. Ammonium extractable bases, cation exchange capacity, and base saturation data for transect core #3.

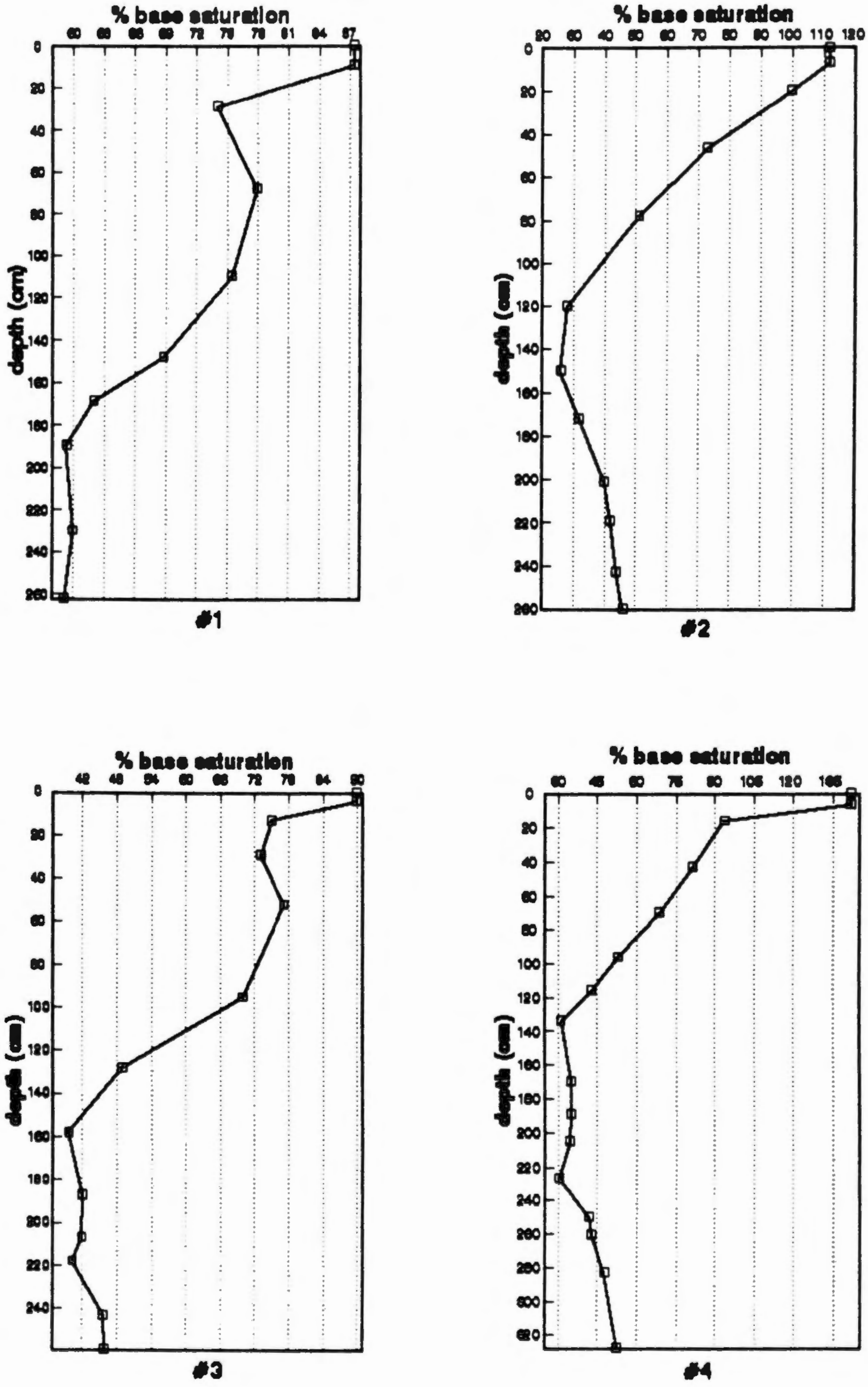
sample #	horizon	bottom depth (cm)	Ca	Mg	K	Na	CEC	% base saturation (NH_4OAc, pH 7)
			------cmol kg^{-1} soil------					
9532	Ap1	4	6.98	0.50	0.74	0.06	9.21	89.90
9533	Ap2	13	5.88	0.28	0.31	0.04	8.68	75.00
9534	Bt1	29	7.27	0.40	0.24	0.05	10.88	73.16
9535	Bt2	52	9.34	0.86	0.23	0.08	13.61	77.22
9536	Bt3	95	8.17	1.55	0.24	0.11	14.39	69.98
9537	BC1	128	4.39	1.56	0.20	0.10	12.76	48.98
9538	BC2	158	2.54	1.15	0.23	0.11	10.15	39.70
9539	BC3	187	2.28	1.04	0.21	0.10	8.62	42.11
9540	2BC4	207	2.35	1.07	0.20	0.08	8.81	42.00
9541	2BC5	218	2.51	1.08	0.20	0.07	9.98	38.68
9542	2BC6	243	2.54	1.06	0.19	0.12	8.55	45.73
9543	2BC7	259+	2.77	1.12	0.19	0.08	9.06	45.92

Table 16. Ammonium extractable bases, cation exchange capacity, and base saturation data for transect core #4.

sample #	horizon	bottom depth (cm)	Ca	Mg	K	Na	CEC	% base saturation (NH$_4$OAc, pH 7)
			cmol kg^{-1} soil					
9544	Ap1	6	11.27	0.43	0.71	0.07	8.98	141.82
9545	Ap2	16	6.66	0.26	0.25	0.07	7.72	93.78
9546	Bt1	43	10.18	0.79	0.26	0.08	13.86	81.60
9547	Bt2	70	9.23	1.6	0.27	0.11	15.83	70.81
9548	Bt3	96	4.84	1.84	0.25	0.11	13.28	52.86
9549	Bt4	116	3.10	1.38	0.27	0.10	11.29	42.96
9550	Bt5	134	2.05	1.17	0.24	0.10	11.42	31.17
9551	Bt6	170	1.84	1.07	0.24	0.10	9.29	34.98
9552	BC1	189	1.44	0.85	0.19	0.08	7.34	34.88
9553	BC2	205	1.24	0.76	0.16	0.06	6.41	34.63
9554	2Bt1	227	1.79	0.90	0.19	0.06	9.65	30.47
9555	2Bt2	25	2.14	0.97	0.20	0.06	8.04	41.92
9556	2Bt3	261	2.50	1.00	0.19	0.07	8.77	42.87
9557	2Bt4	283	3.74	1.26	0.22	0.10	11.14	47.76
9558	2Bt5	328+	3.88	1.25	0.20	0.11	10.36	52.51

alluvium mix, and exchangeable magnesium values were usually higher in the alluvium mix than in the loess. Exchangeable calcium values appeared to be significantly higher throughout profile #1 than in the other transect profiles, except in the surface horizon. While base saturation values (direct measurement) were generally in the same range in all four profiles, their patterns varied slightly (Figure 11). After initial decrease, values in profiles #1 and #3 appeared to increase slightly in the upper loess before significantly decreasing through the rest of the profile. Cation exchange capacity also varied before and after the discontinuity (Figure 12). Peak values were found in the loess, ranging between 14.39 cmol kg^{-1} soil to 16.29 cmol kg^{-1} soil (Tables 13, 14, 15, and 16).

Based on field and laboratory characteristics, the profiles were classified to the family level of soil taxonomy. Since the soils were expected to be Alfisols or Ultisols the $BaCl_2$ triethanolamine (summation) measurement of base saturation was used for classification. All four profiles were determined to be fine-silty, mixed thermic Typic Hapludalfs, based on base saturation values (by summation) at the critical base saturation depth greater than 35 %. Profile #1 had a critical depth base saturation of 94%, while profile #2 was 72%, profile #3 was 89%, and profile #4 was 85%. A note was made that direct measurement data would have classified profile #1 as an Alfisol, while the other three would have been considered Ultisols.



#1

#2

#3

#4

Figure 11. Percent base saturation in transect profiles.

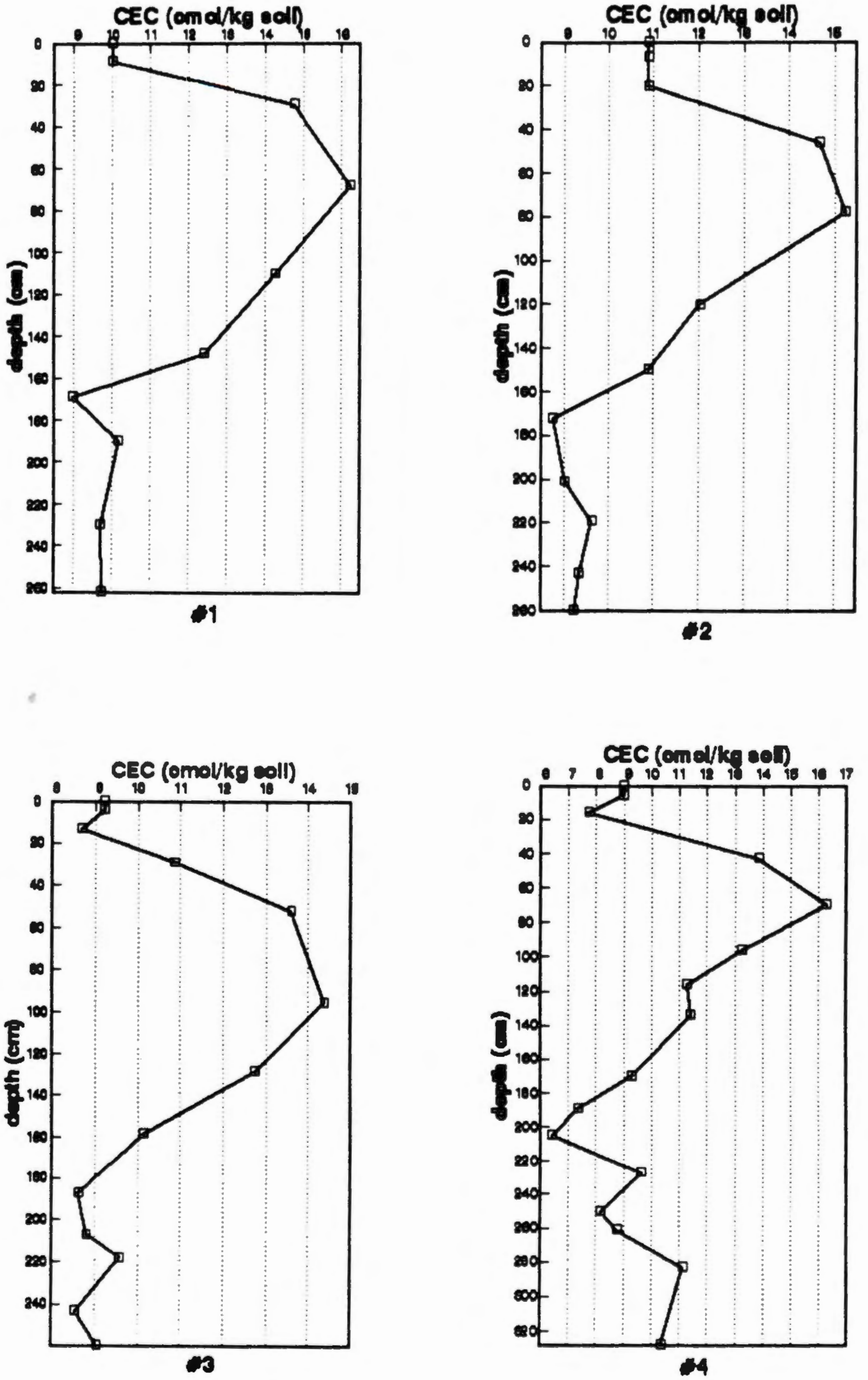


Figure 12. CEC values in transect profiles.

Soil mapping

A high intensity, order 1 soil map was made of the research plot based on laboratory data attained for the four transect cores, and field morphology and notes taken of the 32 well cores (Figure 13). Surface and paleosurface topography and 3-dimensional surface maps were also created, and used as a guide for map unit delineation where appropriate (Figures 14, 15) (Golden Software, 1991). Depressions that appear on the maps are due mainly to slight error in determining elevations. The probe that was used as a marker may have been pushed into the ground, giving the apperance of depressions at many wells.

Soil Map Units

The depth to the discontinuity was used as the primary characteristic for map delineations. Sub-unit distinctions were also made, and were appropriately explained.

Map unit "A" represented fine-silty, mixed, thermic Typic Hapludalfs. Due to significant differences in paleosol depths, sub-units "1" and "2" were delineated. The "A1" unit represents those soils which had a paleosol depth ranging from 170 cm to 200 cm, with SiCL textures. Where the paleosol depth ranged only from 140 cm to 157 cm, the "A2" unit was assigned. Soils in map unit "B" were also fine-silty, mixed, thermic Typic Hapludalfs. The well profiles were separated from those in "A", on the basis of paleosol depth. Map unit "B"

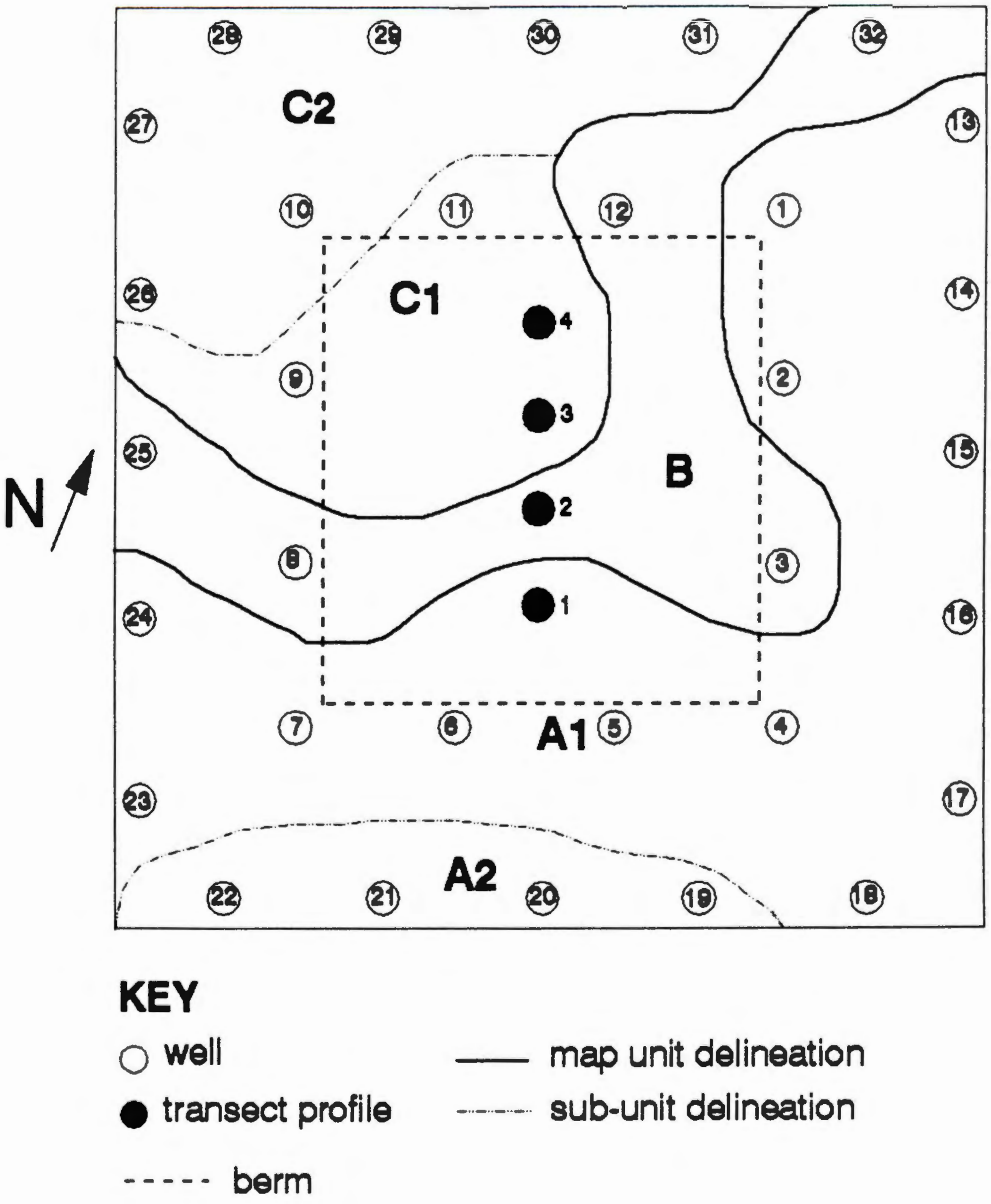


Figure 13. High-intensity, order one, soil survey map of the research plot.

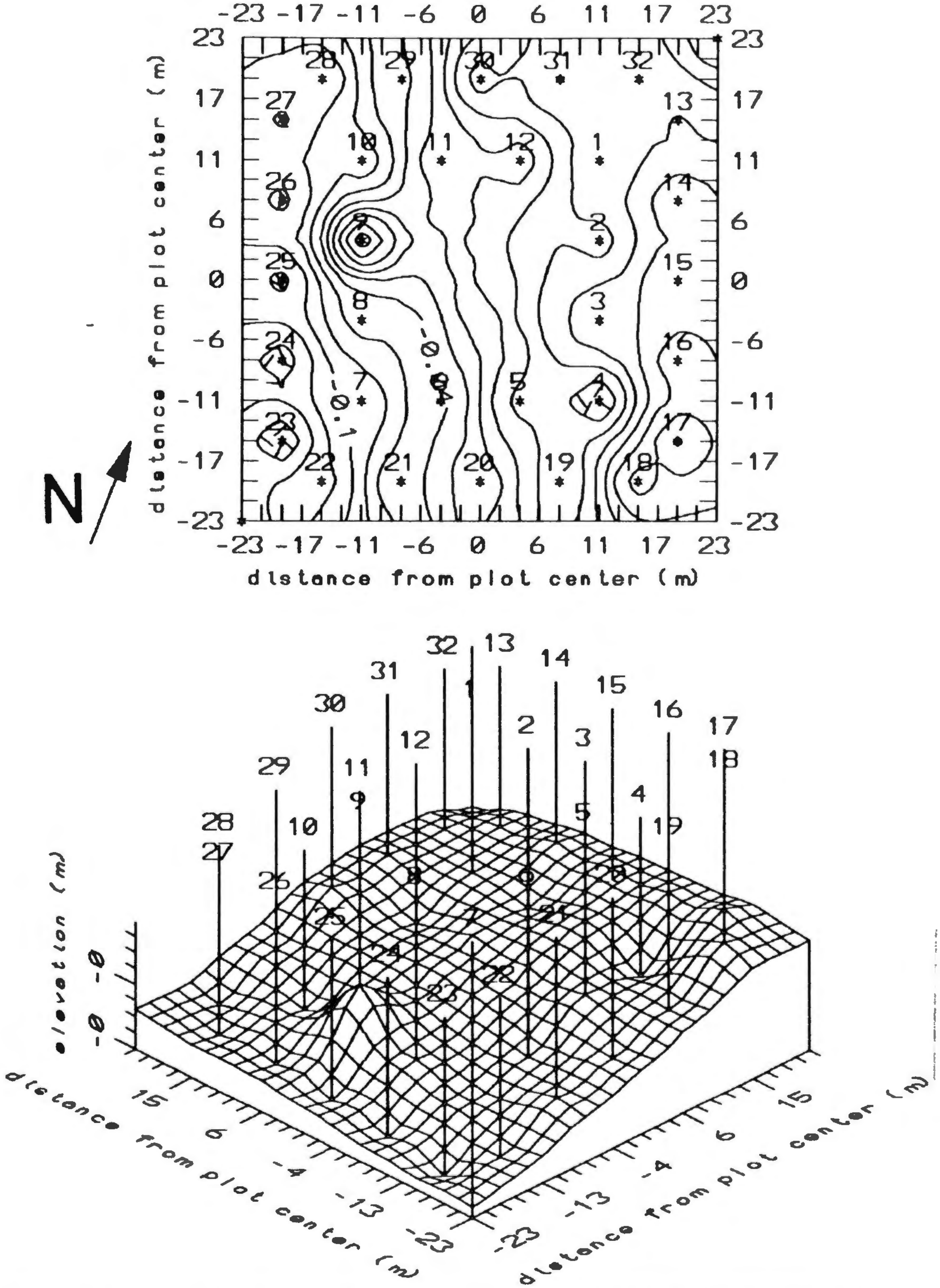


Figure 14. Topography and 3-dimensional surface map of the research plot surface.

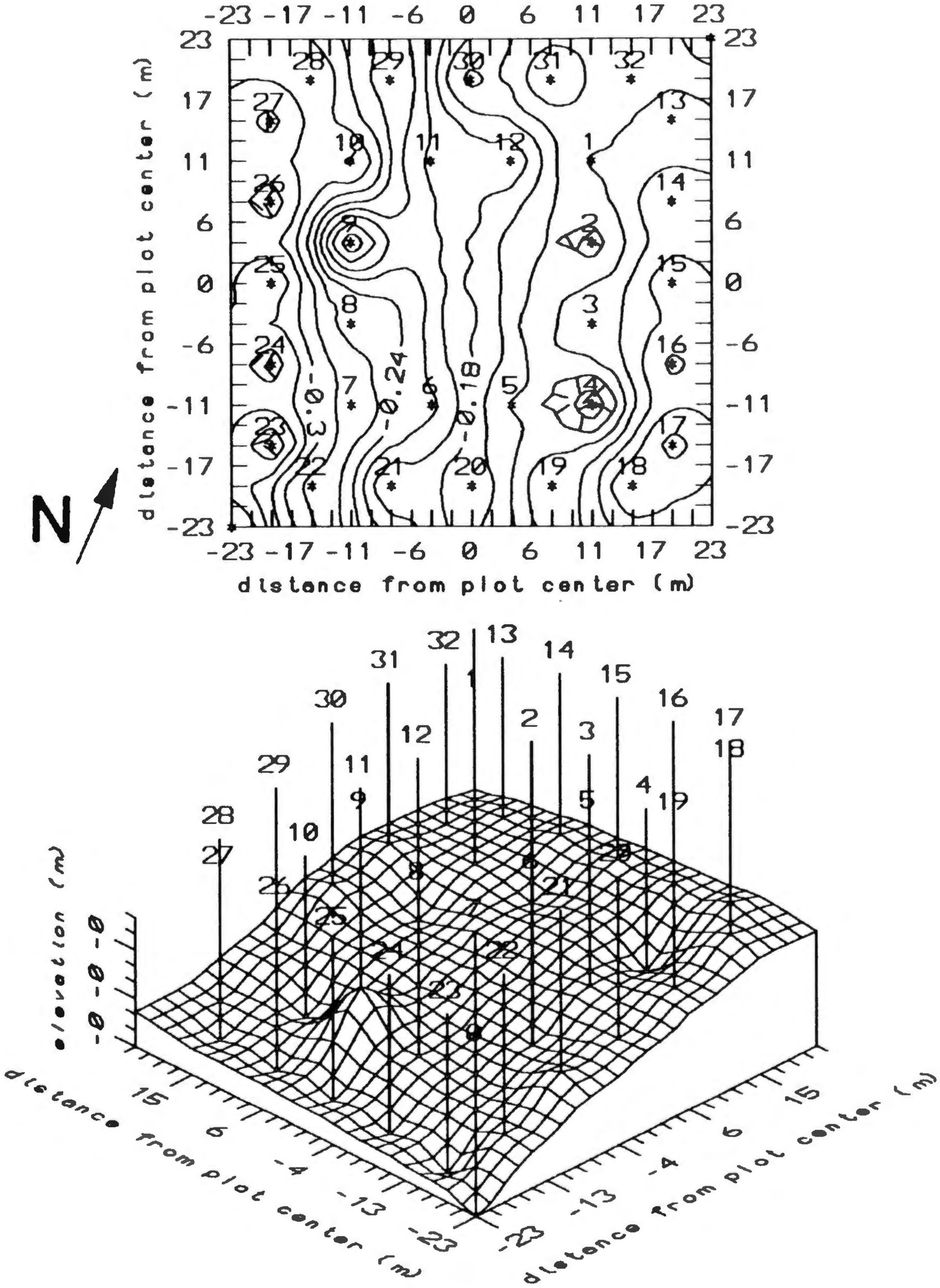


Figure 15. Topography and 3-dimensional surface map of the paleosol surface.

was assigned to those soils whose paleosol was >200 cm deep, like transect profile #2, and had a SiCL paleosol texture.

Map unit "C" also delineated fine-silty, mixed, thermic Typic Hapludalfs, but were found to have more sand and clay in the paleosol. While depth was not a consideration here, sub-unit "1" was delineated on the basis of L and CL paleosol textures. Sub-unit "2" was the soil that had SC, SCL, and SL paleosol textures.

Conclusions

1) A parent material discontinuity was present over the entire release plot. Surface elevations at each transect and well cores were similar, while depths to the discontinuities showed much more range in the profiles. Surface topography was therefore indicated to be a gentler reflection of the underlying alluvial topography. Topography and 3-dimensional surface maps were created for the research plot surface and paleosol surface.

2) According to well and transect profile notes and data, paleosol depths were shallowest on the south side of the research area, and got deeper toward the north side. The shallowest paleosol depth over the entire plot was 1.40 meters at well #21 on the south edge of the plot. The deepest paleosol depth was 2.30 meters at well #10 on the north side of the plot.

3) Textures in the paleosol trended from south to north also, with higher silt content on the south side giving to higher clay and then sand content on the northwest side. High silt content below the discontinuity on the south side of the plot suggested the possibility of Loveland loess. Sandy textures in the north are more indicative of the alluvial material suggested by Saucier (1987).

4) Based on depth to the discontinuity, paleosol texture, and laboratory data where appropriate, three map units were distinguished across the plot, with sub-units in two of them. A high-intensity, order one, soil survey map was successfully created.

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CHAPTER TWO

SOIL WATER PROPERTIES AND MONITORING AT AMES PLANTATION

Introduction

An ongoing water quality research project has been conducted on the University of Tennessee Ames Plantation Agricultural Experiment Station (Figure 16). Soil physical and chemical properties have been analyzed as possible factors affecting water quality, with respect to land management practices. Livingston (1993) found that soil morphology could control the direction of soil water movement, and ultimately affect the possible constituents in our groundwater. In the case that the direction of soil water movement could be predicted on this basis, so could the fate of many agricultural chemicals.

The ability to predict the direction of soil water movement was needed. Assuming that as on the Earth's surface, water would move from higher to lower points, water being perched by a lithologic discontinuity in soil would do the same along that interface while also being affected by soil water potential and preferential flow areas. In a study of soil morphology at the Ames Plantation Centennial field, a map of the alluvial paleosol topography was created (Figure 17). Using this map, along with a basic understanding of the physical properties of soil and soil water, it was believed that the direction of soil water movement could be predicted. The objectives of this study were to: 1) predict the direction

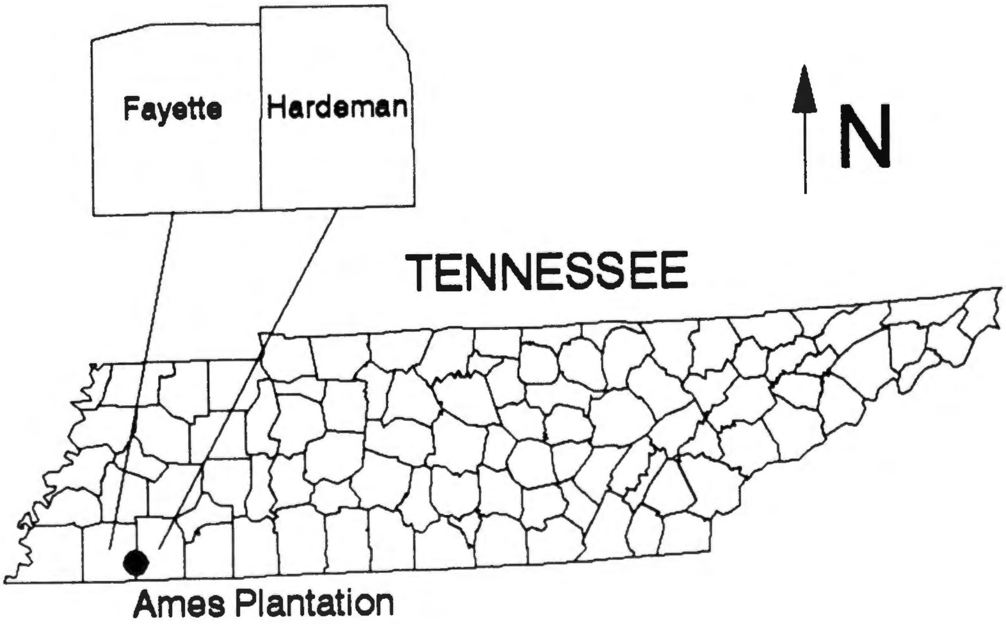

Figure 16. Location of the Ames Plantation Experiment Station.

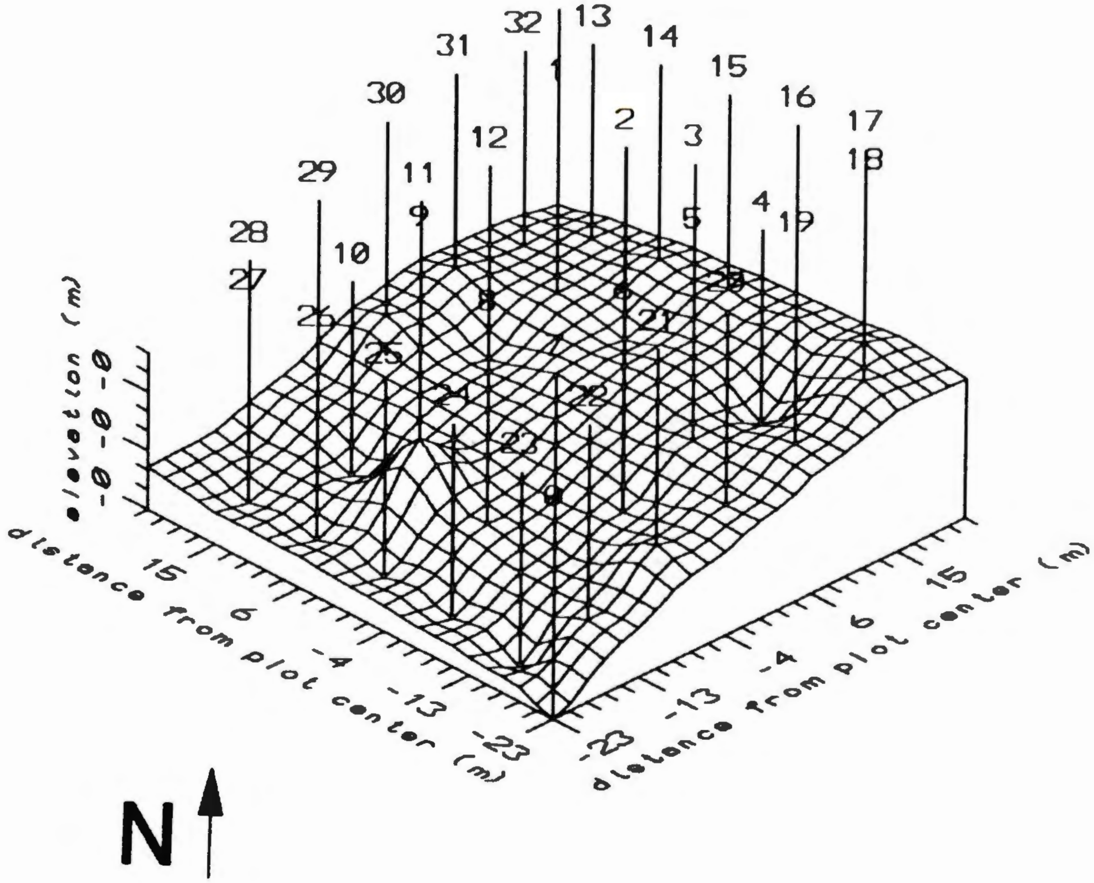

Figure 17. Alluvial paleosurface topography map of the Centennial Field site.

of soil water movement based on paleosurface topography 2) monitor the direction of soil water movement using a chloride tracer, and 3) determine the accuracy of the prediction.

Literature Review

Physical properties of soil

An understanding of the basic physical properties of soil was needed in order to understand the activity of its components. Soil morphology has been hypothesized to affect direction of movement of one of the major components, soil water. Soil was determined to be a polyphasic system consisting of the solid phase (soil matrix), liquid phase (soil solution), and gaseous phase (soil atmosphere) (Figure 18). The soil solution and soil atmosphere occupy pore space, which is approximately half of the soil volume (Boersma et al., 1972; Hillel, 1982; Ghildyal and Tripathi, 1987; Warrick, 1990; Jury et al., 1991). Soils are characteristically heterogeneous because properties within given phases vary. Soil is a particulate, disperse, porous system, as it is subdivided into small particles which have a large interfacial area between them in a given volume (Hillel, 1982).

Quantitative consideration must be given to the volume and mass relationships between the soil phases. Two densities have been of primary

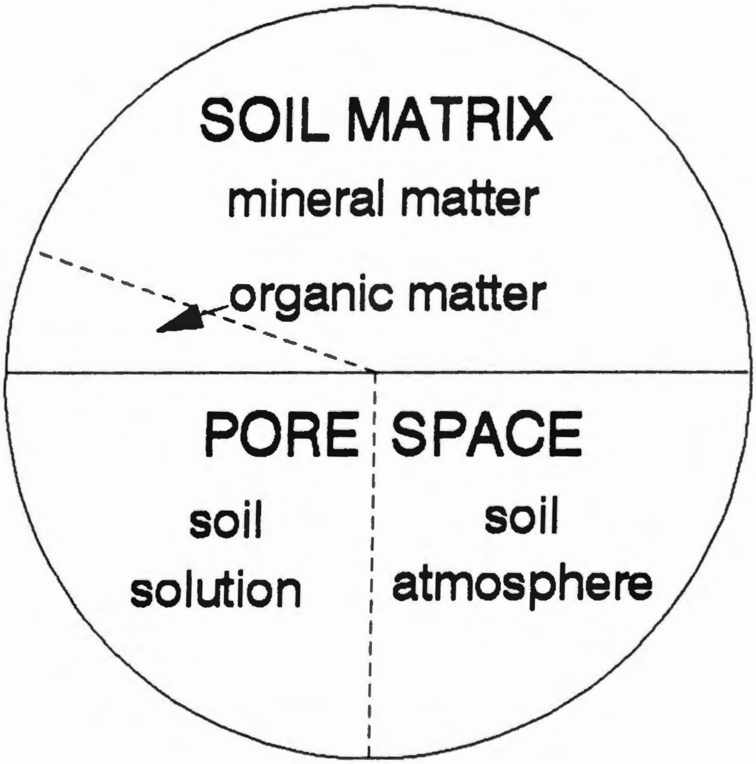

Figure 18. The polyphasic composition of soil (Hillel, 1982).

concern in the porous soil system. Mean particle density is the relationship of the mass of solids to the volume of solids, which is usually near that of quartz(2.6-2.7 g/cm^3) (Hillel, 1982; Warrick, 1990). Dry bulk density is the relationship of the mass of solids to volume of the combined solids and pore space of an undisturbed sample. From these two density measurements, distribution of pore size with respect to total pore space, or porosity, can be determined. Coarse textured soils are less porous than fine textured soils.

Soil wetness can be expressed in many different ways (Hillel, 1982; Warrick, 1990). In terms of relative mass (gravimetrically), water content will usually be <0.5 (50 %) although organic soils could be >1.0 (100%). Relative volume (volumetrically) describes volume of water relative to volume of pores (Hillel, 1982; Warrick, 1990; Jury et al., 1991). Gravimetric and volumetric water contents correspond closely with bulk density. Depth of water describes the amount of water stored in terms of a specific depth. In many cases degree of saturation, a normalized value between 0 and 1, must be considered (Warrick, 1990). These quantitative measurements are interrelated in many cases, and may be manipulated for calculations such that if certain properties are known, others may be determined. Knowledge of these physical parameters of soil, allowed consideration of the physical behavior of soil water.

Soil water

Upon a precipitation event, water infiltrates the soil from the surface, where it is held or even moved through soil pore space, or void space (Saxton and Shiau, 1990). Soil water is a lubricant for root penetration, facilitated microbial activity, and increased nutrient mobility and transport. These properties are best exemplified in medium textured soils, such as silty clay loams. Reservoirs and supply of soil water are affected not only by texture, but also humus content, structure, and compaction of the soil (Miller and Donahue, 1990).

The amount of water and energy of water held in soil were found as important factors in many soil properties as well as plant growth. Knowledge of the amount of water in soil was not sufficient for predicting flow, soil water potential had to also be considered (Hanks, 1992). The amount of kinetic energy of soil water was shown to be negligible due to the slow movement of soil water in most cases, whereas its potential energy was important because it was based on position or internal composition of the water (Clark, 1990; Hanks, 1992).

Soil water potential was defined as "the amount of work that must be done in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water (at the point under consideration)" (Aslyng, 1963). The potential was more simply defined by Warrick (1990) as an expression of the energy level of water in the soil system. Differences in potential energy in soil were responsible for soil water movement, because it flowed from places of higher energy to lower energy trying to obtain equilibrium (Hillel, 1982; Warrick, 1990; Jury et al., 1991).

Based on a critical review of the literature on the subject, Corey and Klute (1985) argued that authors who claimed that a constant "energy level" of soil water throughout a given soil indicated equilibrium of the water, were misinforming individuals who read that literature. They felt that no single potential would indicate equilibrium if constant. Spatial variability of the "energy level" of the soil water was suggested not to be grounds for predicting direction of movement. Summing of potentials that do not refer to the same components (e.g. pressure and gravitational) was criticized, and deemed inappropriate.

Instead of the widely accepted idea of total potential, Corey and Klute (1985) suggested that soil water movement occurs in two ways. The first was by the "convection of the solution or gas phase in which the water exists", as was said to be supported by the Darcy equation. The other was diffusion of the soil water relative to the bulk motion of the phase, occurring as a response to a gradient in the thermodynamic potential of the soil water, as suggested by the second law of thermodynamics.

Despite the arguments of Corey and Klute (1985), the concept of a total potential, and its additive components was still widely accepted and published in the literature. Warrick (1990) named several factors, or components, affecting the work that is needed to "transport", or move water. Elevation, soil matric effects, liquid and air pressures, solutes, temperature, and the overburden were considered as separate contributors to the total soil water potential. The terminology used in the literature varies, along with many concepts.

Hillel (1982) suggested three potentials referred to as gravitational (elevational), pressure, and osmotic. Gravitational potential was the energy stored by the soil water due to being moved to an elevation from a given elevation, and was independent of chemistry or pressure considerations. Pressure potential came from the pressure soil water was under relative to atmospheric potential. When the pressure was higher than atmospheric, potential was positive (saturation or submergence), when lower it was considered negative (capillary or matric). This matric potential was derived from capillary forces or adsorption by the soil matrix. Finally, the osmotic potential was from solutes in soil water which lower the soil water potential. This potential was also referred to as osmotic suction since the solutes would cause "pure pool water" to be drawn into the soil water through a semipermeable boundary (air space, biological, etc.).

Warrick (1990) simplified his components into elevational (gravitational), pressure head (which considered pressure and matric influences), and osmotic head. The reference state for the elevational component had to be known. For saturated conditions, the pressure head was found to be positive, while it was negative in unsaturated conditions.

Jury et al. (1991) suggested three different component potentials, with the third being broken down into five components. Gravitational potential was described as it was above. Solute potential was defined the same as the above osmotic potential. Tensiometer pressure potential considered all effects on soil water except gravitational and solute. Matric potential, air pressure potential, hydrostatic pressure potential, overburden pressure potential, and wetness potential were all considered parts of tensiometer pressure potential.

Hanks (1992) defined three components of soil water potential, called gravitational potential, matric potential, and pressure potential. Gravitational pressure was associated with a given elevation from the reference state, and is independent of soil properties. The matric potential was derived from the adsorptive forces of the soil matrix. Pressure potential or submergence potential was used with saturated soils, and indicated the positive pressure exerted on a point by the overburden pressure (from unsupported solid material).

Clark (1990) suggested that total water potential was composed of pressure, gravimetric, and osmotic components. This work dealt primarily with measurement of the different potentials. Gravimetric (gravitational) potential was suggested to be easy to determine, due to it being relative to a known datum. Pressure and osmotic potentials of unsaturated soils were more difficult to measure. In these cases, other properties of soil were measured and related to the potentials. Gravitational potential was determined as equal to the specific weight of water times the elevation of the point in question relative to the reference datum. Pressure potential was found to be equal to R (gas constant for water vapor), times T (absolute temperature), times the natural log of the relative humidity in the vapor phase. Osmotic potential was calculated by multiplying R*T by the molar concentration of solute particles.

McDaniel et al. (1992) examined differences in total water potential of Ap and Bt horizons, as they did or did not occur at different times. Where differences did occur, the importance of the gravitational effect was shown. Their research dealt primarily with Mn/Fe ratios as indicators of soil water movement on a field scale.

Kim et al. (1992) examined soil water flow in marine clay soils. Water flowed due to shrinking and swelling of the soil material. Matric potential influences were insignificant in these unripe soils, as compared to rigid soils where matric potential was the main driving force for water movement. Overburden potential from movement during the shrinking and swelling process, was used to account for soil water flow due to potential.

Nassar and Horton (1989) were interested in the effect of temperature gradient, along with matric and osmotic potential on the transfer of soil water. The results of this study showed a net transfer of water from hot to cold soil, where water vapor from the hot moved into colder soil and condensed upon establishment of a favorable gradient of matric and osmotic potential.

Water has been shown to move in both saturated and unsaturated soil systems based on the properties discussed previously, its quantity in the soil, and its low resistance to flow (viscosity) (Boersma et al., 1972; Hillel, 1982; Ghildyal and Tripathi, 1987; Jury et al., 1991). Soil water was found to move through pores in the soil, which were non-uniform in size, rough, irregular, and tortuous, containing restrictive necks and even "dead ends" (Hillel, 1982).

In a study of groundwater contamination, Jabbro et. al. (1994) described macropores as pores that are greater than 1 mm in diameter, which water and chemicals move through preferentially while bypassing the soil matrix. This study suggests that movement of chemicals downward is facilitated by macropores.

Flow pathways of soils and solutes in soil formed distinct pathways that were not always predictable (Flury et al., 1994). In many instances these flow pathways were referred to as preferential flow pathways. These were affected by macropore structure, differing initial conditions, or differing boundary conditions. In well structured loamy or clayey soils, some water moved along cracks and fissures. In structureless sandy soils, infiltrating water split into fingers. Lateral and vertical preferential flow pathways also complicated the characterization and quantitative measure of soil water/solute transport (Ghodrati and Jury, 1990).

Funnel-type preferential flowpaths were described as those associated with an inclined soil layer with an abrubt textural discontinuity (Kung, 1993; Ju and Kung, 1993). In this situation, most of the solute in solution passed by the soil matrix. Numerical simulation of soil solution movement based on funnel flow was shown to be possible only if soil layering structures were precisely mapped, and if preferential flow patterns in layered soil profiles were accurately established (Ju and Kung, 1993). Ground penetrating radar was suggested as having great potential for use in non-destructive detection of soil layering in sandy vadose zones.

Biopores, another source of preferential flow pathways in the literature, were pores created by organisms in the soil. Edwards et al. (1993) showed the effectiveness of earthworm burrows as preferential flowpaths for atrazine transport under no-tillage corn production.

Wilson et al. (1993) studied subsurface soil water flow and found it occurred mainly in the upper soil layers after storm events. This was called the stormflow zone. Water and chemicals in micropores moved slowly, somewhat continuously, and in many directions. Macropores were described as the preferential flow paths in which water moved rapidly and discretely following storm events. Substantial flow could have occurred in the soil matrix micropores in addition to preferential flow through macropores.

Haan et al. (1994) determined the effects of different natural weather sequences on chemical transport. Different amounts and types of precipitation, as well as evapotranspiration, were shown to affect soil water transport of solutes.

Conservative chemical tracers, such as KBr and $CaCl_2$, have been effectively used for detecting soil water movement (McMahon and Thomas, 1974; Tyler and Thomas, 1977; Barbee and Brown, 1986; Gerritse and Adeney, 1992; Wilson et al., 1993; Jabbro et al., 1994; Wilson et al., 1994; Yoder and

Mote, 1994). In particular, chloride has been used as an effective simulator of nitrate movement in soils, and is not affected biologically (McMahon and Thomas, 1974; Tyler and Thomas, 1977). The effectiveness of porous ceramic cups versus pan samplers in soil, were also tested using chloride ion (Barbee and Brown, 1986). Gerritse and Adeney (1992) studied the effects of partitioning in soils using chloride tracers, as the negative charges on soil surfaces repel both ions.

Soils at Ames Plantation have been found to be highly susceptible to erosion. Due to this hazard, no-till practices have been used. No-till facilitated macropore development from cracks between soil aggregates, root channels, worm holes, ant tunnels, etc. Continuous macropores allowed preferential flow of water and chemicals. In the loessial soils of west Tennessee, lack of strong soil structure explained lack of macropores (Wilson et al., 1994). Upon consideration of these factors affecting soil water behavior, and the physical parameters of soil, predictions of soil water behavior at the Ames Plantation could be made.

Materials and Methods

Prediction of tracer destination

Field notes describing preferential flow pores, faces, and mottling, as well as water present in the profile around the discontinuity suggested that soil morphology was controlling soil water movement. Based on these notes, and the presence of the discontinuity throughout the plot, paleosol topography was used to predict the direction of soil water movement within the plot.

The paleosol depth from the surface of each shallow well was determined (Figure 17). The surface elevation at plot center was considered zero. A better indication of topography was given here, as opposed to looking at individual depths, which were relative only to their corresponding surfaces.

Assuming that water would flow from higher points to lower points of the paleosurface, several wells were possible destinations for soil water, based solely on topographic postion (Figure 19). From the paleosurface map, the northern and western regions of the research plot seemed likely receptors of water, as they appeared topographically lower than the southern and eastern regions (Figure 17). Well #9 was located at an irregularly high point in the discontinuity, and water was thus expected to preferentially flow around it towards wells #8 and #10. The peak in the discontinuity at well #9, was also expected to hinder some water from reaching wells #25 and #26 which were themselves low in the interface, but directly west of well #9. The irregularly high point at #9 may also have been due to error in measurement, in which case it may have been a likely receptor of water, as well as #25 and #26.

The most probable destinations of soil water were wells #7, #8, #10, #23, #24, and #27. Other less likely possibilities were well #6, #9, #11, #25, #26, #28, and #29. In fact, water found in any part of the predicted zone was a possibility (Figure 19). The rest of the wells appeared to be located such that

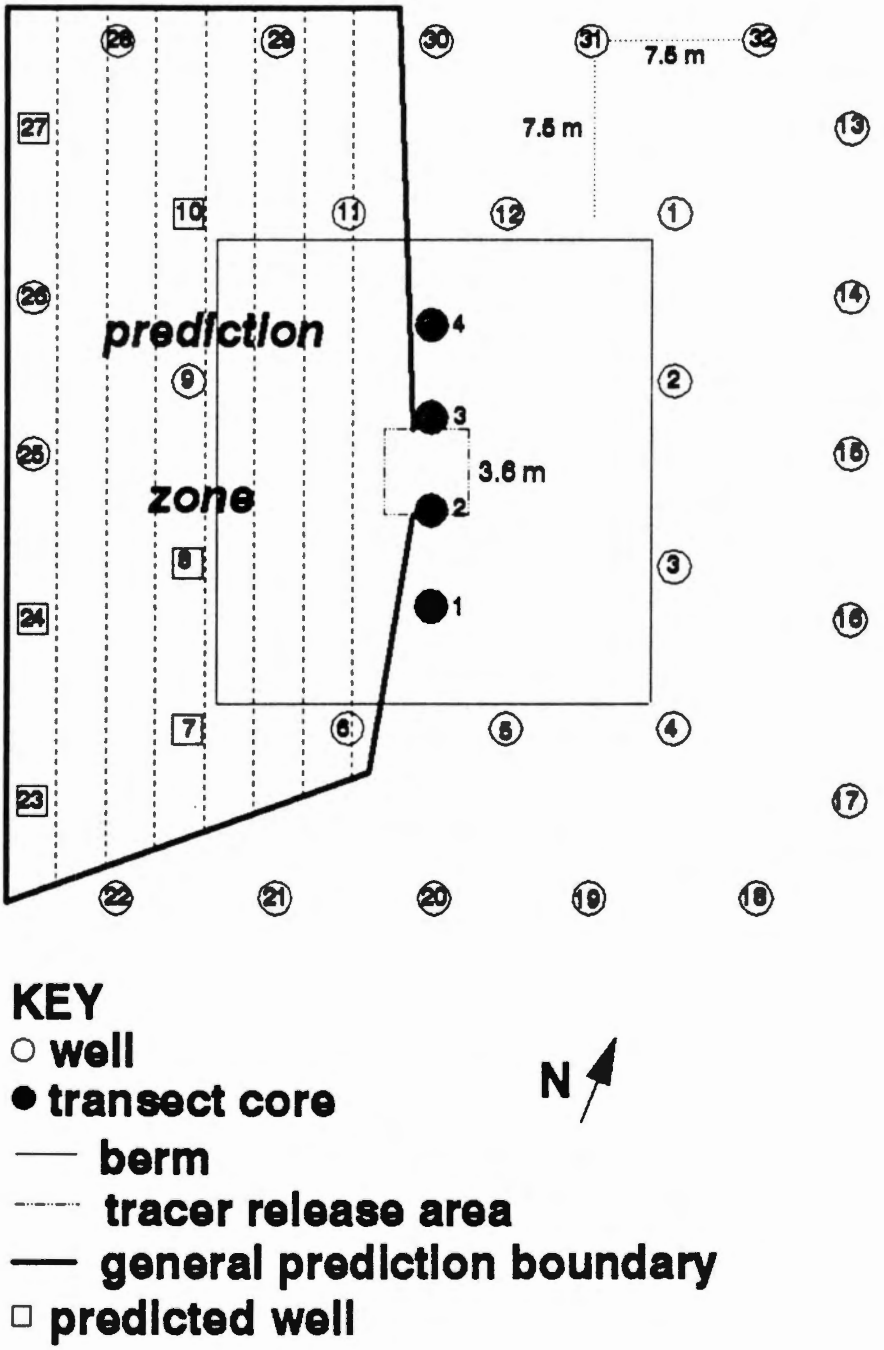

Figure 19. Diagram of the wells predicted to receive water based on topographic position of the discontinuity.

water would have to flow "uphill" to reach them.

Field Methods

Vadose zone sampling wells were installed as suggested in the well placement design (Figure 20). These shallow wells were set to the depth of the alluvial paleosol determined in the field (Figure 21). The wells were arranged so as to determine the initial direction of soil water flow immediately adjacent to the berm, and provide approximately equal spatial monitoring of soil water movement away from the release plot. A 900 ppm $CaCl_2$ tracer release was made within the 0.05 hectare plot. Approximately 13. m^2 , inside the designated release plot, was established as the release area by installing thin steel walls about 0.4 m high. The wall corners were caulked together to avoid leaking, and were secured with the displaced soil at the base (Figure 22 a,b). Before the release, wells 4, 9-12, 14, 16, 20, 24-26, 29, and 30 (Figure 20) were emptied of the background water samples they were holding, and these samples were collected in 500 ml amber glass jars for background laboratory analysis.

The tracer was prepared by mixing calcium chloride in well water from the Ames Plantation, in order to reach a final volume of approximately 1359. L of concentrated tracer solution (10 cm average depth across release area). Once prepared, the solution was applied to the release area on 5-14-96 at 2:22:45pm using two hoses. Due to the uneven surface within, different volumes of tracer pooled in different places of the release area. The tracer release was completed

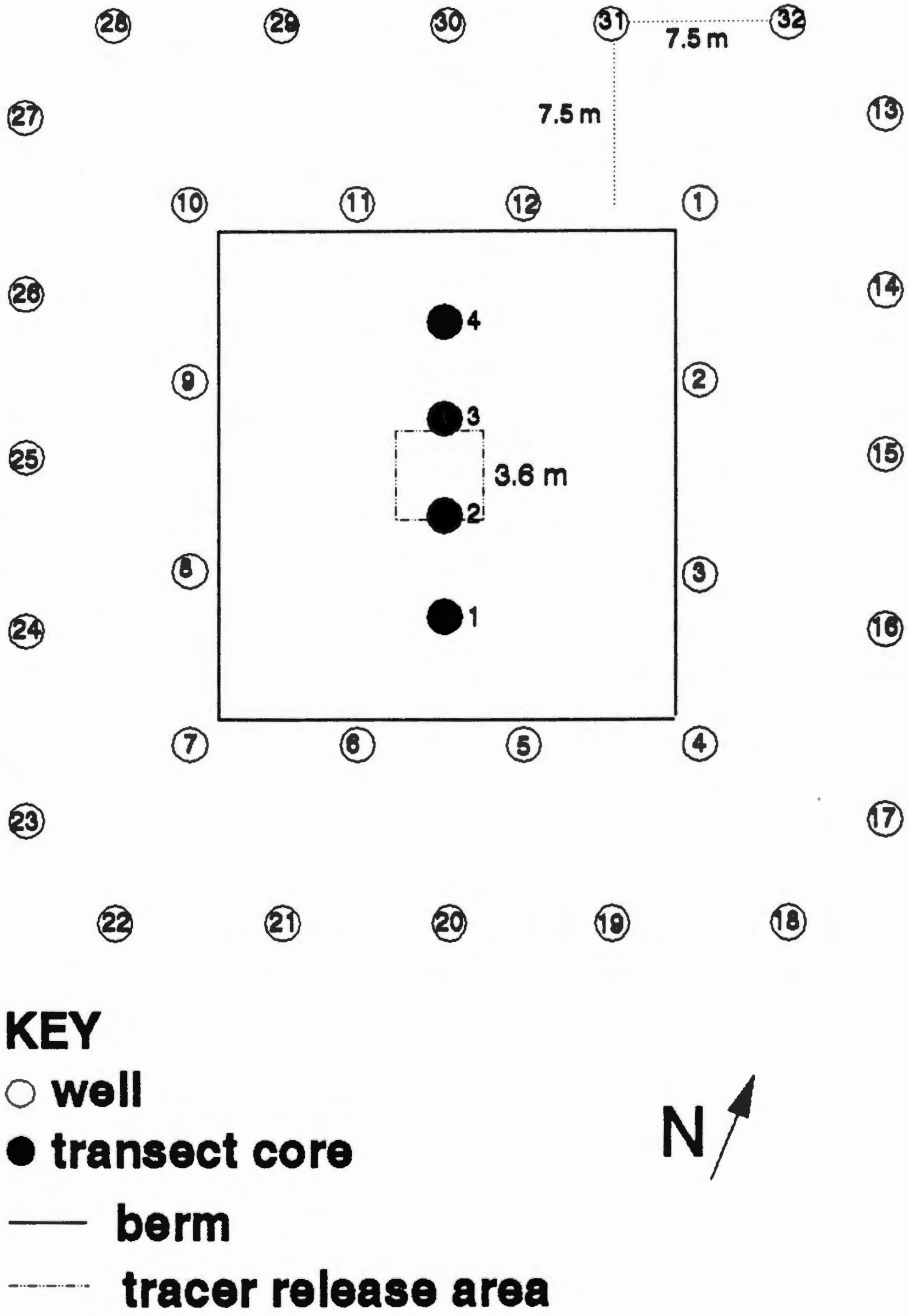

Figure 20. The well placement design.

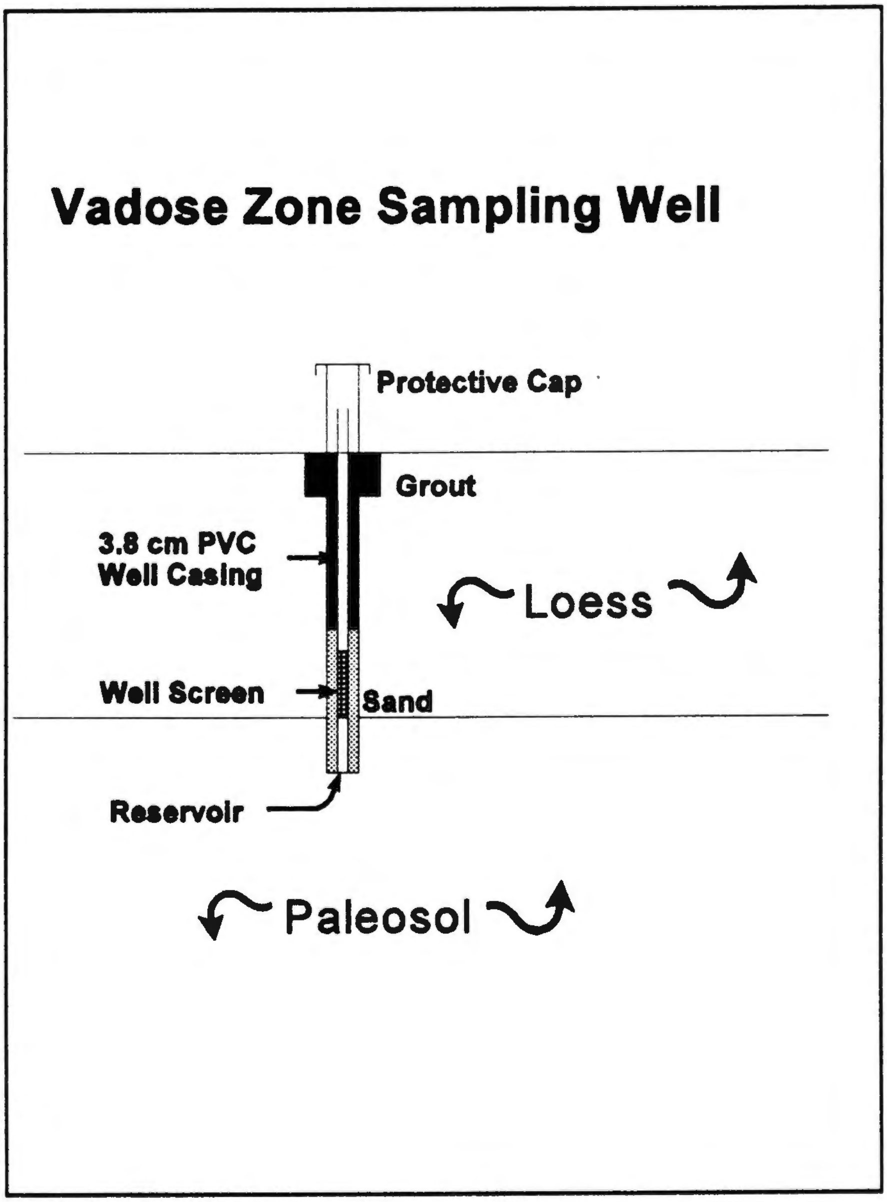

Figure 21. The shallow sampling well design (Yoder, 1995).

Figure 22. a) corners of the release area walls were caulked to avoid leaking. b) The walls were secured by filling the void with displaced soil at the base.

in 14 minutes 35 seconds (Figure 23).

The solution was allowed to move into and through the soil overnight. A note was made that an unmeasured amount of tracer leaked from the release area. Several wells were found to contain water the morning of 5-15-96. Wells 4, 9-12, 16, 20, 25, 26, 28, and 29 (Figure 20) were sampled at 8:30am using a vacuum, into 500 ml amber glass jars for laboratory analysis (Figure 24 a,b). Another sampling was done 5-16-96 at 8:30am, with wells 4, 14, 20, 24, 25, and 28 yielding samples. Since samples were decreasing markedly in volume, about 1359 L of plain well water was applied to the field at 1:30pm and allowed to move into and through the soil overnight in order to flush out the area. No samples were found at 8:30am 5-17-96, but future sampling would be conducted as necessary. All well samples were kept cool for transport back to the laboratory. Upon reaching the lab, samples were refrigerated until analysis.

Laboratory Methods

Moist sub-samples of soil from the 47 transect core samples prior to tracer release, had been placed in clean glass jars and refrigerated upon sampling. Analysis for background chlorine and nitrates was done on these sub-samples using ion chromatography (Pfaff et al., 1989). Refrigerated water samples taken from the above shallow wells were analyzed for chloride using ion chromatography (Pfaff et al., 1989). Both background chloride, and tracer chloride amounts were measured on the well samples.

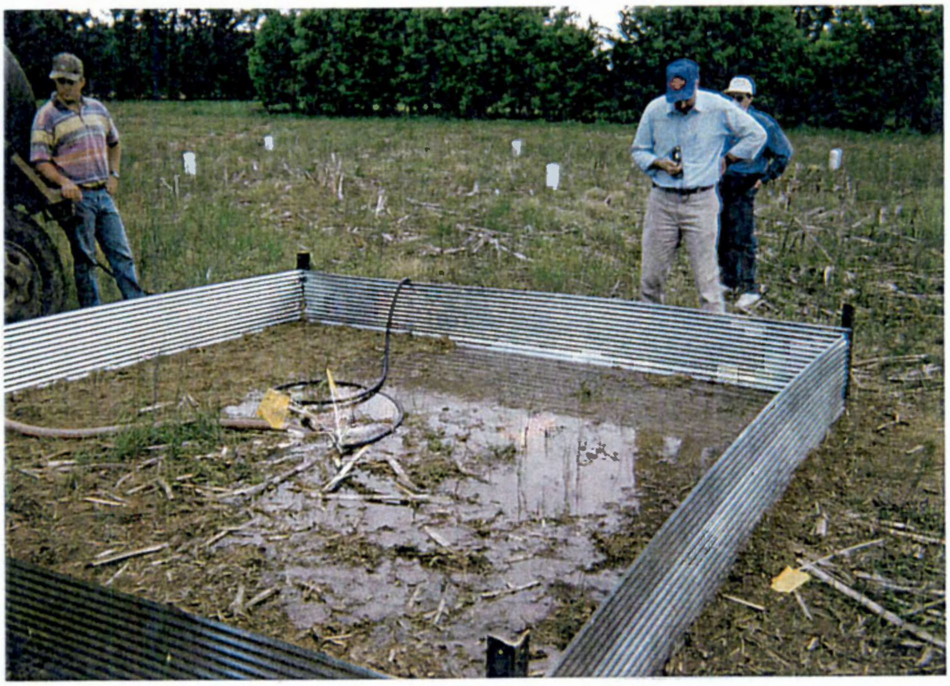

Figure 23. Approximately 1359. L of the tracer solution was applied to the release area.

Figure 24. a) Wells were checked for water by blowing through a plastic tube extending to the bottom of the well. b) Samples were taken into amber glass jars using a vacuum pump.

Results and Discussion

Background amounts of chloride ion in transect soil samples were found to be very low in most cases (Tables 17, 18, 19, 20). Only three surface horizons of all 47 samples had values appearing markedly higher than the others. Chloride was an acceptable tracer on the field, assuming that the transect values represent the whole research area.

Water samples taken from the shallow wells on 4/2/96 and 5/14/96, indicated some background levels of chloride in the soil water, which were higher than the previously mentioned soil background values in many cases (Table 21). Precipitation totals applicable to given sampling events must also be considered (Table 22). In many cases there was <5 ml of sample taken to analyze by ion chromatography, so background levels could not be established for all wells. The wells which had been predicted to collect water based on the topographic position of their discontinuity were considered. Well numbers 6, 7, 8, 9, 10, 11, 23, 24, 25, 26, 27, 28, and 29 were thought to be included in the zone of wells that were possible receptors of water (Figure 19).

Based on the ion chromatography results for the wells predicted to receive water, a mean background chloride ion concentration of 3.12 mg kg^{-1} soil (range = 0.00 to 20.28 mg kg^{-1} soil), with a standard deviation of 7.33 mg kg^{-1} soil was calculated (Table 21). Where no sample was taken, a negligible amount of chloride ion was assumed and its concentration was considered zero.

Table 17. Ion chromatography data for transect core #1 soil samples.

sample #	horizon	bottom depth (cm)	Cl^-	NO_2^- - N	NO_3^- - N	SO_4^{2-} - S
			------mg L^{-1}------			
blank	-	-	2.94	-	0.15	2.83
9512	Ap1	9	2.84	-	0.26	3.89
9513	Bt1	29	4.02	-	-	4.20
9514	Bt2	68	2.51	-	-	3.74
9515	Bt3	110	2.06	-	-	3.49
9516	Bt4	148	2.83	-	-	4.67
9517	BC1	169	2.51	-	-	4.45
9518	BC2	190	2.16	-	-	3.86
9519	2Bt1	230	2.34	-	-	3.87
9520	2Bt2	262+	2.61	-	-	5.17

Table 18. Ion chromatography data for transect core #2 soil samples.

sample #	horizon	bottom depth (cm)	Cl^-	NO_2^- - N	NO_3^- - N	SO_4^{2-} - S
			mg L^{-1}			
9521	Ap1	7	20.93	-	14.62	3.87
9522	Ap2	20	2.91	-	0.08	3.31
9523	Bt1	46	3.03	-	-	6.76
9524	Bt2	78	4.02	-	0.20	8.18
9525	Bt3	120	3.97	-	0.17	4.64
9526	Bt4	150	3.91	-	-	3.70
9527	BC1	172	3.79	-	-	3.59
9528	B't1	201	3.75	0.11	0.12	3.61
9529	2B't2	219	3.14	-	0.17	2.73
9530	2B't3	243	3.37	0.12	0.28	3.19
9531	2B't4	260+	3.80	-	-	6.15

Table 19. Ion chromatography data for transect core #3 soil samples.

sample #	horizon	bottom depth (cm)	Cl^-	NO_2^- - N	NO_3^- - N	SO_4^{2-} - S
			-----	-----	$mg\ L^{-1}$	-----
9532	Ap1	4	16.24	-	11.65	3.83
9533	Ap2	13	2.46	-	0.52	3.54
9534	Bt1	29	3.67	-	0.29	5.55
9535	Bt2	52	4.43	-	0.36	5.70
9536	Bt3	95	3.31	-	0.35	4.59
9537	BC1	128	4.96	-	0.44	6.25
9538	BC2	158	3.76	-	0.35	7.11
9539	BC3	187	3.25	-	0.31	3.21
9540	2BC4	207	4.01	-	0.30	3.22
9541	2BC5	218	3.43	-	0.20	3.07
9542	2BC6	243	3.67	-	0.22	4.08
9543	2BC7	259+	4.15	0.13	0.07	2.75

Table 20. Ion chromatography data for transect core #4 soil samples.

sample #	horizon	bottom depth (cm)	Cl^-	NO_2^- - N	NO_3^- - N	SO_4^{2-} - S
			mg L^{-1}			
9544	Ap1	6	18.00	-	11.60	3.31
9545	Ap2	16	3.73	-	1.59	4.33
9546	Bt1	43	3.20	-	-	6.18
9547	Bt2	70	2.86	-	-	4.77
9548	Bt3	96	2.74	-	0.37	7.61
9549	Bt4	116	3.90	-	0.31	7.02
9550	Bt5	134	3.83	-	0.10	4.53
9551	Bt6	170	3.61	-	-	4.56
9552	BC1	189	4.12	-	-	3.64
9553	BC2	205	3.32	-	-	3.42
9554	2Bt1	227	3.36	-	0.10	3.40
9555	2Bt2	250	2.85	-	0.16	3.52
9556	2Bt3	261	3.80	0.09	0.17	3.48
9557	2Bt4	283	3.86	-	0.15	4.05
9558	2Bt5	328+	3.29	-	0.15	2.83

Table 21. Ion chromatography data for shallow well samples prior to the tracer release.

well number	sample date	Cl^-	NO_2^- - N	Br^-	NO_3^- - N	HPO_4^{2-} - P	SO_4^{2-} - S
		$mg\ L^{-1}$					
CF1*	5/14/96	NS**	NS	NS	NS	NS	NS
	4/2/96	10.29	ND***	ND	5.68	0.65	5.63
CF2	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF3	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF4	5/14/96	0.72	0.02	ND	0.80	ND	1.45
	4/2/96	0.38	0.19	ND	0.49	ND	1.40
CF5	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF6	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF7	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF8	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF9	5/14/96	13.83	0.22	ND	8.61	0.58	5.79
	4/2/96	11.40	0.05	ND	6.02	ND	0.67
CF10	5/14/96	20.28	13.46	ND	20.97	7.49	12.62
	4/2/96	NS	NS	NS	NS	NS	NS
CF11	5/14/96	17.53	0.03	ND	6.08	ND	0.48
	4/2/96	NS	NS	NS	NS	NS	NS
CF12	5/14/96	11.65	0.66	ND	9.31	ND	7.95
	4/2/96	9.02	ND	ND	4.57	ND	2.45
CF13	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF14	5/14/96	4.06	0.27	ND	1.52	0.49	2.19
	4/2/96	0.48	0.02	ND	0.75	ND	1.59

Table 21. cont.

well number	sample date	Cl^-	NO_2^- - N	Br^-	NO_3^- - N	HPO_4^{2-} - P	SO_4^{2-} - S
		mg L^{-1}					
CF15	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	16.93	ND	ND	18.74	0.75	0.51
CF16	5/14/96	2.36	0.12	ND	1.69	0.06	3.50
	4/2/96	NS	NS	NS	NS	NS	NS
CF17	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF18	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF19	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF20	5/14/96	0.90	0.01	ND	0.90	0.04	1.78
	4/2/96	0.97	0.97	ND	0.82	0.04	1.45
CF21	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF22	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF23	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF24	5/14/96	17.24	0.93	ND	36.08	1.55	16.78
	4/2/96	NS	NS	NS	NS	NS	NS
CF25	5/14/96	16.72	0.02	ND	11.20	ND	0.95
	4/2/96	16.81	ND	ND	10.44	ND	0.99
CF26	5/14/96	3.50	0.30	ND	1.63	0.72	3.54
	4/2/96	NS	NS	NS	NS	NS	NS
CF27	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS

Table 21. cont.

well number	sample date	Cl^-	NO_2^- - N	Br^-	NO_3^- - N	HPO_4^{2-} - P	SO_4^{2-} - S
		mg L^{-1}					
CF28	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF29	5/14/96	9.59	12.45	ND	6.43	1.17	2.97
	4/2/96	9.14	0.05	ND	4.77	ND	1.83
CF30	5/14/96	22.31	2.05	ND	21.60	1.24	1.03
	4/2/96	21.35	ND	ND	3.93	ND	1.46
CF31	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS
CF32	5/14/96	NS	NS	NS	NS	NS	NS
	4/2/96	NS	NS	NS	NS	NS	NS

*CF=Centennial field well
**NS=no sample taken
***ND=not detectable, <0.02 mg L^{-1}

Table 22. Precipitation totals for given sampling events.

sampling date	precipitation total (cm)	precipitation dates
4/2/96	13.21	2/19/96 - 4/1/96
5/14/96 5/15/96	15.49	4/2/96 - 5/13/96
6/11/96	8.79	5/16/96 - 6/5/96
	8.38	6/6/96 - 6/11/96
6/14/96	2.54	6/11/96 - 6/13/96

Due to the high standard deviation, the actual amount of chloride ion determined could not confidently portray background levels in soil water. Accuracy of the results for predicted wells were also checked for samples taken after the release of $CaCl_2$ tracer (Table 23). A mean chloride ion concentration of 9.48 mg kg^{-1} soil (range = 0.00 to 36.31 mg kg^{-1} soil), with a standard deviation of 8.02 mg kg^{-1} soil was calculated. Once again, low confidence in the chloride values prevented them from being legitimately considered to prove or disprove soil water movement.

Due to the fact that ion chromatography results were not used, the mere presence of water samples had to be considered for the predicted wells. A prediction was considered successful when water was sampled on all three dates (Table 23). Since only one of the wells predicted to be a most likely receptor of water, #10 out of #7, 8, 10, 23, 24, and 27, actually received water on all three sampling dates, predicting an actual well was not that successful (Figure 25).

While the specific well numbers were not successfully predicted, a legitimate prediction of the general direction of soil water movement based on topography was made. Wells #9, 10, 11, 25, 26, 28, and 29 of those in the predicted zone, yielded samples on all three sampling dates (Table 23). These wells were all found in the NNW portion of the research area, within the predicted zone. Just outside of the predicted zone, in the NNW portion of the research plot were wells #12 and #30, also yielding samples on all three

Table 23. Ion chromatography data for shallow well samples reflecting the tracer release.

well number	sample date	Cl^-	NO_2^- N	Br^-	NO_3^- N	HPO_4^{2-} P	SO_4^{2-} S
		mg L^{-1}					
CF1*	5/15/96	NS**	NS	NS	NS	NS	NS
	6/11/96	10.05	ND	ND	3.79	ND	1.50
	6/14/96	9.90	ND	ND	3.70	ND	1.05
CF2	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	10.51	ND	ND	5.30	ND	1.40
	6/14/96	9.89	ND	ND	5.12	ND	0.73
CF3	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	15.10	ND	ND	5.23	ND	5.34
	6/14/96	15.92	ND	ND	5.19	ND	4.98
CF4	5/15/96	1.58	0.06	ND***	1.31	ND	2.34
	6/11/96	18.55	ND	ND	4.38	ND	1.90
	6/14/96	19.49	ND	ND	4.64	ND	1.58
CF5	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	14.46	ND	ND	5.32	ND	3.79
	6/14/96	14.40	ND	ND	4.76	ND	2.01
CF6	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	13.05	ND	ND	6.10	ND	3.41
	6/14/96	12.32	ND	ND	5.76	ND	2.21
CF7	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	12.76	ND	ND	6.65	ND	5.37
	6/14/96	11.63	ND	ND	6.72	ND	4.42
CF8	5/15/96	36.31	ND	ND	58.51	3.11	76.79
	6/11/96	NS	NS	NS	NS	NS	NS
	6/14/96	3.58	ND	ND	4.61	ND	4.26
CF9	5/15/96	3.79	0.16	ND	1.65	0.37	2.15
	6/11/96	9.26	ND	ND	7.33	ND	1.55
	6/14/96	2.39	ND	ND	5.98	ND	10.81
CF10	5/15/96	19.35	0.42	ND	23.80	4.61	8.07
	6/11/96	21.05	ND	ND	5.44	ND	0.89
	6/14/96	5.08	ND	ND	5.11	ND	5.65

Table 23. cont.

well number	sample date	Cl^-	NO_2^- N	Br^-	NO_3^- N	HPO_4^{2-} P	SO_4^{2-} S
		mg L^{-1}					
CF11	5/15/96	17.19	0.01	ND	6.12	ND	0.5
	6/11/96	17.89	ND	ND	5.71	ND	0.71
	6/14/96	18.82	ND	ND	5.72	ND	0.84
CF12	5/15/96	10.74	0.25	ND	9.73	0.62	7.14
	6/11/96	12.26	ND	ND	4.02	ND	1.34
	6/14/96	11.63	ND	ND	4.23	ND	1.03
CF13	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	11.86	ND	ND	6.41	ND	2.74
	6/14/96	11.77	ND	ND	6.10	ND	1.13
CF14	5/15/96	4.33	0.50	ND	4.58	1.66	18.99
	6/11/96	15.53	ND	ND	5.59	ND	1.20
	6/14/96	15.27	ND	ND	6.40	ND	1.22
CF15	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	4.67	ND	ND	12.04	ND	5.15
	6/14/96	6.26	ND	ND	12.80	ND	4.98
CF16	5/15/96	3.97	0.15	ND	3.43	1.13	8.35
	6/11/96	3.16	ND	ND	7.35	ND	10.67
	6/14/96	2.90	ND	ND	6.37	ND	9.61
CF17	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	19.64	ND	ND	4.31	ND	2.85
	6/14/96	19.08	ND	ND	4.91	ND	1.90
CF18	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	16.15	ND	ND	5.59	ND	4.40
	6/14/96	15.34	ND	ND	4.95	ND	3.31
CF19	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	12.93	ND	ND	3.55	ND	2.28
	6/14/96	13.39	ND	ND	3.84	ND	1.58
CF20	5/15/96	2.54	0.09	ND	3.25	ND	4.13
	6/11/96	12.70	ND	ND	6.50	ND	2.49
	6/14/96	3.10	ND	ND	5.68	ND	15.36

Table 23 . cont.

well number	sample date	Cl^-	NO_2^--N	Br^-	NO_3^- N	HPO_4^{2-} P	SO_4^{2-} S
		mg L^{-1}					
CF21	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	14.47	ND	ND	8.19	ND	5.50
	6/14/96	18.33	ND	ND	6.74	ND	3.61
CF22	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	16.98	ND	ND	7.26	ND	3.73
	6/14/96	18.60	ND	ND	7.08	ND	1.79
CF23	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	12.15	ND	ND	7.06	ND	2.69
	6/14/96	13.30	ND	ND	6.71	ND	1.78
CF24	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	3.02	ND	ND	4.84	ND	2.16
	6/14/96	12.37	ND	ND	5.00	ND	2.12
CF25	5/15/96	15.83	0.02	ND	14.19	0.09	1.46
	6/11/96	18.38	ND	ND	8.52	ND	3.15
	6/14/96	18.76	ND	ND	8.69	ND	2.75
CF26	5/15/96	27.52	ND	ND	26.93	7.87	41.11
	6/11/96	12.06	ND	ND	6.29	ND	1.99
	6/14/96	14.55	ND	ND	5.33	ND	2.59
CF27	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	10.94	ND	ND	7.25	ND	2.82
	6/14/96	9.19	ND	ND	6.57	ND	1.69
CF28	5/15/96	5.29	0.15	ND	5.43	ND	18.47
	6/11/96	16.50	ND	ND	5.04	ND	6.22
	6/14/96	4.94	ND	ND	4.22	ND	22.57
CF29	5/15/96	3.22	0.36	ND	0.79	0.28	1.72
	6/11/96	10.95	ND	ND	6.20	ND	2.22
	6/14/96	12.32	ND	ND	5.52	ND	1.52
CF30	5/15/96	28.39	ND	ND	12.07	0.74	9.05
	6/11/96	18.28	ND	ND	6.00	ND	7.19
	6/14/96	19.01	ND	ND	4.84	ND	3.61

Table 23. cont.

well number	sample date	Cl^-	NO_2^- N	Br^-	NO_3^- N	HPO_4^{2-} P	SO_4^{2-} S
		mg L^{-1}					
CF31	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	9.80	0.37	ND	17.86	ND	8.14
	6/14/96	10.80	ND	ND	20.42	ND	7.71
CF32	5/15/96	NS	NS	NS	NS	NS	NS
	6/11/96	19.84	ND	ND	8.88	ND	1.61
	6/14/96	19.88	ND	ND	8.62	ND	0.57

*CF=Centennial field well
**NS=no sample taken
***ND=not detectable, <0.02 mg L^{-1}

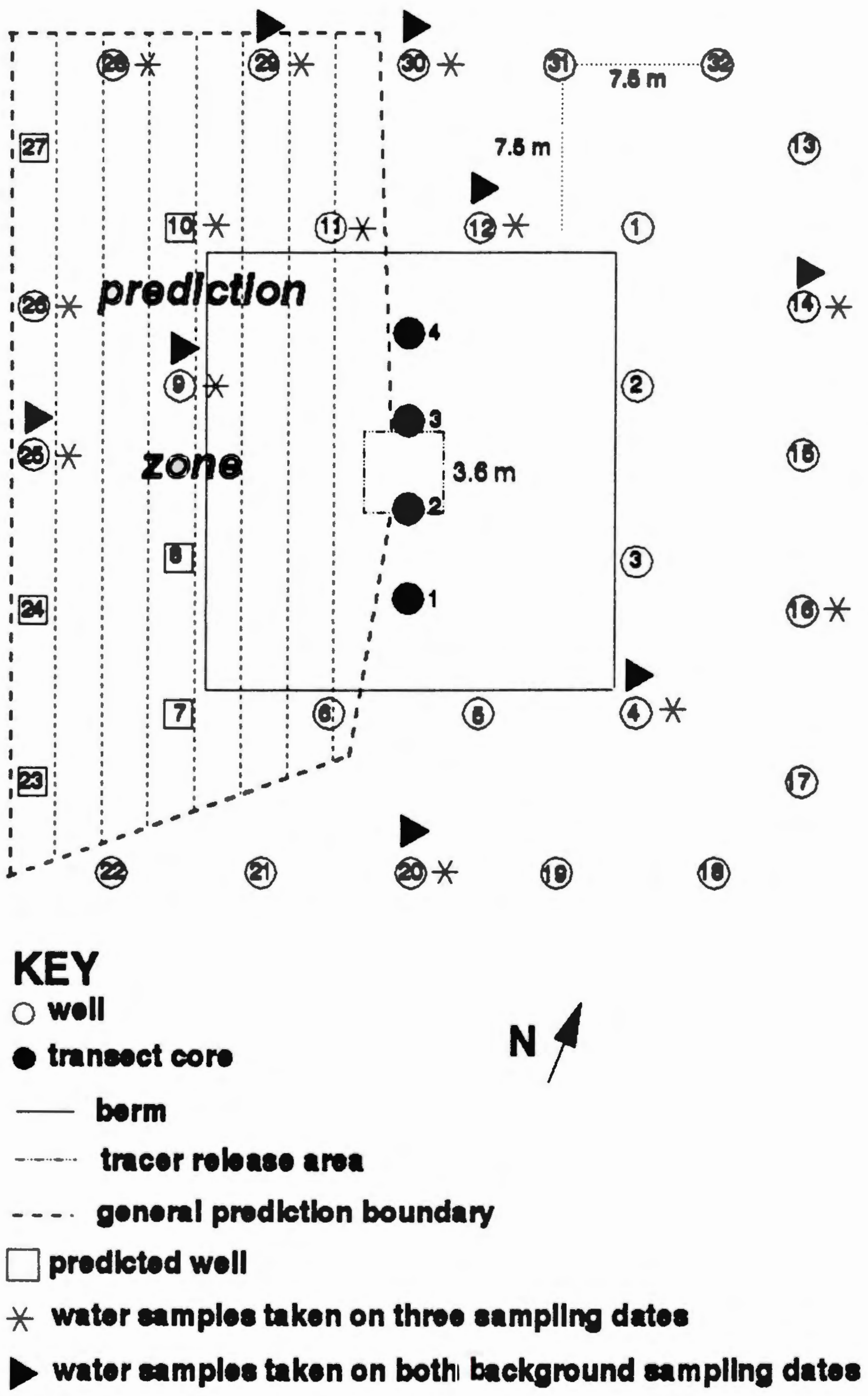

Figure 25. Diagram of wells that actually received water.

sampling dates. In fact, nine of thirteen wells which yielded samples on all three dates,were located in the NW portion of the research area (Figure 25, Table 23). Considering the paleosol topography, this was the general expected direction of movement (Figure 17). The high intensity, order one, soil survey map which was created in Chapter 1 (Figure 13), also showed that the clump of the wells that yielded three samples in the NW corner of the plot, were in soils with higher amounts of sand and clay in their paleosols. The additional clay most likely enhanced the abiility of the discontinuity to perch the soil water.

Wells that yielded samples in an "uphill" position from the release, may have received the water from an area outside the research plot. Since nothing was known of the paleosol topography outside of the research area, it was possible that water moved "downhill" to the wells from the east or northeast. This kind of result has been found in similar work on the Hancock site at Ames Plantation. The results for wells that received water on all three post release sampling dates were comapared to the results for the two background sampling dates. All eight wells that recieved water on both background sampling dates, also yielded three post release samples (Figure 25). Five of these eight wells were outside of the prediction zone. This further supports the idea that water found in the "uphill" wells after the tracer release, was there from other sources. This also suggests that the wells that yielded three samples within the prediction zone, better reflect the tracer release. Only three of the seven prediction zone wells that yielded three post release samples had two background samples.

Conclusions

1) Chloride was a poor tracer for this experiment, as levels determined statistically inconclusive as indicators of soil water movement. Laboratory or field error may have contributed to the ineffectiveness of the $CaCl_2$ tracer, but tracers such as KBr have been found to work best in past studies. Future work with alternative tracers is suggested. A release of the chloride tracer over the entire release area extending out to the berm may work better, but a release of potassium bromide would probably be most effective .

2) Specific wells could not be successfully predicted as soil water destinations based on soil morphology. However, the general direction of soil water movement could be determined based on the paleosol topography. In future work, a thorough knowledge of all underlying paleosol topography is recommended, as much of the paleosol topography of the release area was unknown in this experiment.

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APPENDICES

APPENDIX A:
KCl exchangeable acidity, Al^{3+}, percent carbon, and pH data for transect core #1

Table A-1. KCl exchangeable acidity, and Al^{3+} in transect core #1.

sample #	horizon	bottom depth (cm)	KCl exchangeable acidity	Al^{3+}
			cmol kg^{-1}soil	
9512	Ap	9	0.015	0
9513	Bt1	29	0.031	0
9514	Bt2	68	0.008	0
9515	Bt3	110	0.023	0
9516	Bt4	148	0.008	0
9517	BC1	169	0.008	0
9518	BC2	190	0.008	0
9519	2Bt1	230	0.015	7.41×10^{-4}
9520	2Bt2	262+	0.008	1.48×10^{-3}

Table A-2. Percent carbon, HCl test for presence of free carbonates, and pH data for transect core #1.

sample #	horizon	bottom depth (cm)	percent total carbon	free CO_3^{2-}	pH 1:1 H_2O	pH 1:1 $CaCl_2$
9512	Ap1	9	1.500	none	5.75	5.20
9513	Bt1	29	0.363	none	5.60	4.95
9514	Bt2	68	0.197	none	5.70	5.20
9515	Bt3	110	0.180	none	5.80	5.35
9516	Bt4	148	0.204	none	5.70	5.55
9517	BC1	169	0.199	none	5.65	5.40
9518	BC2	190	0.218	none	5.60	5.35
9519	2Bt1	230	0.284	none	5.25	5.25
9520	2Bt2	262+	0.207	none	5.30	5.30

APPENDIX B:
KCl exchangeable acidity, Al^{3+}, percent carbon, and pH data for transect core #2

Table B-1. KCl exchangeable acidity, and Al^{3+} in transect core #2.

sample #	horizon	bottom depth (cm)	KCl exchangeable acidity	Al^{3+}
			cmol kg^{-1}soil	
9521	Ap1	7	0.023	0
9522	Ap2	20	0.023	7.41×10^{-4}
9523	Bt1	46	0.023	0
9524	Bt2	78	0.400	0.026
9525	Bt3	120	1.210	0.083
9526	Bt4	150	0.950	0.063
9527	BC1	172	0.480	0.033
9528	B't1	201	0.350	0.026
9529	2B't2	219	0.310	0.023
9530	2B't3	243	0.240	0.020
9531	2B't4	260+	0.130	9.27×10^{-3}

Table B-2. Percent carbon, HCl test for presence of free carbonates, and pH data for transect core # 2.

sample #	horizon	bottom depth (cm)	percent total carbon	free CO_3^{2-}	pH 1:1 H_2O	pH 2:1 $CaCl_2$
9521	Ap1	7	1.85	none	5.70	5.30
9522	Ap2	20	0.63	none	5.70	4.80
9523	Bt1	46	0.19	none	5.85	5.20
9524	Bt2	78	0.18	none	4.60	3.95
9525	Bt3	120	0.13	none	4.15	3.60
9526	Bt4	150	0.16	none	4.15	3.65
9527	BC1	172	0.21	none	4.25	3.80
9528	B't1	201	0.22	none	4.30	3.90
9529	2B't2	219	0.19	none	4.35	3.95
9530	2B't3	243	0.14	none	4.30	4.00
9531	2B't4	260+	0.11	none	4.30	4.05

APPENDIX C:
KCl exchangeable acidity, Al^{3+}, percent carbon, and pH data for transect core #3

Table C-1. KCl exchangeable acidity, and Al^{3+} in transect core #3.

sample #	horizon	bottom depth (cm)	KCl exchangeable acidity	Al^{3+}
			cmol kg^{-1}soil	
9532	Ap1	4	0.016	2.60×10^{-3}
9533	Ap2	13	0.016	3.71×10^{-3}
9534	Bt1	29	0.008	3.34×10^{-3}
9535	Bt2	52	0.023	2.97×10^{-3}
9536	Bt3	95	0.008	2.22×10^{-3}
9537	BC1	128	0.016	3.34×10^{-3}
9538	BC2	158	0.420	0.021
9539	BC3	187	0.160	0.019
9540	2BC4	207	0.160	0.014
9541	2BC5	218	0.170	0.013
9542	2BC6	243	0.170	0.012
9543	2BC7	259+	0.170	0.010

Table C-2. Percent carbon, HCl test for presence of free carbonates, and pH data for transect core # 3.

sample #	horizon	bottom depth (cm)	percent total carbon	free CO_3^{2-}	pH 1:1 H_2O	pH 2:1 $CaCl_2$
9532	Ap1	4	1.410	none	5.00	5.25
9533	Ap2	13	0.834	none	5.60	5.45
9534	Bt1	29	0.377	none	5.60	5.20
9535	Bt2	52	0.248	none	5.65	5.30
9536	Bt3	95	0.170	none	5.80	5.50
9537	BC1	128	0.152	none	5.15	4.90
9538	BC2	158	0.176	none	4.50	4.05
9539	BC3	187	0.196	none	4.30	3.80
9540	2BC4	207	0.176	none	4.30	3.90
9541	2BC5	218	0.162	none	4.25	4.00
9542	2BC6	243	0.110	none	4.25	4.00
9543	2BC7	259+	0.122	none	4.25	4.10

APPENDIX D:
KCl exchangeable acidity, Al^{3+}, percent carbon, and pH data for transect core #4

Table D-1. KCl exchangeable acidity, and Al^{3+} in transect core #4.

sample #	horizon	bottom depth (cm)	KCl exchangeable acidity	Al^{3+}
			-cmol kg^{-1}soil-	
9544	Ap1	6	0.032	2.22×10^{-3}
9545	Ap2	16	0.008	2.22×10^{-3}
9546	Bt1	43	0.008	2.59×10^{-3}
9547	Bt2	70	0.008	2.59×10^{-3}
9548	Bt3	96	0.023	5.19×10^{-3}
9549	Bt4	116	0.410	0.028
9550	Bt5	134	0.610	0.039
9551	Bt6	170	0.400	0.025
9552	BC1	189	0.320	0.021
9553	BC2	205	0.220	0.018
9554	2Bt1	227	0.240	0.018
9555	2Bt2	250	0.200	0.014
9556	2Bt3	261	0.210	0.016
9557	2Bt4	283	0.150	0.014
9558	2Bt5	328+	0.120	0.010

Table D-2. Percent carbon, HCl test for presence of free carbonates, and pH data for transect core # 4.

sample #	horizon	bottom depth (cm)	percent total carbon	free CO_3^{2-}	pH 1:1 H_2O	pH 2:1 $CaCl_2$
9544	Ap1	6	1.151	none	5.25	5.50
9545	Ap2	16	0.778	none	5.55	5.40
9546	Bt1	43	0.292	none	5.50	5.25
9547	Bt2	70	0.201	none	5.50	5.35
9548	Bt3	96	0.124	none	4.80	4.80
9549	Bt4	116	0.131	none	4.40	4.15
9550	Bt5	134	0.146	none	4.25	4.00
9551	Bt6	170	0.143	none	4.25	4.05
9552	BC1	189	0.114	none	4.30	4.05
9553	BC2	205	0.111	none	4.30	4.10
9554	2Bt1	227	0.118	none	4.25	4.10
9555	2Bt2	250	0.106	none	4.40	4.15
9556	2Bt3	261	0.094	none	4.40	4.20
9557	2Bt4	283	0.111	none	4.40	4.30
9558	2Bt5	328+	0.086	none	4.45	4.25

APPENDIX E:
Key to all abbreviations for Tables 1, 2, 3, and 4.

Table E-1. Key to all abbreviations in Tables 1, 2, 3, and 4.

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boundary
A = abrupt, C = clear, G = gradual

texture
S = sand, Si = silt, C = clay, L = loam
SiL = silt loam, SiCl = silty clay loam, CL = clay loam,

structure
1 = weak, 2 = moderate
f = fine, m = medium
gr = granular, pl = platy, sbk = subangular blocky

concretion
f = few, c = common, m = many
Mn = manganese

mottles
f = few, c = common, m = many

misc.
f = few, c = common, m = many
roots = roots were present, argillans = argillans were present
pores = pores were present,
pref. flow = preferential flow was indicated by wetness, mottling, concretions, etc.

VITA

Holly Ann Carter was born in Royal Oak, Michigan on June 20, 1971. She was raised in a small suburb of Detroit, Michigan called Clawson. She attended school in Clawson, until she got her diploma from Clawson High School in June, 1989. In August of the same year she began attending Central Michigan University in Mt. Pleasant, Michigan. While at CMU she worked in the cooperative education program at the Dow Chemical Company in Midland, Michigan as a student laboratory technician. She obtained her Bachelor of Science in Earth Science, with a minor in Chemistry in May, 1994. The following August she began attending graduate school at the University of Tennessee in Knoxville, where she also played on the UT Women's Rugby team. In December, 1996 she received a Master of Science degree in Plant and Soil Science.