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Characteristics and potentials of selected soils in the Peten Region of Guatemala

Luis Carlos Donado

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To the Graduate Council:

I am submitting herewith a thesis written by Luis Carlos Donado entitled "Characteristics and potentials of selected soils in the Peten Region of Guatemala." 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.

Michael D. Mullen, Major Professor

We have read this thesis and recommend its acceptance:

John T. Ammons, John Foss

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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John T. Ammons

John E Foss

Accepted for the Council:

CW Minkel

Associate Vice Chancellor
and Dean of the Graduate School

CHARACTERISTICS AND POTENTIALS OF SELECTED SOILS IN THE PETEN REGION OF GUATEMALA

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

Luis Carlos Donado

May, 1996

DEDICATION

This thesis is dedicated to:

my parents

Lic. Luis Alfredo Donado Figueroa
and
Dra. Gladys Stella Torres de Donado

my brothers and sister

Julio, Aldo and Susy

who have given me their love, support and an irreproachable good example in every sense.

ACKNOWLEDGEMENTS

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My special thanks to Dr. Joanne Logan and Janice Branson for their friendship and support.

ABSTRACT

A pedological study of tropical soils in and around the Mayan Biosphere Reserve in Peten, Guatemala was undertaken in order to study the characteristics and potentials of different soils for the better management of natural resources. The objectives of this research were: i) to describe the main characteristics of selected soils in the Peten; ii) to better understand the genesis of these soils; iii) to classify the soils according to the U.S. soil taxonomy system; and iv) to determine the potentials and management of the soils.

With the cooperation of several Guatemalan institutions, six sites were chosen and the soils at each site were fully characterized. After field characterization, the soil samples were transported to the laboratory for physical and chemical analysis. The analysis includes: pH, total carbon and total nitrogen contents, organic carbon, calcium carbonate equivalent, total elemental analysis, exchangeable bases, cation exchange capacity, KCl exchangeable aluminum and exchangeable acidity, archeological extract, and particle size analysis.

The first three soil sites were located in the Yaxja area. A soil-landscape position relationship was established; Mollisols occupied upland and sloping positions and Vertisols occupied depressional areas in the lowlands. The rest of the sites were scattered in other areas inside, as well as outside, the Mayan Biosphere Reserve.

The soil orders found in the research area were Mollisols, Vertisols and Alfisols. The Mollisols and Vertisols developed from calcareous parent materials and the Alfisol from alluvial deposits. The soils developed from the carbonated rocks are rich in clay, especially montmorillonitic clay. The pH ranged from strongly acid (Alfisol) to moderately alkaline. The average organic matter content of the topsoil of the different sites (4.84%) is comparable to those of temperate climates. The abundance of clay and organic matter resulted in high CEC values for the first five soil sites; however, the total elemental analysis showed serious deficiencies, especially in phosphorus, potassium and nitrogen.

The soils were classified as Aquic Hapludolls, Typic Endoaquerts, Typic Rendolls, Eutrochreptic Rendolls, and Typic Paleudalfs. In terms of the land capability classification, the soils were classified as: site 1: IIw, site 2: IIIw, site 3: VIe, site four: IIe, site five: IVe and site six: IIf.

The soils, as well as other natural resources in the Peten, are rapidly being degraded. Mismanagement, improper use and deforestation are depleting the soils. A management system based on land layout, mulches, management of cracking, fertilization, and liming was proposed to improve the productivity of the soils. This, along with sustainable agricultural practices will reduce the degradation of the natural resources.

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INTRODUCTION

Soils are among the most valuable natural resources of the earth. For thousands of years mankind has depended upon the soils for food and fiber. They are intimately connected with geological materials beneath, vegetative materials within and above, and underground water percolating through the soils.

Soils are an integral and vital part of our environment and may be defined as natural bodies produced by interactions of climate, biota, topography, time and surficial geologic materials on the earth's surface. Soils vary from place to place in landscapes, and often within even short distances. Although the great importance of soils, it is only within the last 100 years that soils have been studied scientifically. Fundamental research is necessary in order to discover principles from which practical applications can be made in the field. According to Dent and Young (1981), an assessment of the soil properties is required in agriculture and forestry for informed decision making in planning for feasibility and design studies in land development projects, and for many other situations.

The main purpose of this research is to make a contribution in the field of tropical soils by presenting updated information about selected soil in the northern Department of Peten in the Republic of Guatemala. This region has attained tremendous importance, especially in the last few years due to its great richness in biodiversity and archeological sites. The Mayan Biosphere (Figure 1) was created in January 1990 to protect this valuable region (Agrar und Hidrotechnic, and Asesoria y Promocion Economica, 1992, AHT/APESA 1992). The biosphere reserve

Figure 1. The Mayan Biosphere Reserve in Peten, Guatemala.

encompasses 1.5 million hectares in the northern section of the Peten. This reserve is an area of intense international interest as part of the Maya Tri-national Region which encompasses southern Mexico, the Peten in Guatemala, and Belize. This area has been chosen by the Tropical Ecosystem Directorate of the U. S. Man and Biosphere Program (TED-MAB, 1992) for further study of the impacts of social, political and economical factors on this valuable natural resource.

The department of Peten encompasses approximately 36,000 km^2, and has a hot, humid environment with rainfall of approximately 300 cm annually and a mean annual temperature of 28 C. (Univ. Rafael Landivar, 1987). The soils consist of high shrink-swell potential Vertisols; strongly weathered Ultisols; deep, moderately weathered Alfisols; shallow and moderately deep Rendolls, and slightly weathered Inceptisols. The area is dominated by humid, subtropical broadleaf forest vegetation.

The impact of human population growth and colonization of the Peten is a growing problem. In the Peten region, the rate of deforestation is approximately 300 km^2/year. Of this, 90% is due to the expansion of agriculture and livestock, 8% is due to fires, and 2% is from logging (AHT/APESA, 1992). This deforestation represents an irretrievable loss of the natural ecosystems and biodiversity of the region. In addition to the loss of biodiversity, deforestation and resulting agricultural activities often lead to severe soil erosion and surface water degradation, especially in the shallow, limestone-derived soils.

Most of the natural biological diversity of the Maya Reserve is still intact, but it is under threat of rapid degradation. This current deterioration contrasts with the ability that the Mayan civilization had 2,000 years ago, when based on agriculture, the Mayans were able to sustain for more than a 1,000 years a population triple the size of the present one (AHT/ASESA, 1992).

PART 1

SUMMARY OF CLIMATE, GEOLOGY, PHYSIOGRAPHY, GEOMORPHOLOGY, SOILS, SOIL-VEGETATION RELATIONS, AND LAND USE PATTERNS IN THE PETEN REGION OF GUATEMALA

LITERATURE REVIEW

CHARACTERISTICS OF THE STUDY AREA

LOCATION

The study area was located in the northern Department of Peten in Guatemala, Central America. It includes the Yaxja area within the limits of the southern portion of The Mayan Biosphere Reserve, as well as agricultural lands towards the south of the Mayan Ruins of Tikal and the city of Flores (Figure 2). The area is comprised by the physiographic regions of The Yucatan Platform in the north and The Cinturon Plegado del Lacandon in middle Peten.

CLIMATE

The climate in The Peten is tropical hot and humid, typical for the lowlands in this latitudes. A long rainy season (May to December) alternates with a dry season which eventually lasts from December to May, depending upon location in The Peten. Based on the Thornthwaite classification, (AHT/APESA, 1992) the types of climate are: the Br A'a", Br B'b in the majority of the territory and C2r A'b' in the northeast (Table 1).

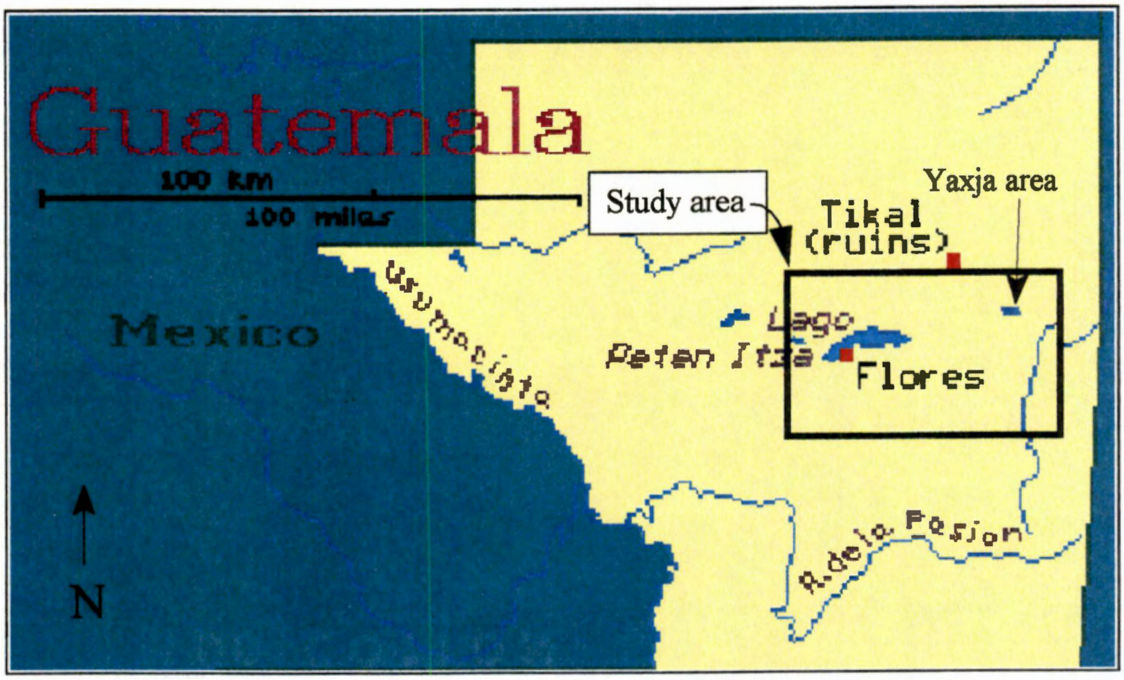

Figure 2. Location of the general study area in the Peten Region.

TABLE 1. CLIMATIC CLASSIFICATION BASED ON THORNTHWAITE

KEY	PARAMETER	CLASSIFICATION
A'	temperature	hot
a'	variations of temperature	not well defined cold season
b'	variations of temperature	benign winter
B	humidity	humid
C	humidity	semi-dry
r	distribution of rainfall	not well defined dry season

Source: Insivumeh, 1988.

TEMPERATURE:

The mean monthly temperature ranges from 22 C in January to 29 C in May. The maximum mean temperature varies from 27 C to 37 C, and the minimum mean temperatures from 17 C to 23 C (AHT/APESA, 1992 and URL, 1987).

RAINFALL AND WINDS:

The Caribbean Sea is the most important source of moisture for The Peten. The relative proximity of the sea influences the moisture flow related to tropical storms and cyclones. There are no orographic obstacles in the Peten, with the exception of The Maya Mountains and Sierra del Lacandon. In most of the territory, rainfall is of a cyclonic origin. The relative humidity is very high (80-95%) most of the time, but can drop to 50-60% at noon.

The predominant winds are Alisios and blow from the northeast and southeast, with a low mean velocity. Between May and October, some sporadic tropical storms develop and wind velocities can reach 75 km^{-1}. On several occasion Peten has been hit by hurricanes and tropical storms coming from the east.

Annual rainfall ranges from 1,200 to 3,000 mm, and it is the most variable climatic factor. Besides the dry season which is relatively well defined, there is a period of time called Canicula (a period of no rain that lasts several weeks) in the first third of the rainy season. The months with the least precipitation are March and April (AHT/APESA, 1992).

GEOLOGY OF THE SUBWATERSHED PASO CABALLOS/SEDIMENTARY PLATFORM OF YUCATAN

AHT/APESA (1992) described the geology of the Yucatan platform. This platform is located in the northern section of Peten. Structurally, the subwatershed of Paso Caballos is a continuation towards the south of the platform of the Yucatan peninsula, which is an area of little tectonic deformation.

The central part of the platform is formed by horizontal layers of gypsum and marl from the Eocene (Tertiary) and it is called the Peten Group. This group is mostly in the north of La Libertad Arch and includes the Santa Amelia formation in the south, and the Buena Vista formation in the north.

The Santa Amelia formation is characterized by microgranular dolomites and limestones of light color and intercalated with red evaporitic clays and gaps of limestone and thin layers of gypsum. It has a width of 1000 meters. Its age is Inferior Eocene. The Santa Amelia formation shows little development of the karstification in relation to other formations due to its clayey rocks.

The Buena Vista formation consist of dolomites and granular clayey limestones with lenticular intercalations of gypsum. Total thickness is 300 meters. The presence of gypsum is responsible for the high levels of sulfate in the waters of the San Pedro River.

Paleocene and Eocene marine sediments spread out from Laguna Perdida to Melchor de Mencos. In the northeast, and between San Pedro and Candelaria rivers, and also around Yaxja lagoon and the watershed of Rio Azul, Quaternary alluvial deposits are common. The sediments of the Tertiary and Quaternary period cover other layers of the Secondary period.

GEOLOGY OF THE CINTURON PLEGADO DEL LACANDON

This physiographic region spreads out from Sierra del Lacandon in the west of Peten to the Maya Mountains in the east. It consists of sedimentary rocks of the Cretaceous period (Secondary), mainly marine carbonatic rocks, marked by a succession of folds of short intervals and high frequency (AHT/APESA, 1992).

PHYSIOGRAPHY AND GEOMORPHOLOGY OF THE YUCATAN PLATFORM

This platform is mostly flat and has elevations between 50 to 350 meters (Figure 3). The Yucatan platform can be divided in 5 landscapes, but we will consider only the ones in the research areas. The whole platform has karstic characteristics and it is divided in high areas of denuded karst with subsurface drainage and low areas covered with calcareous alluvium where subsurface drainage is more or less obstructed.

The zone of eroded karstic hills in terraces spreads out from Peten Itza Lake to Dos Lagunas in the north, and to Yaxja and Melchor de Mencos in the east. It has elevations up to 420 meters. Sinuous hills of low altitude are common. They are strongly eroded and without the stiff relief of Conic karst typical in the Cinturon del Lacandon (AHT/APESA, 1992).

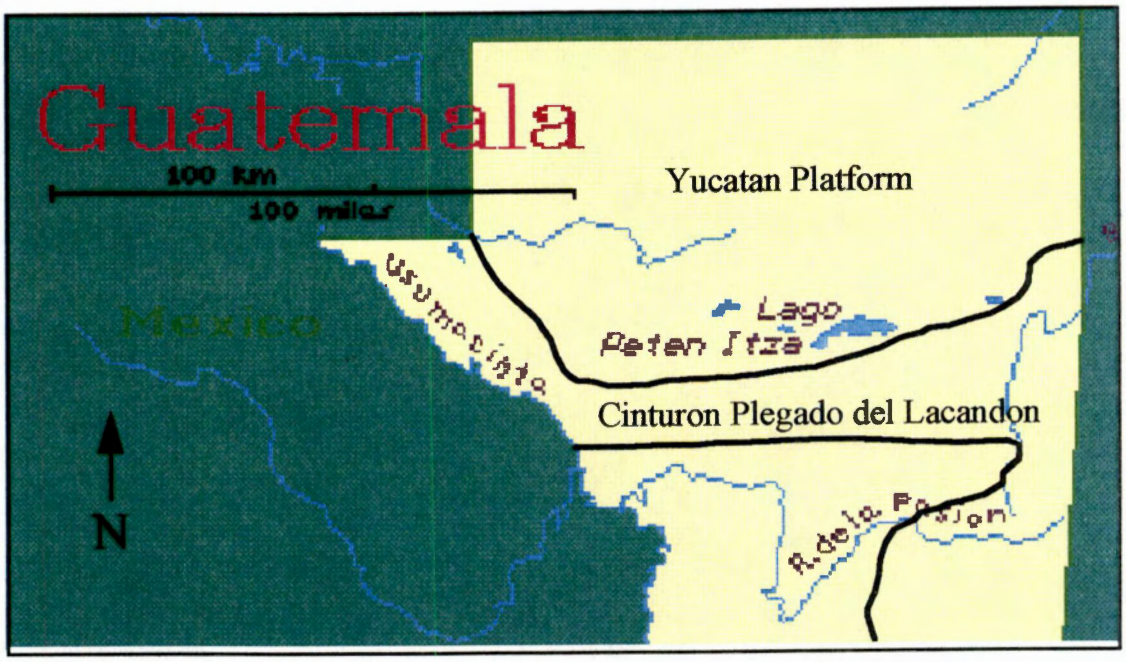

Figure 3. Physiographic regions of interest in the Peten

PHYSIOGRAPHY AND GEOMORPHOLOGY OF THE CINTURON PLEGADO DEL LACANDON

The Cinturon del Lacandon presents the roughest relief of The Peten (Figure 3). It has the characteristic Conic Karst formed by the dissolution of an overelevated plateau of limestone rocks through a system of fractures, producing depressions due to erosion in sinuous trenches. The residual elevations have steep slopes. The Cinturon is separated by grasslands and depressions.

A unit landscape of interest in this research is the lacustrine grassland of the Peten Itza lake, narrow and long, spreads out from Saipuy to Yaxja, passing by the south of the lake. It is composed of slightly undulated depressions formed by a filled karst (AHT/APESA, 1992).

VEGETATION AND SOIL-VEGETATION RELATIONS

Lundell (1937), recognized 1,400 species of plants in the Peten. He also considered three physiographic regions: the north, the south and the savannahs in the middle of Peten. Descriptions of vegetation for this research will include the north portion, the central savannahs and the karstic hills.

According to Holdridge (1950), the north of The Peten has a hot subtropical humid forest, and the south a hot subtropical very humid forest.

VEGETATION IN THE NORTHERN REGION

The vegetation in the lowlands of the north is characterized by a mixed forest which is affected by the soil moisture in the dry season, and the lack of aeration and periodic floods. In the central part and around the flooded portions, the Tintal formation is common and dominated by the palo de tinte (Haematoxilum campechanum) and the indicators Lysiloma desmotachys and Alibertia edulis. Elevations generally ranges from 5 to 11 meters. There are many small palms like botan (Sabal sp.) and the escoba (Crysophila argenteae). At the highest portions of the lowlands, the tintal is progressively replaced by the escobal dominated by the palma de escoba. The tintal and escobal are characterized by small and bent trees with numerous epiphytic plants (a plant growing on, but not nourished by, another plant). In soils with better drainage, the botanal is common and dominated by palma botan with small varieties of chicozapote and caoba.

In humid and well drained soils, generally along the rivers, the corozal formation develops, and it is characterized by the palma de corozo (Orbignya cohune), associated with caoba (Swietenia macrophylla), chicozapote (Achras sapote) and ficus.

In the flat lands with good drainage in the north, Lundell (1937) found a climax forest with trees up to 50 meters tall. In the Rendolls located on the higher elevations, the forest may have mesoxerophytic characteristics (mesophytic: plants whose habitat is neither very wet, nor very dry; xerophytic: plants that can survive only in dry sites and are no taller than 20 meters). Dominant species include caoba, the chicozapote, the ramon (Brosium alicastrum) and several Ficus species. Other species include the pimienta (Pimenta officinalis), the ceiba (Ceiba pentandra), Lucuma, and other tree species.

VEGETATION OF THE CENTRAL SAVANNAHS

Lundell (1937) believed that the occurrence of savannahs was due to a combination of soil factors and the influence of man through fires and possibly agriculture during the Mayan period.

The savannahs are mostly covered by herbaceous vegetation. There are two type of associations: the first is the field or savannah in drained lands, which is characterized by perennial herbaceous species resistant to fire, such as *Trachypogon angustifolius*, *Axonopus purpusii*, *Andropogon sp.*, *Paspalum plicatulum*. The Paspalum is dominant in the dry season and Andropogon in the rainy season. Several legumes grow in association with the grasses, and so do bushes, pyrophytic trees (species adapted to survive severe fires) like *Curatella americana* and *Birsonima crassifolia*, and the palma de cocoyol, *Acrocomia mexicana*. The bobolar association occurs in the swampy savannahs and it is characterized by clusters of the herbaceous plants, among which one can find several Cyperaceous plants and the lirio zac, *Hymanocallis littoralis*.

The savannah is cut off by forest formations. A subclimax forest grows in the savannah areas. This forest is influenced by fires that originate in the savannah and the trampling of cattle. This type of forest is relatively low and open, and include species like Caoba, Terminalia, Cassia, *Xilopia frutescens*, *Spondias mombin*, *Bursera simaruba* and *Matayba oppositifolia*. In the more humid areas and at the base of the Karstic hills that surround the savannah, this subclimax forest shows greater development, approximating the composition of the mature forest, and includes ramon, caoba, corozo, but no chicozapote. Lundell believed that without the effect of the fires this forest would progressively colonize the savannah.

In transition zones, there are also formations associated with the Exkikil soils. These zones are dominated by oak, (Quercus oloides).

KARSTIC HILLS (areas of conic karst strongly eroded)

According to AHT/APESA (1992) the Karstic portion in the central part of Peten has a typical limestone occurring vegetation, and is particularly susceptible to fire. In the upper part of the hills, with Lithosol soils of little water retention and exposed to winds, there is a xerophytic open vegetation with bushes such as Protium copal, Clusia flava and Bursera simaruba; if fire reaches the area, a chechemal with Metopium brownei will be developed.

The hillsides support a taller and thicker forest that reach 15 meters high, and include Hirtella americana, Plumeria acutifolia, Protium copal and some Achras sapota. The rocky hillsides support a bushy association called the Pedregal. The valleys are occupied by a tall forest, dominated by pioneers species such as Schizolobium parahyba, Enterolobium cyclocarpum and Terminalia exscelsa. Corozal is frequent in these valleys.

SOILS

According to AHT/APESA (1992), the soil survey study of the Republic of Guatemala performed by Simmons et al. in 1959 is still the main reference to soils in Peten. The soil survey describes 26 different soil series in Peten. However, the survey map has several errors which make land use interpretation difficult (Figure 4.)

Using the correlations defined in the original study of soils with the physiographic units, a new soil map was established, and in which the same series are presented, but with a correlation to the new physiographic map.

Table 2 shows the relative area of the different series, compared with the original map. Later on, the correlations between the series and the FAO classification were established, and those are shown in Table 3. The correlation between the FAO/UNESCO classification and the USDA system is presented in Table 4. Finally the correlations between the landscape units and the soil series are shown in Table 5.

The soil series can be grouped in six classes corresponding to the landscape units. In the following paragraphs, those of interest to this study will be described.

KARSTIC HILLS

The Conic Karst areas strongly broken and characterized by successions of hills and valleys, go along the Cinturon Plegado del Lacandon and the foot hills of the Maya Mountains. There are three different soil series that cover more than 7,000 km^2 . The soil series can be differentiated by the substrate, bedrock or parent material.

In the areas of conic Karst, the Cuxu and Chacalte series are developed on soft and hard limestone, respectively. The depressions have colluvial clayey and deep soils, that are fertile but with slow drainage during the rainy season. These soil

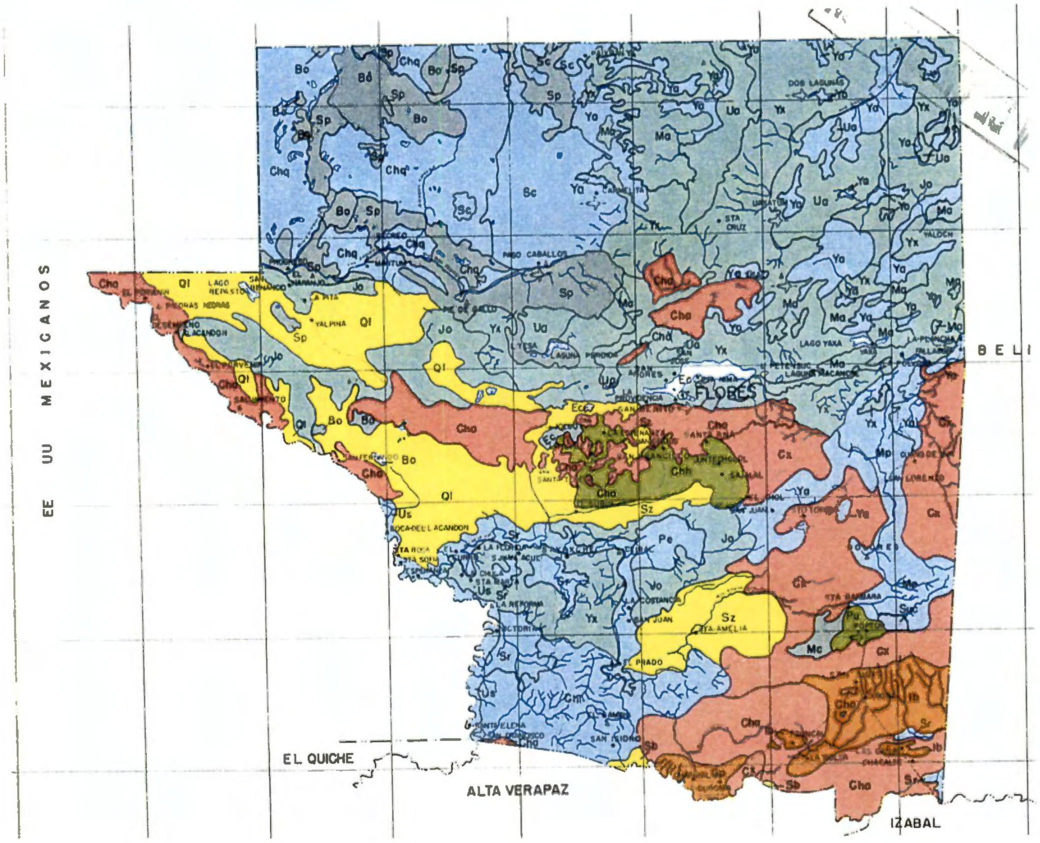

Figure 4. Soil series map for the Peten region (Simmons, 1959).

TABLE 2. APPROXIMATE SURFACE OF THE DIFFERENT SOIL SERIES ACCORDING TO THE SOIL SURVEY MAP (1959) AND THE NEW APPROXIMATION.

SERIES	1959 km²	1991 km²
Bolon	771.12	356.08
Chacalte	3532.62	4032.73
Chachaclum	631.69	523.69
Chapayal	1329.86	1012.87
Chocop	2653.07	2061.92
Cuxu	3067.33	2814.85
Exkikil	86.44	18.52
Ixbobo-Guacapa	1057.25	822.92
Jolja	1927.68	1935.95
Macanche	1848.51	427.79
Mopan	1023.99	603.70
Palmasito	-	212.1
Petexbatun	219.43	207.93
Poptun-Suchachin-Machaquila	239.41	262.46
Quinil	2675.98	2930.05
Quinil-Cuxu	-	721.73
Quinil-Yaxja	-	1601.39
Sacluc	1196.88	2087.10
Saipuy	1815.28	2114.49
Sarstun	1015.72	735.31
Sotz	1277.91	443.86
Suelos pantano	-	1044.67
Uaxactun	1190.23	938.43
Usumacinta	206.13	98.94
Yaloch	2295.63	1534.08
Yaloch-macanche	-	689.06
Yaxja	5625.30	5922.41

Source: Simmons et al. 1959 and AHT/APESA, 1992

TABLE 3. CORRELATION OF THE SOIL SERIES TO FAO CLASSIFICATION

Chacalte	Lithosols/Rendzinas/Cambisols
Cuxu	Lithosoles/Rendzinas/Cambisols
Quinil	Rendzinas/Cambisols/Vertisols
Quinil-Cuxu	Rendzinas/Cambisols/Vertisols/Gleysols
Ixbobo-Guacapa	Humic Cambisols
Yaxja	Rendzinas/Cambisols/Vertisols
Uaxactun	Rendzinas/Cambisols/Vertisols
Chapayal	Rendzinas/Cambisols/Vertisols
Cuxu	Cambisols/Vertisols/Gleysols
Palmasito	Cambisols
Chachaclum	Chromic Cambisols/Luvisols
Exkikil	Chromic Cambisols
Poptun/Machaquila/Suchachin	Gleyic Cambisols
Bolon	Gleyic Cambisols /Gleysols
Sarstun	Eutric Gleysols/Fluvisols
Mopan	Vertic-gleyic Cambisols/Fluvisols
Jolja	Calcic Cambisols/Chromic Vertisols/Luvisols
Usumacinta	Eutric Fluvisols/Eutric Gleysols
Petexbatun	Dystric Fluvisols
Sotz	Chromic-Gleyic Cambisols/Chromic Luvisols
Chocop	Gleyic Cambisols
Sacluc	Eutric Cambisols
Saipuy	Gleyic Cambisols
Yaloch	Pelic Vertisols
Macanche	Pelic Vertisols
Suelos de pantano	Gleysols

Source: FAO in AHT/APESA, 1992

TABLE 4. CORRELATION FAO/UNESCO TO USDA SYSTEM

FAO/UNESCO	USDA SYSTEM
Luvisols	Alfisols
Vertisols	Vertisols
Rendzinas	Mollisols
Cambisols	Inceptisols
Gleysols	Inceptisols and Rendolls
Acrisols	Ultisols
Regosols	Entisols and Inceptisols
Planosols	Alfisols, Ultisols and Mollisols
Phaeozems	Mollisols
Andosols	Andisols
Nitosols	Ultisols and Alfisols
Fluvisols	Entisols and Inceptisols
Histosols	Histosols

Source: Lof, 1987

TABLE 5. CORRELATION LANDSCAPE UNIT/SOIL SERIES

LANDSCAPE UNITS	CORRESPONDING SERIES
Conic Karst (kegelkarst)	Chacalte (hard limestone)
	Cuxu (soft limestone)
	Chacalte/Cuxu (indeterminated)
Filled Karst	Quinil (colluviums of the Chacalte series)
	Quinil-Cuxu (colluviums and residual karst of the Cuxu series)
Slatic hills	Ixbobo/Guapaca
Eroded karstic hills	Yaxja, Cuxu
Karstic platform	Yaxja (undulated)
	Uaxactun (slightely undulated)
	Sacluc (low terraces)
Eroded karstic hill in terraces	Yaxja
Flattened karst	Quinil/Yaxja
Non limestone mountains	Palmasito
Colluvial plains	Chachaclum (savannahs)
	Exkikil (savannahs with oaks)
	Poptun/Machaquila/Suchachin (pine savannahs)
Colluvial-alluvial plains	Quinil
	Jolja
	Sotz
Alluvial plains	Mopan
	Sarstun
	Chapayal (undulated)
	Bolon (floodable savannahs)
	Saipuy (low plain)
	Chocop (old alluvial terraces)
	Petexbatun (old trimmed terraces)
Recent alluvial terraces	Sarstun
	Usumacinta
	Petexbatun (flood valleys)
Bajos	Saypuy
	Yaloch
	Macanche
Swamps	-

Source: AHT/APESA, 1992

are Pelic Vertisols and Gleysols (Table 4). According to Wright (1959), the peasants prefer the shallow Rendzinas located on the hillsides due to their better drainage. However, these soils are very susceptible to erosion due to slopes up to 50%.

The tops of the hills and plateaus are characterized by rocky Lithosols with pockets of fertile soil. In the lower parts of the slopes, soils are more developed and are classified as Cambisols (AHT/APESA).

AREAS OF FLATTENED KARST (Karst areas totally flattened and filled by Colluvial material)

The Chocop, Machaquila, Quinil, Sacluc, and Sotz series can be found in the areas of strongly eroded karst. They cover more than 7,800 km^2. The relief is flat to slightly undulating and the parent material is limestone. Soils are rich in clay, with slow drainage in the lower landscape (specially in the Chocop and Machaquila series). These soils are classified as Gleyic Cambisols. The flat and well drained lands with Quinil and Sotz series, neutral or slightly acid, are among the most fertile areas in Peten. However, its adhesivety limits the possibility of mechanization. The soils are classified as Cromic Cambisols, with Vertisols in the depressions and Rendzinas in areas of greater slope and elevation (AHT/APESA, 1992).

TERRACES AND KARSTIC PLAINS

According to AHT/APESA (1992), the series Jolja, Yaxja, and Uaxactun are associated with the terraces and plains of limestone and to the eroded Karstic hills. They cover 8,700 km^2. The Jolja series has been developed in plain and undulating relief. Most of the calcium has been washed away in the flat areas; the pH is slightly acid. The areas with corozal vegetation have the most fertile soils, rich in organic matter. The soils are Calcic Cambisols, and in the depressions, Vertisols occur. Mechanized agriculture is possible in these soils, and as a consequence they undergo a rapid deforestation. The more undulating areas have more shallow and rocky soils (Rendzinas).

The Yaxja series has the greatest extension in the Peten (approximately 6,500 km^2). This series has been developed in a more broken relief than the series Jolja. The soils are black, rich in clay, and organic matter. The depressions have Vertisols or Gleyisols with slow drainage and are neutral or slightly alkalinic, and can provide a good yield in the dry season. On the other hand, the hilly areas have shallow and rocky Rendzinas with good drainage and fertility. The texture is lighter and the soils are sensitive to drought (Collinet, 1989).

The Uaxactun series include Eutric Cambisols and Rendzinas with drainage limitations in some areas.

SAVANNAHS IN THE NORTH

The savannas in the north have clay loam texture and are developed on limestone residuum. The Chachaclum series includes Cambisols and Chromic Luvisols. The Exkikil series have soils with poor drainage, covered with a low forest of oaks, and they are Eutric Cambisols. Both series include acid soils not appropriate for agriculture, but are used for extensive livestock production. They cover 700 km^2 (AHT/APESA, 1992).

cover 700 km^2 (AHT/APESA, 1992).

BAJOS (Colluvial depressions)

These depression which are flooded during part of the year include the Bolon, Macanche, Saipuy and Yaloch series, and cover more than 6,700 km^2 mostly in the northern part of Peten.

The Bolon series, that support natural and floodable savannahs, and the Saipuy and Yaloch, with small bushes and palms, are Gleyic and Vertic Cambisols, Vertisols and Gleysols. The Bolon soils, due to their scarce nutrient supply and acidity, and the Saipuy soils, due to their slow drainage, are not good for economic purposes at the present. The Yaloch soils have better fertility and can be used for cattle grazing purposes where adequate drainage exists.

The Macanche soils have better drainage, with semi-undulated relief. They are classified as Pelic Vertisols with poor drainage, but they are fertile. They are used by peasants in periods with less rain (AHT/APESA, 1992).

PATTERNS OF LAND USE

THE MAYA PERIOD

The history and use of resources in The Peten goes back approximately 4,000 years with the beginnings of The Mayan civilization in southern Mexico and Central America (Willey 1982).

Maize farming was the basis of Early Preclassic village life in The Peten, and it continued to be throughout Maya history. In the 16th century, Spaniards reported apparently on a large scale (Harrison and Turner, 1978). These authors reported the use of extensive terracing or "silt trapping" in the Rio Bec area, and artificially raised fields constructed in swampy regions or along sluggish stream beds. The raised fields provide both drainage and irrigation, and their productiveness is much greater than the sweden system.

There are several studies of ancient Maya agriculture and land use that mainly focus on areas such as the Puuc Zone, Rio Bec, Rio La Pasion, the Pulltrouser and Cobweb swamps in Belize, or the Nakbe region. For example, Dunning (1992) reported that the current farmers of the Puuc area (northwest of the Yucatan Peninsula) prefer the same soils chosen by the Mayas before. They cultivate well drained valley margin soils such as Puslum (a cumulic Ustirendoll) and kankab-tzekel (a lithic Rhodustalf). Olson (1981) stated that the Mayas in Tikal avoided the Vertisol areas for construction purposes, and built dense clusters of ruins on the Mollisols which were also preferred for agriculture. The Vertisols were also used by the Mayas for agricultural and other purposes as their population increased.

The Mayans supplemented their agriculture with infield or kitchen garden cropping of foods such as breadnuts, avocados, palm nuts, and many other trees and fruits.

By the year 300 A.D. much of the vast tropical forest had been cut and species composition altered (Turner, 1983; Turner and Miksicek 1984; Pohl 1985). During the later stages of The Maya civilization, perhaps as much as 75% of the region had been altered for intensive cultivation. The 1,100 year-long population collapse was accompanied by the return of the preexisting environment, tropical forest, albeit in an altered state (Turner, 1990).

CURRENT LAND USE PATTERNS

According to AHT/APESA (1992), and based on a study in seven communities and the use of aereal photographs and Landsat images, there are three main patterns of land use:

a) A scattered centrifuge pattern common in new colonization areas in which new established without an apparent sequence. This may be the result of the intention of peasants to get more land, or to more homogeneous conditions of soils and topography, or may be to the lack of criteria for soil selection.

b) A semi-aggregated pattern common in regions of traditional agriculture in the watershed of the lake Peten Itza and also in the north. The peasants colonize the land according to soil quality forming agricultural islands limited by the type of soil. The maize rotate within the islands.

c) A nuclear pattern in which colonization follows a well defined agriculture front developing from a central nucleus. This pattern is the result of the collective type of work adopted by some native communities such as the Kekchi group. Eventually the agricultural frontiers from the different communities will meet together in a continuous field as a result of demographic pressures, the quality of soils and the generalized use of the semi-permanent system with green manures.

manures.

In general the agricultural colonization has followed preferential patterns related to the topography and types of soil, and originating from roads and rivers (AHT/APESA, 1992). The landscape units of preference are:

1) Well drained areas of moderate relief, such as the surroundings of the Peten Izta Lake with Rendoll soils of the Yaxja series.
2) The colonization at the karstic hills is slower due to the difficult access and limited agricultural surface area.
3) The areas of fertile alluvial soil such as the Macanche and Mopan series, are not colonized permanently due to drainage problems. They are then occupied by cattle farmers.
4) Areas of little or no colonization include the "bajos", particularly the Yaloch, Bolon, and Saypuy series. Also the poorly drained and acid soils such as the Petexbatun series and the savannah soils.

PART 2

MORPHOLOGY, CHARACTERISTICS, GENESIS, AND CLASSIFICATION OF SELECTED SOILS IN THE PETEN REGION OF GUATEMALA

INTRODUCTION

Although soils have been recognized as one of the major components of ecosystems and mankind directly depend on them for food and fiber, few pedological studies have been conducted in the Peten region of Guatemala. The long distance to the main population centers and lack of roads are mainly responsible for the few studies of soils and other natural resources in this region.

A soil survey was carried out in the late 1950's (Newton and Duisberg, 1978). However, for today's standards and needs, a more detailed study of soils is required. According to Buol, Hole and McCracken (1989), the study of morphology and characterization of soils provide the basic information necessary for the interpretation and management of soil resources. For this purpose, a study area located in middle Peten was selected in cooperation with several Guatemalan institutions.

The main objectives of the research are: 1) to describe the main characteristics of selected soils in the Peten; 2) to better understand the genesis of these soils; and 3) to classify the soils according to the U.S. soil taxonomic system.

LITERATURE REVIEW

GENESIS OF SOILS

Buol et al.(1989) defined soil genesis as the study of the formation (factors and processes) of soils on the land surface of the earth. This science is dependent upon the supportive and correlative activities of morphology, characterization, and soil geography.

The formation of soils generally comprises two different phases. The first stage involves the accumulation of the raw (parent) material for the soil; it is the change from a consolidated mass (rock), to an unconsolidated (loose) layer of material that can support plants if conditions of climate and water are suitable. The second stage (soil development) involves the formation of the soil from the parent material, ie, the changes occurring within the loose material as time passes. The parent material may result from in situ disintegration and decomposition of rocks and minerals, a process described as rock weathering; or from the transportation and deposition of rock debris by water, ice and wind, which also involves rock weathering (Miller, 1990 and Faniran, 1978).

Birkeland (1974), describes weathering as the physical and chemical alteration of rocks and minerals at or near the surface of the earth because they are not in equilibrium with the temperature, pressure, and moisture conditions of the environment. This results in disintegration of the rocks and decomposition and/or modification of both primary and secondary minerals to more stable forms in the environment.

The stage of soil development is driven by a complex or sequence of events called pedogenic processes (processes of soil formation). This includes both complicated reactions and comparatively simple rearrangements of matter, that intimately affects the soil in which they operate. Rode (1962) and Simonson (1959) agreed that various events may take place simultaneously or in sequence to mutually reinforce or contradict each other. These events or processes involve or may cause additions to the soil, losses from the soil, translocation of materials within the soil, and transformations of substances within the soil by decomposition and synthesis or by modifications (Buol et al. 1989). According to Sanchez (1976), these soil-forming processes proceed at a faster rate in tropical environments with rainy and hot climates, due to the constant downward movement of water, large amounts of biomass added to the soil, and the constant high temperatures.

Jenny (1941) stated that the internal pedogenic processes are driven by external forces such as parent material, climate, organisms, topography, and time which are known as the factors of soil formation.

Variation in any soil factor can produce a change in soil properties. Sometimes the factors vary in such a way that their combined influences are additive; at other times they interact so that the effect of one compensates or nullifies the effect of another. The most apparent changes in properties of soils can be identified with differences in climate and vegetation; where as, parent material and topography do differ from place to place. Similarly, time for development has been sufficient in most of the cases to bring about significant change in the nature of the parent material (Hausenbuiller, 1981).

As stated above, climate plays a major role in the formation and properties of soils, and it is the soil forming factor that differentiates the temperate zones from the tropical regions such as the Peten in Guatemala. According to Brengle (1982), climate is one of the active factors and generally the dominant one, although its effect is modified by other factors to give rise to a variety of individual soils in a given climatic region.

SOIL CLASSIFICATION

Buol et al. (1989) defined soil classification as "the categorization of soils into groups at varying levels of generalization according to their morphological properties and/or assumed genesis important for the objectives of classification."

The classification of soils began with the early work of the Russian scientist V. V. Dukuchaiev, but by the 1960's, the system became too limited to handle the new knowledge in an ever-expanding field of study. Hence, a new system was developed. The 1960 system reorganized the processes of soil formation (used in the previous system) but actually classified soil according to their properties (Sopher and Baird, 1982). This is also the case for tropical soils that were previously classified according to stereotyped concepts of uniform tropical environment, implying that the soils were uniform, highly weathered, and subject to being transformed into brick-like laterite when cleared for cultivation (Sanchez, 1976).

The current U.S. system has six categories of classification, starting with the very broad groups of soils and moving downward to the individual soil with a distinct set of properties. The levels are:

ORDERS: the soil order is the highest category in the classification scheme and the distinguishing characteristic of the order is the degree of profile development.

SUBORDERS: are a refinement of the orders on the basis of characteristics such as wetness and temperature. For example, forest soils develop properties which are due to a combination of the influence of climate and vegetation. The suborders are named by adding a connotative element to the formative elements of the order, that is an Aquult would be a wet (aqu) Ultisol. (Vandeford 1950, and Sopher and Baird, 1982).

GREAT GROUPS: are subdivision of suborders based on soil horizons and their arrangement, temperature regimes, and similar base saturation. The great group name consists of adding a one or two-element prefix to the suborder name. The prefix suggests something about the horizonation, temperature, or base status in the great group.

SUBGROUP: are refinements of the great groups to include the central concepts of the great groups; great groups that grade toward other orders, suborders and great groups; and great groups of soils that neither fit in the central concept nor grade to other areas of the classification system.

SOIL FAMILY: is a group of soil within a subgroup. Soils are grouped into families based on properties that affect soil use. The names are formed by using descriptive terms that reveal texture, mineralogy, temperature, thickness of root zone and other properties that affect plant growth and engineering properties.

SOIL SERIES: are basically the modern product of the five factors of soil formation. It is the lowest recognized category of soil classification. Soil series are named after the areas, towns, or communities where they were first found. The properties that determine the soil series are often the same as those that determine the higher groups, but more properties are involved and the allowable range for each series is rigidly defined. The properties that determine the soil series are: horizon order and sequence, horizon development and thickness, texture of horizons, organic matter content, pH of horizons, parent materials, depth to hard rock, pan horizons present, soil color, structure, type of clay present and any other factor that make the soil different (Sopher and Baird, 1982).

SOIL CHARACTERIZATION

Buol et al. (1989) defined soil characterization as the measurement of soil properties by laboratory procedures, using soil samples from pedons, morphology of which has been described by standard procedures, and nomenclature, conducted for the purposes of aiding in its classification in supporting of a soil survey program or for a better understanding of soil genesis. This activity also includes the development of methods of analysis for determination of soil properties.

LOCATION OF SOIL SITES

Several soil sites, considered to be representative of the different soil types of the area of study were chosen in cooperation with Centro Maya (an organization that promotes sustainable agriculture in the Peten), University Rafael Landivar and CONAP (National Commission for Protected Areas) in Guatemala. For that purpose, aspects such as the needs for research and preservation of natural resources of the region were taken into consideration. Furthermore, attention to the topography of the region, and landscape positions were also considered. The location of the different soil sites can be seen in Figures 5, 6, 7, and 8.

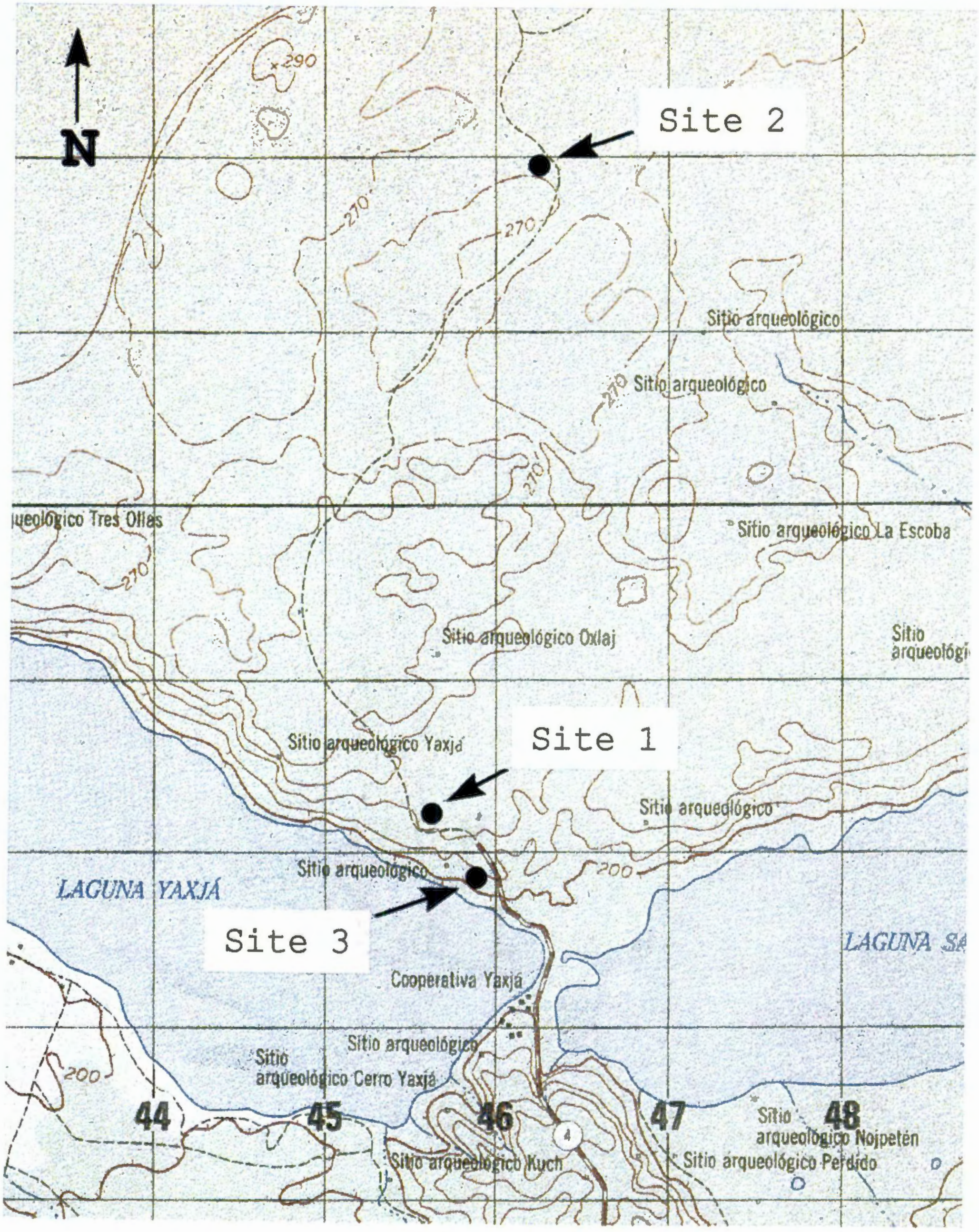

Figure 5. Locations of sites 1,2, and 3. Sites are marked with a filled circle. Each square is equal to one square kilometer. Figure taken from the Yaxja map sheet.

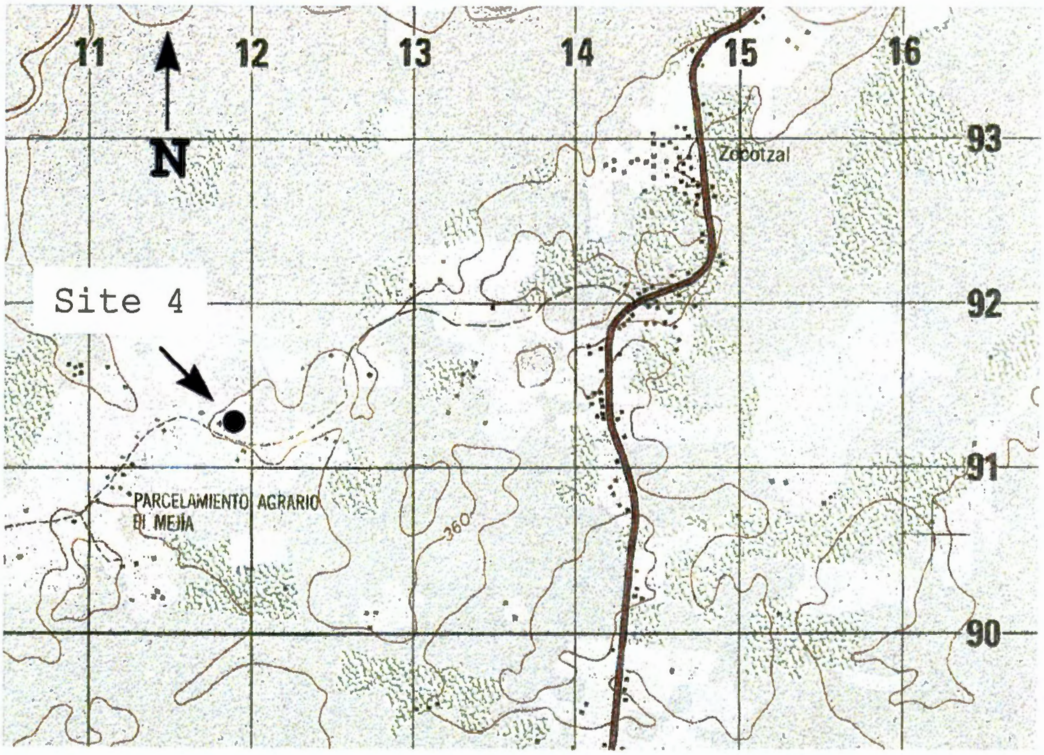

Figure 6. Location of site 4. Site is marked with a filled circle. Each square is equal to one square kilometer. Figure taken from the El Caoba map sheet.

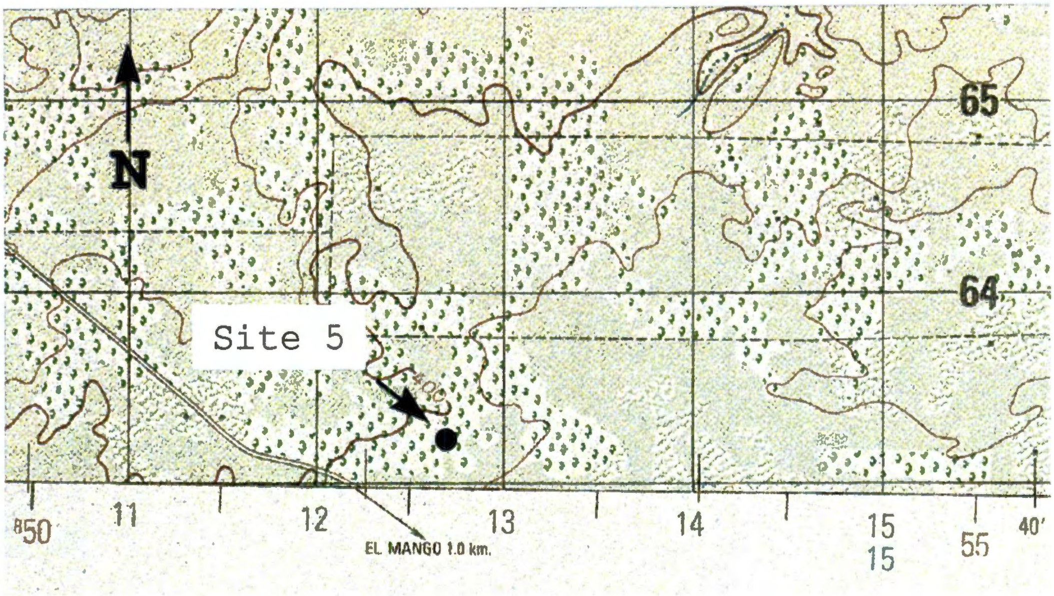

Figure 7. Location of site 5. Site is marked with a filled circle. Each square Is equal to one square kilometer. Figure taken from El Remate map sheet.

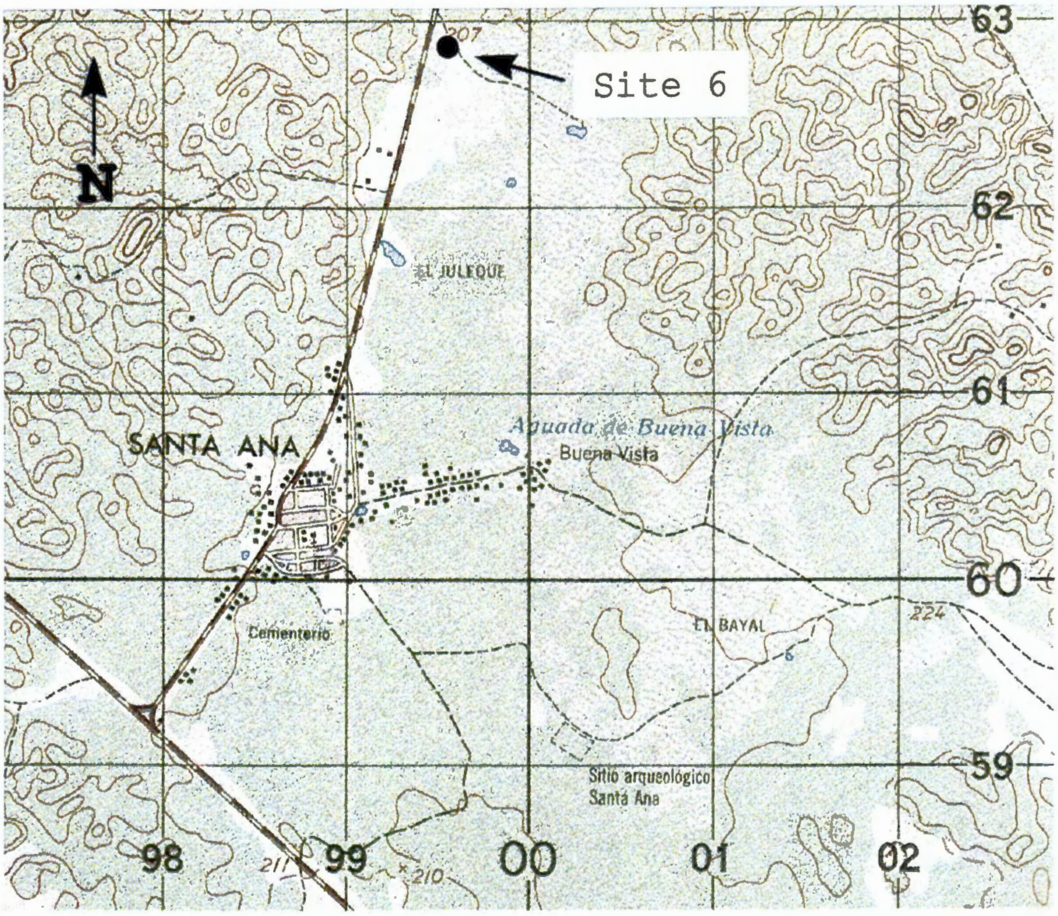

Figure 8. Location of site 6. Site is marked with a filled circle. Each square is equal to one square kilometer. Figure taken from the San Francisco map sheet.

MATERIALS AND METHODS

FIELD METHODS

The morphological description of each site was completed according to the Soil Survey Manual (Soil Survey Division Staff, 1993). Field notes included: horizon designation, depth, color, texture, structure, consistence, reaction, and boundary. The presence of roots, concretions, and mottling was recorded. The elevation, vegetation, drainage, erosion, parent material, and permeability were included as well.

Samples from each profile were taken and transported to the University of Tennessee for chemical and physical characterization. These analysis included: pH, total carbon and nitrogen content, organic carbon, calcium carbonate equivalent, total elemental analysis, exchangeable bases, cation exchange capacity, KCl-exchangeable aluminum and exchangeable acidity, "archeological" extract, and particle size analysis. Soil morphology and the results of the laboratory analysis were used to classify each pedon according to accepted soil survey techniques (Soil Survey Staff, 1992).

LABORATORY METHODS

SAMPLE PREPARATION

The purpose of preparing the sample for laboratory analysis is to obtain a small representative portion from which smaller subsamples can be taken for the separate determinations (Wright 1939). The soil samples were air dried and then sieved through a 2 mm screen. One fourth of each sample was ground to < 60 mesh (Soil Survey Staff, 1993). Coarse fragments were estimated based on field observations.

PHYSICAL ANALYSIS

Particle size analysis (percent of sand, silt and clay) was determined by the pipette method of Kilmer and Alexander (1949). All the soil samples that had previously reacted with 10% HCl were treated with Na-acetate buffered at pH 5 to remove the carbonates. Further centrifugation at 2,000 rpm for 15 minutes was required for the majority of the samples due to the presence of fine clays in suspension. Later on, 30% hydrogen peroxide (H_2O_2) was used to remove organic matter. Several soil samples required up to 9 applications of 10 ml of H_2O_2 to remove the organic matter. Dispersion of the soil samples was obtained with Na-Hexametaphosphate and Na-Carbonate. The sand fraction was dried and then sieved into very coarse, coarse, medium, fine and very fine components (Gee and Bauder, 1986). The silts were divided into fine and coarse fractions. The fine-clay fraction was pipetted following centrifugation (Jackson, 1969).

CHEMICAL ANALYSIS

Soil pH was determined by glass electrode using both a 2:1 0.02 M $CaCl_2$ and 1:1 soil-water solutions (McLean, 1982). Total carbon was determined on the < 60 mesh samples by a dry combustion technique using the high-temperature induction furnace: LECO CR 12 total carbon analyzer (Nelson and Sommers, 1982).

Total nitrogen was determined on < 60 mesh samples by dry combustion using a Carlo-Erba NA 1500 total N analyzer. The Walkley-Black procedure (wet combustion) was used for the determination of organic carbon. In this procedure, an excess of the oxidant $K_2Cr_2O_7$ and H_2SO_4 was used to digest the organic carbon, and then a back titration with $FeSO_4$ was used to determine the amount of unused oxidant.

The potassium chloride method was used to determine KCl exchangeable Al^{3+} and exchangeable acidity (Thomas, 1982) on 2 mm soil samples. The concentration of aluminum was determined using atomic absorption spectrophotometry, and the exchange acidity by titration with 0.01 N NaOH (sodium hydroxide). The ammonium acetate extractant in combination with the centrifuge procedure variation were used to extract exchangeable cations (bases) on 2 mm soil samples (Thomas 1982). This procedure uses a ratio of 50 ml of NH_4OAc for 2 g of soil; however, due to the abundance of calcium and mangesium in the soil samples, a ratio of 100 ml NH_4OAc to 2 g of soil was used to start with a dilution of 50. These two elements were determined using atomic absorption spectrophotometry. Sodium and potasium in the extracts were determined using atomic emission spectrophotometry. Ammonium acetate saturation was used to determine the cation exchange capacity (CEC) on 2 mm soil samples. The ammonium saturated samples were then extracted with a solution of 10% NaCl to displace adsorbed NH_4^+. This extract was distilled with a Lab Conco distillation unit to determine cmol(+) kg^{-1} (Chapman, 1965). Calcium carbonate equivalent was determined on < 60 mesh samples by a method modified from Sobek et al. (1978). Due to the abundance of carbonates in some of the soil samples, 20 to 60 ml of 0.5 N HCl was added to the soil, and the unconsumed acid was then titrated with standardized 0.5 N NaOH.

Total elemental analysis was determined on < 60 mesh samples by a microwave oven digestion technique (modified from Nadkarni, 1984). A combination of HFl-boric acid and aqua regia was used to bring the elements into solution. Extractable index elements were determined by the archeological extract method (Lewis et al. 1992). A combination of 0.60 N HCl and 0.16 N HNO_3 was used as the extracting solution.

RESULTS AND DISCUSSION

SOIL-LANDSCAPE RELATIONS

During the two visits to the study area in the summer of 94 and 95, it was observed that certain patterns of occurrence of different soil types corresponded to particular landscape units. Although it is recognized that substantial variation of soils occurs within short distances, it is of great value to establish soil-landscape relations for the prediction of the occurrence of soils in similar geomorphologic surfaces.

The study area presented great variability of soils, with Vertisols, Mollisols, Alfisols, and Inceptisols being the main soil orders found throughout the region. This variability was not considered to all its extent in the soil survey study of the late 1950's (Simmons, 1959) due mainly to the mapping scale used at that time. Vertisols, such as the one in site two, were found to occur in depressional (bajos) and nearly level areas where there was no evidence of lacustrine influences. This tendency was also observed in the road to San Andres towards the west of Flores (this profile is not included). Moreover, Olson (1977) reported Vertisols in the bajo swamps of Tikal (the main Mayan city in the Peten) with soil properties extremely poor for heavy urban construction. The Mollisols (sites one, three, four, and five) occupied slopes and more stable upland positions, with shallow and rocky Rendolls common on steeper slopes. The soil-landscape relations of sites one, two, and three can be easily observed in Figure 9. Olson (1977) also reported the occurrence of Mollisols in upland positions at the ruins of Tikal. Alfisols were found to occur in the savannahs of the area investigated, and Inceptisols were common in the floodplain of Lake Yaxja.

The soil-landscape patterns explained above coincide with the distribution of soils on the different landscape units presented by AHT/APESA (1992) in the soil section of chapter 1 of this thesis.

SOIL MORPHOLOGY

Site one was located in an upland position with a 4% slope and was described to a depth of 140 cm (Table 6). The soil developed from limestone parent material and presented a well developed mollic epipedon with no surface organic layer accumulations on top. There was a drastic change in color below the mollic horizon. Colors went from dark brown to grayish brown to light gray, denoting water saturation conditions (Figure 10).

Texture was clayey throughout the profile, with moderate to strong medium

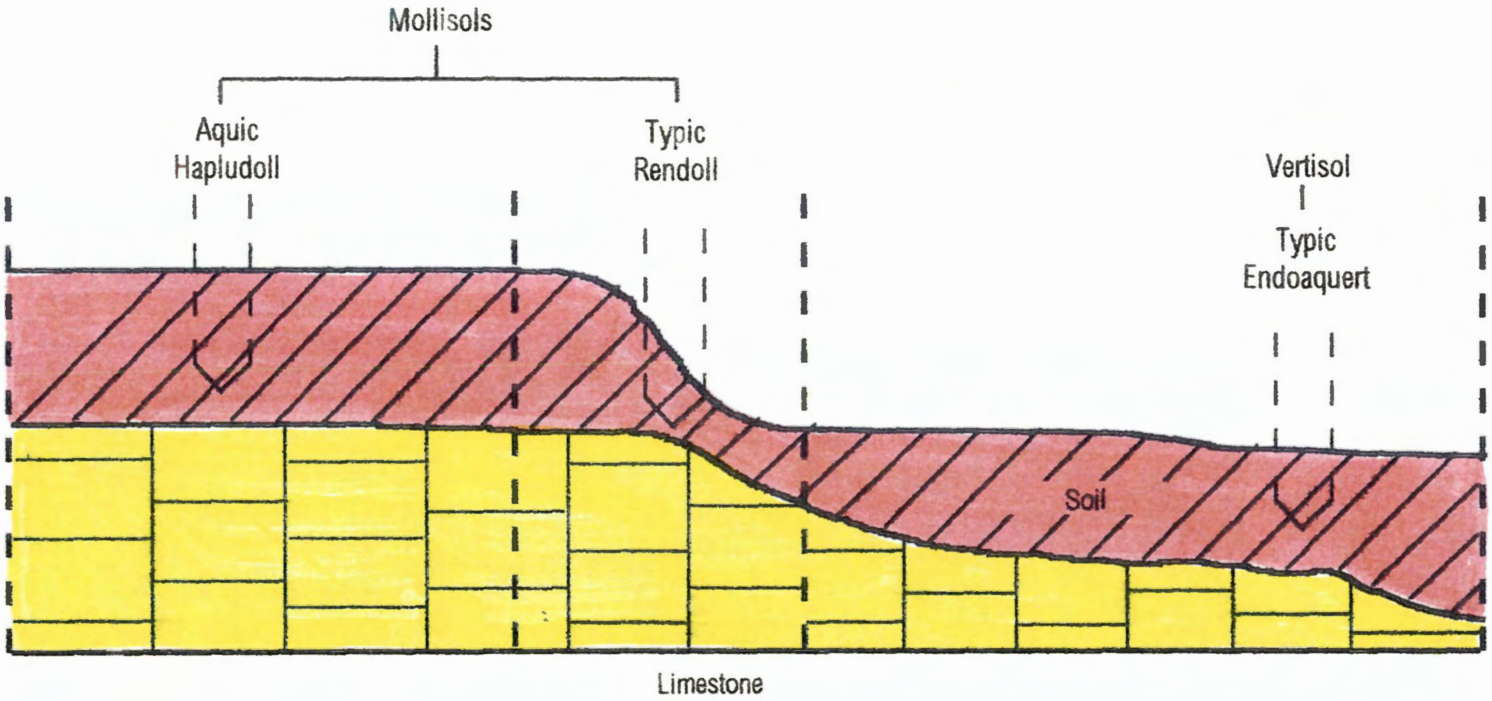

Figure 9: Soil Landscape Relations of Sites 1, 2, and 3

TABLE 6. SOIL MORPHOLOGICAL DATA FOR SITE 1

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCE
A1	0-12	10YR 2/1	c	3mabk	vfi
A2	12-25	10YR 3/2	c	2mabk	vfi
AB	26-36	10YR 3/3	c	2mabk	fi
Bw	36-51	10YR 5/2	c	1m-labk	fi
Bg	51-78	2.5Y 6/1	c	1m-labk	fi
BC	78-90	2.5Y 7/2	c	0mam-lab	fi
C1	90-120	5Y 7/2 10YR 8/1(lime)	c	0ma	fi
C2	120-140	5Y 7/2 10YR 8/1(lime)	c	0ma	fi

* Abbreviations defined in Appendix A

Figure 10. Photograph of the Aquic Hapludoll (site 1).

angular blocky structure in upper horizons and structureless massive conditions at the bottom. Effervescence was generally weak throughout the profile. Manganese concretions were present in the C2 horizon. No lithological discontinuities were found.

The pedon at site two was described to a depth of 125 cm (Table 7). The soil was located in a depressional area with nearly level slope, and developed from limestone parent material. The site had an O horizon of mainly undecomposed organic material above the A horizon.

The color varied from black in the surface to gray at the bottom, denoting water stagnation problems. There was a mixing of light colored materials in the Bssg1 horizons (Figure 11). The structure was mostly massive, except in the A1 horizon. Slickensides were well developed with shiny and fluted surfaces (horizons A2 to BC). Gilgai microtopography, a common feature of Vertisols, was particularly noticeable.

Site three, was described to a depth of 60 cm (Table 8). The soil profile can be observed in Figure 12. This soil developed on very gravelly material. The parent material was residuum from Tertiary limestone. The site was located in a forested area with a slope of 15% facing the north east end of lake Yaxja. The soil presented a less developed mollic epipedon as can be noted by the type of coloration at the bottom of this surface horizon. The soil was very rich in clay, and the effervescence was generally weak throughout the profile.

The soil profile of site four (Figure 13) was described to a depth of 90 cm, where the limestone bedrock was found (Table 9). The site was located at a corn-

TABLE 7 SOIL MORPHOLOGICAL DATA FOR SITE 2

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCE
O	3-0	-	-	-	-
A1	0-17	10YR 2/1	c	2mabk	fi
A2	17-35	10YR 2/1	c	0ma	fi
BA	35-50	10YR 2/1	c	0ma (slickensides)	fi
Bssg1	50-90	N4	c	0ma (slickensides)	fi
Bssg2	90-100	N4, 2.5Y 5/1	c	0ma (slickensides)	fi
BC	100-110	2.5Y 5/1	c	0ma (slickensides)	fi
C	110-125	10YR 8/1	sil	0ma	fi

* Abbreviations defined in Appendix A

Figure 11. Photograph of the Typic Endoaquert (site 2)

TABLE 8. SOIL MORPHOLOGICAL DATA FOR SITE 3

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCE
A1	0-18	10YR 2/1	c	2-3msbk	fi
A2	18-31	10YR 3/1	gc	2mabk	fi
AB	31-48	10YR 5/1	vgc	0ma,1mabk	fi
BC	48-60	2.5Y 7/2	vgc	0ma,1mabk	fi

* Abbreviations defined in Appendix A

Figure 12. Photograph of the Typic Rendoll (site 3)

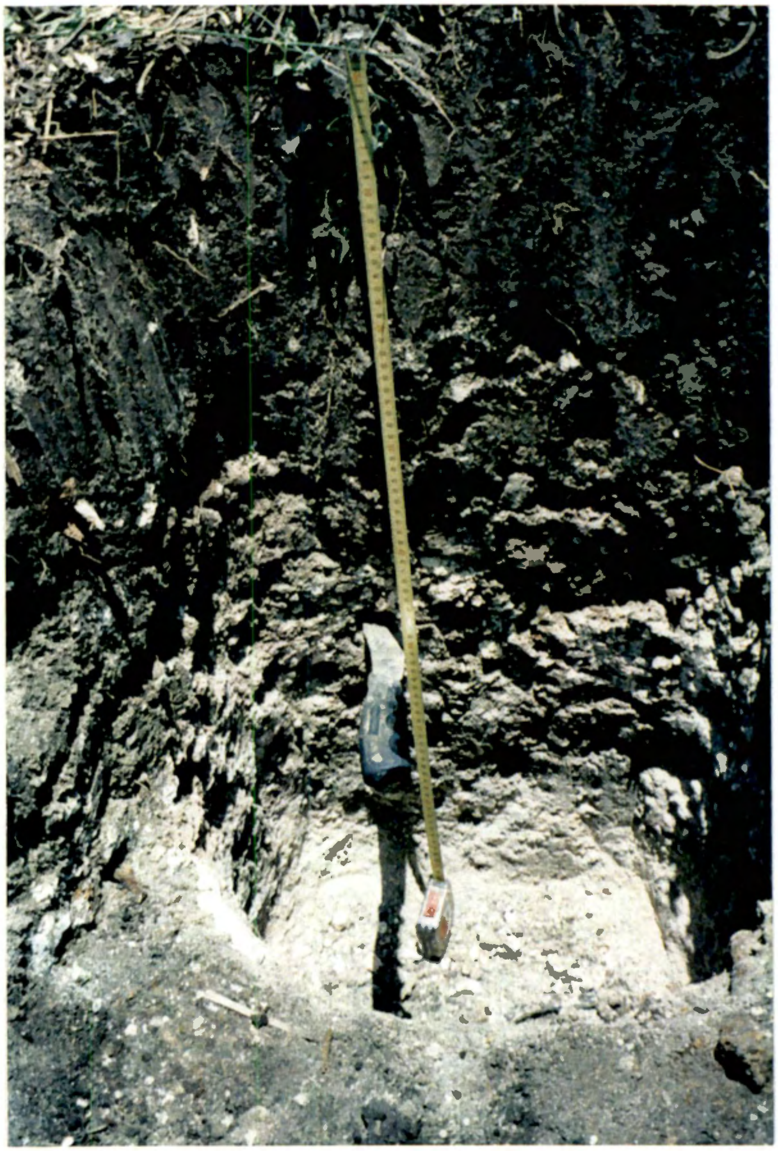

Figure 13. Photograph of the Eutrochreptic Rendoll (site 4)

TABLE 9. SOIL MORPHOLOGICAL DATA FOR SITE 4

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCE
A1	0-18	10YR 2/1	sil	2-3,fgr	fr
A2	18-35	10YR 3/1	sil	2,mgr	fr
Bw	35-58	10YR 3/2	sil	1,f-msbk	fr
2BC	58-73	10YR 4/2	cl	1msab	fr
2C	73-90	10YR 4/2 10YR 8/1(10%)	cl	1msbk	fr
2R	90+	Limestone Bedrock	-	-	-

* Abbreviations defined in Appendix A

bean plantation of rolling hills (karst); it had a slope of 4%, and was surrounded by forest vegetation. The soil appeared to be typical of the moderate-deep Rendoll type for this area. It developed from colluvium over limestone (located at a depth of 90 cm., R horizon). Site four had a well developed dark mollic epipedon with a moderate to strong granular structure at the top. One of the main characteristics of this soil is the very strong effervescence throughout the profile. The soil had a silt loam texture in the upper horizons and a clay loam texture in the lower horizons. The difference in parent material, as well as the difference in texture (Table 10), suggests that there is a lithological discontinuity at a depth of 58 cm. Coarse fragments ranged from 3% in the A1 horizon to 65% in the Bw horizon.

Site five was described to a depth of 80 cm (Table 11). The soil profile can be observed in Figure 14. This site had a slope of 10%, and was situated in the middle of a squash plantation burned 10 days before planting. The soil developed from colluvium over residuum limestone as can be seen in the the texture change and sand distribution at 42 cm (Table 10). The soil had a well developed mollic epipedon with clay textures in the upper horizons and clay loam textures in the lower horizons. Especially noticeable was the sharp difference of effervescence between the upper three horizons and the last two. It changed from weak to very strong, and this was due to the influence of the parent material.

Coarse fragments were common again in this type of Mollisol; they ranged from < 1% at the surface to 70% at the bottom of the profile.

The 2 C/B horizon was formed mainly by rock material with some B clayey material mixed in. Many coarse and medium distinct and prominent mottles of

TABLE 10. SAND DISTRIBUTION, TEXTURE, AND MINERAL CEC-CLAY RATIO.

HORIZON	DEPTH (cm)	VCOS %	COS %	MS %	FS %	VSF %	SAND %	SILT %	CLAY %	MINERAL CEC-CLAY RATIO
SITE 1										
A1	0-12	1.1	1.2	0.5	1.6	1.2	5.9	19.1	75.0	1.0
A2	12-25	11.0	1.3	0.3	0.9	1.5	13.8	9.7	76.6	1.0
AB	25-36	7.5	0.1	0.6	1.1	0.6	10.3	7.9	81.8	1.0
Bw	36-51	0.7	0.1	0.6	0.0	0.8	3.3	6.4	90.3	0.9
Bg	51-78	0.7	0.1	0.5	0.6	0.8	3.5	7.1	89.4	0.9
BC	78-90	0.5	0.1	0.3	0.8	0.3	2.7	6.5	90.8	1.0
C1	90-120	0.9	0.1	1.4	1.1	0.8	4.4	6.9	88.7	1.0
C2	120-140	0.7	0.1	0.4	1.0	0.6	3.7	24.5	71.8	1.2
SITE 2										
A1	0-17	4.5	1.2	0.7	1.2	0.8	8.2	10.6	81.2	1.1
A2	17-35	2.4	1.8	0.6	2.0	1.2	7.6	18.6	73.8	1.1
BA	35-50	2.9	1.6	0.8	1.2	1.1	8.1	7.6	84.3	1.0
Bssg1	50-90	3.4	2.0	0.9	1.4	1.1	8.1	7.0	84.9	1.0
Bssg2	90-100	3.0	1.2	0.5	1.3	1.0	6.8	8.0	85.2	1.0
BC	100-110	2.8	1.5	0.7	1.0	0.5	6.7	6.7	86.7	1.0
C	110-125	0.1	0.2	0.2	0.4	0.5	1.3	85.5	13.2	2.5
SITE 3										
A1	0-18	4.3	1.7	0.7	1.7	5.2	9.6	9.4	81.0	1.0
A2	18-31	4.6	2.8	0.3	2.0	1.3	11.4	18.4	70.2	1.1
AB	31-48	6.9	2.0	0.9	1.6	0.9	13.0	14.1	72.9	1.0
BC	48-66	18.4	2.8	1.3	2.0	2.0	24.0	12.6	63.4	1.2

TABLE 10. (continued)

HORIZON	DEPTH (cm)	VCOS %	COS %	MS %	FS %	VSF %	SAND %	SILT %	CLAY %	MINERAL CEC-CLAY RATIO
SITE 4										
A1	0-18	5.8	4.8	2.2	2.9	2.7	17.8	66.9	15.3	1.8
A2	18-35	11.5	6.8	2.4	3.6	2.9	27.2	60.8	12.0	1.2
Bw	35-58	9.6	6.8	3.0	4.3	2.6	26.4	59.8	13.7	0.8
2BC	58-73	13.2	8.0	3.3	4.7	2.9	32.2	40.2	27.7	0.5
2C	73-90	22.3	8.2	3.3	4.0	2.7	40.1	31.3	28.6	0.4
SITE 5										
A1	0-9	0.4	3.6	1.6	5.5	3.2	15.7	16.9	67.4	0.7
A2	9-26	2.6	1.4	0.8	1.4	1.3	7.5	8.3	84.2	0.7
Bw1	26-42	2.0	1.0	0.5	1.0	0.8	5.5	11.0	83.5	0.7
2Bw2	42-65	7.9	3.6	2.0	4.9	6.7	25.7	45.5	28.8	0.7
2C/B	65-80	6.8	3.5	1.6	3.4	6.7	21.3	41.7	37.0	0.6
SITE 6										
A	0-8	3.9	4.0	5.7	1.1	1.0	4.6	73.2	22.3	0.8
Bt1	8-23	1.7	3.8	2.7	6.6	4.5	18.8	13.4	67.9	0.2
Bt2	23-42	3.8	2.6	1.7	3.3	2.4	13.8	9.8	76.5	0.2
Bt3	42-66	1.2	1.1	1.2	2.0	2.1	7.4	10.3	82.3	0.2
Bt4	66-95	2.2	1.7	1.4	1.7	1.0	10.6	7.7	81.7	0.2
2Bt5	95-115	1.3	1.7	1.6	4.3	4.4	13.3	7.5	79.2	0.2
2Bt6	115-145	0.8	1.5	1.5	4.7	4.6	13.1	10.0	76.9	0.3
2Bt7	145-175	0.2	0.4	0.1	1.1	1.7	8.7	8.6	82.7	0.3
2Bt8	175-225	1.3	2.9	2.0	4.5	3.8	14.1	11.2	74.7	0.3

TABLE 11. SOIL MORPHOLOGICAL DATA FOR SITE 5

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCE
A1	0-9	7.5YR 2.5/2	c	2msbk (3mgr upper 3cm)	fi
A2	9-26	7.5YR 2.5/1	c	1mabk	vfi
Bw1	26-42	7.5YR 3/2	c	3mabk	fi
2Bw2	42-65	7.5YR 5/4 7.5YR 8/1(25%) m3d 7.5YR (5/8)	cl	2msbk	fi
2C/B	65-80	7.5YR 4/6(40%) 7.5YR 8/1(60%) m2p 10R 5/8	gcl	1msbk	fi

* Abbreviations defined in Appendix A

Figure 14. Photograph of the Eutrochreptic Rendoll (site 5)

strong brown and red color were present in the Bw's and 2 C/B horizons, which suggests water fluctuation. Common thick discontinuous coatings were common in the Bw horizons.

The soil profile at site six was described to a depth of 225 cm, using the auger below 115 cm (Figure 15). The site was located in a savannah area with a 3% slope. The soil developed from alluvium parent material, and had a probable lacustrine influence. The vegetation was particularly different in the savannah soils, and it consisted of grasses, some bushes and scattered trees.

The soil had an ochric epipedon with a silt loam texture at the surface and mostly kaolinitic clay in the rest of the horizons. This soil presented a complex morphology (Table 12), with reticulate mottling as one of the main characteristics. The mottling started at a depth of 66 cm. with colors that ranged from yellowish to red, to gray. This reticulate mottling resulted from the constant fluctuation of the water table through time.

The profile presented a stone line mostly concentrated at a depth of 95 cm, suggesting a different deposition of alluvial material, which has been interpreted as a lithological discontinuity.

Manganese and iron shots were abundant. The content of manganese increased sharply with depth, and it constituted 50-60% of the 2Bt8 horizon. Also, discontinuous clay coatings were common in the Bt horizons.

PHYSICAL AND CHEMICAL CHARACTERISTICS

The soils in the Peten are generally high in clay, as it can be easily noted in

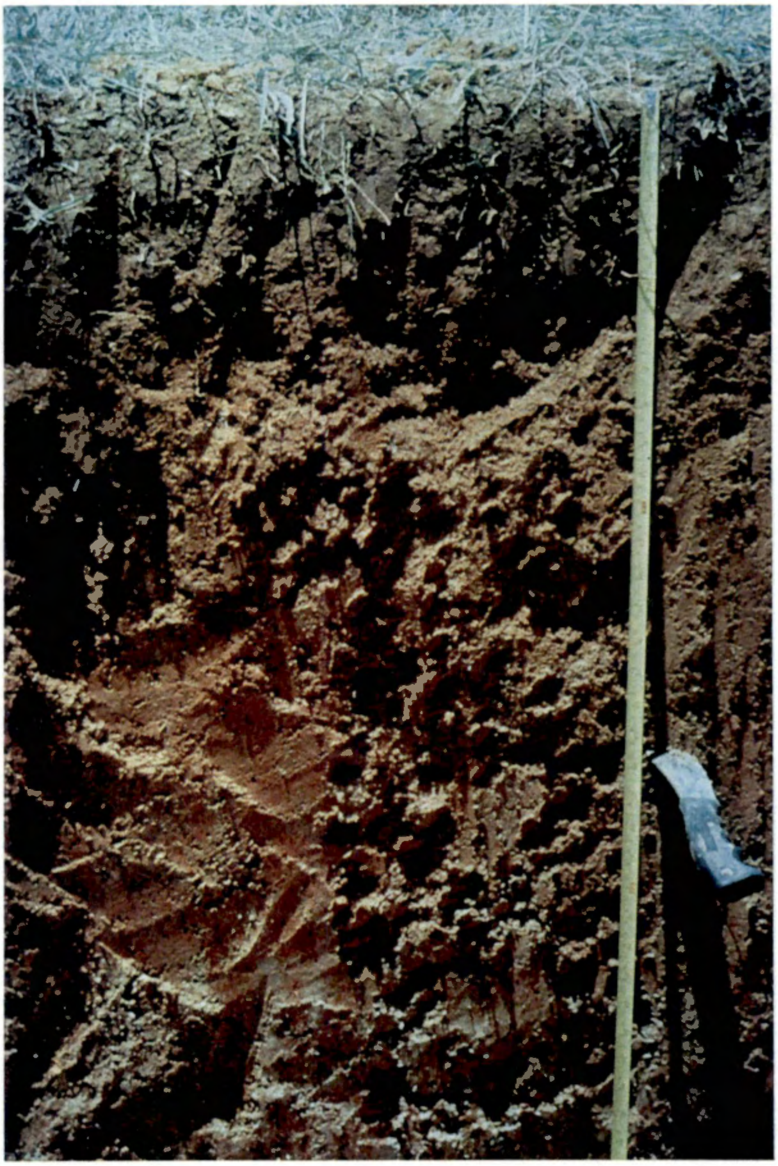

Figure 15. Photograph of the Typic Paleudalf (site 6)

TABLE 12. SOIL MORPHOLOGICAL DATA FOR SITE 6

HORIZON	DEPTH (cm)	COLOR	TEXTURE	STRUCTURE	MOIST CONSISTENCE
Ap	0-8	7.5YR 3/3	sil	1mabk	fr
Bt1	8-23	7.5YR 4/6	c	1cpl,2mabk	fr
		5YR 4/6(spots)			
Bt2	23-42	7.5YR 4/6	c	2,f-msbk	fr
		5YR 4/6 (spots)			
Bt3	42-66	5YR 4/6	c	2msbk	fi
Bt4	66-95	rm 5YR 4/6,	c		
		10YR 7/1,	c, grc		
		10R 4/6		2msbk	fi
2Bt5	95-115	rm 2.5YR 3/6	c	2msbk	vfi
		2.5YR 3/6			
		10YR 7/1			
		7.5 YR 5/8			
2Bt6	115-145	rm 10R 4/6	c	-	vfi
		10YR 7/1			
		2.5YR 3/6			
2Bt7	145-175	rm 10R 4/6	c	-	fi
		10YR 7/1			
		7.5YR 5/6			
2Bt8	175-225	7.5YR 5/6(50% black Mn)	c	-	fi
		m3p 10YR 4/6			
		10YR 7/1			

* Abbreviations defined in Appendix A

most of the soil profiles, except site four. Clay percentages in the profiles varied from 13% up to 91% (Table 10). The vertical sequum of sites one, two, and five showed the usual clay increase to a maximum within a few feet of the surface and then a decrease. Site six showed more or less this pattern, having a second clay content increase at the 2 Bt7 horizon, probably resulting from a different deposition of alluvium previously expressed as a discontinuity. Site three presented its highest amount of clay (81%) in the upper horizon and then decreased with depth. Finally, site four presented high amounts of silt in the upper horizons that decreased with depth. This may be the result of the location of the site, a small and nearly level bench in the middle of rolling hills which received silt depositions from soils in upper positions.

Based on the CEC-Clay ratio (Table 10), site one, two, and three were extremely rich in montmorillonitic clay which according to Young (1976), causes the stickiness, high CEC, and marked swelling when wet and shrinkage when dry. Site four and five had mixed mineralogies, and site six was mainly composed of kaolinitic clay. According to Lal (1986), the soils in sites one, two, three, four, and five can then be categorized into soils containing high-activity clays and those of mixed mineralogies, and site six would belong to the soils containing predominantly low-activity clays.

Soil pH (1:1, soil:solution) varied from slightly acid to moderately alkaline, except at site six in which pH ranged from slightly acid to strongly acid due to the alluvium parent material and the more strongly weathered minerals (Table 13).

The $CaCl_2$ method was also used as a comparative analysis of pH's in the

TABLE 13. KCl TOTAL ACIDITY AND PH

HORIZON	DEPTH (cm)	pH(1:1)	pH 0.2 M CaCl2	KCL-AL	KCL ACIDITY	KCL-H
				---------	cmol/kg	---------
SITE 1						
A1	0-12	5.68	5.73	0.05	0.00	0.00
A2	12-25	5.53	4.65	0.69	0.00	0.00
AB	25-36	5.95	4.67	0.74	0.07	0.00
Bw	36-51	5.87	5.41	0.68	0.03	0.00
Bg	51-78	6.68	6.18	0.34	0.00	0.00
BC	78-90	7.41	6.76	0.17	0.00	0.00
C1	90-120	6.88	6.78	0.28	0.00	0.00
C2	120-140	7.43	6.84	0.22	0.00	0.00
SITE 2						
A1	0-17	5.55	6.37	0.65	0.00	0.00
A2	17-35	5.76	6.18	0.51	0.00	0.00
BA	35-50	5.85	6.65	0.26	0.00	0.00
Bssg1	50-90	7.05	6.33	0.03	0.10	0.00
Bssg2	90-100	6.05	6.25	0.16	0.10	0.00
BC	100-110	7.12	6.72	0.15	0.00	0.00
C	110-125	7.67	7.37	0.17	0.00	0.00
SITE 3						
A1	0-18	6.80	6.42	0.22	0.00	0.00
A2	18-31	6.80	6.20	0.38	0.00	0.00
AB	31-48	6.76	6.25	0.10	0.00	0.00
BC	48-60	7.19	6.60	0.14	0.00	0.00

TABLE 13 (continued)

HORIZON	DEPTH (cm)	pH(1:1)	pH 0.2 M CaCl2	KCL-AL	KCL ACIDITY	KCL-H
				----------	cmol/kg	---------
SITE 4						
A1	0-18	7.73	7.36	0.05	0.00	0.00
A2	18-35	7.46	7.38	0.21	0.00	0.00
Bw	35-58	8.00	7.30	0.14	0.00	0.00
2BC	58-73	7.99	7.20	0.25	0.00	0.00
2C	73-90	8.05	7.18	0.21	0.00	0.00
SITE 5						
A1	0-9	7.11	6.92	0.22	0.00	0.00
A2	9-26	7.71	6.93	0.06	0.00	0.00
Bw1	26-42	7.64	6.93	0.06	0.00	0.00
2Bw2	42-65	8.04	7.10	0.00	0.00	0.00
2C/B	65-80	7.53	6.84	0.00	0.00	0.00
SITE 6						
A	0-8	6.04	4.30	1.21	0.18	0.00
Bt1	8-23	5.67	4.11	2.76	0.52	0.00
Bt2	23-42	6.06	4.13	3.29	0.56	0.00
Bt3	42-66	5.49	4.14	4.36	0.87	0.00
Bt4	66-95	5.59	4.30	2.68	0.45	0.00
2Bt5	95-115	6.25	4.20	4.03	0.80	0.00
2Bt6	115-145	6.19	4.17	3.83	0.71	0.00
2Bt7	145-175	5.60	4.18	3.64	0.65	0.00
2Bt8	175-225	5.66	4.29	2.31	0.40	0.00

soils. This solution tends to mask small differences in salt contents without displacing a large fraction of the H^+ or Al^{3+} ions (Schofield and Taylor, 1955; Graham, 1959; Woodruff, 1967). The results were the expression of the ability of this method to measure the exchangeable acidity, whereas the water pH method measures active acidity. Hence, $CaCl_2$ data resulted in lower pH's for all the soil sites, especially in the Alfisol in which aluminum contents were greater (Table 13). At low pH, the Al^{3+} is present in the exchange complex and diffuses in the soil solution where it may cause toxicities.

The KCl aluminum data, closely related to pH, (Table 13) showed low concentrations of aluminum in the Mollisols, as well as in the endopedons of the Vertisol, but were significantly higher in site six, in which values ranged from 2.42 to 8.72 cmol+ kg^{-1} of soil. The Mollisol that showed the highest exchangeable Al content was site number one (values up to 1.48 cmol+ kg^{-1} in the upper horizons).

As it can be expected, the values of KCl acidity of the soil samples that were above a pH of 5.5 turned out to be zero. Consequently, the values of the KCl-H^+ (Table 13) were zeros as well. It is important to remember that data from two separate types of analysis (instrumental and titration) is being used, and that these analysis have varying errors of measurement associated with them. Combining these errors in estimating the exchangeable H^+ may yield an erroneous result, especially if there was no measurable KCl-acidity.

The percent of calcium carbonate equivalent (Table 14) was particularly important due to the alkaline nature of many of the soils in the Peten. Exceptions

TABLE 14. CALCIUM CARBONATE EQUIVALENT, TOTAL CARBON, ORGANIC AND INORGANIC CARBON AND TOTAL NITROGEN

HORIZON	DEPTH (cm)	CALCIUM CARBONATE EQUIVALENT (CCE) %	TOTAL CARBON %	INORGANIC CARBON (from CCE) %	ORGANIC CARBON (from W/B) %	TOTAL NITROGEN %
SITE 1						
A1	0-12	1.18	3.77	0.14	3.44	0.40
A2	12-25	1.56	1.50	0.19	1.46	0.24
AB	25-36	2.17	1.54	0.26	1.03	0.17
Bw	36-51	1.25	0.58	0.15	0.48	0.05
Bg	51-78	1.26	0.37	0.15	0.28	0.03
BC	78-90	1.29	0.23	0.15	0.16	0.02
C1	90-120	1.69	0.16	0.20	0.06	0.01
C2	120-140	1.81	0.18	0.22	0.05	0.00
SITE 2						
A1	0-17	2.26	3.73	0.27	2.08	0.34
A2	17-35	1.54	1.33	0.18	0.84	0.13
BA	35-50	1.68	1.18	0.20	0.79	0.11
Bssg1	50-90	1.09	0.47	0.13	0.32	0.04
Bssg2	90-100	1.65	0.68	0.20	0.44	0.05
BC	100-110	3.18	0.65	0.38	0.32	0.04
C	110-125	44.68	6.06	5.37	0.17	0.01
SITE 3						
A1	0-18	1.53	6.18	0.18	4.29	0.59
A2	18-31	1.24	3.48	0.15	2.50	0.42
AB	31-48	2.27	1.63	0.27	1.25	0.20
BC	48-60	2.03	0.56	0.24	0.31	0.05

TABLE 14 (continued)

HORIZON	DEPTH (cm)	CALCIUM CARBONATE EQUIVALENT (CCE) %	TOTAL CARBON %	INORGANIC CARBON (from CCE) %	ORGANIC CARBON (from W/B) %	TOTAL NITROGEN %
SITE 4						
A1	0-18	61.19	12.27	7.35	3.42	0.39
A2	18-35	65.23	10.53	7.83	1.63	0.20
Bw	35-58	64.07	10.79	7.69	0.66	0.08
2BC	58-73	62.58	10.08	7.52	0.65	0.08
2C	73-90	61.91	9.98	7.44	0.54	0.05
SITE 5						
A1	0-9	1.51	4.29	0.18	4.13	0.49
A2	9-26	1.27	2.64	0.15	1.87	0.34
Bw1	26-42	1.79	1.75	0.22	1.31	0.18
2Bw2	42-65	53.01	6.97	6.37	0.23	0.05
2C/B	65-80	55.31	7.25	6.64	0.00	0.02
SITE 6						
A	0-8	0.53	3.00	0.06	2.84	0.23
Bt1	8-23	1.09	1.77	0.13	1.48	0.13
Bt2	23-42	0.26	0.82	0.03	0.77	0.10
Bt3	42-66	0.13	0.77	0.02	0.70	0.09
Bt4	66-95	1.20	0.64	0.14	0.42	0.06
2Bt5	95-115	0.66	0.20	0.08	0.13	0.04
2Bt6	115-145	0.57	0.18	0.07	0.12	0.04
2Bt7	145-175	0.46	0.18	0.06	0.10	0.03
2Bt8	175-225	0.13	0.12	0.02	0.01	0.03

occurred in the savannah soils that formed on a different parent material and were strongly weathered. Percent of $CaCO_3$ changed dramatically in the lower horizons of sites two and five, denoting the influence of the calcareous parent material. In site four, results were high throughout the profile, denoting that the free carbonates have been probably mixed due to the colluvial material that has been deposited over the original residuum parent material.

Percent of inorganic carbon was derived from the percent calcium carbonate equivalent data. The values were generally lower than the organic carbon values, excepting when a considerable effervescence was recorded for the different soil horizons (Table 14).

It is a common belief that soils in the tropics have lower organic matter levels than soils in temperate regions (McNeil, 1964; Gourou, 1966; Bartholomew, 1972; Jordan, 1985). However, studies involving large numbers of pedons (Post et al., 1982; Zinke et al., 1984; Sanchez et al., 1982) now confirm the prevalent view that soil organic matter contents vary equally in temperate and tropical regions (Duxbury, 1989). Results of organic carbon in the sites studied in the Peten are not the exception. They had an average of 2.42% in the topsoil (Table 14), with the Mollisols having the highest values. The Vertisol had the lowest value, with only 1.5% (average), and the Alfisol had 2.8% (average) organic carbon. Due to the difficulties in calculating organic matter content directly, the value can be estimated by multiplying the organic carbon (a value that can be easily and accurately measured) by a factor of 2 (Nelson and Sommers, 1982). Therefore, the estimated average of organic matter for the topsoil of the sites investigated was: $2.42 * 2 = 4.84\%$

Total nitrogen levels of the topsoils showed averaged values of 0.27, 0.24, and 0.18% for site one, two, and six, respectively. The averaged values for sites three, four, and five were 0.51, 0.30, and 0.42%, respectively (Table 14).

Cation exchange capacity (CEC) values were especially high in the first three sites due to the close relation with the type of clay (montmorillonitic) and organic matter contents. The remaining three sites showed more moderated values, especially the Alfisol that belong to the low activity clay soils (Table 15). No low CEC values (CEC less than 7 cmol kg^{-1}) were found in soils investigated, therefore, there is no limiting ability to retain nutrient cations against leaching.

Calcium and magnesium ions dominated the exchange sites in all of the profiles investigated, with calcium concentration significantly higher than magnesium. These ions showed greater concentrations in the Mollisols than in the Vertisol and Alfisol (Table 15). It is important to remember that in the presence of free carbonates ($CaCO_3$), Ca^{2+} extraction is not totally accurate (Barshad, 1954).

The exchangeable K values, which are generally a good indicator of a soil's ability to supply K to plants, were very low for all the sites investigated, especially, sites one, two and six, with an average of 0.13, 0.16, and 0.30 cmol+kg^{-1} respectively (topsoil). The Rendolls, sites three, four, and five presented higher values, with averages of 0.35, 0.71, and 1.55 cmol+kg^{-1} respectively (topsoil) (Table 15).

The percent base saturation was very high in the different soil sites, particularly in the Mollisols in which the values went well over 100% (Table 15). This again, is due to the abundance of free calcium carbonates in the soil. Site six

TABLE 15. CATION EXCHANGE CAPACITY, EXCHANGEABLE BASES, pH, AND PERCENT BASE SATURATION

HORIZON	DEPTH (cm)	pH(1:1)	pH 0.2 M CaCl2	Ca++	Mg++	K+	Na+	CEC	%BASE SAT.
				----------------		cmol/kg	----------------		
SITE 1									
A1	0-12	5.68	5.73	68.79	9.42	0.22	0.88	73.88	107.47
A2	12-25	5.53	4.65	65.11	7.53	0.10	2.02	75.30	99.29
AB	25-36	5.95	4.67	66.55	7.34	0.07	2.74	81.48	94.14
Bw1	36-51	5.87	5.41	67.01	6.33	0.00	3.61	81.73	94.17
Bg	51-78	6.68	6.18	71.84	6.01	0.00	5.40	82.34	101.10
BC	78-90	7.41	6.76	72.64	6.20	0.00	6.24	86.76	98.07
C1	90-120	6.88	6.78	80.91	6.32	0.00	6.62	84.79	110.69
C2	120-140	7.43	6.84	73.82	5.79	0.00	7.06	87.73	98.79
SITE 2									
A1	0-17	5.55	6.37	73.06	8.72	0.25	0.56	89.32	92.47
A2	17-35	5.76	6.18	67.66	7.47	0.07	0.71	82.32	92.22
BA	35-50	5.85	6.65	71.42	7.06	0.00	0.87	80.25	98.88
Bssg1	50-90	7.05	6.33	67.24	6.89	0.04	0.97	85.75	87.64
Bssg2	90-100	6.05	6.25	73.22	6.46	0.00	1.04	84.19	95.87
BC	100-110	7.12	6.72	79.92	6.52	0.08	1.08	82.34	106.39
C	110-125	7.67	7.37	61.43	3.10	0.03	0.66	33.04	197.40
SITE 3									
A1	0-18	6.80	6.42	70.84	6.74	0.40	0.28	78.02	100.30
A2	18-31	6.80	6.20	121.11	7.38	0.45	0.42	76.70	168.66
AB	31-48	6.76	6.25	124.94	4.38	0.20	0.53	73.16	177.77
BC	48-60	7.19	6.60	133.11	3.10	0.10	1.20	76.98	178.64

TABLE 15. (continued)

HORIZON	DEPTH (cm)	pH(1:1)	pH 0.2 M CaCl2	Ca++	Mg++	K+ cmol/kg	Na+	CEC	%BASE SAT.
SITE 4									
A1	0-18	7.73	7.36	101.82	3.56	1.23	0.13	27.17	392.88
A2	18-35	7.46	7.38	91.26	2.61	0.18	0.09	13.88	678.30
Bw	35-58	8.00	7.30	85.41	1.47	0.19	0.08	10.81	806.16
2BC	58-73	7.99	7.20	81.01	1.81	0.38	0.08	14.30	582.34
2C	73-90	8.05	7.18	93.63	2.84	0.37	0.08	12.20	794.51
SITE 5									
A1	0-9	7.11	6.92	103.99	7.66	1.84	0.17	48.79	232.94
A2	9-26	7.71	6.93	104.38	7.17	1.26	0.11	59.02	191.32
Bw1	26-42	7.64	6.93	107.21	5.85	0.86	0.11	56.82	200.70
2Bw2	42-65	8.04	7.10	91.66	2.03	0.30	0.07	20.86	450.93
2C/B	65-80	7.53	6.84	97.31	2.22	0.24	0.06	20.89	477.88
SITE 6									
A	0-8	6.04	4.30	10.53	1.50	0.30	0.14	17.36	71.88
Bt1	8-23	5.67	4.11	7.73	0.53	0.00	0.06	14.12	59.00
Bt2	23-42	6.06	4.13	8.43	0.53	0.00	0.05	11.62	77.61
Bt3	42-66	5.49	4.14	9.04	0.35	0.00	0.04	15.60	60.44
Bt4	66-95	5.59	4.30	12.88	0.40	0.00	0.05	15.69	84.96
2Bt5	95-115	6.25	4.20	14.99	0.61	0.00	0.05	18.24	85.83
2Bt6	115-145	6.19	4.17	16.54	0.68	0.00	0.05	19.19	90.02
2Bt7	145-175	5.60	4.18	22.38	0.99	0.00	0.04	21.51	108.81
2Bt8	175-225	5.66	4.29	26.19	1.08	0.01	0.03	25.23	108.22

presented a different case in which soil pH and calcium carbonate equivalent were low, but the base saturation percentage still remained high, categorizing the soil as an Alfisol.

It is evident by observing the data from the total elemental analysis (Table 16) that the soils investigated are very low in phosphorus and potassium (exchangeable potassium is also low, Table 15). Phosphorus was always higher at the surface than in the rest of the profile, but concentrations were not enough for crop production. Site four had higher levels than the rest of the sites, probably due to agricul- tural practices applied to this soil for more than a decade. Sulfur results were low for the first two sites, but higher values were observed in the rest of the sites, especially site four (Table 16). On the other hand, calcium and magnesium values were high in most of the soils, especially the Mollisols. The exception was again site six.

In regard to the results of the archeological extract analysis, the extractable Ca content of the profiles sampled showed a wide range of values (Figure 16). Profile six showed the lowest content of extractable Ca, with values less than 6,000 mg kg^{-1}. The highest levels of Ca were found in profiles four, five, and two. Profiles four and five were typical of Rendolls with high levels of Ca in parts or all of the profiles. Profile four, for example, had over 200,000 mg kg^{-1} throughout the soil horizons and were strongly calcareous in the field as evidenced by the testing with HCl.

Profile six is quite contrasting in Mg content in comparison to the other profiles sampled in the study area (Figure 17). It had less than 100 mg kg^{-1} of

TABLE 16. TOTAL ELEMETAL ANALYSIS, MACRO AND MICRO NUTRIENTS .

HORIZON	DEPTH (cm)	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
		mg/kg										
SITE 1												
A1	0-12	15950	26	34560	<400	8316	487	<5	380	<50	<50	122
A2	12-25	14790	16	34550	<400	8452	286	<5	521	<50	<50	119
AB	25-36	20750	30	50770	<400	11790	461	<5	873	<50	<50	143
Bw	36-51	13700	22	36052	400	8500	160	<5	757	<50	<50	99
Bg	51-78	14800	21	36250	400	9020	405	<5	1233	<50	<50	255
BC	78-90	15170	21	35590	<400	8881	199	<5	1369	<50	<50	89
C1	90-120	17400	22	35320	560	9100	466	<5	1840	<50	<50	116
C2	120-140	18500	26	35023	500	9550	536	<5	1682	<50	<50	255
SITE 2												
A1	0-17	21070	28	26830	740	10382	2097	<5	283	72	<50	138
A2	17-35	15400	30	29840	671	11230	1936	<5	328	<50	<50	361
BA	35-50	16020	32	28980	600	11010	1979	<5	287	<50	<50	98
Bssg1	50-90	15940	20	28660	500	11261	1864	<5	307	<50	<50	162
Bssg2	90-100	18260	21	29990	715	11470	1870	<5	324	<50	<50	101
BC	100-110	26230	22	28210	960	13190	1535	<5	288	<50	<50	174
C	110-125	253170	12	12700	1385	10520	291	<5	<250	<50	<50	202
SITE 3												
A1	0-18	15700	26	25560	<400	8100	949	<5	<250	196	443	355
A2	18-31	13890	24	28000	<400	8035	870	<5	<250	78	208	80
AB	31-48	19500	21	30340	401	7662	453	<5	<250	<50	<50	124
BC	48-60	14300	21	29920	<400	8340	135	<5	437	<50	<50	295

TABLE 16. (continued)

HORIZON	DEPTH (cm)	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
		mg/kg										
SITE 4												
A1	0-18	303370	11	6635	920	3136	412	<5	<250	1312	485	44
A2	18-35	325740	6	6352	590	2810	295	<5	<250	704	248	69
Bw	35-58	360500	12	4418	480	3655	166	<5	<250	273	170	283
2BC	58-73	346370	12	6142	800	2900	272	<5	<250	404	116	51
2C	73-90	347380	5	5900	500	2790	166	<5	<250	<50	263	40
SITE 5												
A1	0-9	12280	14	33350	700	4764	1512	<5	<250	<50	320	247
A2	9-26	1200	17	41193	760	4811	1513	<5	<250	<50	394	133
Bw1	26-42	15560	9	41100	600	5300	1431	<5	<250	<50	166	99
2Bw2	42-65	249430	9	18570	400	2995	784	<5	<250	<50	92	73
2C/B	65-80	258740	<5	16660	<400	3153	741	<5	<250	<50	<50	68
SITE 6												
A	0-8	2734	54	64260	<400	998	2894	<5	<250	113	397	25
Bt1	8-23	6740	47	65520	<400	1088	1803	<5	<250	55	275	131
Bt2	23-42	1480	48	72100	<400	1195	3916	<5	<250	<50	105	200
Bt3	42-66	1420	45	60790	<400	1318	207	<5	<250	<50	59	85
Bt4	66-95	7730	97	70890	<400	1376	265	<5	<250	<50	<50	248
2Bt5	95-115	2580	58	63900	<400	1418	160	<5	<250	<50	<50	162
2Bt6	115-145	4560	73	57520	<400	1395	1099	<5	<250	<50	<50	125
2Bt7	145-175	9300	86	57500	<400	1657	746	<5	<250	<50	<50	202
2Bt8	175-225	12440	331	42830	<400	1659	20652	<5	<250	<50	<50	232

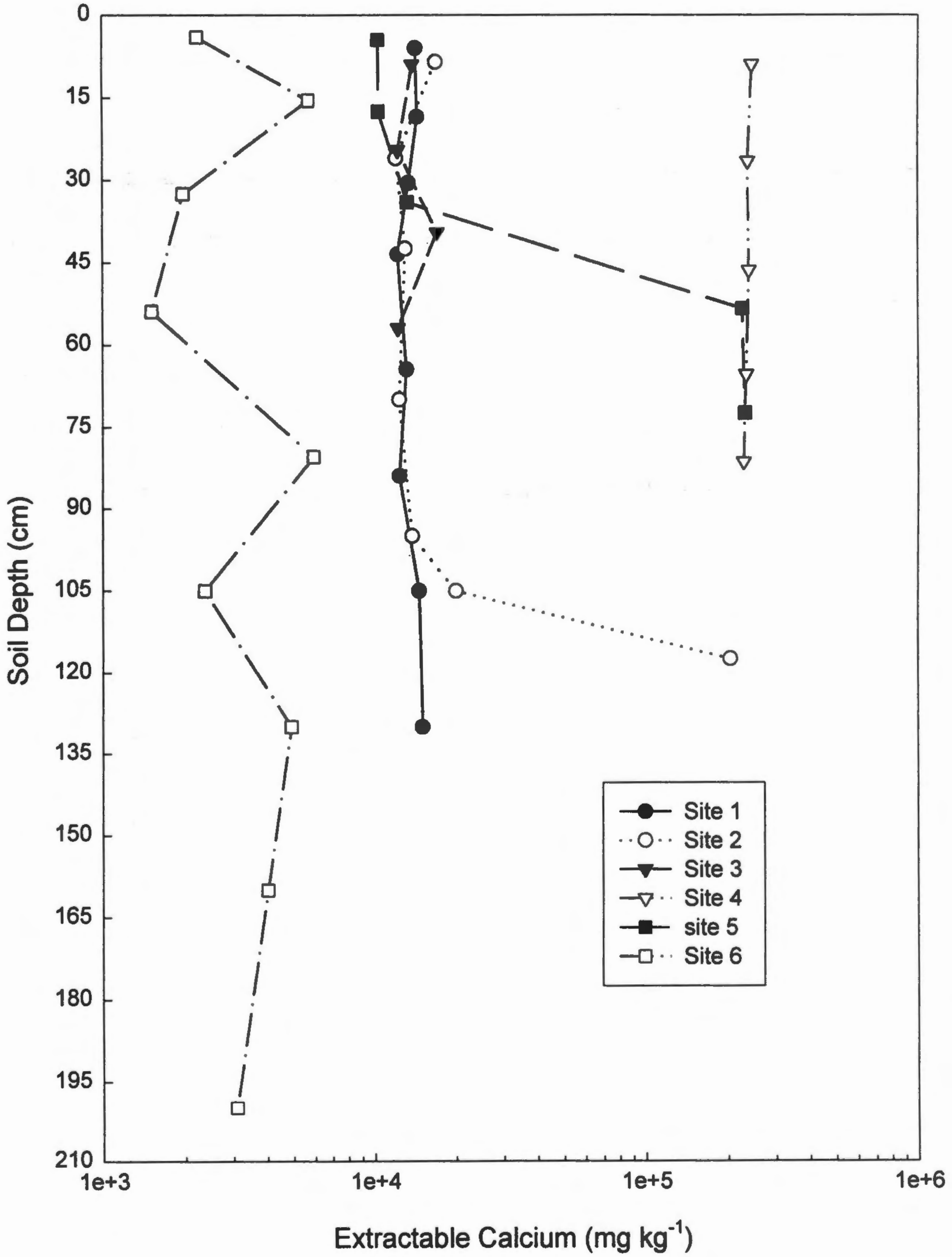

Figure 16. Extractable calcium for all depths at each site.

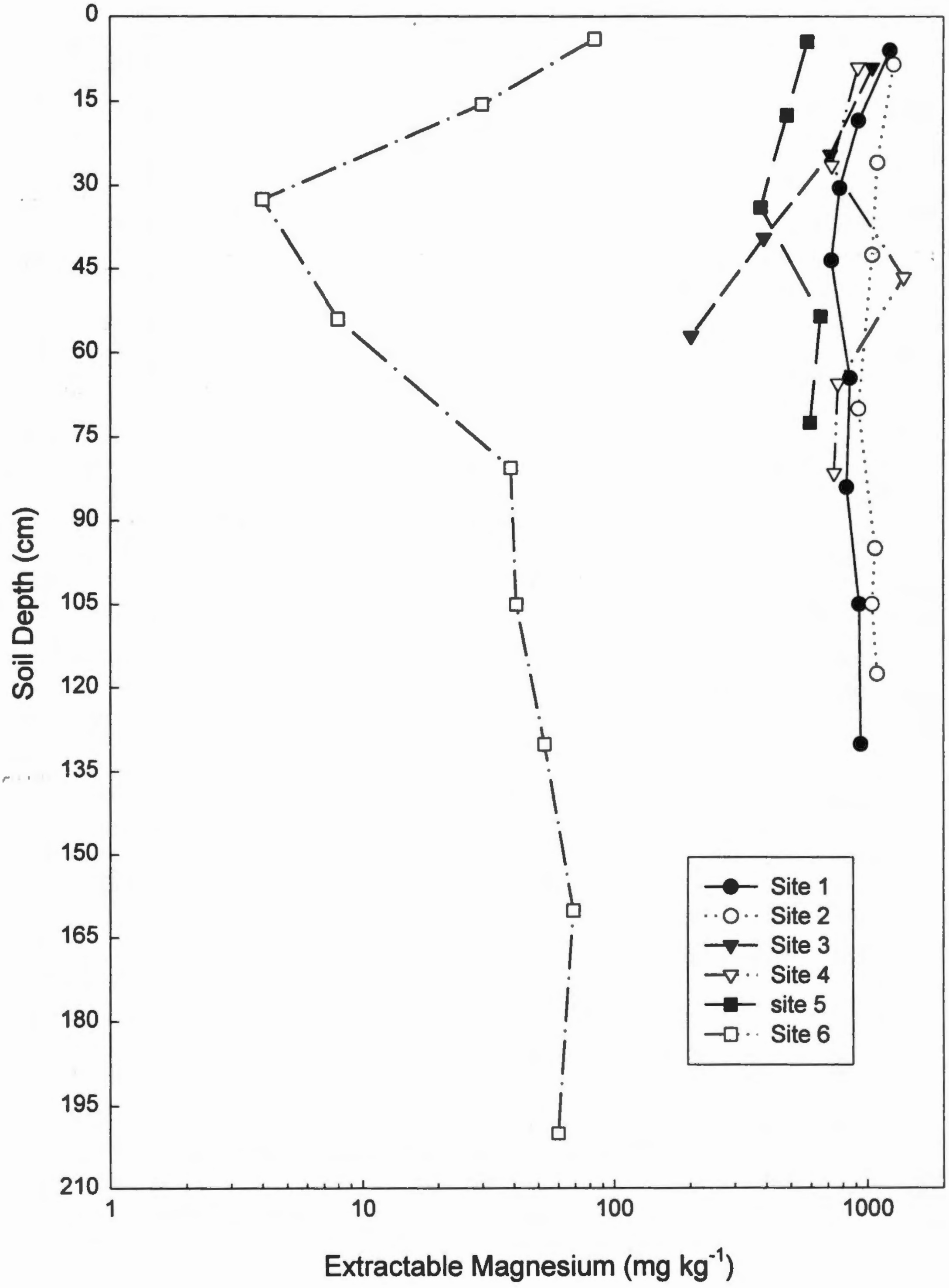

Figure 17. Extractable magnesium for all depths at each site.

extractable Mg throughout the profile, while the other sites sampled generally had values exceeding 400 mg kg^{-1}. This may be the result of two major factors. First, the other profiles sampled were derived directly from limestone residuum or alluvium, and second, site six is located on an old landscape position that was probably derived from preweathered sediments. The low extractable Mg in profile six, in addition to other nutrients, may have significant implications in the potentials for agricultural crops in this area.

Another interesting feature of the extractable Mg contents of these profiles is the apparent recycling of Mg. For example, in profile three the surface horizon had over 1,000 mg kg^{-1} and in the B/C horizon drops 200 mg kg^{-1}. Most of the profiles showed increased extractable Mg contents in surface horizons as contrasted to the subsoils. Other elements such as Ba, Mn, Co, B, K, and P showed similar relationships (Appendix F).

SOIL GENESIS

One of the major components in any pedological study is the understanding of the factors and processes of soil formation. Soils develop from solid rock masses, unconsolidated transported materials, and organic residues. Even the loose, unconsolidated materials were developed by the weathering of rock masses to stones, gravels, sands, silts, clays and soluble ions (Miller and Donahue, 1990).

The majority of the soils in the different study sites were developed from calcareous sedimentary rocks. The shallow, high base status, and dark Rendolls evolved from these calcareous rocks that are associated with caves and karst topography. Site three developed from rounded gravelly material weathered in situ. The Vertisols in this area also developed from these basic parent materials, that produce large amounts of cations favoring the formation of montmorillonitic clay. The exception was the soil in site six which developed from alluvial parent material, probably already preweathered.

As with any parent material, limestone influences the rate of weathering, as well as the nutrients contained in the soils. The influence of limestone can be easily seen in the first five profiles, in which the inorganic carbon generally increased with depth, although profile four showed very high values throughout the entire profile (Table 14). Soils over these carbonated rocks are dark and rich in clay, mostly montmorillonitic clay. This type of clay requires high concentrations of silica and magnesium for its synthesis, and this is precisely the case in sites one, two, three and five (Table 16, see also Appendix E for Silica values). According to Young (1976) montmorillonite development requires an environment rich in magnesium and calcium; magnesium occurs in the structure of montmorillonite, while the presence of calcium maintains favorable conditions to its formation. This situation is again present in those sites. On the other hand, kaolinite is sythesized in the relative absence of Mg and other bases (Table 16). Miller and Donahue (1991) explained that the combination of high rainfall and well drained soils result in the leaching of silica and basic cations down into the profile. Less silica present in the remaining solution means the proportion of alumina will be high enough to result in kaolinite formation rather than montmorillonite. This is the case in site six. According to Kalpage (1974), the formation of kaolinite or kaolinization, also known as

Laterization or Ferralization, is the main soil forming process in the hot, humid tropical regions.

Climate has played a major role in the formation of the soils studied. All the sites are located in a hot and humid environment that promotes an intense weathering due to plenty of rainfall and a mean annual temperature greater than 22 C. This type of climate results in leaching, eluviation-illuvia- tion, acidification, enhanced chemical and biological activity and erosion of soil on sloping lands.

According to Dunning (1992) there is an increase in rain in the Yucatan Peninsula as one moves south through the region. The calcareous parent material, dominant throughout the region, and climatic relationships, largely explain the regional distribution of soils: generally tending from shallower, well drained, calcareous soils in the north to deeper, more poorly drained, calcareous soils in the south.

The climatic conditions are so important in soil formation, that a combination of a dry-wet season, typical throughout the Peten, is the main prerequisite for the formation of Vertisols. FitzPatrick (1980) stated that two of the important requirements for the formation of these soils, are a period of complete saturation with water, followed by a marked dry season. According to Young (1976) the formation of Vertisols require four basic conditions: 1) a parent material yielding a fine-textured weathering product; 2) a slope of < 3%; 3) a mean annual rainfall of 250-1500 mm; and 4) a dry season. This seems to explain why Vertisols occur in depressional areas in which waterlogged conditions are favored by the type of topography (other Vertisols, not described in this study, also occur in depressional areas with nearly level slopes).

Climate has also influenced soil formation indirectly through its action on biota (plants and animals). A plentiful supply of water has resulted in a luxurious vegetation covering most of the landscapes in the Peten, except the savannahs, which are occupied by grasses, bushes, and scattered trees (vegetation and soil-vegetation relations are thoroughly described in chapter one). This is true for all the sites, excepting sites four and five in which the original primary vegetation has been removed for agricultural purposes. The warm temperatures enhance the action of microorganisms that decompose organic matter and also, according to Miller and Donahue (1990), form weak acids that dissolve minerals faster than pure water.

The relief has an influence in the depth of soils. This can be seen in site three where there is a shallow and rocky Rendoll. Soils in upland and depressional positions are generally deeper and more stable (more gentle slopes) as seen at sites one, two, four and six. It is important to remember that chemical weathering is definitely more influential in hot and humid environments than physical weathering. This is due to the lack of extreme differences in temperatures that result in the freezing and thawing of the rocks. Another influence of the relief can be observed in the amount of organic matter that can accumulate in depressional areas. This can be seen in site two.

According to Van Wambeke (1992), the angle of incidence of sunshine depends, among other things, on the aspect of slopes. However, given the low latitude of the Peten (located in the tropics), the north or south aspect of hill slopes does not cause the large differences in soil temperature that exists in temperate zones. Hence, there are no warmer and drier slopes, making moisture, fertility, and drainage conditions more important when selecting agricultural areas.

In regard to the time factor and according to Mohr and Van Baren (1954), horizons tend to develop faster under warm, humid, forested conditions, that are all prevalent in the Peten. The development of soil proceeds at a rate that is a combination of the effects of time plus the intensities of climate and organisms, further modified by the effects of relief and type of parent material. The parent material which is alkaline in nature (limestone for the majority of the sites) resists the climatic factor which through the effect of precipitation leaches the basic cations down into the profile making the soils more acidic. The pH manifested in the majority of sites are the result of these two inverse factors. The former, keeping the soil from becoming strongly acid, by keeping a constant supply of basic cations, and the latter making the soil acidic. The exception occurs in site six. This is an older landscape with a more acidic soil.

When it comes to the evaluation of the effects of soil development, there are two different kinds of soil properties that are recognized. Properties inherited from parent materials, and those that have been acquired as a result of the soil forming processes.

According to Hausenbuiller (1981), the combination of processes relevant to the development of a soil can be judged on the basis of the types of horizons comprising the profile. Each horizon is normally identified by one or more features reflecting the dominant influence of one or more processes on its formation.

The dark colors in the epipedons of the first five sites indicate the accumulation of organic matter in the A horizons of the soils. These dark colors are the result of melanization and humification processes that resulted in the formation of mollic epipedons. Color in these epipedons varied from 10YR 2/1 to 10YR 3/3, and 7.5YR 2.5/1 to 7.5YR 2.5/2 (Ta- bles of soil morphology). In regard to the dark color of the Vertisols, Singh (1956) suggested that it might be due to the dark colored complex of organic matter and montmorillonite which forms in the wet environment when these soils are flooded during the rainy season. In general terms, FitzPatrick (1980) stated that the color of the upper horizons usually changes from brown to dark brown to black as the organic matter content increases, and there is a tendency for the organic matter to become darker in color with increasing humifiction.

The gray colors in the subsurface horizons (gleizations) in sites one and two were indicative of water stagnation problems that resulted in the reduction of iron oxides, usually of red hues under aerobic conditions. Moreover, the stagnant water reduces the leaching process of silica and basic cations, a situation that favors the synthesis of montmorillonitic clays, abundant in these type of soils.

The B horizons, present in all the soils investigated, are the result of the eluvial-illuvial process by which materials are translocated as a sequence of movements from one part to another in a soil profile. Site six is a good example of accumulation of silicate clay in the B horizons, which are named Bt horizons due to this feature. The eluvial-illuvial process is also very important in the development of the Mollisols. It has produced cambic horizons in site five and an argillic horizon in site four. The discontinuous clay coatings in the B horizons of site five and six are another indication of the illuvial accumulation of clay in this part of the profile. However, the accumulation of clay in site five, has not been sufficient to consider the B horizons as argillic.

The processes of erosion, cumulization, and then enrichment through agricultural practices have resulted in a rich silt texture in site four. The silt fraction decreases with depth (Table 13), and this supports the combination of processes described above.

The erosion process may also explain why the highest concentration of clay was found at the surface of site three. Alternatively, it may be the remains of a subsurface horizon of a younger soil that developed or was deposited above the site by a previous erosion process that moved soil from an upper position.

The main pedological process acting on the formation of the Vertisol is pedoturbation. This process of self-mixing of the soil is driven by the wet-dry cycles that occur every year. In the rainy season, the expanding material presses and slides the aggregates against each other, developing the slickensides with shiny and fluted surfaces that are very common in profile two.

At the surface of the Vertisol, littering has resulted in the formation of an organic horizon of mainly undecomposed organic materials. The location of this Vertisol in a depressional area has helped to maintain the litter in place.

SOIL CLASSIFICATION

Guatemala was covered by a soil survey in the late 1950's (Newton and Duisberg, 1978), and according to AHT/APESA (1992) is still the major source of reference to soils for the Peten region. Some semidetailed studies of soils have been performed by institutions such as DIGESA (Agricultural Extention Office) , IGN (Mapping Agency) and INAFOR (National Forestry Institution). In addition, ICTA (Agricultural Technology Office) has done some more detailed soil survey at the level of local areas, but apparently not connected with the modern classification (Newton and Duisberg, 1978). In his study of the Watershed of The Peten Itza lake, and using the modern classification system, Aragon (1987) classified the soils in this area as Ustropepts, Humitropepts, Rendolls, Troporthents, Ustorthents, Ustropepts, and Ditropepts. Moreover, SEGEPLAN (National Planning Office) and KREDITANSTALT FUR WIEDERRAUFBAU (1990) performed a toposequence study of several soil series groups using the FAO classification system.

For its time, the soil survey study by Simmoms (1959) was adequate and probably the most advanced in Central America. However, this study and the classification system need to be updated. A tentative classification of the different soil sites investigated in this study, using the 7th approximation is presented in Table 17.

SUMMARY AND CONCLUSIONS

1. The study area located in the Peten region was comprised mainly of Mollisols in upland and sloping positions, Vertisols in depressional areas, and Alfisols in the savannahs.

TABLE 17. TENTATIVE CLASSIFICATION OF THE SIX STUDY SITES

SITE	CLASSIFICATION
1	very fine, montmorillonitic, isohyperthermic Aquic Hapludoll
2	very fine, montmorillonitic, isohyperthermic Typic Endoaquert
3	very fine, montmorillonitic, isohyperthermic Typic Rendoll
4	fine loamy, mixed, isohyperthermic Eutrochreptic Rendoll
5	very fine, mixed, isohyperthermic Eutrochreptic Rendoll
6	very fine, kaolinitic, isohyperthermic Typic Paleudalf

Note: In regard to soil temperature and moisture regimes, the above classification was based on The Global SoilMoisture and Temperature Regimes Study by H. Eswaran, E. van den Berg, P. Reich, R. Almaraz, B. Smallwood, and P. Zdruli (1995).

2 Low chromas in sites one and two, as well as Mn concretions and reticulate mottling in sites one and six, suggested water stagnation problems for these soil.

3. Clay mineralogy at the first three sites were mainly composed of montmorillonitic clay. Sites four and five had mixed mineralogies, and site six was mainly composed of kaolinitic clay.

4. oil pH varied from slightly acid to moderately alkaline, except site six in which pH ranged from slightly acid to strongly acid. Values of KCl acidity as well as KCL-H turned out to be zero for soils with pH of more than 5.5, and aluminum data was only significant in site six.

5. Calcium carbonate equivalent data reflected the alkaline nature of the parent material, as the values increased with depth in the profile. The exception was again site six.

6. The estimated average value of organic matter for the topsoil of the different sites was 4.84%, a value that is similar to that of temperate soils.

7. CEC values were high for the first five sites. This was due to the type, amount of clay, and organic matter (the latter only at the surface) of these soils. The kaolinitic clay of site six presented lower values. Moreover, Ca and Mg ions dominated the exchange sites in all the profiles, with calcium concentration higher than magnesium.

8. Nitrogen, phosphorus and potassium values were generally low, with the Mollisols having the highest concentrations.

9. The percent base saturation was very high in the different soil sites, particularly

in the Mollisols, in which the values were more than 100%.

10. The archeological extract analysis suggested the apparent recycling of Mg. Most of the profiles showed increased extractable Mg contents in surface horizons as contrasted to the subsoil. Other elements such as Ba, Mn, Co, B, K, and P showed similar relationships.
11. The majority of the soils in the study area were generally composed of high amounts of clay, and the parent materials were residual limestone, colluvium over residuum and alluvium.
12. The influence of the calcareous parent material can be easily seen in the first five profiles. Soil over these carbonated rocks are dark and rich in clay.
13. Climate has played a major role in the formation of these soils. Temperature and rainfall and their influence on biota and topography with time, have molded the genesis of soils in the Peten region. The hot temperatures and high rainfall accelerate the weathering process that is somehow counteract by the calcareous parent material and its constant supply of basic cations.
14. Site number one was classified as a very fine, montmorillonitic, isohyperthermic Aquic Hapludoll; site two, as a very fine, montmorillonitic, isohyperthermic Typic Endoaquert; site three, as a very fine, montmorillonitic, isohyperthermic Typic Rendoll; site four, as a fine loamy, mixed, isohyperthermic Eutrochreptic Rendoll; site five, as a very fine, mixed, isohypethermic Eutrochreptic Rendoll; and site six, as a very fine, kaolinitic, isohyperthermic Typic Paleudalf.

PART 3

POTENTIALS AND MANAGEMENT OF SELECTED SOILS IN THE PETEN REGION OF GUATEMALA

INTRODUCTION

The northern department of the Peten in Guatemala embraces the largest remaining rain forest in Central America. This region has been recognized, since the last decade, as an area of great biodiversity and natural resources. However, this richness of resources is being rapidly depleted by an increasing population that soon may feel the consequences of their environmental degradation. The problem seems to be complex and tied up in a vicious circle of poverty, diseases, inadequate policies, and environmental degradation (USAID, 1993). This situation can be greately improved by the use of information and technology that will also help to unravel the true potentials of the natural resources, while procuring their preservation and their sustained exploitation.

Among the array of resources, one can find the soils, that are key components of natural ecosystems. The soil resource should be one of the main targets of the information and technology strategies that are going to be used to address the problems. The soils in the Peten are being severely affected by inappropriate use, mismanagement, and deforestation which create the need for clearing more land (primary rain forest) to satisfy the needs of the increasing population. Chapter two discussed the main characteristics of the different soil orders found in the area of study, and in this chapter, the potentials and management of the selected soils will be discussed.

LITERATURE REVIEW

SOIL INTERPRETATION AND LAND USE EVALUATION

This branch of soil science refers to the analysis of soil morphology and the making of inferences about the potential use of soils, limitations and problems in their use, and also their productivity under defined levels of inputs. Soil interpretation is the process in which the data, knowledge, and estimates, theories and hypotheses are put to the test of practical, applied uses (Buol et al., 1989).

Land evaluation is defined by Dent and Young (1981) as the process of estimating the potential of land for alternative kinds of use. These include productive uses, such as arable farming, livestock production and forestry, together with uses that provide services or other benefits, such as water catchment areas, recreation, tourism, and wildlife conservation. The determination of the suitability of the land and its soils in the Peten is of foremost importance in this study for the sustainable management of the natural resources.

The most important feature of land evaluation is the comparison of the requirements of land use with the resources offered by the land. It is important to remember that different kinds of use have differing requirements.

Vanderford (1950) stated that when information on land use is added to the knowledge of soil conditions, supplementary uses, and practices necessary to maintain or increase production, retard erosion, and otherwise conserve soil resources, can be planned.

LAND CAPABILITY CLASSIFICATION

The purpose of utilitarian classification is to organize the soils into classes to show their suitability for a particular use (Hausenbuiller, 1981). The main characteristics of the soil that are considered, are those that regard plant growth. Based on these characteristics, the soils are organized into different categories known as Land Use Capability Classes. There are eight different capability classes. Suarez (1980) presented a brief description of them:

CLASS I: soils can be used for continue crop production using good farming practices.

CLASS II: due to moderately steep slopes, the soil require simple soil conservation practices for continue crop production.

CLASS III: continue crop production can be carried out with intense soil conservation practices due to steep slopes, shallow soil, and shallow water tables.

CLASS IV: the soils sustain occasional crop production through the use of intensive conservational practices.

CLASS V: soil are inappropriate for crop production due to wetness and boulders, but can be used for permanent vegetation such as pasture or woodland.

CLASS VI: steeper slopes and shallow soils will require moderate conservation practices to sustain permanent vegetation as in class V.

CLASS VII: soils have severe limitations that require intensive conservation practices to sustain vegetation as in class V.

CLASS VIII: the steep slopes, swamps, rocks, etc. make the soils difficult to manage and it is economically impossible to establish any type of crop.

MATERIALS AND METHODS

After the main characteristics of the different soil sites were studied and described in chapter two, the inferences about the potential of the selected soils and their appropriate management can be discussed. The physical and chemical characteristics will suggest the ease of tillage for the soils, the water holding capacity, the infiltration rate, drainage, run off, risk of erosion, cation exchange capacity, etc. All these properties will determine the capabilities and limitations of the selected soils, and will also indicate the the appropriate management for the conservation of the soil resource.

RESULTS AND DISCUSSION

CURRENT PROBLEMS AND LIMITATIONS OF THE SELECTED SOILS

Sites number one, two, and three are located in the Yaxja region, a pristine area inside The Mayan Biosphere Reserve. This Reserve has been set aside for the protection and conservation of the rain forest and its rich biological diversity. Therefore, severe limitations for agricultural, industrial, or any other type of development (excepting eco-tourism) apply. Although site four is also located inside The Reserve, this particular area has been under agricultural use for more than 15 years (prior to the establishment of The Reserve) and it seems that it will continue this way in the future. The rest of the sites are located to the south of The Reserve and no limitations (by law) apply.

The rapid deterioration of resources in the Peten region was easily noticed during the last visit to the area in the summer of 1995. This deterioration results in a generalized deforestation, forest fragmentation, soil and water depletion, and loss of biodiversity even in areas previously designated as biosphere reserves or national parks. Such is the case of The Mayan Biosphere Reserve, the largest remaining tropical forest in Central America. The severe alteration of the natural environment may well soon render the land incapable of coping with the needs of the population. Therefore, it is critical for the future of the Peten to have a better understanding of the characteristics and potentials of the soils and other resources in the Biosphere Reserve, as well as the surrounding areas (buffer zones), to use the soil and related resources in a sustainable way (several strategies to achieve sustainable agriculture are proposed in Appendix G). If the soil resource is appropriately managed in the areas surrounding the Biosphere Reserve, and agricultural yields can be improved, there will be no need to disturb resources within the perimeters of The Reserve and other national parks.

POTENTIALS AND LAND CAPABILITY CLASSES OF THE SELECTED SOILS

The soil in the sites investigated present different potentials, according to their particular characteristics, landscapes, and several other features that influence the soils.

The slope is important when considering the risk or potential of erosion (Table 18). The majority of the sites presented gentle slopes (3-4%), excepting sites three and five with 15 and 10% slopes respectively. Based on the slope, texture, structure,

TABLE 18. SITE CHARACTERISTICS AND LAND USE CAPABILITY

SITE	SLOPE %	DRAINAGE	AVAILABLE WATER	RESTRICTIVE LAYERS	EROSION RISK	LAND CAP. CLASS.
1	4	swpd	low	90 cm	slight	IIw
2	2	pd	low	50 cm	slight	IIIw
3	15	mwd	very low	31 cm	high	VIe
4	4	wd	low	90 cm	moderate	IIe
5	10	mwd	very low	65 cm	moderate	IVe
6	3	mwd	low	75 cm	slight	IIf

mwd = moderated well drained
wd = well drained
swpd = somehow poorly drained
pd = poorly drained
w = wetness
e = erosion risk
s = shallow
f = fertility

organic matter content, and permeability, the erosion potential is moderate for sites four and five; high for site three, and minimal for sites one, two and six.

Based upon redoximorphic features, the drainage of the soils has been classified as moderately well drained for sites three, five, and six; well drained for site four; somehow poorly drained for site one, and poorly drained for site two (Table 18).

The restrictive layers have been critical in determining the available water at the different sites (Table 18). The dense, structureless massive clay layers, and waterlogged conditions (gray colors) in sites one, two and three present unfavorable conditions for the development of roots. Bedrock, gravelly material and stoniness also restricted roots in sites three, four, and five. Therefore, available water is low for sites one, two, four, and six, and very low for sites three and five.

The land capability classes were developed for relative fertile and temperate soils. However, in the case of site six, the main limitations of the soils are its high acidity and low fertility; therefore the land capability subclass "f" will be used to designated this soil.

The combination of the above characteristics has resulted in the land capability classification of the soils that are presented in Table 18.

Laboratory data have shown that the soils investigated lack adequate amounts of phosphorus and potassium for crop production. Any agricultural effort should include high inputs of these and other nutrients such as nitrogen.

As it is widely known, the real fertility in many tropical soils is not in the soil, but in a constant cycle between the forest vegetation and the upper soil horizons.

The shifting cultivation widely practiced in The Peten region depends on forest fallow periods as the source of nutrients to crops. Sanchez (1976) stated that the nutrients are gradually accumulated during the fallow period and provide an alternative to fertilization. But shifting cultivation cannot always be categorized as sustainable agriculture. In some areas, especially on steep slopes or marginal land with high population densities, the traditional slash and burn agriculture has caused major soil erosion and environmental degradation. However, according to Greenland (1975) in the low land tropics with "low population densities and relatively fertile soil", the traditional system has proved to be economically and ecologically stable. In general, the clearing and burning associated with shifting cultivation causes the loss of most N, S, and C in gases during burning and the exposure of plant nutrients to situations prone to loss by erosion and leaching, and the destruction of humus and deterioration of physical properties.

MANAGEMENT OF VERTISOLS

Vertisols are of great importance in tropical areas (Dudal and Eswaran, 1988). The Peten region is not the exception. Vertisols often occur in the nearly level depressional areas of this territory. The soil examined has a high CEC and low permeability which help to retain added fertilizers, an average of 2.46% organic matter in the top soil, a pH that goes from strongly acid to slightly basic (top to bottom), and higher potassium than the rest of the soils. However, the management of the Vertisols is difficult due to the high clay content and nature of the clay. A second reason is waterlogging, and the general difficulty of water control without drainage systems. In general, Van Wanbeke (1992) stated that the physical properties are very critical in Vertisols. This is because serious problems occur in the preparation of a seed bed that provides adequate water and air to plants.

Correctly managed, many Vertisols are capable of supporting annual cropping at moderate to high yields (Young, 1976). Moreover, the nearly level conditions of the Vertisols make them suitable for irrigation systems that would produce a sustainable level of production that justifies the investment. The quality of the water used for irrigation is important too. This is due to the slow percolation of water in Vertisols that would result in the salinization of the soil, if high salt concentrations were present in the water (Ahmad, 1989).

The specific nature and properties of the Vertisol are important factors relating to the management of the soil (Ahmad, 1983). These particular soil conditions will determine the type of crops to be grown. Van Wambeke (1992) stated that rainfed crops present the advantage of not requiring irrigation or drainage systems which is very convenient for small farmers (water conservation practices such as mulching are recommended though). The water holding capacity and the depth of the soil are critical in this type of cropping system. However, if rainy season crops are chosen, special attention should be given to avoiding surface ponding. Systems of beds, ridges and furrows are recommended. This will place plants above flooding levels and the furrows can drain water away, increase infiltration, and reduce erosion. The system of ridges and furrows can be used in a reverse pattern in dry areas or the dry season. In this case plants would be planted in the furrows, and the ridges can concentrate rainfall in the furrows. If there is a need for subsurface drainage, Ahmad (1988) recommended a mole drainage system for Vertisols with an aquic moisture regime.

Other important features in management are soil depth, important for root development, texture - the finer, the more difficult the management, and the clay mineralogy, and nature of cation saturation. These last two factors are directly related to the hardness and size of peds on drying and the self mulching properties of the soil (Ahmad, 1989). The Vertisol in site two is high in Ca and montmorillonite and this facilitates the self-mulching behavior which is a favorable agricultural feature.

The following factors considered by Ahmad (1989), are also important for the appropriate management of the Vertisol:

1) Tillage is essential for Vertisols. However, the nature and extent must be considered. Tillage loosens the soil, improves infiltration, controls weeds, and helps in the incorporation of residual fertilizers. The loosening of the soils facilitates the construction of ridges, furrows, and beds that would be essential for plant production.
2) Since water movement is negligible in wet Vertisols, the P, and K applications would remain at the surface (during the rainy season). Moreover, if irrigation is used, salts left by evaporation will also accumulate at the surface. These problems can be solved by the tillage of the soil.
3) As mentioned above, the land layout not only helps to facilitate external drainage (water from rain or irrigation), but also can prevent erosion, and compaction

due to trafficking (weeding, fertilizing, spraying, etc.) when the soil is wet. Moreover, concentrating on the more fertile top soil, facilitates nutrient uptake.

4) Fertilization results would be generally negligible if water is lacking. For example, the response to nitrogen fertilization depends on the soil moisture conditions during the growing season. Moreover, the dark color of the surface horizon of site two (10YR 2/1), if the soil is exposed, would create high temperatures that may restrict root development, making applications of fertilizers of doubtful relevance. In the case of N applications and due to the high CEC of Vertisols, Fullerton et al. (1988) indicated that ammonification of urea occurs rapidly, but the resulting NH_3-N does not increase pH. The author recommended incorporation of fertilizers and the mulching of the soil to reduce losses. The Vertisol in site two is rich in Ca and Mg; the level of potassium at the surface is 740 mg kg^{-1}, decreasing with depth to the mid profile, and then increasing to 1385 mg kg^{-1} in the bottom horizon. The ability of the soil to fix K is unknown, and according to Ahmad and Jones (1969), the high levels of Ca and Mg may result in a difficulty for plants to obtain adequate supplies of K.

Phosphorous levels are below 50 mg kg^{-1} except at the surface (72 mg kg^{-1}). The low mobility of P is particularly critical in this soil, due to the nature of Vertisols that limit the growth of roots which inhibits the ability of them to absorb nutrients.

Finally, adverse soil conditions of aeration and water relations may give little importance to the use of legumes for N fixation.

The management of cracks is also important in Vertisols. Some cracking is needed to permit aeration of the subsoil and channels for root growth. However, excessive cracking results in increased evaporation, root shearing, soil desiccation, and soil hardening. Plants grown on Vertisols should have vigorous and extensive roots systems that can withstand damage caused by soil cracking and root shearing (Ahmad, 1989). However, with the use of ridges, and furrows, mounds, cambered beds, etc., and the strict attention to layout and drainage, a greater variety of crops may be grown.

The maintenance of a surface mulch is not only important for root penetration but also for water management (Van Wanbeke, 1992). In the dry season (approx. from December to May in the Peten) the mulch would help to conserve water, and in the rainy season, it can increase infiltration and reduce any erosion, sealing, and crusting risks.

Mulches are generally very important in tropical agriculture. They can maintain and improve fertility considerably. They do not compete with crops, also lower soil temperature, conserve moisture, help control weeds, reduce soil erosion, improve infiltration, and enhance biological activities (Kalpage, 1974).

MANAGEMENT OF MOLLISOLS

The Mollisols of site three, four, and five present better physical and chemical characteristics than the rest of the soils. These soils have been only slightly leached and their base saturation remains very high. Moreover, the soils have good drainage, and according to AHT/APESA (1992), their capacity of vegetative regeneration limits weed proliferation. However, the main restrictions of these soils are the slope (15% and 10% sites three and five respectively), and the abundance of coarse fragments that limit the use of mechanization, and result in uneven ripening of crops due to the patchiness of the soil. Also, the lack of sufficient moisture during the dry season is critical for crop development.

Soil and water conservation practices are of utmost importance when the relief is pronunciated, as in site three, and five.

Since sites four and five are already under cultivation, the suggestions to achieve sustainable agriculture presented in this paper should be considered (Appendix G). Although these soils presented better conditions, if high yields are expected, significant quantities of fertilizer are required. Sanchez (1976) stated that in order to produce high yields in the tropics, organic sources are unlikely to add enough nitrogen to satisfy crop requirements at higher yield levels.

The Rendolls (Rendzinas) were the preferred soils of the ancient Maya farmers for growing maize (FAO-UNESCO, 1975); and are still preferred for maize production by current farmers due to their good drainage, satisfactory fertility (peasant standards), fairly quick rotation (three to five years), and weed control capacity (AHT/APESA, 1992).

Although site one was also classified as a Mollisol, the soil presented different characteristics than site three and four. The soil in site one classified as an Aquic Hapludoll, is more acidic than its relatives, the Rendolls. It presented less favorable conditions such as organic matter, nutrients, and clay content.

MANAGEMENT OF ALFISOLS

The Alfisol at site six requires a different management approach than the soils described above. The main characteristics of the soil are its acidic nature, kaolinitic mineralogy, amount of clay, and high base saturation (from 60 to 100%). Moreover, the total elemental analysis data show a soil poor in nutrients. Many of these characteristics are the result of the strong weathering process.

As part of the overall management of the soil resource in the Peten region, it would be convenient to utilize the soils in the savannahs for agricultural purposes. This management approach would release pressure on the resources inside the Biosphere Reserve. However in order to do this, the soils have to be amended with lime to decrease the acidity. According to the pH data, the soil in site six has a pH that ranges from slightly acid to strongly acid (pH 1:1), and very strongly acid throughout the profile according to the $CaCl_2$ method.

Not far away from site six, there are several quarries of cretaceous chalk that are currently being used to obtain construction materials for towns nearby. Some of these quarries are rich in crystalline limestone, and others in marl/chalk. More samples of crystalline limestone were also taken from another site close to Yaxja lake. These limestone deposits can be easily used to raise the pH of the acid soils in the savannahs. Moreover, the liming expenses would be relatively low, due to the proximity of several of the quarries.

Samples of three quarries (designated as ST1S1, ST1S2 and Yaxja) were taken in order to have an idea of the total elemental analysis. The results can be seen in Table 19.

TABLE 19. TOTAL ELEMENTAL ANALYSIS, MACRO AND MICRO NUTRIENTS

HORIZON	DEPTH (cm)	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
							mg/Kg					
ST1S1	-	430233	<5	940	<400	1585	33	<5	<250.00	<50	1023	365
ST1S2	-	428503	<5	1002	<400	1440	18	<5	<250.00	<50	583	208
YAXJA	-	435380	<5	764	<400	2621	50	<5	1620.3	<50	<50	197

The liming process should be combined with appropriate fertilization and other measures of sustainable agriculture to permit a greater use of the savannah soils.

SUMMARY AND CONCLUSIONS

1. The soils in the Peten region are rapidly being deteriorated due to mismanagement, inappropriate use and deforestation.
2. The characteristics and potentials of several soils are presented in this thesis; however, the soil sites in the Yaxja area are subjected to severe limitations in their use due to their location within the limits of the Mayan Biosphere Reserve.
3. The potentials and land capability classes for the different soils were established based on slope, drainage, restrictive layers, available water, and erosion risk.
4. According to the land capability classes the soil sites were classified as: site 1: IIw; site 2: IIIw; site 3: Vie site 4: IIe; site 5: IVe; and site 6: IIf.
5. The soils investigated have low contents of phosphorous and potassium, and this suggests that any crop production intended in these soils should consider adequate applications of fertilizers (Again, sustainable agriculture principles should be pursued).
6. The management techniques will depend upon the type of soil that needs to be managed.

7. For Vertisols, the management should focus on:
    - Avoiding surface ponding through a system of beds, ridges and furrows that will also help infiltration and reduce erosion.
    - The tillage of the soil will facilitate the construction of beds, ridges and furrows, will incorporate the fertilizer, improve the infiltration and control weeds.
    - Fertilization is important if high yields are expected.
    - Crack management is necessary in order to improve aeration and pathways for root growth.
    - The maintenance of mulches preserve water in the dry season and increase infiltration and reduce erosion in the rainy season.
8. The Mollisols presented better physical and chemical characteristics for crop production; however, especial attention should be placed to fertilization and soil conservation practices to maintain the fertility of the soils.
9. The Alfisol found in the savannah, presented an acidic nature that will require its amendment with limestone if profitable crops are expected. The calcareous material to amend the soil can be easily obtained from quarries near by. Putting these soils into production will decrease the pressure over the land resources inside the Mayan Biosphere Reserve.

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APPENDICES

APPENDIX A

EXPLANATION OF ABBREVIATIONS USED IN THE MORPHOLOGY TABLES

1. SOIL TEXTURE:

A. Texture Classes:

c = clay
cl = clay loam
sil = silt loam

B. Texture Modifiers:

g = gravelly
vg = very gravelly

2. SOIL STRUCTURE:

A. Grade:

0 = structureless
1 = weak
2 = moderate
3 = strong

B. Size:

f = fine
m = medium
l = large

C. Type of Structure:

gr = granular
abk = angular blocky
sbk = subangular blocky
cpl = coarse platty

3. MOIST CONSISTENCE:

fr = friable
fi = firm
vfi = very firm

4. SOIL COLOR:

rm = reticulate mottling

5. MOTTLES:

Abundance:

m = many

Size:

2 = medium
3 = coarse

Contrast:

d = distinct
p = prominent

APPENDIX B

SOIL MORPHOLOGY

PEDON DESCRIPTIONS

SITE 1:

DESCRIBED: June, 6, 1994 by Dr. J. Foss and L. Donado
LOCATION: North of Laguna Yaxja
LATITUDE/LONGITUDE: 17° 3' 49" N   89° 23' 19" W
ASPECT: North
ELEVATION: 250 m
PHYSIOGRAPHY: Gently rolling
SLOPE: 4%
PARENT MATERIAL: Limestone
PERMEABILITY: Slow
VEGETATION: Forested area
EROSION: None to slight
CLASSIFICATION: Very fine, montmorillonitic, isohyperthermic, Aquic Hapludoll.

MORPHOLOGY:

A1	0-12 cm; black (10YR 2/1) clay; strong, medium, angular blocky structure; very firm; no effervescence; clear smooth boundary.
A2	12-25 cm; very dark grayish brown (10YR 3/2 clay; moderate, medium, angular blocky structure; very firm; very weak effervescence; clear smooth boundary.
AB	25-36 cm; dark brown (10YR 3/3) clay; moderate, medium, angular blocky structure; firm; weak effervescence; clear smooth boundary.
Bw	36-51 cm; grayish brown (10YR 5/2) clay; weak, medium to large, angular blocky structure; firm; no effervescence; gradual smooth boundary.
Bg	51-78 cm; gray to light brownish gray (2.5Y 6/1-6/2) clay; weak, medium to large, angular blocky structure; firm; no effervescence; gradual smooth boundary.
BC	78-90 cm; light gray (2.5Y 7/2) clay; structureless massive, and medium to large angular blocky structure; firm; no effervescence; gradual and smooth boundary.
C1	90-120 cm; light gray (5Y 7/2), and white (10YR 8/1) clay; structureless massive; firm; very weak effervescence; gradual and smooth boundary

C2 120-140 cm; light gray (5Y 7/2), and white (10YR 8/1) clay; structureless massive; firm; very weak effervescence; Mn concretions.

NOTE: Roots: many 0-51 cm; few 51-90 cm; very few >90 cm.

SITE 2:

DESCRIBED: June, 6, 1994 by Dr. J. Foss and L. Donado
LOCATION: North of Laguna Yaxja
LATITUDE/LONGITUDE: 17° 0,84' 0" N 89° 23' 7" W
ELEVATION: 255 m
PHYSIOGRAPHY: Bajo
SLOPE: nearly level
PARENT MATERIAL: Limestone
PERMEABILITY: Slow
VEGETATION: Forested area
EROSION: None to slight
CLASSIFICATION: Very fine, montmorillonitic, isohyperthermic, Typic Endoaquert.

MORPHOLOGY:

O 3-0 cm; mainly undecomposed organics.

A1 0-17 cm; black (10YR 2/1) clay; moderate, medium, subangular blocky structure; firm; weak effervescence; clear smooth boundary.

A2 17-35 cm; black (10YR 2/1), and very dark gray (10YR 3/1) clay; structureless massive; firm; no effervescence; gradual and smooth boundary.

BA 35-50 cm; black (10YR 2/1) clay; structureless massive, slickensides; firm; very weak effervescence; gradual and smooth boundary.

Bssg1 50 -90 cm; dark gray (N4) clay, mixing of light colored material; structureless massive, slickensides; firm; no effervescence; gradual smooth boundary.

Bssg2 90-100 cm; dark gray (N4), and gray (2.5Y 5/1) clay; structureless massive, slickensides; firm; weak effervescence; gradual smooth boundary.

BC 100-110 cm; gray (2.5Y 5/1, 6/1) clay; structureless massive, slickensides; firm; moderate effervescence; clear smooth boundary.

C 110-125 cm; white (10YR 8/1) silt loam; structureless massive; friable; very strong effervescence.

NOTE: Auger used to describe below 110 cm; slickensides are well developed with shiny and fluted surfaces.
Roots: many 0-50 cm; few 50-90 cm.
Flat limestone pebbles; small reddish gravel.
Gilgai microtopogrphy present.
Gray material at 90 cm of profile, at 42 cm, about 1 m. from point of description.

SITE 3:

DESCRIBED: June, 6, 1994 by Dr. J. Foss and L. Donado
LOCATION: North of Laguna Yaxja
LATITUDE/LONGITUDE: 17° 3' 39" N 89° 23' 20" W
ASPECT: South
ELEVATION: 215 m
PHYSIOGRAPHY: Steep slope to lake
SLOPE: 15%
PARENT MATERIAL: Residuum from tertiary limestone
PERMEABILITY: Moderate
VEGETATION: Forested area
EROSION: None to slight
CLASSIFICATION: Very fine, montmorillonitic, isohyperthermic Typic Rendoll.

MORPHOLOGY:

A1 0-18 cm; black (10YR 2/1) clay; moderate to strong, medium, subangular blocky structure; firm; very weak effervescence; clear smooth boundary; < 5% coarse fragments.

A2 18-31 cm; very dark gray (10YR 3/1), and dark gray (10YR 4/1) gravelly clay; moderate, medium, angular blocky structure; firm; no effervescence; clear smooth boundary; 20% coarse fragments.

AB 31-48 cm; gray (10YR 5/1), and dark gray (10YR 4/1) gravelly clay; structureless massive, and weak, medium, angular blocky structure, firm; weak effervescence; clear smooth boundary; 50-60% coarse fragments.

BC 48-60 cm; light gray (2.5Y 7/2) clay; structureless massive, and weak, medium angular blocky structure; firm; weak effervescence; 50-60% coarse fragments.

NOTE: Soil developed on very gravelly material (rounded) with a great of clay forming matrix; very difficult to excavate, with coarse fragments and clayey matrix.

SITE 4:

DESCRIBED: June, 7, 1994 by Dr. J. Foss and L. Donado
LOCATION: South of Tikal (18 Km approx.)
LATITUDE/LONGITUDE: 17° 30' 0" N 89° 42' 32" W
ASPECT: North
ELEVATION: 500 m
PHYSIOGRAPHY: Rolling hills, Karst
SLOPE: 4%
PARENT MATERIAL: Limestone
PERMEABILITY: Moderate
VEGETATION: Plot with corn and beans rotation
EROSION: None to slight
CLASSIFICATION: Fine loamy, mixed, isohyperthermic, Eutrochreptic Rendoll.

MORPHOLOGY:

A1 0-18 cm; black (10YR 2/1) silt loam; moderate to strong fine granular structure; friable; very strong effervescence; clear smooth boundary; 3% coarse fragments.

A2 18-35 cm; very dark gray (10YR 3/1) silt loam; moderate, medium, granular structure; friable; very strong effervescence; clear smooth boundary; 8% coarse fragments.

Bw 35-58 cm; very dark grayish brown (10YR 3/2) silt loam; weak, fine to medium, subangular blocky structure; friable; very strong effervescence; gradual smooth boundary; 65% coarse fragments.

2BC 58-73 cm; dark grayish brown (10YR 4/2), and very dark grayish brown (10YR 3/2) clay loam; weak medium, subangular blocky structure; friable, very strong effervescence; gradual smooth boundary; 8% coarse fragments.

2C 73-90 cm; dark grayish brown (10YR 4/2), and very dark grayish brown (10YR 3/2) clay loam with white (10YR 8/1) streaks (10%); weak, medium subangular blocky structure; friable; very strong effervescence; abrupt smooth boundary; 15% coarse fragments.

2R 90+ cm; limestone bedrock.

NOTE: Soil appears to be typical of the moderate-deep Rendoll type for this area.
Roots: many, upper 35 cm.

SITE 5:

DESCRIBED: June, 7, 1994 by Dr. J. Foss and L. Donado
LOCATION: Aldea El Mango, southeast of Flores
LATITUDE/LONGITUDE: 16° 14' 0" N 89° 41' 46" W
ASPECT: West
ELEVATION: 400 m
PHYSIOGRAPHY: Upland limestone region
SLOPE: 10%
PARENT MATERIAL: Limestone (colluvium over residuum limestone)
PERMEABILITY: Slow
VEGETATION: Planted recently in row crop squash
EROSION: None to slight
CLASSIFICATION: Very fine, mixed, isohyperthermic
Eutrochreptic Rendoll.

MORPHOLOGY:

A1 0-9 cm; black (7.5YR 2.5/1), and very dark brown (7.5 YR 2.5/2) clay; moderate, medium, subangular blocky structure, and strong, medium granular structure (upper 3 cm); firm; no effervescence; clear smooth boundary; <1% coarse fragments.

A2 9-26 cm; black (7.5YR 2.5/1) clay; weak,medium, angular blocky structure, and structureless massive; very firm; very weak effervescence; clear smooth boundary; 2% coarse fragments.

Bw1 26-42 cm; dark brown (7.5YR 3/2) clay; strong, medium, angular blocky structure; firm; weak effervescence; clear smooth boundary; 10% coarse fragments; common, thick discontinuous clay coatings.

2Bw2 42-65 cm; brown (7.5YR 5/4), and 20-30% white (7.5YR 8/1) clay loam; many, coarse, distinct strong brown (7.5YR 5/8) mottles; moderate, medium, subangular blocky structure; firm; very strong effervescence; gradual smooth boundary; 20% coarse fragments; common, thick discontinuous clay coatings.

2C/B 65-80 cm; 60% white (7.5YR 8/1), and 40% strong brown (7.5YR 4/6) gravelly clay loam; many medium prominent red (10R 5/8) mottles; weak, medium subangular blocky structure; firm; very strong effervescence; 60-70% coarse fragments; mainly rock material, some B, clayey material mixed in.

NOTE: Site was burned 10 days prior to sampling.
Coarse fragments numerous below 42 cm; some limestone boulders noted, some as large as 42 cm across.
Roots: many 0-26 cm; few 26-65 cm.
Stoniness: many below 65 cm.

SITE 6:

DESCRIBED: June, 8, 1994 by Dr. J. Foss and L. Donado
LOCATION: Savannah area; SE of Flores
LATITUDE/LONGITUDE: 16° 49' 52" N 89° 49' 11" W
ASPECT: West
ELEVATION: 210 m
PHYSIOGRAPHY: Nearly level plain
SLOPE: 3%
PARENT MATERIAL: Alluvium
PERMEABILITY: Slow to moderate
VEGETATION: Grasses, cultivated
EROSION: None to slight
CLASSIFICATION: Very fine, kaolinitic, isohyperthermic, Typic Paleudalf.

MORPHOLOGY:

A 0-8 cm; dark brown (7.5YR 3/3) silt loam; weak, medium, angular blocky structure; friable; very weak effervescence; clear smooth boundary.

Bt1 8-23 cm; strong brown (7.5YR 4/6), and spots of yellowish red (5YR 4/6) clay; weak, coarse platy, and moderate, medium, angular blocky structure; friable; weak effervescence; clear smooth boundary.

Bt2 23-42 cm; strong brown (7.5YR 4/6), and spots of yellowish red (5YR 4/6) clay; moderate, fine to medium subangular blocky structure; friable; very weak effervescence; gradual smooth boundary; many Mn-Fe shots, 2-5 mm diameter; few, thin, discontinuous clay coatings.

Bt3 42-66 cm; yellowish red (5YR 4/6) clay; moderate, medium, subangular blocky structure; firm; no effervescence; gradual wavy boundary; common Mn-Fe shots, 2-5 mm diameter; few, thin, discontinuous clay coatings.

Bt4 66-95 cm; reticulate mottling: yellowish red (5YR 4/6), light gray (10YR 7/1, and 10YR 7/2), and dark yellowish brown (10YR 4/6) clay, and gravelly clay in lower portion (75-95 cm); moderate, medium subangular blocky structure; firm; weak effervescence; gradual smooth boundary; many, thin, discontinuous clay coatings, common Mn-Fe concretions, few plinthite.

2Bt5 95-115 cm; reticulate mottling: dark red (2.5YR 3/6), strong brown (7.5YR 5/8), and light gray (10YR 7/1) clay; moderate, medium subangular blocky structure; very friable; very weak effervescence; many, thin, discontinuous clay coatings; common Fe-Mn concretions; few plinthite.

2Bt6 115-145 cm; reticulate mottling: dark red (2.5YR 3/6), red (10R 4/6), and light gray (10YR 7/1) clay; very firm; weak effervescence; 5% Mn.

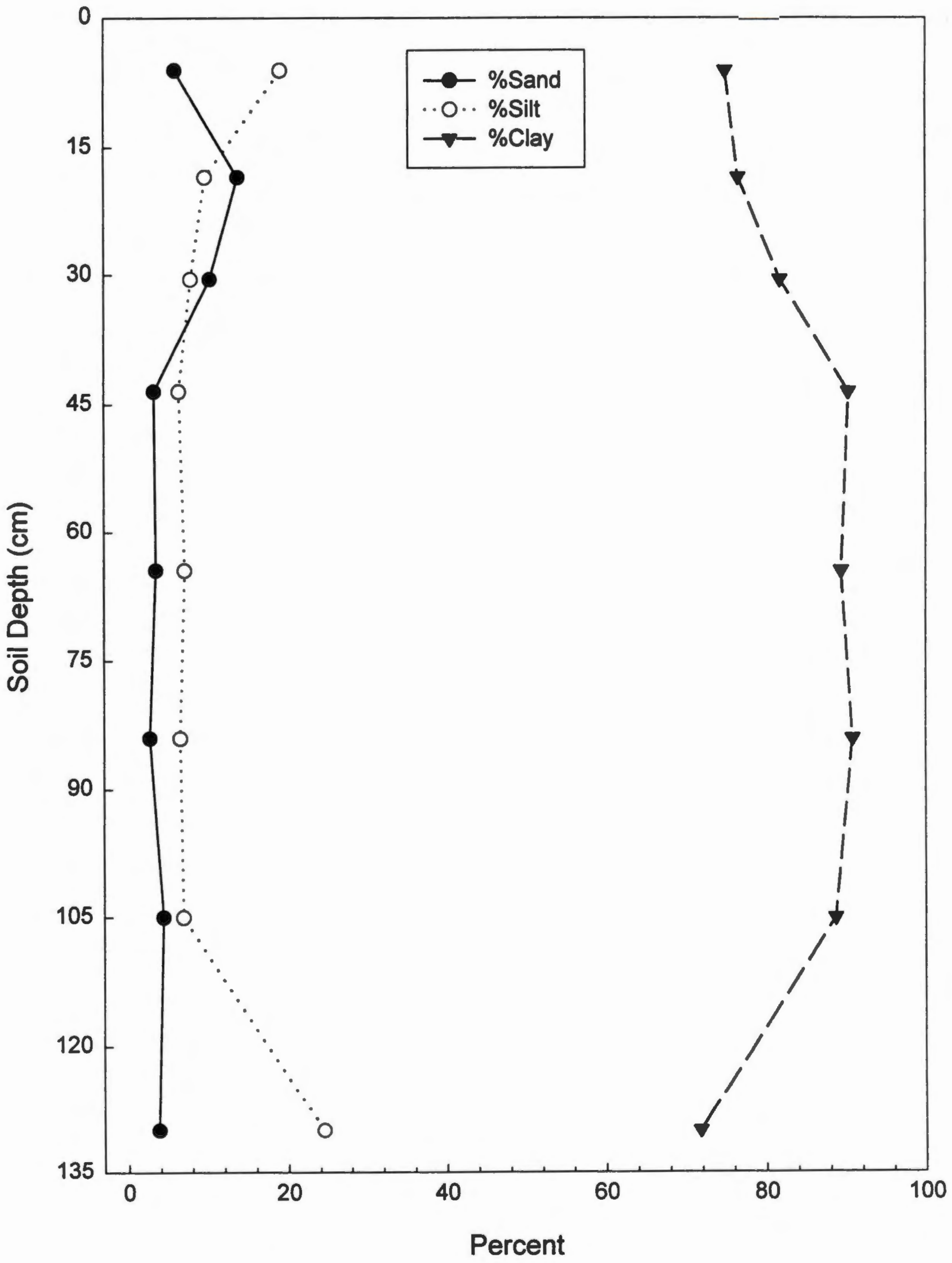
2Bt7 145-175 cm; reticulate mottling: red (10R 4/6), light gray (10YR 7/1), and strong brown (7.5YR 5/6) clay; firm; very weak effervescence; 5% Mn.

2Bt8 175-225 cm; strong brown (7.5 YR 5/6), and 50-60% black Mn clay; many, coarse, prominent red (10R 4/6), and light gray (10YR 7/1) mottles; firm; no effervescence; 50-60% Mn.

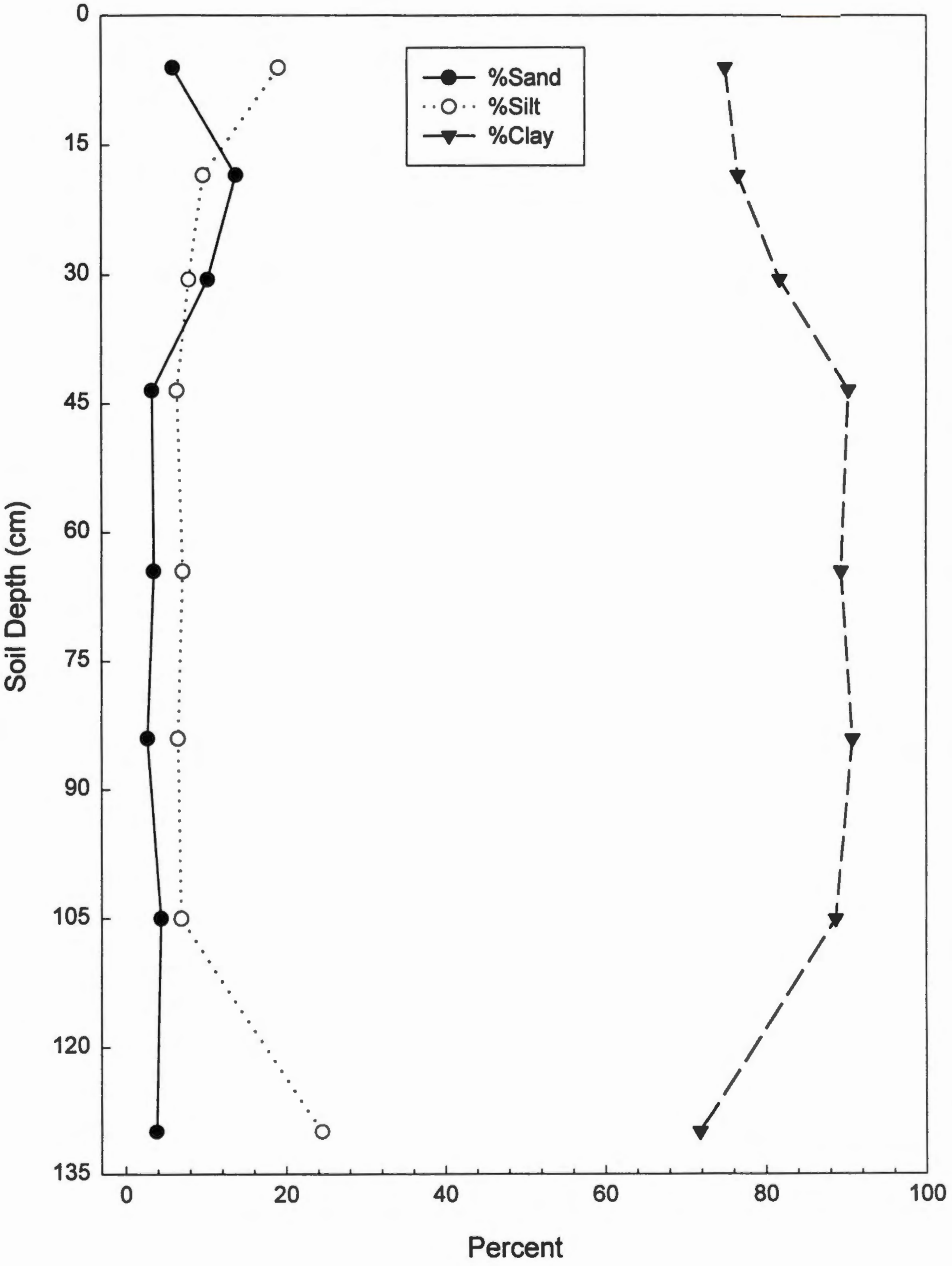
NOTE: Auger used for description below 115 cm.
Discontinuity probably exists at the pebble-cobble layer at 95 cm.
Coarse fragments composed mainly of chert, strongly weathered.
Non calcareous throughout profile.
Roots: many 0-23 cm; few below 23 cm.
Stoniness: 66-95 - concentrated 75-95 (diameter 12 cm.)

APPENDIX C

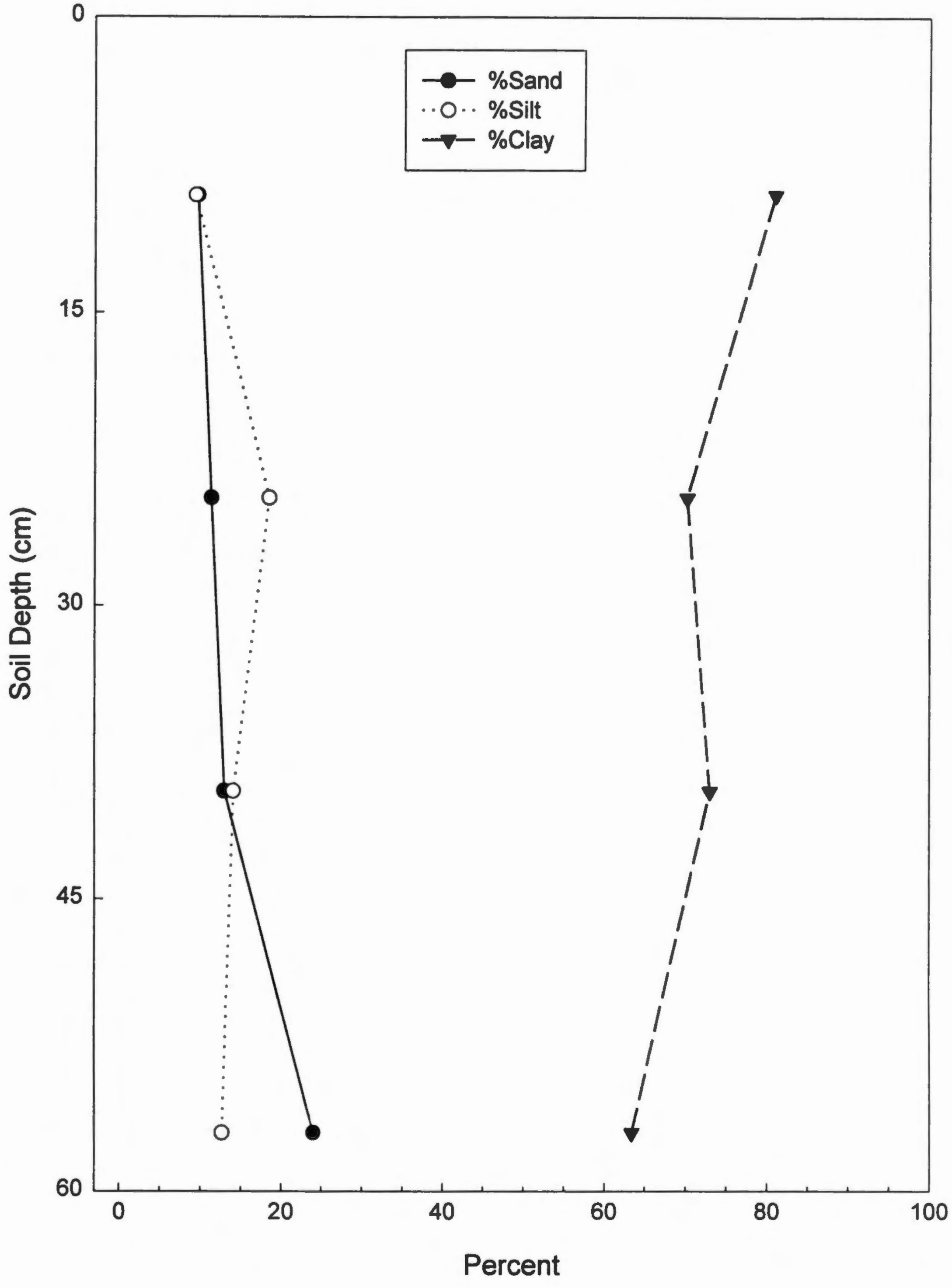
GRAPHS OF PARTICLE SIZE DATA



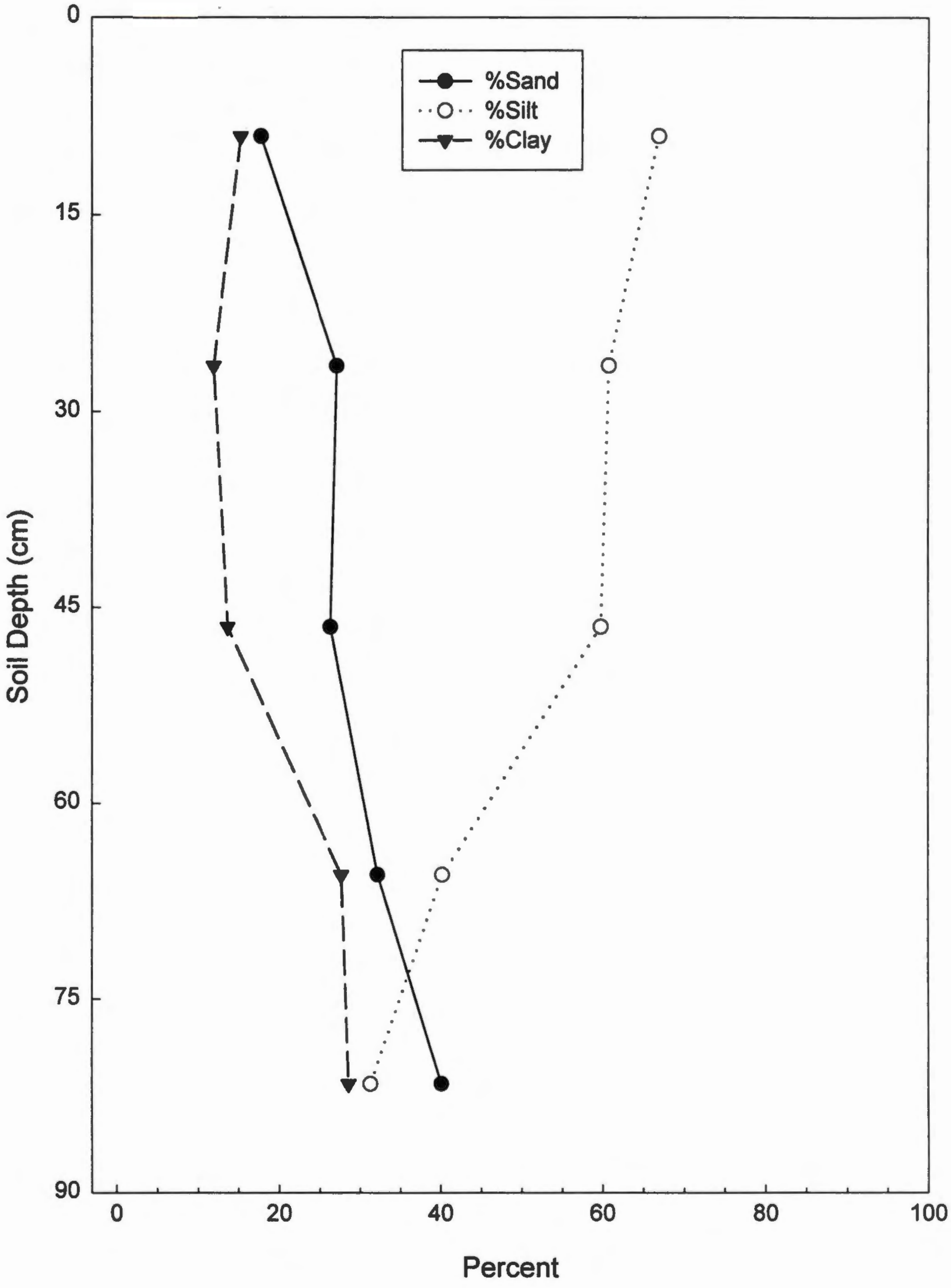
Particle size distribution for site 1



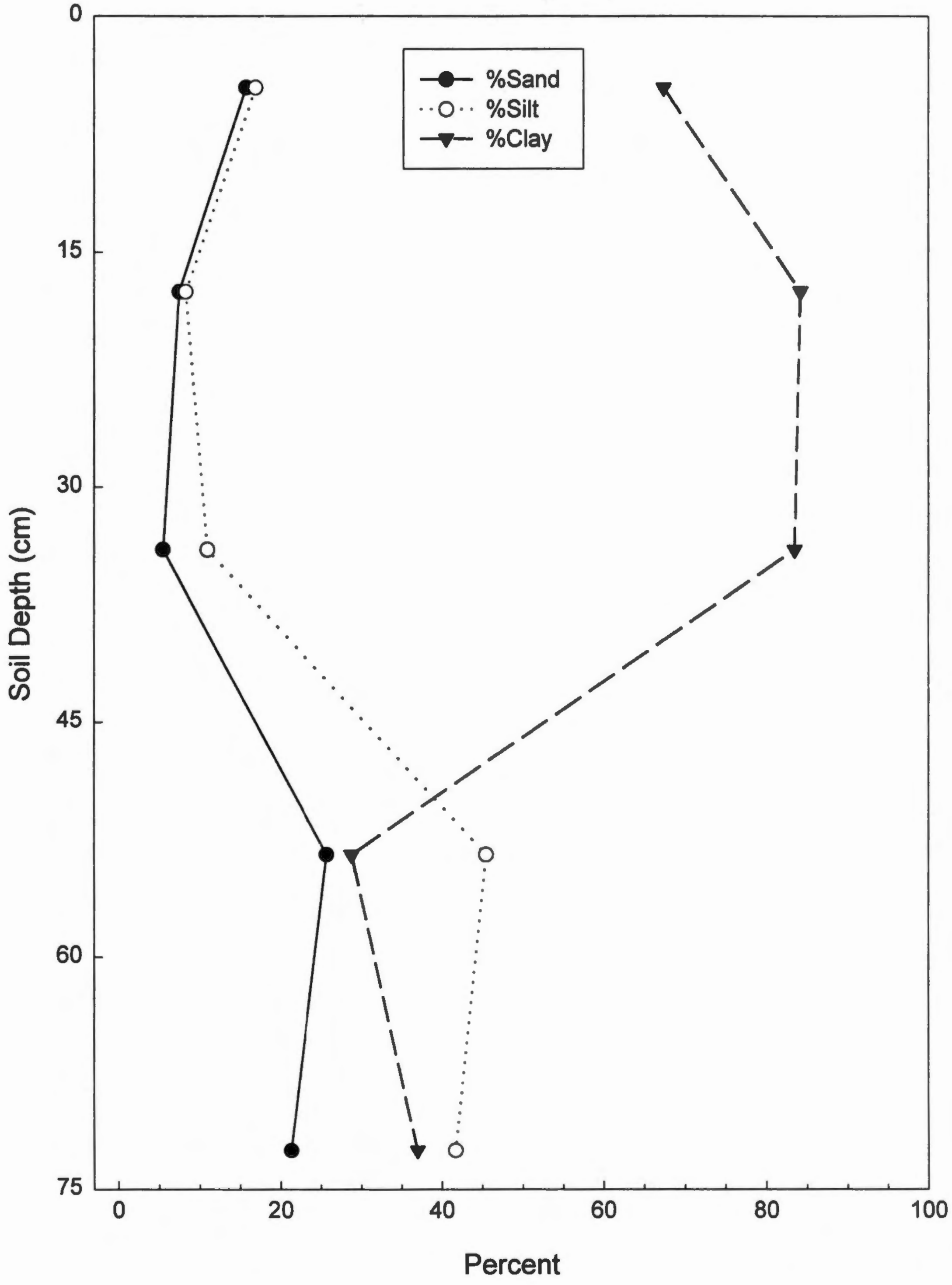
Particle size distribution for site 2.



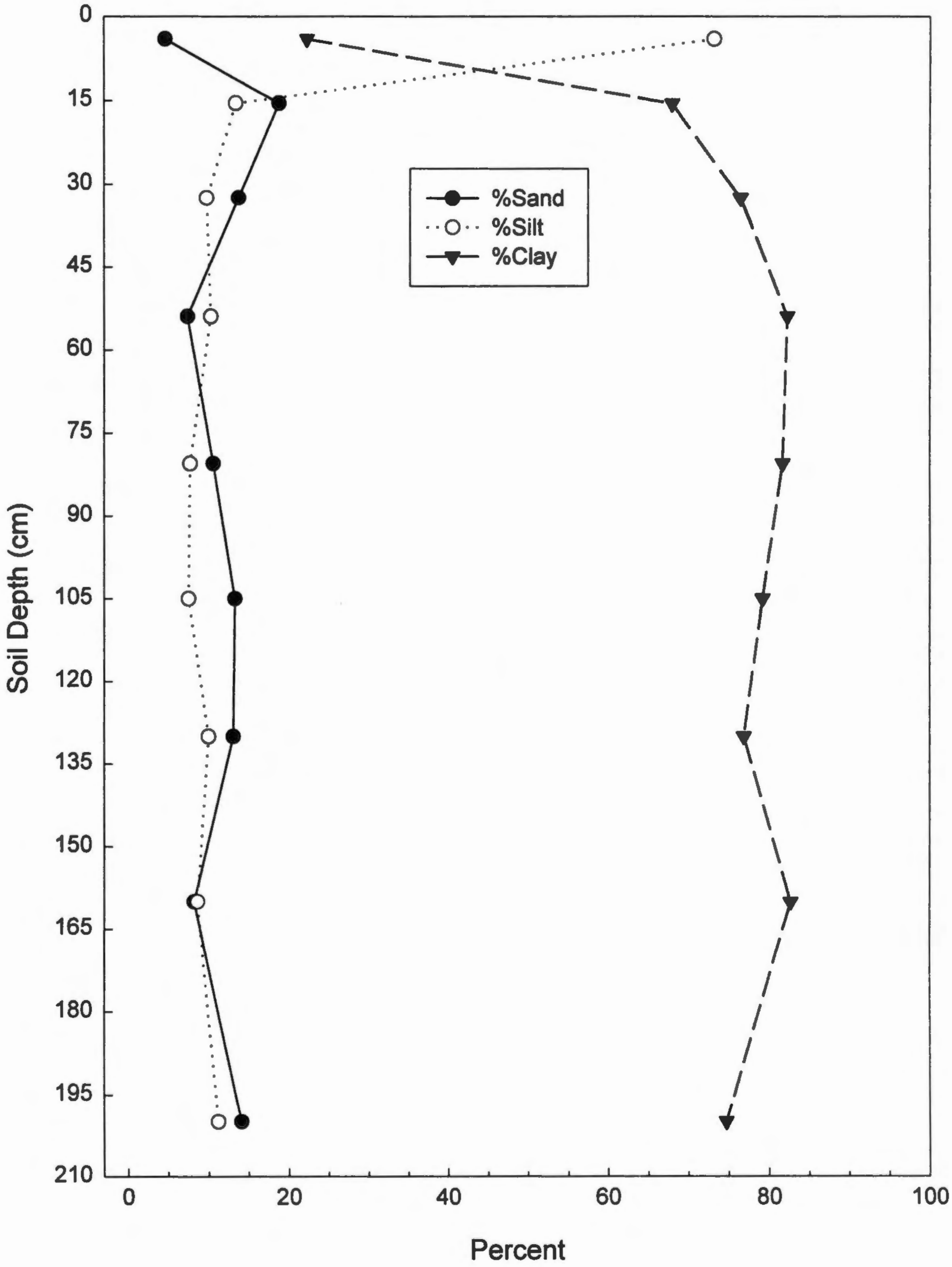
Particle size distribution for site 3.



Particle size distribution for site 4.



Particle size distribution for site 5.



Particle size distribution for site 6.

APPENDIX D

COARSE AND FINE SILT DATA FOR PROFILES ONE THROUGH SIX

COARSE AND FINE SILT DATA

HORIZON	DEPTH (cm)	FINE SILT %	COARSE SILT %
SITE 1			
A1	0-12	17.23	1.88
A2	12-25	4.43	5.23
AB	25-36	5.21	2.68
Bw1	36-51	5.18	1.24
Bg	51-78	6.81	0.28
BC	78-90	5.22	1.29
C1	90-120	3.94	3.00
C2	120-140	2.91	21.59
SITE 2			
A1	0-17	6.17	4.38
A2	17-35	13.53	5.04
BA	35-50	4.87	2.76
Bssg1	50-90	5.95	1.09
Bssg2	90-100	3.15	4.86
BC	100-110	-	-
C	110-125	74.86	10.67
SITE 3			
A1	0-18	5.39	4.00
A2	18-31	18.19	0.29
AB	31-48	6.62	7.52
BC	48-60	9.55	3.05

FINE AND COARSE SILT DATA (continued)

HORIZON	DEPTH (cm)	FINE SILT %	C. SILT %
SITE 4			
A1	0-18	52.87	14.04
A2	18-35	46.23	14.61
Bw	35-58	45.65	14.19
2BC	58-73	28.99	11.18
2C	73-90	12.92	18.39
SITE 5			
A1	0-9	14.37	2.54
A2	9-26	5.69	2.64
Bw1	26-42	3.25	7.76
2Bw2	42-65	-	-
2C/B	65-80	10.42	31.27
SITE 6			
A	0-8	25.55	47.63
Bt1	8-23	7.74	5.62
Bt2	23-42	4.76	5.00
Bt3	42-66	3.59	6.71
Bt4	66-95	5.28	2.40
2Bt5	95-115	1.59	5.94
2Bt6	115-145	4.93	5.07
2Bt7	145-175	3.89	4.71
2Bt8	175-225	-	-

APPENDIX E

TOTAL ELEMENTAL ANALYSIS DATA OF THE SELECTED SOILS

NOTE: For appendix E and F:
SITE1 Includes the soil samples G1 through G8
SITE 2 Includes the soil samples G10 through G16
SITE 3 Includes the soil samples G17 through G20
SITE 4 Includes the soil samples G21 through G26
SITE 5 Includes the soil samples G27 through G31
SITE 6 Includes the soil samples G32 through G40

TOTAL ELEMENTAL ANALYSIS

SAMP #	ELEMEN	(ICP) ppm	ELEMENT IN SOIL (mg/kg)	SAMP #	ELEMENT	(ICP) ppm	ELEMENT IN SOIL (mg/kg)
G1	Al	173.69	86414.19	G20	Al	155.416	77630.35
G1	As	0.10	49.75	G20	As	0.1	49.95005
G1	Ba	0.13	62.48	G20	Ba	0.14751	73.681319
G1	Ca	32.06	15948.46	G20	Ca	28.6591	14315.24
G1	Cd	0.00	1.99	G20	Cd	0.004	1.998002
G1	Co	0.03	14.30	G20	Co	0.01954	9.7602398
G1	Cr	0.10	47.57	G20	Cr	0.08599	42.952048
G1	Cu	0.05	26.45	G20	Cu	0.04142	20.689311
G1	Fe	69.46	34556.44	G20	Fe	59.9117	29925.939
G1	K	0.80	398.01	G20	K	0.8	399.6004
G1	Mg	16.72	8316.39	G20	Mg	16.6911	8337.2028
G1	Mn	0.98	487.40	G20	Mn	0.27097	135.34965
G1	Mo	0.01	4.97	G20	Mo	0.00999	4.99001
G1	Na	0.76	380.14	G20	Na	0.87439	436.75824
G1	Ni	0.09	42.76	G20	Ni	0.07784	38.881119
G1	P	0.01	4.97	G20	P	0.00999	4.99001
G1	Pb	0.11	53.26	G20	Pb	0.11834	59.110889
G1	S	0.05	24.88	G20	S	0.05	24.975025
G1	Si	443.81	220803.42	G20	Si	489.243	244377.2
G1	Sr	0.07	35.49	G20	Sr	0.12775	63.811189
G1	Ti	5.56	2764.36	G20	Ti	5.06161	2528.2767
G1	Zn	0.24	121.81	G20	Zn	0.59022	294.81518
G1	Zr	0.24	118.00	G20	Zr	0.30543	152.56244
							0
G2	Al	180.24	89404.18	G21	Al	36.6842	18232.679
G2	As	0.10	49.60	G21	As	0.1	49.701789
G2	Ba	0.11	56.41	G21	Ba	0.09069	45.074553
G2	Ca	29.82	14789.45	G21	Ca	610.379	303369.09
G2	Cd	0.00	1.98	G21	Cd	0.004	1.9880716
G2	Co	0.03	12.78	G21	Co	0.006	2.9821074
G2	Cr	0.10	47.43	G21	Cr	0.03617	17.977137
G2	Cu	0.03	16.49	G21	Cu	0.02255	11.207753
G2	Fe	69.65	34550.72	G21	Fe	13.3493	6634.841
G2	K	0.80	396.83	G21	K	1.8494	919.18489
G2	Mg	17.04	8451.74	G21	Mg	6.31	3136.1829
G2	Mn	0.58	286.10	G21	Mn	0.82936	412.20676
G2	Mo	0.01	4.96	G21	Mo	0.00999	4.9652087
G2	Na	1.05	521.46	G21	Na	0.01999	9.9353877
G2	Ni	0.07	36.82	G21	Ni	0.03295	16.37674
G2	P	0.01	4.96	G21	P	2.64023	1312.2416
G2	Pb	0.09	44.50	G21	Pb	0.05	24.850895
G2	S	0.05	24.80	G21	S	0.97508	484.63221
G2	Si	458.83	227595.42	G21	Si	83.1868	41345.313
G2	Sr	0.07	34.40	G21	Sr	0.11435	56.833996
G2	Ti	5.39	2673.80	G21	Ti	1.16804	580.53678
G2	Zn	0.24	118.64	G21	Zn	0.08915	44.309145
G2	Zr	0.24	121.16	G21	Zr	0.03982	19.791252
			0.00				
G3	Al	271.77	135275.34	G22	Al	35.07	17500.48
G3	As	0.10	49.78	G22	As	0.10	49.90
G3	Ba	0.17	84.52	G22	Ba	0.08	41.87
G3	Ca	41.70	20754.41	G22	Ca	652.79	325745.45
G3	Cd	0.00	1.99	G22	Cd	0.00	2.00
G3	Co	0.04	18.73	G22	Co	0.01	2.99
G3	Cr	0.15	74.18	G22	Cr	0.04	18.35
G3	Cu	0.06	29.92	G22	Cu	0.01	5.97
G3	Fe	102.00	50773.15	G22	Fe	12.73	6351.83
G3	K	0.80	398.21	G22	K	1.19	593.26
G3	Mg	23.69	11790.09	G22	Mg	5.63	2810.38
G3	Mn	0.93	460.53	G22	Mn	0.59	295.16
G3	Mo	0.01	4.97	G22	Mo	0.01	4.99
G3	Na	1.75	872.59	G22	Na	0.02	9.98
G3	Ni	0.17	85.96	G22	Ni	0.03	14.00
G3	P	0.01	4.97	G22	P	1.41	704.04
G3	Pb	0.19	95.61	G22	Pb	0.05	24.95
G3	S	0.05	24.89	G22	S	0.50	248.02
G3	Si	681.84	339390.25	G22	Si	77.48	38663.32
G3	Sr	0.10	51.98	G22	Sr	0.11	56.60
G3	Ti	8.77	4365.93	G22	Ti	1.03	511.62
G3	Zn	0.29	142.54	G22	Zn	0.14	68.96
G3	Zr	0.38	188.28	G22	Zr	0.04	21.93

G4a	Al	184.80	92305.46	G23	Al	23.81	11872.98
G4a	As	0.10	49.95	G23	As	0.10	49.88
G4a	Ba	0.10	51.29	G23	Ba	0.08	39.98
G4a	Ca	27.42	13698.51	G23	Ca	722.80	360499.45
G4a	Cd	0.00	2.00	G23	Cd	0.00	2.00
G4a	Co	0.02	9.40	G23	Co	0.01	2.99
G4a	Cr	0.10	51.71	G23	Cr	0.04	18.63
G4a	Cu	0.04	21.90	G23	Cu	0.03	12.48
G4a	Fe	72.18	36051.65	G23	Fe	8.86	4417.94
G4a	K	0.80	399.60	G23	K	0.97	483.16
G4a	Mg	17.02	8499.73	G23	Mg	7.33	3655.14
G4a	Mn	0.32	160.38	G23	Mn	0.33	166.19
G4a	Mo	0.01	4.99	G23	Mo	0.01	4.98
G4a	Na	1.51	756.53	G23	Na	0.07	36.10
G4a	Ni	0.10	49.96	G23	Ni	0.03	16.08
G4a	P	0.01	4.99	G23	P	0.55	272.91
G4a	Pb	0.12	61.61	G23	Pb	0.05	24.94
G4a	S	0.05	24.98	G23	S	0.34	170.14
G4a	Si	464.73	232132.58	G23	Si	56.46	28157.89
G4a	Sr	0.07	36.97	G23	Sr	0.11	56.57
G4a	Ti	6.26	3126.92	G23	Ti	0.64	318.59
G4a	Zn	0.20	99.08	G23	Zn	0.57	282.86
G4a	Zr	0.27	133.65	G23	Zr	0.02	12.17
			0.00				0.00
G4b	Al	184.48	92888.56	G24	Al	33.13	16414.98
G4b	As	0.10	50.35	G24	As	0.10	49.55
G4b	Ba	0.09	46.33	G24	Ba	0.10	50.91
G4b	Ca	26.97	13579.17	G24	Ca	698.98	346371.82
G4b	Cd	0.00	2.01	G24	Cd	0.00	1.98
G4b	Co	0.02	8.92	G24	Co	0.01	2.97
G4b	Cr	0.10	50.80	G24	Cr	0.04	20.57
G4b	Cu	0.04	21.66	G24	Cu	0.02	11.77
G4b	Fe	71.35	35924.96	G24	Fe	12.40	6142.36
G4b	K	0.80	402.82	G24	K	1.63	807.35
G4b	Mg	17.13	8623.44	G24	Mg	5.85	2898.63
G4b	Mn	0.31	155.07	G24	Mn	0.55	271.89
G4b	Mo	0.01	5.03	G24	Mo	0.01	4.95
G4b	Na	1.46	734.96	G24	Na	0.03	15.85
G4b	Ni	0.10	51.93	G24	Ni	0.02	10.07
G4b	P	0.01	5.03	G24	P	0.82	404.03
G4b	Pb	0.12	59.77	G24	Pb	0.05	24.78
G4b	S	0.05	25.18	G24	S	0.23	115.95
G4b	Si	458.65	230939.59	G24	Si	77.16	38238.31
G4b	Sr	0.07	35.92	G24	Sr	0.12	57.13
G4b	Ti	6.46	3251.11	G24	Ti	1.07	527.87
G4b	Zn	0.21	105.98	G24	Zn	0.10	51.29
G4b	Zr	0.27	135.35	G24	Zr	0.04	20.29
			0.00				0.00
G5	Al	184.71	92402.89	G25	Al	33.10	16420.29
G5	As	0.10	50.03	G25	As	0.10	49.60
G5	Ba	0.09	45.44	G25	Ba	0.07	35.84
G5	Ca	29.59	14801.13	G25	Ca	700.31	347376.81
G5	Cd	0.00	2.00	G25	Cd	0.00	1.98
G5	Co	0.02	11.21	G25	Co	0.01	2.98
G5	Cr	0.10	48.82	G25	Cr	0.05	22.36
G5	Cu	0.04	20.71	G25	Cu	0.01	5.37
G5	Fe	72.46	36248.56	G25	Fe	11.90	5902.32
G5	K	0.80	400.20	G25	K	1.01	502.36
G5	Mg	18.03	9018.34	G25	Mg	5.63	2791.33
G5	Mn	0.81	405.06	G25	Mn	0.34	166.36
G5	Mo	0.01	5.00	G25	Mo	0.01	4.96
G5	Na	2.47	1233.13	G25	Na	0.02	9.92
G5	Ni	0.10	50.82	G25	Ni	0.02	9.92
G5	P	0.01	5.00	G25	P	0.01	4.96
G5	Pb	0.11	54.48	G25	Pb	0.05	24.80
G5	S	0.05	25.01	G25	S	0.53	263.11
G5	Si	470.34	235289.27	G25	Si	77.50	38443.93
G5	Sr	0.08	39.36	G25	Sr	0.15	75.52
G5	Ti	6.55	3276.18	G25	Ti	0.89	442.55
G5	Zn	0.51	254.65	G25	Zn	0.08	38.79
G5	Zr	0.27	136.56	G25	Zr	0.04	18.82

G6	Al	183.70	90984.67	G27	Al	210.69	105395.44
G6	As	0.10	49.53	G27	As	0.10	50.03
G6	Ba	0.08	40.68	G27	Ba	0.12	60.05
G6	Ca	30.63	15169.68	G27	Ca	24.55	12279.22
G6	Cd	0.00	1.98	G27	Cd	0.00	2.00
G6	Co	0.02	9.28	G27	Co	0.03	14.04
G6	Cr	0.10	48.66	G27	Cr	0.03	16.61
G6	Cu	0.04	20.92	G27	Cu	0.03	14.12
G6	Fe	71.85	35586.10	G27	Fe	78.66	39347.63
G6	K	0.80	396.24	G27	K	1.41	704.89
G6	Mg	17.93	8880.57	G27	Mg	9.52	4764.30
G6	Mn	0.40	199.44	G27	Mn	3.02	1512.41
G6	Mo	0.01	4.95	G27	Mo	0.01	5.00
G6	Na	2.76	1369.32	G27	Na	0.02	10.00
G6	Ni	0.09	44.89	G27	Ni	0.04	20.35
G6	P	0.01	4.95	G27	P	0.09	45.15
G6	Pb	0.09	45.25	G27	Pb	0.15	76.09
G6	S	0.05	24.76	G27	S	0.64	320.45
G6	Si	471.78	233671.81	G27	Si	375.79	187987.76
G6	Sr	0.08	38.85	G27	Sr	0.05	25.01
G6	Ti	6.31	3124.94	G27	Ti	6.23	3116.50
G6	Zn	0.18	89.19	G27	Zn	0.49	246.84
G6	Zr	0.27	131.91	G27	Zr	0.34	170.83
			0.00				0.00
G7	Al	181.09	90546.10	G28a	Al	220.97	109825.97
G7	As	0.10	50.00	G28a	As	0.10	49.70
G7	Ba	0.79	396.51	G28a	Ba	0.15	73.32
G7	Ca	34.74	17367.51	G28a	Ca	24.54	12199.29
G7	Cd	0.00	2.00	G28a	Cd	0.00	1.99
G7	Co	0.02	10.57	G28a	Co	0.04	18.87
G7	Cr	0.10	49.79	G28a	Cr	0.03	15.9
G7	Cu	0.04	21.52	G28a	Cu	0.03	16.7
G7	Fe	70.64	35322.03	G28a	Fe	82.88	41193.1
G7	K	1.12	559.53	G28a	K	1.41	700.
G7	Mg	18.20	9101.28	G28a	Mg	9.68	4810.
G7	Mn	0.93	465.56	G28a	Mn	3.04	1512
G7	Mo	0.01	5.00	G28a	Mo	0.01	4
G7	Na	3.68	1840.27	G28a	Na	0.02	[illegible]
G7	Ni	0.09	46.50	G28a	Ni	0.06	3
G7	P	0.01	5.00	G28a	P	0.01	[illegible]
G7	Pb	0.13	67.42	G28a	Pb	0.17	[illegible]
G7	S	0.05	25.00	G28a	S	0.79	3
G7	Si	469.89	234947.39	G28a	Si	383.52	190
G7	Sr	0.09	45.72	G28a	Sr	0.05	[illegible]
G7	Ti	6.33	3164.13	G28a	Ti	6.47	3
G7	Zn	0.23	116.37	G28a	Zn	0.27	[illegible]
G7	Zr	0.27	135.45	G28a	Zr	0.35	[illegible]
			0.00				
G8a	Al	187.32	89669.01	G28b	Al	226.00	1
G8a	As	0.10	47.87	G28b	As	0.10	[illegible]
G8a	Ba	0.65	312.50	G28b	Ba	0.46	[illegible]
G8a	Ca	38.93	18634.28	G28b	Ca	25.84	[illegible]
G8a	Cd	0.01	4.91	G28b	Cd	0.00	[illegible]
G8a	Co	0.04	17.66	G28b	Co	0.03	[illegible]
G8a	Cr	0.10	48.93	G28b	Cr	0.03	[illegible]
G8a	Cu	0.07	32.43	G28b	Cu	0.03	[illegible]
G8a	Fe	73.16	35023.01	G28b	Fe	83.85	[illegible]
G8a	K	0.80	382.96	G28b	K	1.5	[illegible]
G8a	Mg	19.78	9467.02	G28b	Mg	10.3	[illegible]
G8a	Mn	1.47	705.71	G28b	Mn	2.9	[illegible]
G8a	Mo	0.01	4.78	G28b	Mo	0.	[illegible]
G8a	Na	3.31	1582.92	G28b	Na	1.	[illegible]
G8a	Ni	0.09	44.14	G28b	Ni	0	[illegible]
G8a	P	0.01	4.78	G28b	P	0	[illegible]
G8a	Pb	0.15	71.21	G28b	Pb	[illegible]	[illegible]
G8a	S	0.05	23.93	G28b	S	[illegible]	[illegible]
G8a	Si	491.01	235045.57	G28b	Si	39	[illegible]
G8a	Sr	0.11	53.97	G28b	Sr	[illegible]	[illegible]
G8a	Ti	6.56	3142.60	G28b	Ti	[illegible]	[illegible]
G8a	Zn	0.29	140.22	G28b	Zn	[illegible]	[illegible]
G8a	Zr	0.28	134.06	G28b	Zr	[illegible]	[illegible]

G8b	Al	181.17	90312.79	G29	Al	234.34	117463.94
G8b	As	0.10	49.85	G29	As	0.10	50.13
G8b	Ba	0.51	256.33	G29	Ba	0.17	82.80
G8b	Ca	37.10	18492.75	G29	Ca	31.04	15558.85
G8b	Cd	0.00	1.99	G29	Cd	0.00	2.01
G8b	Co	0.03	13.66	G29	Co	0.03	15.51
G8b	Cr	0.10	48.00	G29	Cr	0.03	15.75
G8b	Cu	0.05	26.22	G29	Cu	0.02	9.32
G8b	Fe	71.87	35826.37	G29	Fe	82.00	41101.85
G8b	K	1.07	535.54	G29	K	1.23	618.01
G8b	Mg	19.16	9549.22	G29	Mg	10.57	5296.52
G8b	Mn	1.08	536.02	G29	Mn	2.85	1430.79
G8b	Mo	0.01	4.98	G29	Mo	0.01	5.01
G8b	Na	3.38	1686.81	G29	Na	0.02	10.02
G8b	Ni	0.08	40.51	G29	Ni	0.04	19.33
G8b	P	0.01	4.98	G29	P	0.01	5.01
G8b	Pb	0.14	71.81	G29	Pb	0.18	87.87
G8b	S	0.05	24.93	G29	S	0.33	166.16
G8b	Si	464.02	231314.71	G29	Si	387.06	194013.66
G8b	Sr	0.09	46.19	G29	Sr	0.05	25.06
G8b	Ti	6.44	3211.92	G29	Ti	7.23	3624.98
G8b	Zn	0.51	254.98	G29	Zn	0.20	98.56
G8b	Zr	0.27	134.42	G29	Zr	0.38	188.88
			0.00				0.00
G10	Al	156.87	78319.01	G30	Al	102.27	51132.71
G10	As	0.10	49.93	G30	As	0.10	50.00
G10	Ba	0.48	241.73	G30	Ba	0.14	69.99
G10	Ca	42.21	21072.18	G30	Ca	498.86	249429.57
G10	Cd	0.00	2.00	G30	Cd	0.00	2.00
G10	Co	0.05	22.92	G30	Co	0.04	17.71
G10	Cr	0.09	45.76	G30	Cr	0.02	10.68
G10	Cu	0.06	27.72	G30	Cu	0.02	8.71
G10	Fe	53.73	26826.76	G30	Fe	37.13	18567.36
G10	K	1.48	737.48	G30	K	0.80	400.00
G10	Mg	20.79	10381.91	G30	Mg	5.99	2994.86
G10	Mn	4.14	2067.15	G30	Mn	1.57	783.58
G10	Mo	0.01	4.99	G30	Mo	0.01	5.00
G10	Na	0.57	282.50	G30	Na	0.02	10.00
G10	Ni	0.12	60.08	G30	Ni	0.02	10.00
G10	P	0.14	71.85	G30	P	0.01	5.00
G10	Pb	0.12	61.42	G30	Pb	0.06	30.70
G10	S	0.05	24.96	G30	S	0.18	92.02
G10	Si	440.08	219708.09	G30	Si	182.86	91428.83
G10	Sr	0.06	30.71	G30	Sr	0.05	25.00
G10	Ti	3.78	1888.85	G30	Ti	3.28	1640.74
G10	Zn	0.28	137.56	G30	Zn	0.15	72.56
G10	Zr	0.19	97.02	G30	Zr	0.16	81.90
			0.00				0.00
G11	Al	172.07	85950.07	G31	Al	93.79	46546.08
G11	As	0.10	49.95	G31	As	0.10	49.63
G11	Ba	0.42	209.69	G31	Ba	0.16	78.99
G11	Ca	30.86	15415.12	G31	Ca	521.37	258744.53
G11	Cd	0.00	2.33	G31	Cd	0.00	1.99
G11	Co	0.05	23.70	G31	Co	0.01	4.67
G11	Cr	0.10	48.42	G31	Cr	0.02	11.48
G11	Cu	0.06	30.26	G31	Cu	0.01	4.96
G11	Fe	59.74	29838.89	G31	Fe	33.58	16663.50
G11	K	1.34	670.77	G31	K	0.80	397.02
G11	Mg	22.48	11227.74	G31	Mg	6.35	3152.78
G11	Mn	3.88	1936.31	G31	Mn	1.49	740.75
G11	Mo	0.01	4.99	G31	Mo	0.01	4.96
G11	Na	0.66	327.91	G31	Na	0.02	9.92
G11	Ni	0.10	49.18	G31	Ni	0.02	10.09
G11	P	0.01	4.99	G31	P	0.01	4.96
G11	Pb	0.14	72.35	G31	Pb	0.05	24.81
G11	S	0.05	24.98	G31	S	0.05	24.81
G11	Si	479.07	239293.82	G31	Si	172.53	85623.93
G11	Sr	0.06	32.44	G31	Sr	0.05	24.81
G11	Ti	4.37	2180.72	G31	Ti	3.02	1497.53
G11	Zn	0.72	360.64	G31	Zn	0.14	68.17
G11	Zr	0.22	110.78	G31	Zr	0.15	72.53

G12	Al	174.31	86678.71	G32	Al	196.03	97335.77
G12	As	0.10	49.73	G32	As	0.10	49.65
G12	Ba	0.38	191.28	G32	Ba	0.24	119.77
G12	Ca	32.21	16016.37	G32	Ca	5.51	2733.91
G12	Cd	0.00	1.99	G32	Cd	0.00	1.99
G12	Co	0.05	22.85	G32	Co	0.07	36.02
G12	Cr	0.10	48.20	G32	Cr	0.08	39.75
G12	Cu	0.06	31.92	G32	Cu	0.11	53.70
G12	Fe	58.27	28978.10	G32	Fe	129.43	64263.67
G12	K	1.21	600.99	G32	K	0.80	397.22
G12	Mg	22.14	11009.88	G32	Mg	2.01	998.31
G12	Mn	3.98	1978.66	G32	Mn	5.83	2893.83
G12	Mo	0.01	4.97	G32	Mo	0.01	4.96
G12	Na	0.58	287.28	G32	Na	0.02	9.93
G12	Ni	0.12	57.51	G32	Ni	0.08	40.04
G12	P	0.01	4.97	G32	P	0.23	113.35
G12	Pb	0.13	66.27	G32	Pb	0.24	117.04
G12	S	0.05	24.86	G32	S	0.80	397.24
G12	Si	474.89	236145.73	G32	Si	460.23	228515.23
G12	Sr	0.06	28.76	G32	Sr	0.41	204.53
G12	Ti	4.29	2132.03	G32	Ti	9.33	4632.91
G12	Zn	0.20	98.28	G32	Zn	0.53	265.24
G12	Zr	0.23	112.15	G32	Zr	0.36	179.82
			0.00				0.00
G13	Al	172.55	85845.51	G33	Al	225.08	112033.58
G13	As	0.10	49.75	G33	As	0.10	49.78
G13	Ba	0.32	158.16	G33	Ba	0.19	96.28
G13	Ca	32.04	15939.29	G33	Ca	13.55	6742.78
G13	Cd	0.00	1.99	G33	Cd	0.00	1.99
G13	Co	0.04	22.30	G33	Co	0.07	35.02
G13	Cr	0.10	49.54	G33	Cr	0.08	40.44
G13	Cu	0.04	19.81	G33	Cu	0.09	46.89
G13	Fe	57.60	28656.37	G33	Fe	125.60	62519.34
G13	K	1.03	512.21	G33	K	0.80	398.21
G13	Mg	22.63	11260.57	G33	Mg	2.19	1087.69
G13	Mn	3.75	1864.29	G33	Mn	3.62	1803.35
G13	Mo	0.01	4.97	G33	Mo	0.01	4.97
G13	Na	0.62	306.88	G33	Na	0.02	9.95
G13	Ni	0.11	52.87	G33	Ni	0.08	40.84
G13	P	0.01	4.97	G33	P	0.11	55.43
G13	Pb	0.12	60.00	G33	Pb	0.21	103.69
G13	S	0.05	24.88	G33	S	0.55	274.95
G13	Si	492.06	244807.50	G33	Si	438.64	218337.61
G13	Sr	0.06	28.29	G33	Sr	0.07	33.00
G13	Ti	4.50	2237.42	G33	Ti	10.31	5130.44
G13	Zn	0.33	162.03	G33	Zn	0.26	130.96
G13	Zr	0.23	112.41	G33	Zr	0.42	206.64
			0.00				0.00
G13b	Al	174.54	86662.70	G34	Al	267.37	133752.97
G13b	As	0.10	49.65	G34	As	0.10	50.03
G13b	Ba	0.31	156.09	G34	Ba	0.55	275.78
G13b	Ca	32.52	16144.63	G34	Ca	2.97	1484.19
G13b	Cd	0.00	1.99	G34	Cd	0.00	2.00
G13b	Co	0.04	18.90	G34	Co	0.11	56.72
G13b	Cr	0.10	50.75	G34	Cr	0.08	40.05
G13b	Cu	0.05	22.72	G34	Cu	0.10	47.60
G13b	Fe	59.33	29459.52	G34	Fe	144.08	72074.52
G13b	K	0.98	488.97	G34	K	0.80	400.20
G13b	Mg	22.86	11352.68	G34	Mg	2.39	1194.87
G13b	Mn	3.70	1836.92	G34	Mn	7.83	3916.28
G13b	Mo	0.01	4.96	G34	Mo	0.01	5.00
G13b	Na	0.67	334.67	G34	Na	0.02	10.00
G13b	Ni	0.12	60.91	G34	Ni	0.10	49.11
G13b	P	0.01	4.96	G34	P	0.05	22.81
G13b	Pb	0.14	71.26	G34	Pb	0.27	136.18
G13b	S	0.05	24.83	G34	S	0.21	105.45
G13b	Si	489.96	243279.22	G34	Si	389.04	194615.92
G13b	Sr	0.12	58.17	G34	Sr	0.05	25.01
G13b	Ti	4.70	2335.87	G34	Ti	9.49	4747.28
G13b	Zn	0.41	201.91	G34	Zn	0.40	200.10
G13b	Zr	0.23	114.67	G34	Zr	0.43	213.31

G14	Al	176.30	88061.22	G35	Al	293.02	146439.11
G14	As	0.10	49.95	G35	As	0.10	49.98
G14	Ba	0.27	136.70	G35	Ba	0.07	34.22
G14	Ca	36.56	18263.41	G35	Ca	2.85	1423.92
G14	Cd	0.00	2.00	G35	Cd	0.00	2.00
G14	Co	0.05	22.79	G35	Co	0.02	11.11
G14	Cr	0.11	53.36	G35	Cr	0.07	36.75
G14	Cu	0.04	21.42	G35	Cu	0.09	45.48
G14	Fe	60.04	29990.07	G35	Fe	121.63	60785.18
G14	K	1.43	715.48	G35	K	0.80	399.80
G14	Mg	22.96	11469.97	G35	Mg	2.64	1318.31
G14	Mn	3.74	1868.69	G35	Mn	0.41	207.14
G14	Mo	0.01	4.99	G35	Mo	0.01	4.99
G14	Na	0.65	324.23	G35	Na	0.02	9.99
G14	Ni	0.11	56.59	G35	Ni	0.13	62.73
G14	P	0.01	4.99	G35	P	0.01	4.99
G14	Pb	0.14	71.37	G35	Pb	0.18	89.48
G14	S	0.05	24.98	G35	S	0.12	59.06
G14	Si	476.24	237879.69	G35	Si	382.02	190913.41
G14	Sr	0.06	29.02	G35	Sr	0.05	24.99
G14	Ti	5.04	2516.19	G35	Ti	8.64	4318.42
G14	Zn	0.20	100.92	G35	Zn	0.17	84.52
G14	Zr	0.23	116.81	G35	Zr	0.43	216.47
			0.00				0.00
G15	Al	168.31	84026.74	G36	Al	277.12	138216.50
G15	As	0.10	49.93	G36	As	0.10	49.88
G15	Ba	0.35	174.69	G36	Ba	0.05	25.90
G15	Ca	52.54	26228.87	G36	Ca	15.50	7728.38
G15	Cd	0.00	2.00	G36	Cd	0.00	2.00
G15	Co	0.04	20.04	G36	Co	0.02	10.28
G15	Cr	0.11	55.97	G36	Cr	0.07	36.38
G15	Cu	0.04	22.28	G36	Cu	0.19	96.72
G15	Fe	56.33	28122.70	G36	Fe	142.14	70892.83
G15	K	1.92	960.95	G36	K	0.80	399.00
G15	Mg	26.43	13193.89	G36	Mg	2.76	1375.92
G15	Mn	3.07	1535.02	G36	Mn	0.53	264.96
G15	Mo	0.01	4.99	G36	Mo	0.01	4.98
G15	Na	0.58	287.59	G36	Na	0.02	9.97
G15	Ni	0.11	55.79	G36	Ni	0.08	38.47
G15	P	0.01	4.99	G36	P	0.01	4.98
G15	Pb	0.12	58.45	G36	Pb	0.23	115.37
G15	S	0.05	24.96	G36	S	0.05	24.94
G15	Si	484.66	241968.98	G36	Si	399.25	199128.49
G15	Sr	0.19	92.76	G36	Sr	0.07	37.10
G15	Ti	4.41	2199.24	G36	Ti	8.74	4359.40
G15	Zn	0.35	174.42	G36	Zn	0.50	248.35
G15	Zr	0.22	112.18	G36	Zr	0.42	209.67
			0.00				0.00
G16	Al	79.48	39660.20	G37	Al	270.08	134435.81
G16	As	0.10	49.90	G37	As	0.10	49.78
G16	Ba	0.35	175.00	G37	Ba	0.07	35.40
G16	Ca	507.36	253172.12	G37	Ca	5.19	2582.23
G16	Cd	0.00	2.00	G37	Cd	0.00	1.99
G16	Co	0.01	5.74	G37	Co	0.02	10.73
G16	Cr	0.09	44.75	G37	Cr	0.07	33.06
G16	Cu	0.02	12.35	G37	Cu	0.12	57.67
G16	Fe	25.48	12714.12	G37	Fe	128.42	63921.37
G16	K	2.78	1384.88	G37	K	0.80	398.21
G16	Mg	21.08	10517.56	G37	Mg	2.85	1417.79
G16	Mn	0.58	291.42	G37	Mn	0.32	159.54
G16	Mo	0.01	4.99	G37	Mo	0.01	4.97
G16	Na	0.32	159.41	G37	Na	0.04	22.07
G16	Ni	0.08	40.16	G37	Ni	0.06	30.72
G16	P	0.01	4.99	G37	P	0.01	4.97
G16	Pb	0.05	24.95	G37	Pb	0.19	95.98
G16	S	0.05	24.95	G37	S	0.06	27.72
G16	Si	236.83	118177.43	G37	Si	421.61	209861.16
G16	Sr	0.15	73.63	G37	Sr	0.05	24.89
G16	Ti	2.00	997.88	G37	Ti	10.08	5017.26
G16	Zn	0.40	201.63	G37	Zn	0.33	162.11
G16	Zr	0.10	49.42	G37	Zr	0.44	219.73

G17	Al	136.43	68042.79	G38	Al	261.28	130185.07
G17	As	0.10	49.88	G38	As	0.10	49.83
G17	Ba	0.71	353.60	G38	Ba	0.12	62.25
G17	Ca	31.49	15707.60	G38	Ca	9.15	4556.96
G17	Cd	0.00	2.00	G38	Cd	0.00	1.99
G17	Co	0.03	15.70	G38	Co	0.15	73.35
G17	Cr	0.07	36.08	G38	Cr	0.07	34.28
G17	Cu	0.05	25.67	G38	Cu	0.15	72.92
G17	Fe	51.25	25559.85	G38	Fe	126.29	62925.09
G17	K	0.80	399.00	G38	K	0.80	398.60
G17	Mg	16.24	8099.69	G38	Mg	2.80	1394.74
G17	Mn	1.90	948.51	G38	Mn	2.21	1098.77
G17	Mo	0.01	4.98	G38	Mo	0.01	4.98
G17	Na	0.21	102.45	G38	Na	0.02	9.96
G17	Ni	0.05	26.23	G38	Ni	0.08	40.88
G17	P	0.39	196.31	G38	P	0.01	4.98
G17	Pb	0.11	56.11	G38	Pb	0.28	140.48
G17	S	0.89	443.22	G38	S	0.05	24.91
G17	Si	431.14	215033.08	G38	Si	365.02	181873.21
G17	Sr	0.12	61.76	G38	Sr	0.05	24.91
G17	Ti	3.95	1970.25	G38	Ti	8.93	4450.45
G17	Zn	0.71	354.61	G38	Zn	0.25	125.04
G17	Zr	0.20	100.99	G38	Zr	0.42	207.21
			0				0.00
G18	Al	144.1467	72037.311	G39	Al	289.05	144235.57
G18	As	0.1	49.975012	G39	As	0.10	49.90
G18	Ba	0.61225	305.97201	G39	Ba	0.12	61.40
G18	Ca	27.77443	13880.275	G39	Ca	18.66	9310.34
G18	Cd	0.004	1.9990005	G39	Cd	0.00	2.00
G18	Co	0.02816	14.072964	G39	Co	0.08	40.01
G18	Cr	0.07947	39.715142	G39	Cr	0.08	37.58
G18	Cu	0.04749	23.733133	G39	Cu	0.17	86.39
G18	Fe	56.02721	27999.605	G39	Fe	115.27	57521.30
G18	K	0.8	399.8001	G39	K	0.80	399.20
G18	Mg	16.07777	8034.8676	G39	Mg	3.32	1656.99
G18	Mn	1.7404	869.76512	G39	Mn	1.50	746.01
G18	Mo	0.00999	4.9925037	G39	Mo	0.01	4.99
G18	Na	0.06566	32.813593	G39	Na	0.02	9.98
G18	Ni	0.09817	49.06047	G39	Ni	0.08	38.84
G18	P	0.15679	78.355822	G39	P	0.01	4.99
G18	Pb	0.14096	70.444778	G39	Pb	0.22	108.82
G18	S	0.41688	208.33583	G39	S	0.05	24.95
G18	Si	455.6238	227698.05	G39	Si	395.06	197133.24
G18	Sr	0.10788	53.913043	G39	Sr	0.05	24.95
G18	Ti	4.20353	2100.7146	G39	Ti	8.64	4309.83
G18	Zn	0.15992	79.92004	G39	Zn	0.41	202.30
G18	Zr	0.21789	108.89055	G39	Zr	0.43	214.84
			0				0.00
G19	Al	148.5059	74439.048	G40	Al	303.78	150461.72
G19	As	0.1	50.125313	G40	As	0.10	49.53
G19	Ba	0.42071	210.88221	G40	Ba	4.55	2255.98
G19	Ca	38.90583	19501.669	G40	Ca	25.12	12441.21
G19	Cd	0.004	2.0050125	G40	Cd	0.00	1.98
G19	Co	0.02018	10.115288	G40	Co	1.92	951.72
G19	Cr	0.08777	43.994987	G40	Cr	0.01	4.95
G19	Cu	0.04259	21.348371	G40	Cu	0.67	330.95
G19	Fe	60.53133	30341.519	G40	Fe	86.47	42827.04
G19	K	0.8	401.00251	G40	K	0.80	396.24
G19	Mg	15.28522	7661.7644	G40	Mg	3.35	1658.95
G19	Mn	0.9039	453.08271	G40	Mn	41.70	20651.81
G19	Mo	0.00999	5.0075188	G40	Mo	0.01	4.95
G19	Na	0.09989	50.070175	G40	Na	0.05	22.79
G19	Ni	0.06311	31.634085	G40	Ni	0.23	112.18
G19	P	0.04951	24.817043	G40	P	0.01	4.95
G19	Pb	0.12079	60.546366	G40	Pb	0.05	24.76
G19	S	0.05	25.062657	G40	S	0.05	24.76
G19	Si	476.2344	238713.97	G40	Si	367.63	182087.61
G19	Sr	0.11759	58.942356	G40	Sr	0.05	24.76
G19	Ti	5.12692	2569.8847	G40	Ti	8.89	4405.32
G19	Zn	0.24733	123.97494	G40	Zn	0.47	231.62
G19	Zr	0.25959	130.1203	G40	Zr	0.42	206.35

APPENDIX F

EXTRACTABLE INDEX ELEMENT DATA OF THE SELECTED SOILS

	G1	G2	G3	G4	G5	G6	G7	G8
Al	2386	2261	1990	1603	1489	1453	1650	1778
As	0	0	0	0	0	0	0	0
B	2.615	1.786	1.229	0.900	1.096	0.506	1.463	0.977
Ba	49.6	38.7	32.3	24.5	23.4	20.5	215.6	166.7
Ca	14249	14469	13405	12227	13182	12422	14682	15084
Cd	0	0	0	0	0	0	0	0
Co	3.314	3.350	1.384	0.504	0.913	0.761	1.221	1.342
Cr	0.307	0.446	0	0.964	0	0.283	0	0
Cu	4.35	4.18	1.59	3.75	3.10	3.45	4.27	2.37
Fe	997	1061	696	796	501	656	587	374
Hg	0	0	0	0	0	0	0	0
K	120.8	71.1	48.0	44.8	39.0	41.2	48.2	50.2
Mg	1227	924	778	721	854	827	928	940
Mn	417	268	104	34	164	74	223	146
Mo	0	0	0	0	0	0	0	0
Na	161	291	456	669	1077	1282	1412	1480
Ni	2.97	2.40	1.56	2.38	2.54	1.58	1.56	1.53
P	4.64	1.97	0	0	0	0	0	0
Pb	7.04	8.92	6.14	4.05	3.76	2.59	4.33	3.36
S	13.7	2.0	0	0	6.6	18.9	91.4	111.9
Se	0	0	0	0	0	0	0	0
Si	1554	1426	1143	1119	1468	1407	1493	1527
Sr	24.9	23.5	23.3	24.3	26.3	26.0	31.3	31.0
Ti	0	0	0	0	0	0	0	0
Zn	5.548	2.851	1.926	1.518	1.301	1.389	1.515	1.788
Zr	0.519	0.820	0.841	1.248	0.558	0.455	0.401	0.371

	G10	G11	G12	G13	G14	G15	G16	G17
Al	2778	2661	2762	1857	2605	1715	566	1611
As	0	0	0	0	0	0	0	0
B	1.071	0.090	0	0	0	0.123	0	3.649
Ba	160.0	136.9	113.9	82.3	73.9	94.5	68.9	276.2
Ca	16921	12074	13052	12394	13833	20037	204496	13861
Cd	0.036	0	0.051	0	0	0	0.109	0.064
Co	6.96	6.52	4.17	3.07	4.39	3.71	1.00	5.98
Cr	0	0.592	0	0.393	0.456	0.532	0.957	0.134
Cu	6.86	6.48	4.81	3.47	4.67	2.69	4.28	4.99
Fe	1393	1512	1030	535	874	721	199	773
Hg	0	0	0	0	0	0	0	0
K	98	56	65	46	75	96	74	140
Mg	1270	1098	1047	921	1074	1045	1093	1045
Mn	905	766	467	274	426	376	90	714
Mo	0	0	0	0	0	0	0	0
Na	60	106	162	185	199	216	203	44
Ni	8.42	9.81	7.76	5.13	5.65	6.99	1.83	5.59
P	9.1	0	0	0	0	0	0	21.4
Pb	9.86	10.42	9.75	7.66	9.21	6.79	3.62	9.56
S	4.1	0	0	0	0	24.0	160.3	29.4
Se	0	0	0	0	0	0	0	0
Si	1609	1481	1588	1411	1700	1614	981	1395
Sr	17.7	15.8	15.7	15.8	16.4	17.8	56.6	47.0
Ti	0	0	0	0	0	0	0	0
Zn	3.007	2.366	2.607	1.762	2.691	1.566	1.771	3.109
Zr	0.642	0.499	0.497	0.358	0.429	0.439	1.504	0.457

	G18	G19	G20	G21	G22	G23	G24	G25
Al	1615	1517	914	0	0	0	0	0
As	0	0	0	0	0	0	0	0
B	1.496	0.535	0	1.959	0.682	0	0	0
Ba	231.2	142.5	29.7	30.3	25.2	17.6	17.6	16.3
Ca	12254	17131	12263	245257	237228	239619	233994	229140
Cd	0	0	0	0.164	0.222	0	0	0
Co	5.895	3.546	0.407	0.615	0.216	0	0	0
Cr	1.359	1.442	0.477	0.425	0.482	0	0	0
Cu	6.32	3.93	2.22	0	0	0	0	0
Fe	1547	1516	410	85	176	73	73	87
Hg	0	0	0	0	0	0	0	0
K	83	63	23	242	73	0	0	0
Mg	714	391	202	916	724	1394	763	738
Mn	662	278	11	214	93	87	121	91
Mo	0	0	0	0	0	0	0	0
Na	61	77	187	66	89	224	249	209
Ni	6.316	3.672	0.762	0.866	0.736	0	0	0
P	4.99	2.02	0	0	0	0	0	0
Pb	9.45	8.48	5.18	0	0	0	0	0
S	13.5	3.7	0	153.9	137.6	0	0	0
Se	0	0	0	0	0	0	0	0
Si	1443	1501	1299	335	113	30	63	31
Sr	41.7	44.8	50.3	49.6	43.1	36.7	37.5	44.0
Ti	0	0	0	0	0	0	0	0
Zn	2.87	2.07	0.96	0	10.19	53.39	54.25	53.30
Zr	0.430	0.687	0.960	0	0.053	0	0	0

	G26	G27	G28	G29	G30	G31	G32	G33
Al	0	3347	4043	3573	975	726	3676	3713
As	0	0	0	0	4.758	7.695	0	0
B	0	1.077	0.475	0.293	0.243	0	0	0
Ba	15.1	45.1	48.8	46.6	33.9	30.9	45.1	25.9
Ca	212403	10355	10387	13257	226776	231942	2219	5710
Cd	0	7.136	0	0	0.128	0.059	0	0
Co	0	8.174	7.032	5.315	5.221	1.078	14.659	12.390
Cr	0	0	0	0	0.658	0.660	0	0
Cu	0	4.60	3.50	2.21	1.57	0.13	8.95	7.26
Fe	51	2471	2448	1326	277	141	3146	1872
Hg	0	0	0	0	0	0	0	0
K	0	289	181	170	59	54	51	32
Mg	675	577	482	380	654	594	84	30
Mn	74	1125	882	635	268	158	1426	653
Mo	0	0	0	0	0	0	0	0
Na	217.6	3.9	0.3	0	64.5	59.3	7.9	0
Ni	0	4.412	3.066	2.157	1.106	0.863	1.026	1.604
P	0	0	0	0	0	0	0	0
Pb	0	15.18	13.91	14.19	1.86	0	30.24	23.14
S	0	14.07	33.23	9.22	121.44	119.06	34.43	29.20
Se	0	0	0	0	0	0	0	0
Si	1198	1578	1591	1639	682	389	748	706
Sr	42.05	2.13	2.50	2.72	19.92	23.59	3.03	2.91
Ti	0	0	0	0	0	0	1.214	0.768
Zn	54.24	3.88	2.20	2.47	10.81	9.25	1.34	0.63
Zr	0	1.003	1.225	1.298	1.763	0.345	1.887	0.928

	G34	G35	G36	G37	G38	G39	G40
Al	3290	3042	2492	1986	1893	1582	1923
As	0	0	0	0	0	0	0
B	0.117	0.245	0	0	0.364	0	0.037
Ba	40.5	16.7	17.7	17.9	24.4	24.3	109.1
Ca	1975	1515	5977	2374	4922	4031	3091
Cd	0	0	0	0	0	0	0
Co	14.37	1.45	1.06	0.48	17.89	5.61	34.85
Cr	0	0	0	0	0	0	0
Cu	4.00	2.85	2.43	2.93	4.23	3.88	17.89
Fe	1587	691	627	572	563	368	474
Hg	0	0	0	0	0	0	0
K	12.5	11.1	13.3	12.3	16.2	19.4	22.2
Mg	4	8	39	41	53	69	60
Mn	637	38	22	17	220	93	663
Mo	0	0	0	0	0	0	0
Na	0	0	0	0	0	13.3	3.3
Ni	1.835	1.058	0.896	0.675	0.755	0.378	1.819
P	0	0	0	0	0	0	0
Pb	23.10	8.95	8.12	5.45	26.69	10.46	0
S	13.57	15.07	6.46	10.84	8.78	4.71	0.24
Se	0	0	0	0	0	0	0
Si	649	580	671	692	725	742	916
Sr	2.20	1.85	3.30	2.74	3.01	2.26	1.87
Ti	0.974	0.601	0.284	0.514	0.335	0.217	0.502
Zn	0.716	0.183	0.826	0.306	0.558	1.327	2.851
Zr	0.657	0.875	0.811	0.831	0.775	0.823	0.763

APPENDIX G

STRATEGIES FOR SUSTAINABLE AGRICULTURE

SUSTAINABLE AGRICULTURE: a system develop to maximize the internal resources of the farm, minimize environmental impacts, and increase profits by reducing external inputs.

Sustainable agriculture should focus on:a

a) Implementation of soil and water conservation practices.

b) Implementation and improvement of agronomic and cultural practices such as: rotations, organic matter inputs, crop breeding, integrated pest management, intercropping, trap crops, contour cropping, mulching (very important in tropical agriculture), etc.

c) Watershed management: combination of traditional and nontraditional agriculture with improved water use, forest soil, pest control and protected areas.

d) Strengthening two-way linkages between farmers, extentionists and research scientists.

e) Increase programs for diversification and diversity (mixed cropping systems, fisheries, agroforestry, and maintaining diversity of germplasm and species).

f) Develop creative approaches to strengthen institutions (eg. linkages between public and private sectors, extension, university networks, etc.)

g) Overcome marketing constraints and improve market opportunities (eg. ensure linkage between demand and research on technology and improve marketing information systems).

h) Strengthen incentives for private sector as participant in all agricultural programs.

I) Link the development of infrastructure in rural areas to goals of sustainability, and Integrate rural people in the wider economy. A community-based approach to economic development now appears to be absolutely vital to ensure that people fully participate in the decisions affecting their economic livelihoods.

j) Encourage the provision of physical infrastructure, services, and education in rural areas.

k) Support innovative financing arrangements to overcome credit constraints, such as debt for development swaps.

l) Encourage the development of policies and taxation to promote appropriate land use.

m) Reorient regional research toward sustainable agriculture.

n) Encourage the use of native technologies (specially the Mayan technologies) that are far more sustainable that the standard agriculture.

Note: these agricultural strategies should also be accompanied by the management of protected areas, and the enforcement of appropriate policies required to maintain the natural resource that provide the country with water and many other raw materials for agriculture, industry and human consumption.

VITA

Luis Carlos Donado Torres was born on August 12, 1964 in Guatemala City, Guatemala to Mr. Luis Alfredo Donado and Mrs. Gladys Stella Torres de Donado. Luis attended elementary, middle and high school at "La Preparatoria School" in Guatemala City. Upon graduation he entered Rafael Landivar University in Guatemala and in 1989 he decided to attend the University of Tennesse at Martin to study English and take several courses in agriculture as part of a special program sponsored by The International Agency for Development (AID). He received an award for being an outstanding student from the International Programs Office of U.T. Martin. In 1991, after completing his thesis in Guatemala, he graduated from Landivar University with a degree in Agricultural Engineering, where he received an award for his thesis entitled: "Formulation of Computerized Model for Machinery Management".

In 1992 Luis began working at Landivar University as the coordinator in the area of agricultural engineering, and as the coordinator of the linkage program between the U.T. institutions and Landivar University. As a result of this linkage program, Luis entered to U.T. Knoxville in 1993 to study for a Masters degree in Soil Science at the Plant and Soil Science Department. While at UTK he participated as an instructor and translator in the training program: Manejo Sostenido de los Recursos Naturales y Proteccion Medio Ambiental, sponsored by The International Programs for Agriculture and Natural Resources. His area of research dealt with tropical soils obtained in the Mayan Biosphere Reserve in northern Guatemala.

Luis is a member on the College of Engineers in Agriculture in Guatemala, and also belongs to the Honor Society of Agriculture: Gamma Sigma Delta.

Upon completion of the M. S. degree, he will be hired to work for the Department of Plant and Soil Science in the field of tropical pedology and as a trainer for courses sponsored by the International Programs for Agriculture and Natural Resources.

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