EVALUATION OF CHARACTERISTICS OF CAMBISOLS DERIVED FROM LIMESTONE IN LOW TABLELANDS IN NORTHEASTERN BRAZIL: IMPLICATIONS FOR MANAGEMENT[1]

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ABSTRACT - Soils of the low tablelands in Northeastern Brazil have high natural fertility, however, little is known about them. The objective of this study is to provide basic information about the soil and how soil properties relate to their use and management. Two Cambisol pedons were morphologically described and were submitted to physical, chemical and mineralogical analyses. The soils on mid to upper landscape positions are Eutrophic Cambisols and those in lower positions are Vertic Cambisols. For both soils, pH is above 7 and base saturation is higher than 90%. In order to ensure crop production, N, P and micronutrients have to be added as fertilizers. Water runs off the Eutrophic Cambisols and runs on to the Vertic Cambisols, so the Vertic soils have more water available for plant growth. In the Eutrophic Cambisols the main constraints are susceptibility to drought and erosion, while in the Vertic Cambisols the waterlogging risk and mechanization impediments are the critical limitations. Soil properties such as landscape position, color, drying velocity and shrinkage are easily-identifiable field attributes that can be used to recognize different soils that should be managed differently.

Index terms: drainage, incipient soils, vertic soils.

AVALIAÇÃO DE CARACTERÍSTICAS DE CAMBISSOLOS DERIVADOS DE CALCÁRIO EM CHAPADAS DO NORDESTE BRASILEIRO: IMPLICAÇÕES PARA MANEJO

RESUMO - Os solos das chapadas do Nordeste brasileiro têm alta fertilidade natural, contudo, são pouco estudados. Os objetivos deste trabalho foram fornecer informações básicas a respeito dos solos e de como suas propriedades afetam seu uso e manejo. Dois perfis de Cambissolos foram descritos e diversas análises, físicas, químicas e mineralógicas, feitas. Os solos da porção superior da paisagem são Cambissolos eutróficos, enquanto os Cambissolos vérticos ocupam as posições inferiores. Em ambos, o pH é acima de 7 e a saturação por bases superior a 90%. Para assegurar a produtividade, N, P e micronutrientes têm de ser adicionados. Uma vez que a água drena dos Cambissolos eutróficos para os vérticos, estes têm mais água disponível para as plantas. Nos Cambissolos eutróficos, os principais impedimentos são a susceptibilidade à seca e à erosão, enquanto que nos Cambissolos vérticos o risco de inundação e os impedimentos à mecanização são as limitações mais críticas. Propriedades do solo, tais como posição na paisagem, cor, velocidade de secamento e fendilhamento são atributos facilmente identificáveis no campo que podem ser usados para reconhecer solos que devem ser manejados diferentemente.

Termos para indexação: drenagem, solos incipientes, solos vérticos.

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INTRODUCTION

Cambisols with high-activity clay and predominantly low relief are the main soils of the low tablelands in Northeastern Brazil where limestone is the parent rock. They cover 3,976 km^2 in Rio Grande do Norte State, and are also extensive in other Brazilian states, mainly in Bahia, Ceará, Minas Gerais and Sergipe. The area is part of the Dry Polygon region and the main land uses are cotton field and pasture for cattle.

These tablelands are being promoted by government programs to be used for improving food production as they have good agricultural potential (Brasil, 1971). However, little is known about the soils of the tablelands and their use and management. Silva (1973), Fonseca (1977), Ernesto Sobrinho (1980), Soares (1980) and Moura (1988) included some information about Cambisols from this area in their studies. However, there is a need for more detailed studies of these soils. This information can be used to suggest new farming methods appropriate for local conditions.

The objectives of this study were: (i) to identify and characterize the members of the Cambisols hydrosequence, (ii) to identify their main constraints for agriculture and (iii) to suggest easily-identifiable field attributes that can be used to identify soils that should be managed differently.

MATERIAL AND METHODS

Studied soils and environment

The Cambisols studied are in the Chapada do Apodi region in the northwest part of Rio Grande do Norte State, Northeastern Brazil (approximately, 37°15' to 38° W and 5° to 5°40' S). The parent rock is fine-grained limestone (Jandaíra formation) (Brasil, 1971). This limestone has dolomitic features and may present fossils (Beurlen, 1967). Its color can be white, grayish or yelow, with indistinct stratification (Silva, 1973). Such limestone presents muscovite as one of its main impurities (Ernesto Sobrinho, 1980).

The region is under a hot semi-arid climate, BSw'h' of the Köppen classification (Brasil, 1971). The rainy seasons are not well distributed; February, March and April are the rainest months, while the others are practically dry (Silva & Lima, 1982). The primitive vegetation is represented by the “caatinga” community, which consists of hyperxerophilous sparse small trees, variable in terms of height and density (Brasil, 1971).

The soil average annual temperature is more than 22°C, with small annual variation (Ernesto Sobrinho, 1980). The general drainage is good, but it varies locally. Even during the rainy season, the soils in the upper part of the landscape do not present water saturation at any depth. Soils under similar conditions, but outside the studied area, have presented only 50 consecutive days per year with available water to plants (Ernesto Sobrinho et al., 1983). On the other hand, soils in the lower part of the landscape have, during the short wet season, a 0.5 m-deep perched water table and, in the horizons above 0.5 m, negative water potentials near zero.

A representative area, near Mossoró (RN), was chosen and every horizon from two Cambisols, one high and one low in the local landscape, was sampled and described (Lemos & Santos, 1984; Larach et al., 1988). The horizons sequences were A, Bi (incipient B horizon), BC, C and Cr for the first soil, and A, Biv (incipient B horizon with vertic characteristics), BC, C and Cr for the latter. The classification of the soils, according to Soil Taxonomy (Estados Unidos, 1994), is Typic Eutropept and Vertic Eutropept, respectively. The slope gradient varies between 0% and 3% and the altitude from 10 m to 160 m above the sea level (Fig. 1). Table 1 summarizes the pedon description of the two soils.

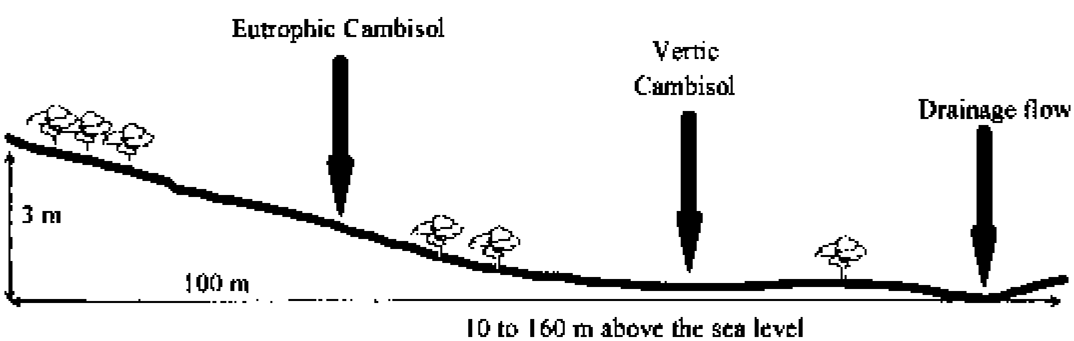

FIG. 1. Schematic representation of the soil distribution on the landscape.

Chemical, physical and mineralogical analyses

The following physical analyses were performed: particle-size-distribution (pipette method, adapted by Ernesto Sobrinho, 1980), water-dispersible clay (Grohmann & Raij, 1974), particle density (Black & Hartge, 1986), specific surface area (Heilman et al., 1965) and moisture retention curve (Klute, 1986).

The following chemical analyses were made: sulphuric acid digestion; organic C by wet oxidation with $K_2Cr_2O_7$; calcium carbonate equivalent; Ca, Mg and Al extracted with 1 M KCl (1:10); K and Na extracted with 0.05 M HCl and 0.05 M H_2SO_4; determination of acidity (pH 7.0 $Ca(OAc)_2$) by titration with NaOH solution; available P extracted with 0.05 M HCl and 0.05 M H_2SO_4 (Vettori, 1969; Embrapa, 1979); micronutrients by Mehlich-1 extractant; SO_4^{2-}- S extracted with $Ca(H_2PO_4)_2$ (Tedesco et al., 1985, with modifications); total free iron oxides, Fe_d, by citrate dithionite-bicarbonate (Mehra & Jackson, 1960); and less crystalline iron oxides, Fe_o, by acid ammonium oxalate (Schwertmann, 1964).

The fine sand and silt fractions were submitted to X-ray diffraction analysis (XRD), using the powder method. Clay mineralogy was interpreted from diffractograms obtained from oriented samples, untreated or previously treated with CDB, saturated with Mg (25°C) and glycolated, saturated with K (25°C) and heated to 350°C and 550°C. The iron oxides mineralogy was also analysed by XRD (powder method), after treatment of clay fraction samples with 5 M NaOH for concentrating them (Kämpf & Schwertmann, 1982). It was utilized a Philips diffractometer with Cu tube and Ni filter. The diffractometer worked at 48 kv and 18 mA.

Information obtained through informal interviews with farmers (Chapada do Apodi Project - SUDENE/FGD/SOILS Accord 1984/85) was also summarized.

RESULTS AND DISCUSSION

The particle density, particle-size-distribution, water-dispersible clay and specific surface area data are presented in Table 2.

The values of particle density are within the expected range, 2.6 Mg m^{-3} to 2.8 Mg m^{-3}. The Eutrophic Cambisol has more clay, more water-dispersible clay and more silt than the Vertic one. The higher silt content makes the Eutrophic soil more subjected to soil crusting and its higher position in the landscape causes it to be more subjected to erosion, which is in accordance with the data of Moura (1988). The results of specific surface area corrected by clay content are higher in the Vertic soil, a reflection of its higher clay activity.

It is important to stress that, although the analytical data (Fig. 2) show about the same values of available water (0.033 MPa to 1.5 MPa), the Vertic Cambisol retains more water during the year as compared to the Eutrophic Cambisol. The differences in moisture regime are probably due more to run-on and run-off than to available water holding capacity differences. This occurs because the Vertic Cambisol receives run-on. These findings emphasize the need for considering the field relations the soil samples represent (Daniels, 1988).

The obtained values for pH, exchangeable cations, P from sulphuric acid digestion and available P are presented in Table 3. The pH data, high in both soils, reflect the amounts of $CaCO_3$ equivalent (Fig. 3). The high values of exchangeable bases in both Cambisols are related to the high content of them in the parent material and the low degree of weathering and leaching due to the semi-arid climate.

The exchangeable Ca values follow those for $CaCO_3$ equivalent (Fig. 3). The K^+ values are higher in the Eutrophic soil probably due to its greater amount of mica. This nutrient is present in higher quantities in upper soil horizons, which demonstrates the importance of vegetation recycling. The opposite behavior was revealed by Na^+ (higher amounts in the Vertic soil and a tendency to increase with depth). This can be explained by the low landscape position of the Vertic soil and by the greater Na^+ mobility. The CEC per 100 g of clay is higher in the Vertic soil, a consequence of its greater amount of smectite.

The amount of P_2O_5 extracted by H_2SO_4 (an index of total P) is very low, showing the unequivocal need for phosphate fertilization to ensure crop production. The available P is low because the parent material is poor in this nutrient. The hypothesis that much P is fixed as calcium phosphates of low solubility (Raij, 1981) is not supported in the present case, because the Mehlich-1 extractant would solubilize such compounds.

The results of analyses of organic carbon, micronutrients and SO_4^{2-}-S, Fe_d and Fe_o are included in Table 4.

The amounts of organic C are higher in the Eutrophic soil due to its greater clay content (Table 2); apparently the humus-clay complex minimizes microbial action (Russell, 1976; Medeiros, 1977). In the Vertic soil, the periodic fissures probably favor a higher organic matter degradation because of good local aeration and, its adverse physical properties (which result from its higher quantity of smectite) affect plant growth because of injuries to roots (Ernesto Sobrinho, 1980).

The Vertic Cambisol contains more micronutrients, probably due to its lower pH. In the Eutrophic soil, the micronutrients should preferentially be in the hydroxide form. The low content of Cu in this soil is probably related to the formation of stable compounds with the higher amounts of organic matter (Table 4). The much higher contents of Fe and Mn in the surficial horizons of the Vertic Cambisol are probably due to lateral movement of these micronutrients together with water from the upper landscape positions.

Sulfate-S values are higher in the two surficial horizons compared with deeper ones, which is consistent with their greater quantities of organic matter. These data are classified as adequate for the A horizon and as medium for the B horizon (Vitti, 1989).

TABLE 1. Selected morphological properties of the soils.

Soil/horizon	Depth	Moist color	Structure[1]	Consistence[2]
	cm			
Eutrophic Cambisol				
A	0-8	5YR 3/3	mfg/mfs	h fr pl st
Bi[3]	8-15	5YR 4/4	mfs	h fr vpl vst
BC	15-31	5YR 4/4	mvfs	h fr vpl vst
C	31-57	10YR 5/4	mmb/mfs	vh fm vpl vst
Cr	57-70 +	2.5YR 5/4	mfs	sh vfr vpl vst
Vertic Cambisol				
A	0-3	10YR 3/3	mfs	sh fr pl st
Biv[4]	3-22	10YR 3/3	mfs/mmb	h fm vpl vst
BC	22-38	10YR 4/4	mfs/mmb	h fm vpl vst
C	38-48	10YR 5/3	mvfs	sh fr pl st
Cr	48-68 +	5Y 7/3	mvfs	h fm pl st

1 mfg = moderate fine granular; mfs = moderate fine subangular blocky; mvfs = moderate very fine subangular blocky; mmb = moderate medium angular blocky.
2 h = hard; vh = very hard; sh = slightly hard; fr = friable; fm = firm; vfr = very friable; pl = plastic; vpl = very plastic; st = sticky; vst = very sticky.
3 Incipient B horizon.
4 Incipient B horizon with vertic characteristics.

TABLE 2. Selected physical properties of the soils.

Soil/horizon	Particle density	Total sand	Silt	Clay	Water disper. clay	Spec. surf. area of clay
	$Mg\ m^{-3}$	------------------------------ $g\ kg^{-1}$			------------------------------	$m^2\ g^{-1}$
Eutrophic Cambisol						
A	2.67	290	340	370	310	550
Bi[1]	2.62	250	290	460	390	480
BC	2.60	240	290	470	130	430
C	2.57	230	290	290	60	720
Cr	2.74	200	580	220	40	840
Vertic Cambisol						
A	2.69	720	170	110	80	1190
Biv[2]	2.72	550	250	200	190	750
BC	2.65	540	180	280	110	670
C	2.79	410	360	230	40	790
Cr	2.72	220	570	210	30	850

1 Incipient B horizon.
2 Incipient B horizon with vertic characteristics.

TABLE 3. pH, exchangeable cations, CEC, base saturation, P_2O_5 from H_2SO_4 dissolution and available P of the soils.

Soil/horizon	pH		Exchangeable cations					CEC[1]	Base	P_2O_5	Avail.
	H_2O	KCl	Ca	Mg	K	Na	Al		sat.		P
			---------------------- cmol (+) kg^{-1} --------------------						%	g kg^{-1}	mg kg^{-1}
Eutrophic Cambisol											
A	7.6	6.7	18.5	6.6	1.4	0.1	0	53.5	96	0.3	2
Bi[2]	8.3	7.1	21.2	7.2	0.8	0.2	0	57.7	99	0.2	2
BC	8.4	7.2	21.6	8.1	0.6	0.3	0	60.8	100	0.2	1
C	8.4	7.3	29.5	4.5	0.2	0.3	0	113.5	100	0.1	0
Cr	8.7	7.5	13.6	9.0	0.1	0.3	0	99.7	98	0.1	0
Vertic Cambisol											
A	7.2	6.2	13.1	5.1	0.7	0.3	0	141.1	95	0.1	6
Biv[3]	7.1	5.2	17.0	7.4	0.2	0.3	0	122.5	94	0.1	1
BC	7.6	5.8	24.4	8.4	0.1	0.3	0	115.4	98	0.1	1
C	8.2	6.6	24.5	7.6	0.1	0.4	0	142.0	98	0.1	1
Cr	8.5	7.3	11.4	7.1	0.1	0.5	0	90.4	98	0	0

[1] CEC per 100 g of clay, after discounting the organic matter contribution.
[2] Incipient B horizon.
[3] Incipient B horizon with vertic characteristics.

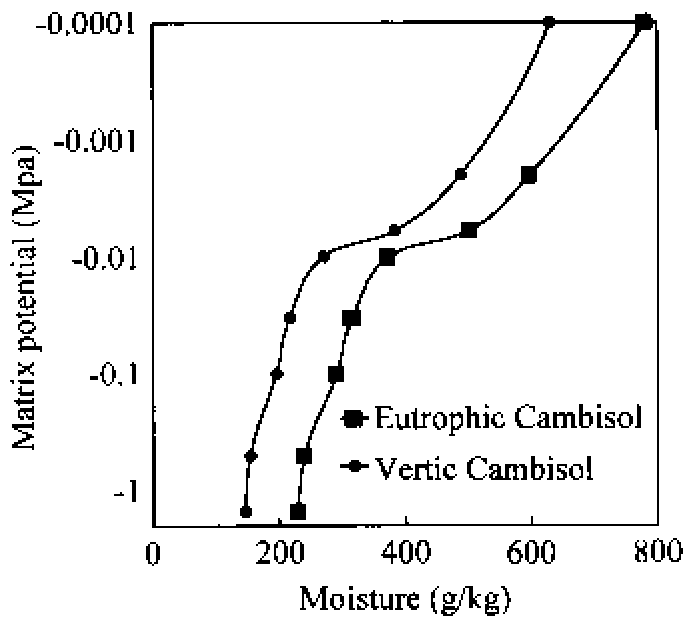

FIG. 2. Moisture retention curves of the studied soils (B horizon, Eutrophic Cambisol: 8-15 cm; Vertic Cambisol: 3-22 cm).

The $CaCO_3$ equivalent curves (Fig. 3) show that the Vertic soil is leached deeper than the Eutrophic soil, probably because surface water moves from upper to lower landscape positions where it moves down in the profile. At depth, however, the two soils have similar $CaCO_3$ values, which indicates that in the area as a whole the climate is insufficient to remove the $CaCO_3$ from the system, and the parent materials are similar.

Although the "total" Fe is lower in the Vertic Cambisol (33.1 g kg^{-1} and 40.1 g kg^{-1} to Vertic and Eutrophic Cambisol, respectively), its Fe_d content is higher (20.7 g kg^{-1} and 12.8 g kg^{-1} to Vertic and Eutrophic Cambisol, respectively), which suggests an attack by CDB on the smectitic clay of this soil, releasing Fe (Borggaard, 1988). The more elevated Fe_o/Fe_d ratio in this soil (0.10 g kg^{-1} and 0.03 g kg^{-1} to

Vertic and Eutrophic Cambisol, respectively) indicates greater proportion of less crystalline iron oxides, which is consonant with its wetter environment (Schwertmann & Kämpf, 1983).

The mineralogy of the fine sand fraction for both Cambisols mainly revealed quartz, feldspar and calcite, whereas the silt fraction also contains mica (muscovite). These findings indicate a good nutrient reserve, which is consistent with the nature of their parent material. These diffractograms are not shown because they all are about the same for both soils.

In the clay fraction (Figs. 4 and 5) mica, kaolinite, goethite and anatase were identified in both soils. The Eutrophic Cambisol (7.5YR hue) also contained mica-vermiculite intergrade and hematite, while smectite was present in the Vertic one (10YR hue). Sodalite was identified (Fig. 5), but it is an expected artificial consequence of the 5 M NaOH treatment (Kämpf & Schwertmann, 1982).

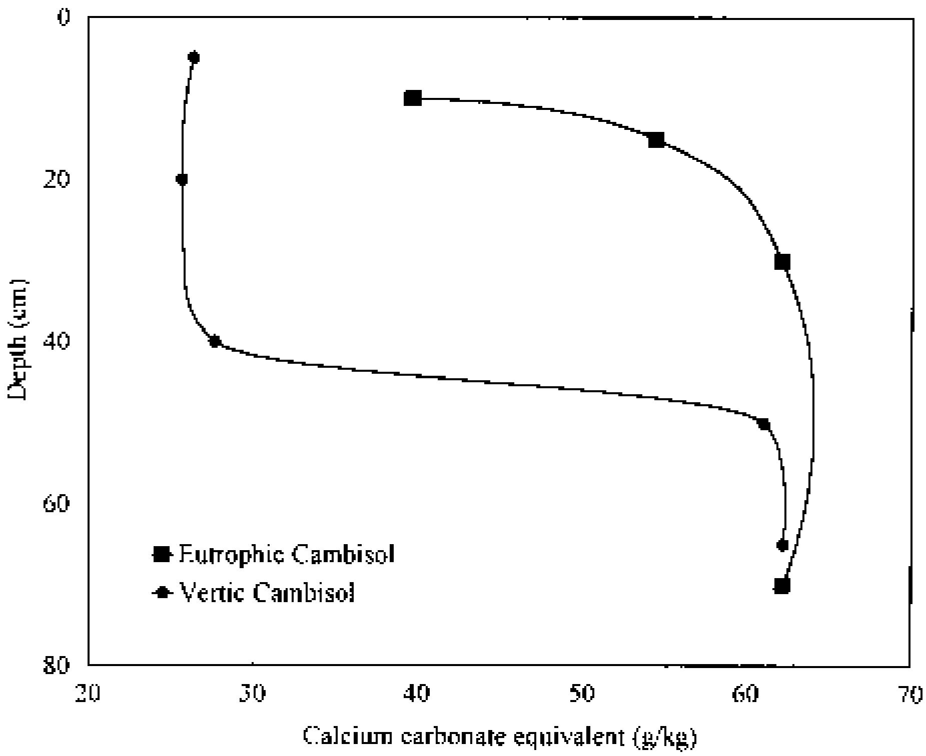

FIG. 3. Variation of $CaCO_3$ equivalent, with depth, in the studied soils (B horizon, Eutrophic Cambisol: 8-15 cm; Vertic Cambisol: 3-22 cm).

TABLE 4. Organic C, micronutrients and SO_4^{2-}-S.

Soil/horizon	Organic C	Micronutrients				SO_4^{2-}-S
		Cu	Zn	Fe	Mn	
	g kg^{-1}	---------------- mg kg^{-1}				-----------------
Eutrophic Cambisol						
A	17.3		1.0	8.2	130.7	16.2
Bi[1]	7.0		0.2	0.8	7.1	9.4
BC	4.2		0.7	0.5	1.0	4.1
C	3.5		0.1	0.6	0.8	6.2
Cr	2.8		0.1	0.4	0.8	6.2
Vertic Cambisol						
A	10.4	2.8	2.4	282.6	249.0	19.8
Biv[2]	4.2	1.9	1.2	249.0	90.0	8.1
BC	3.5	2.2	1.5	274.8	80.4	6.2
C	1.4	0.3	1.6	3.5	12.2	5.8
Cr	0.7	0.3	0.8	0.5	4.5	0.9

[1] Incipient B horizon.
[2] Incipient B horizon with vertic characteristics.

The diffractograms of the natural samples from horizon Cr to A (Fig. 6) revealed in both soils a decrease in the intensity of the 0.498 nm-peak. This fact suggests the mica transformation into kaolinite towards the profile surface which corroborates the higher amounts of K^+ in the same direction (Table 3). The Eutrophic soil contained more mica, in accordance with its greater values of K^+ (Table 3).

Silica probably moves laterally, together with other cations, to the depressional parts of the landscape, and the high Si content there promotes the formation of smectite. The aspects that support this hypothesis are: high pH favoring silica dissolution and the presence of kaolinite in high amounts in the Eutrophic Cambisol in spite of its high pH and presence of free $CaCO_3$ (if lateral movement of silica would not happen smectite should be detected in this soil). In accordance with this, the ratio between the SiO_2 content (H_2SO_4 digestion) and the amount of clay for the solum of the Eutrophic Cambisol is 0.69 and for the solum of the Vertic one is 0.79. The smectite content in the Vertic Cambisol explains its higher CEC and surface area per 100 g of clay (Table 3), and is responsible for greater intensity of physical problems related to soil management.

The main limitations for agricultural use of the soil as interpreted from soil data, from informal interviews with farmers (Chapada do Apodi Project-SUDENE/FGD/SOILS Accord 1984/85) and from knowledge of the region are shown in Table 5, as well as suggestions for use and management of the soils.

Water deficiency is the main problem in farming the Eutrophic soil. So, it becomes critical that the water losses through erosion measured by Moura (1988) in this soil be reduced. Oxygen deficiency, caused by seasonal excess water, is a critical problem with Vertic Cambisols. Also the smectite in its clay fraction imposes difficulties for management, because the soil has a very narrow range of moisture in which the soil is suitable for farm operations.

The Table 6 is included in order to establish simple field criteria for recognizing soil differences significant for management purposes by non-pedologists (technology transfer).

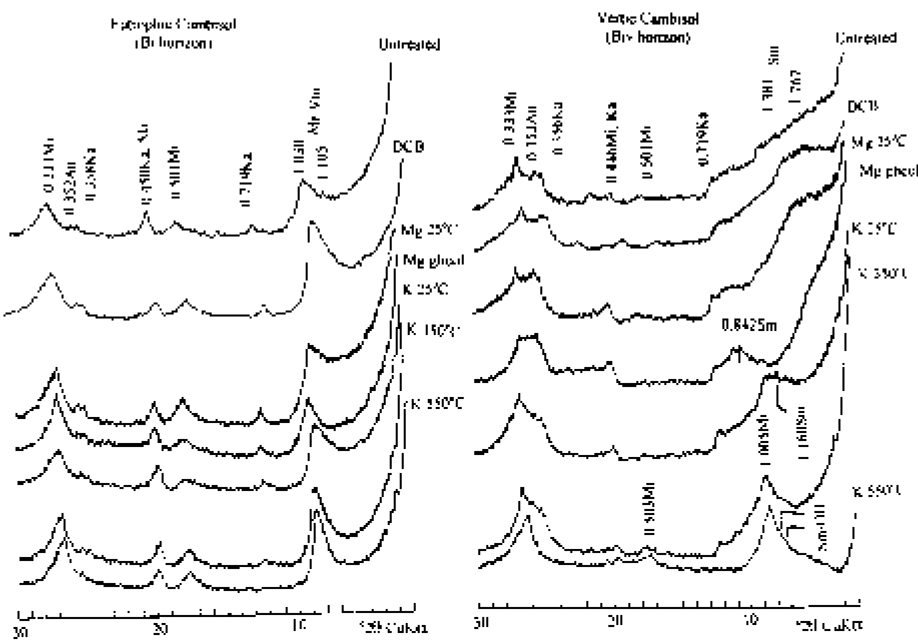

FIG. 4. X-ray diffractograms of the clay fraction (oriented samples), before and after citrate-bicarbonate-dithionite treatment. Mi-Vm = mica-vermiculite; Ka = kaolinite; An = anatase; Sm = smectite; Sm-OH = smectite with hydroxide interlayer. Numbers represent d spacings in nm.

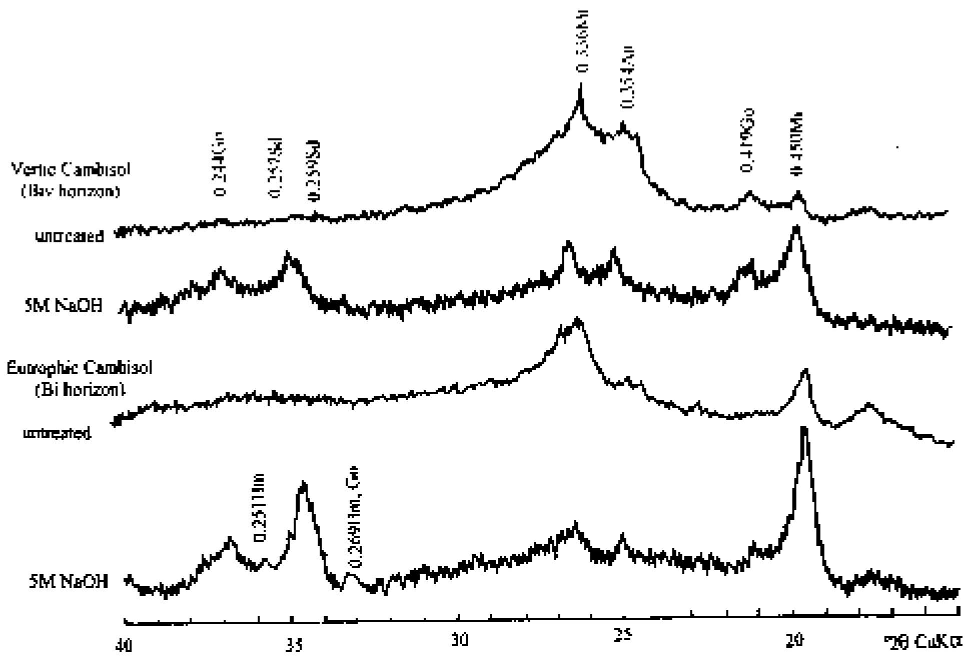

FIG. 5. X-ray diffractograms of the clay fraction (powder method), after NaOH treatment. Mi = mica; Go = goethite; An = anatase; Hm = hematite; Sd = sodalite (artifact produced by the NaOH treatment). Numbers represent d spacings in nm.

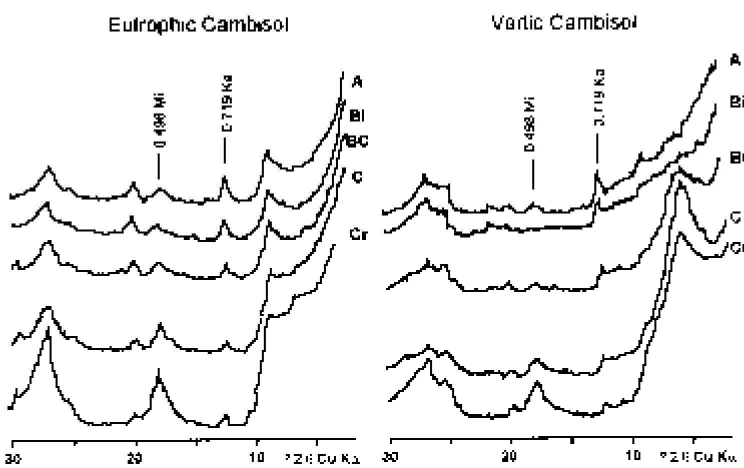

FIG. 6. X-ray diffractograms of the untreated clay fraction (oriented samples). Mi = mica; Ka = kaolinite. Numbers represent d spacings in nm.

TABLE 5. Main soil constraints and suggestions for use and management .

Main constraints	Suggestions for use and management
	Eutrophic Cambisol
Water deficiency	Irrigation; mulching; selected varieties; dry farming; short--cycle plants; cotton plantation
Susceptibility to erosion	Contour planting; pasture; crop rotation; mulch tillage
Low amounts of P, micronutrients and N	Corrective fertilization; selected varieties; naturally tolerant varieties
	Vertic Cambisol
High risk of waterlogging (oxygen deficiency)	Early planting; construction of small drainage channels; corn planting (for green harvesting)
Mechanization impediments due to shrink-swell	Use of small implements (including animal traction) and even manual implements
Low amounts of P and N	Corrective fertilization; selected varieties; naturally tolerant varieties

TABLE 6. Easily-identifiable field attributes for differential soil recognition and for management purposes.

Soil	Field criteria
Eutrophic Cambisol	Redder color Higher and medium section of the landscape Faster drying
Vertic Cambisol	Grayer color Lower (more depressional) part of the landscape Cracks during the dry season

CONCLUSIONS

1. Variations in soil properties between Cambisols depend on the soil position in the landscape.
2. Color, drying velocity and shrinkage are easily-identifiable field attributes which can be used to differentiate these soils.

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