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CONTRIBUTION OF ORGANIC MATTER TO EXCHANGE PROPERTIES OF OXISOLS

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Centre (ISRIC), Wageningen, the Netherlands, and Soil Science Department of
UFRGS, Porto Alegre, Brazil

ISRIC

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

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ABSTRACT

Organic matter, clay content and cation exchange capacity (CEC) were determined on 39 profiles of Oxisols of the International Soil Reference and Information Centre's monoliths collection. These soils were described and sampled in 14 tropical countries. By means of multiple regression analysis the contribution of organic matter to the CEC was calculated.

The mean CEC of 1 g of carbon was found to be 3.36 me (range: 1.4-9.4 me) and is slightly lower in Haplorthox, Haplustox and Acrorthox, than in Humox, Acrustox and Eutrustox + Eutrorthox. The contribution of organic matter to soil CEC is high ($\bar{x}$ = 51%) in A horizons, especially in Acrustox (44 to 77%), Acrorthox (49-76%) and Humox (39-68%). In the B horizons this contribution is lower ($\bar{x}$ = 18%), being very low in Haplorthox (8-18%) and Haplustox (3-35%). This contribution should be considered in determining the CEC of the clay fraction, a parameter used in the classification of Oxisols. The type of vegetation and climatic zones in which these soils occur do not significantly influence the CEC of the organic fraction.

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* Joint contribution of the International Soil Reference and Information Centre - ISRIC, Wageningen, the Netherlands and Soil Science Department of UFRGS, Porto Alegre, Brazil

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INTRODUCTION

The decomposition products of plant and animal tissue constitute the principal carbon source for humus formation in soils (Tate & Theng, 1980). The general concept that tropical soils contain lower amounts of organic carbon than soils found in temperate regions, due to strong humification and mineralization processes in the tropical environment has been disproved (Sanchez, 1976; Jenkinson and Ayanaba, 1977; Bohn, 1978; Tate & Theng, 1980). Jenkinson and Ayanaba (1977) found that the decomposition rate of fresh plant material added to soils was four times higher in Nigeria than in England. Similar data have been presented by Sanchez (1976), who concluded that under tropical rain forest the production and decomposition of organic matter is four times higher, with the result that the final addition is equivalent in these different regions.

Factors such as temperature, precipitation and soil conditions control the production and decay of organic matter. Production mostly increases with increasing precipitation (Birch & Friend, 1956) while the optimum temperature for plant growth is between 20-25°C; but that for bacterial activity and organic matter decomposition between 30-35°C (Mohr & Van Baren, 1954). This is the reason for increased organic matter accumulation with altitude (Birch & Friend, 1956), since the precipitation mostly increases and temperature decreases with increasing altitude.

Clearing of tropical forest for crop production strongly increases the decomposition of organic matter. This is associated to the reduction of rates of incorporation of organic matter residues to soils under agriculture and leads to a decrease in soil organic matter in cultivated tropical soils (Young, 1976), and hence to a decrease in their cation exchange capacity (CEC). Brams (1971) reported a 30% reduction in soil CEC when the level of organic matter was reduced in 50% by cultivation.

Minerals in the clay fraction also contribute to the CEC of tropical soils. The main species are kaolinite, iron and aluminium (oxihydro) oxides and poorly crystallised aluminosilicates (Rodrigues & Klamt, 1976; Juo, 1980; Herbillon, 1980; Wada, 1980); but the charge density of humic substances averages 300 me/100 g at pH 7.0 (Tate & Theng, 1980), which is 30 times that of kaolinite (Goh, 1980).

The contribution of organic matter to the exchange properties is difficult to determine in detail, because of the intimate association between humic substances and inorganic soil constituents. Goh (1980) presented two alternatives to study this subject: a) the selective removal of the organic or mineral component or b) the use of multiple regression analysis to separate the effect of the different components. The statistical alternative was chosen because it does not interfere with the soil charge characteristics.

MATERIALS AND METHODS

Thirty-nine profiles of Oxisols of the International Soil Reference and Information Centre's monoliths collection, sampled and described in fourteen countries, were used for the present study.

Samples were air-dried and slightly crushed to pass a 2 mm sieve. This fine earth fraction was used to perform the analysis of organic matter expressed as organic carbon; particle size distribution and CEC, by methods described in details by Van Reeuwijk (1986). Organic matter determination followed the wet combustion method, while clay content by pipette method after removal of organic matter with H_2O_2 and CEC by replacing the NH_4 of samples leached with NH_4OA_c1N pH 7.0 by Na, using 1N NaOAc pH 7.0. After washing the excess Na with 50% ethanol and replacement of the absorbed Na by NH_4, samples were leached again with 1N NH_4OAc pH 7.0 and Na was determined by flame emission (modified from USDA, 1972). The CEC obtained was corrected for organic matter by regression analysis using the equation proposed by Bennema (1966) and Bennema and Camargo (1979):

$CEC_{soil} = a'X_1 + b'X_2$, in which

CEC_{soil} = CEC of 100 g soil,
X_1 = amount of clay,
X_2 = amount of organic carbon,
a' = CEC of 1 g of clay, and
b' = CEC of 1 g of organic carbon

By multiplying the equation by $100/X_1$, it becomes:

$100\ CEC_{soil}/X_1 = 100\ a' + 100\ b'\ X_2/X_1$, which can also be written as:

$Y = a + b\ X$, in which:

$Y = 100\ CEC_{soil}/X_1 = 100\ CEC_{soil}/\%\ clay$,

$X = 100\ X_2/X_1 = 100\%\ C/\%\ clay$,

a = CEC of 1 g of carbon, and

b = 100 a' = CEC of 100 g clay

Graphically this equation (Figure 1[1/]) results in a straight line, in which the intercept b represents the CEC of 100 g of clay and the slope a the CEC of 1 g of carbon. This procedure is valid only if: a) the CEC of the soils is originated only from organic matter and clay and, b) the CEC per gram of organic matter and per 100 grams of clay is constant in the solum, which is the case in the Oxisols studied, in view of the straight uniform lines obtained.

The contribution of organic carbon to soil CEC was calculated by the equation:

$$\frac{\text{CEC of 1 g carbon X \% C}}{CEC_{soil}} \times 100$$

RESULTS AND DISCUSSION

The Oxisols under investigation show a mean content of 2.73% organic carbon in the surface horizon (Table 1), ranging from 0.64 to 10.19%. In the B horizon the mean value is 0.48% (0.-07-1.37). The surface horizons of Humox (x = 3.87), Haplorthox (x = 3.42) and Acrorthox (x = 3.18) have slightly higher values than Haplustox (x = 1.44), Eutrustox + Eutrotthox (x = 1.99) and Acrustox (x = 2.79). Humox, Acrustox and Acrorthox, with mean values of 1.11, 0.63 and 0.57% respectively have higher contents of organic carbon in subsurface horizons than Haplustox, Haplorthox and Eutrustox + Eutrorthox with 0.23, 0.39 and 0.48% respectively.

[1/] The graphs have been reversed in comparison to the form presented by Bennema and Camargo (1979) because CEC is dependent on organic matter and thus plotted at the ordinate and not as used by those authors. Problems related to analytical procedures, as for example dispersion of samples for particle size analysis, combustion of organic matter and replacement of absorbed ions in CEC determination, may affect the value of the present contribution.

Table 1. Content of Organic Carbon; clay; CEC of soil, carbon and clay and contribution of carbon to Soil CEC

SRIC ODE	SAMPLING SITES		MOISTURE	TEMP.	LAND USE	SOIL CLASSIFICATION		CARBON-%		CLAY-%		CEC-me				CONTRIBUTION OF C TO CEC-%	
	COUNTRY	PROVINCE	REGIMES *			FAO/UNESCO	SOIL TAXONOMY	A**	B_w***	A	B_w	100g SOIL		1gC	100g CLAY	A	B_w
												A	B_w				
RA.03	BRASIL	RIO DE JANEIRO	US/UD	HT	GRASSLAND	ACRIC FERRALSOL	ACRUSTOX	1.74	0.52	50	59	4.1	1.8	2.0	1.4	71	43
.04	BRASIL	SÃO PAULO	UD	HT	SUGAR CANE	RHODIC FERRALSOL	EUTRORTHOX	1.98	0.52	61	56	12.0	4.5	5.1	2.7	79	50
.05	BRASIL	SÃO PAULO	UD	HT	GRASS + SUGAR CANE	HUMIC/ACRIC FERRALSOL	ACRORTHOX	2.47	0.80	61	65	7.7	1.6	3.6	-1.7	-	-
.06	BRASIL	SÃO PAULO	US	HT	GRASSLAND	RHODIC FERRALSOL	HAPLUSTOX	0.83	0.22	15	22	3.3	1.4	3.2	4.4	38	14
.08	BRASIL	PARANÃ	UD	TH	MAIZE SOYBEANS	HUMIC FERRALSOL	ACRORTHOX	2.58	0.75	82	84	12.2	7.3	2.5	6.8	49	22
.09	BRASIL	PARANÃ	UD	TH	GRASSLAND	HUMIC FERRALSOL	ACROHUMOX	3.67	1.09	76	74	17.9	9.0	3.4	7.4	63	33
.10	BRASIL	PARANÃ	UD	TH	GRASS + CROPS	HUMIC FERRALSOL	ACROHUMOX	5.52	1.37	55	55	20.3	8.3	3.1	8.1	68	18
.11	BRASIL	PARÃ	US	IH	GRASSLAND	XANTHIC FERRALSOL	HAPLUSTOX	1.42	0.20	9	28	6.7	1.4	4.5	1.7	79	35
.13	BRASIL	PARÃ	US	IH	TROPICAL FOREST	ACRIC FERRALSOL	ACRUSTOX	2.64	0.35	84	92	6.9	2.6	2.2	1.7	77	31
.14	BRASIL	FEDERAL DISTRICT	US	HT	HIGH CERRADO	RHODIC FERRALSOL	HAPLUSTOX	2.26	0.86	44	43	7.3	4.1	2.6	4.2	58	35
.15	BRASIL	FEDERAL DISTRICT	US	HT	CERRADO	HUMIC/ACRIC FERRALSOL	ACRUSTOX	2.98	1.16	75	71	6.6	2.5	2.0	-0.1	-	-
$.SP_1$	BRASIL	RIO DE JANEIRO	US	TH	GRASS + BUSHES	XANTHIC FERRALSOL	HAPLORTHOX	2.06	0.40	42	48	6.4	3.4	2.0	5.4	43	13
$.SP_2$	BRASIL	RIO GRANDE DO SUL	UD	TH	MAIZE	RHODIC FERRALSOL	HAPLORTHOX	2.30	0.42	74	83	13.0	6.7	3.4	6.5	55	18
CO.18	COLOMBIA	SAN JOSÉ	UD	HT	TROPICAL FOREST	XANTHIC FERRALSOL	HAPLORTHOX	1.60	0.18	11	25	5.1	3.9	2.2	4.8	42	8
BN.01	GABON	LAYON	UD	IH	TROPICAL FOREST	XANTHIC FERRALSOL	HAPLORTHOX	3.27	0.36	56	57	12.6	5.6	2.3	7.4	50	10
.04	GABON	LEBAMBA	US	IH	GRASSLAND	XANTHIC FERRALSOL	HAPLORTHOX	2.73	0.29	18	27	9.8	1.6	3.5	-0.8	-	-
NS.01	INDONÉSIA	PARUNG	UD	IH	BANANAS	ORTHIC FERRALSOL	EUTRORTHOX	1.40	0.32	85	90	12.1	8.1	4.4	7.7	44	16
.15	INDONÉSIA	KALIMATAN	UD	IH	TROPICAL FOREST	XANTHIC FERRALSOL	HAPLORTHOX	10.19	0.30	35	41	25.0	3.0	2.2	7.4	74	8
CI.04	IVORY COAST	TAI FOREST	UD	IH	TROPICAL FOREST	XANTHIC FERRALSOL	HAPLORTHOX	0.93	0.38	10	38	2.3	3.0	1.8	6.6	20	9
JA.03	JAMAICA	MADEVILLE	UD	IH	CITRUS ORCHARD	ACRIC/ORTHIC FERRALSOL	ACRORTHOX	3.75	0.05	68	67	17.3	4.6	3.4	6.5	66	4
AK.06	KENYA	EMBU	US	TH	GRASSLAND	RHODIC FERRALSOL	EUTRUSTOX	2.59	0.74	54	67	15.9	7.4	4.8	6.8	65	34
.07	KENYA	EMBU	US	TH	BUSHED GRASSLAND	HUMIC FERRALSOL	HAPLOHUMOX	2.31	0.96	72	87	19.5	12.4	5.7	8.2	62	40
.11	KENYA	KILIFI	US	IH	FOREST	RHODIC FERRALSOL	HAPLUSTOX	0.70	0.12	15	37	3.3	3.3	2.4	8.3	17	3
.29	KENYA	KILIFI	US	IH	COCOA + CACHEW	RHODIC FERRALSOL	HAPLUSTOX	0.64	0.07	10	23	6.5	1.9	9.4	4.4	60	13
AL.01	MALASYA	SERDANG	UD	IH	FOREST	ACRIC FERRALSOL	ACRORTHOX	1.38	0.34	69	71	4.3	2.4	2.0	2.4	54	22
.03	MALASYA	KUATANG	UD	IH	RUBBER	HUMIC FERRALSOL	ACRORTHOX	5.18	0.73	55	74	16.4	5.3	2.7	4.4	76	31
.05	MALASYA	KUATANG	UD	IH	FOREST	ACRIC FERRALSOL	ACRORTHOX	4.12	0.55	91	94	14.8	2.0	3.7	-0.3	-	-
.07	MALASYA	PUCHONG	UD	IH	BUSHES	ACRIC FERRALSOL	ACRORTHOX	2.78	0.34	60	65	6.1	3.2	1.4	3.4	53	12
SK.06	SARAWAK	KUCHING	UD	IH	RUBBER	ORTHIC FERRALSOL	HAPLORTHOX	6.62	0.87	67	55	23.6	6.6	2.5	8.9	65	18
.07	SARAWAK	LUNDU-SEKAMBAL	PQ	IH	FOREST	XANTHIC FERRALSOL	HAPLORTHOX	1.07	0.30	11	33	5.7	2.9	3.8	13.2	24	8
C.02	MOÇAMBIQUE	LICHINGA	US	TH	MAIZE	RHODIC FERRALSOL	HAPLUSTOX	1.19	0.14	37	62	9.1	5.4	4.9	8.8	40	7
A.02	SOUTH AFRICA	NATAL	US	TH	GRASSLAND	HUMIC FERRALSOL	ACRUSTOX	3.82	0.47	46	52	13.6	6.1	2.3	11.0	44	9
SA.08	UNITED STATES OF AM.	KUNIA	TO	IH	SUGAR CANE	RHODIC FERRALSOL	TORROX	2.32	0.56	33	41	18.1	6.7	6.5	10.8	58	25
09	UNITED STATES OF AM.	WAIPIO	US	IH	MAIZE	RHODIC FERRALSOL	EUTRUSTOX	2.00	0.37	68	74	17.7	12.4	3.3	15.0	31	8
SA.10	UNITED STATES OF AM.	HAWAII WAILVA	UD	IH	GRASSLAND	HUMIC FERRALSOL	GIBBSIHUMOX	3.98	1.04	43	34	16.5	7.8	2.6	16.2	39	14
Z.02	ZAMBIA	KASAMA	US	TH	GRASSLAND	ORTHIC FERRALSOL	HAPLUSTOX	2.68	0.13	21	29	7.1	1.9	2.3	6.8	47	4
.04	ZAMBIA	MBALA	US	IT	WEAT + POTATOS	ORTHIC FERRALSOL	HAPLUSTOX	2.10	0.27	51	61	14.8	9.4	3.7	13.8	36	7
.05	ZAMBIA	KASAMA	US	TH	SRUB + GRASS	XANTHIC FERRALSOL	HAPLUSTOX	0.91	0.14	17	27	3.5	2.8	2.7	7.6	24	5
.09	ZAMBIA	MISANFU	US	TH	FOREST	XANTHIC FERRALSOL	HAPLUSTOX	1.72	0.20	21	45	5.7	5.4	6.8	11.7	50	10
							MEAN	2.73	0.48	47.4	54.5	11.3	4.9	3.36	7.04	51	18
							MINIMUM MAXIMUM	0.64-10.19	0.07-1.37	9-91	22-92	33-25.0	1.4-12.4	1.4-9.4	1.7-33.1	17-79	2-50

* MOISTURE REGIMES: UD = UDIC, US = USTIC, PQ = PERUDIC, TO = TORRIC
TEMPERATURE REGIMES: TH = THERMIC, HT = HYPERTHERMIC, IH = ISOHYPERTHERMIC

** A = SURFACE HORIZON

*** B_w = SUBSURFACE HORIZON WHICH ENGLOBES THE DEPTH OF 100 cm

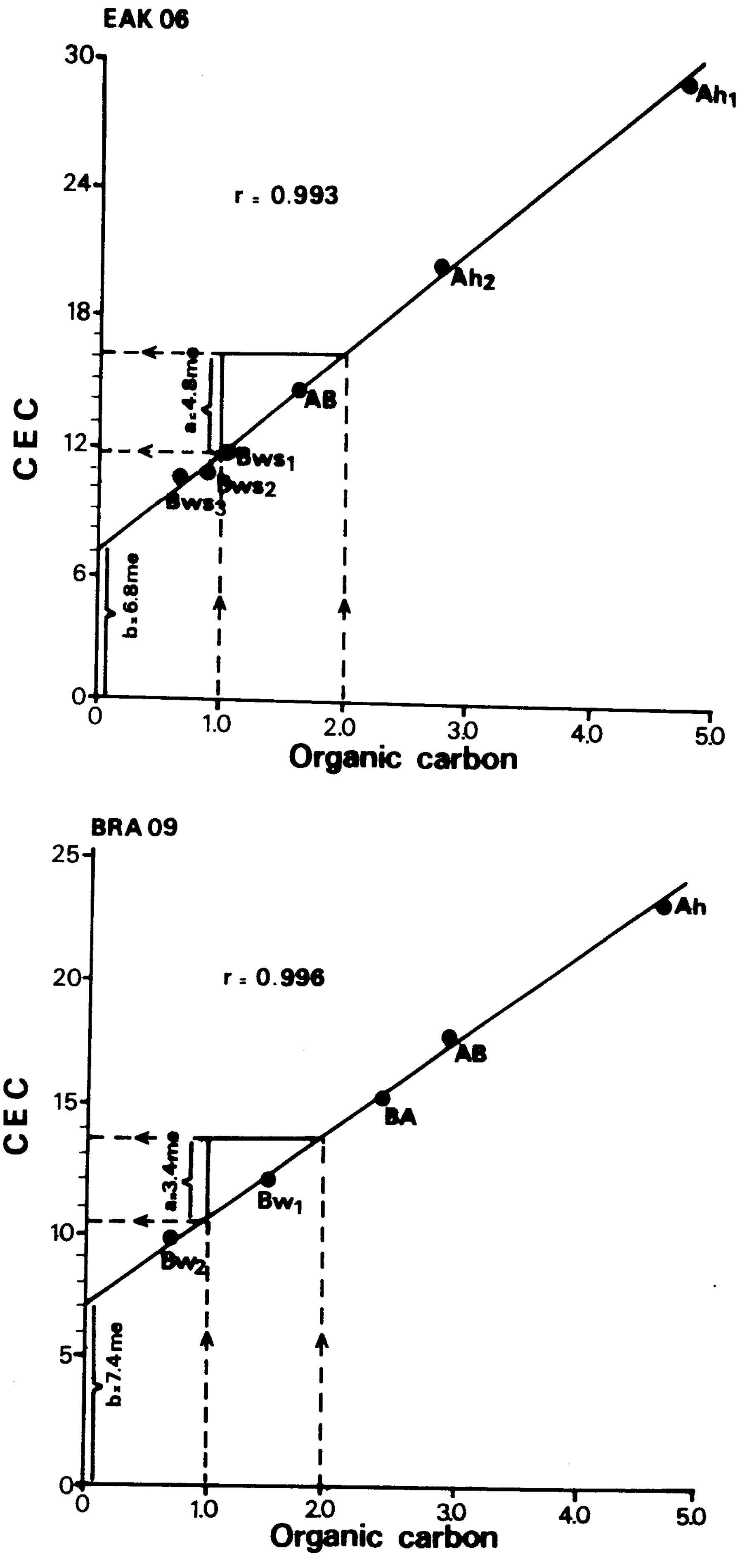


Figure 1. Cation exchange capacity of clay and organic carbon of profiles EAK 06 and BRA 09. Ordinate: CEC soil recalculated to me/100 g clay fraction. Abscissa: organic carbon, recalculated to g/100 g clay fraction. Soil horizons are indicated at data point.

The mean clay content is 47.4% (9-91) and 54.5% (22-92), respectively in the surface and subsurface diagnostic horizons (A and Bw horizons - Table 1).

Mean CEC_{soil} and CEC_{clay} of subsurface horizons of the Oxisols under investigation are respectivfely 4.9 and 10.7 me/100 g (Table 2). The frequency distributions are assymetric since values of the modes are 1.9 and 2.8 me/100 g, for soil and clay respectively.

Regression statistics applied to CEC resulted in low correlation coefficients between CEC_{soil} and clay content, irrespective if all samples ($r = 0.33$) or only of subsurface horizons ($r = 0.37$) were analysed. The coefficients are also low for CEC_{soil} and organic carbon content if all horizons ($r = 0.47$) or only subsurface horizons ($r = 0.32$) were considered.

Table 2. Descriptive statistics of CEC_{soil} and CEC_{clay} in subsurface horizons (Bw) of Oxisols

Properties	VALUES - me/100 g					
	Minimum	Maximum	Mean	Mode	Median	Standard Deviation
CEC_{soil}	0.7	12.5	4.9	1.9	8.9	5.3
CEC_{clay}	1.3	15.9	10.7	2.8	8.7	8.5

Multiple regression analysis in which the independent variables clay, organic carbon and silt content were analysed stepwise, according to their importance in explaining the variation of the dependent variable CEC_{soil}, resulted in the following equation when all horizons (surface and subsurface) were analysed:

$$CEC_{soil} = 1.67 + 2.96\ \text{carbon} + 0.03\ \text{clay}$$

with $r = 0.47$. Organic matter thus explained most of the CEC_{soil}. Similar analysis performed only for subsurface horizons yielded the following equation:

$$CEC_{soil} = 0.66 + 0.55\ \text{clay} + 0.07\ \text{silt}$$

with $r = 0.49$. Because of its low values organic carbon content, when used, did not affect the results of multiple regression analysis in subsurface horizons. The low correlation coefficients obtained are most probably related to the low values and the positively skewed distribution of CEC of Oxisols.

The equation proposed by Bennema (1966) and Bennema & Camargo (1979) to evaluate the contribution of organic matter to the CEC of Oxisols, resulted in very high correlation coefficients (r 0.99 - Figure 1), indicating that in these soils the exchange properties are related mainly to their organic matter and clay content. The contribution of these fractions seems to be constant in the solum. The same procedure when applied to similar soils, such as Ultisols, Inceptisols and Alfisols, resulted in lower correlation coefficients (r = 0.85), indicating that the contribution of organic matter and clay to CEC is not uniform throughout the profile and/or that other mineral fraction also contribute considerably to the exchange capacity.

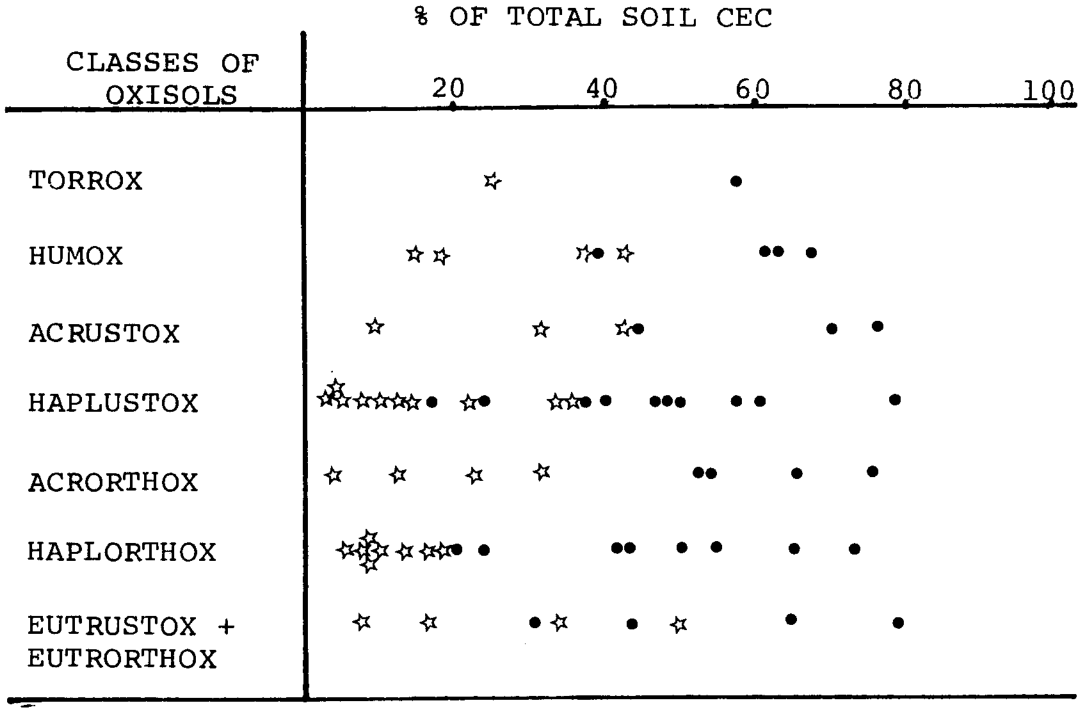
Table 1 shows that the CEC of the clay of predominantly oxidic soils (e.g. BRA 05 and 15, GBN 04 and MAL 05) is negative by this procedure, because their net charge is positive. The average contribution of 1 g of carbon to the CEC is 3.36 me. This value is lower than the correction factor of 4.5 used in the equation:

$$\mathrm{CEC}_{\mathrm{clay}} = \frac{\mathrm{CEC}_{\mathrm{soil}} - (\%\mathrm{C} \times 4.5)}{\%\ \mathrm{Clay}} \times 100$$

which is used to calculate the CEC of the clay fraction corrected for organic matter in the Brazilian System of Soil Classification if no graphical estimate per individual profile is carried out (Brasil, 1971). The value is however close to the 300 me/100 g of the CEC at pH 7 of organic functional groups, as presented by Tate & Theng (1981). The higher correction factor of the Brazilian System may be due in part to the indirect method of CEC determination employed by them.

The CEC per 1 g of carbon appears to be lower in Acrustox ($\bar{x}$ = 2.1), Haplorthox ($\bar{x}$ = 2.6) and Acrorthox ($\bar{x}$ = 2.7) than in Humox ($\bar{x}$ = 3.7), Haplustox ($\bar{x}$ = 4.2) and Eutrustox + Eutrorthox ($\bar{x}$ = 4.4).

The contribution of organic matter to CEC is high in A horizons of all soils (Figure 2) and in particular in Acrustox (44-77%), Acrorthox (49-76%) and Humox (39-68%). As expected, in the B horizon, the contribution is lower, being very low in Haplorthox (8-18%) and Haplustox (3-14%), with two exceptions for Haplustox.



CLASSES OF OXISOLS	MEAN VALUES AND AMPLITUDE OF VARIATION A (●)	B (☆)
TORROX	58	25
HUMOX	58(39-68)	26(14-40)
ACRUSTOX	64(44-77)	28(9 -43)
HAPLUSTOX	45(17-79)	13(3 -35)
ACRORTHOX	60(49-76)	18(4 -31)
HAPLORTHOX	47(24-77)	12(8 -18)
EUTRUSTOX + EUTRORTHOX	55(31-79)	27(8 -50)

Figure 2. Contribution (%) of organic carbon to cation exchange capacity of A (●) and Bw (☆) horizons of Oxisols.

The type of vegetation and land use seems to have some influence on the contribution of organic matter on the CEC of Oxisols. In B horizons of soils found under forest the contribution is in general lower than under other forms of land use (Figure 3). The use of soils for agriculture appears to have no negative influence on the CEC, as was suggested by Brams (1971).

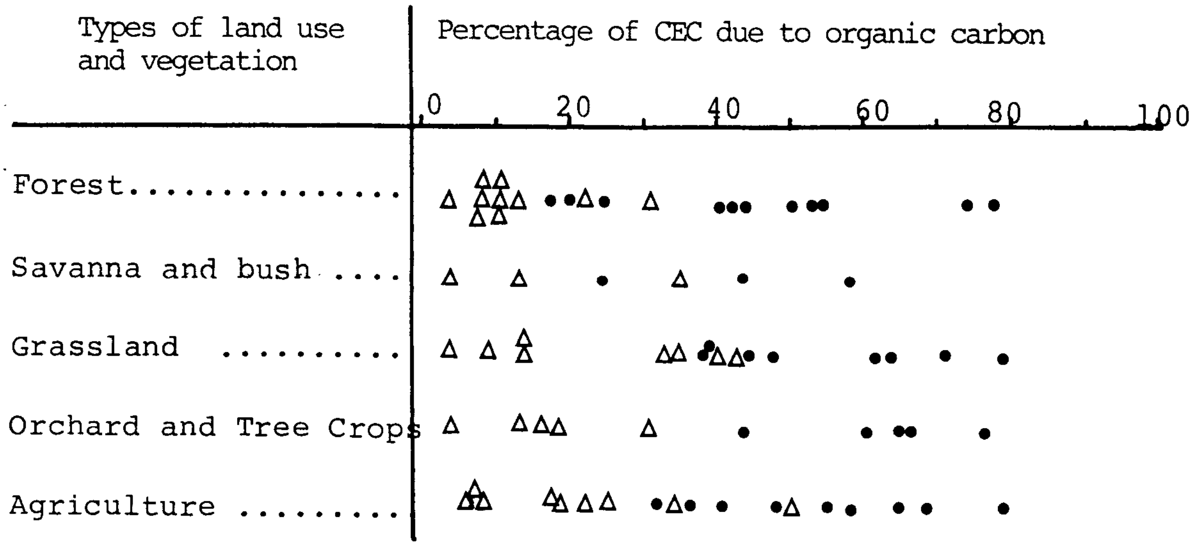


Figure 3. Influence of type of land use and vegetation on the contribution (in %) of organic carbon to the CEC of A (•) and Bw (△) horizons of Oxisols.

The climatic zone in which soils occur appears to have a slight influence on the CEC of organic matter, since in the two soils sampled in Perudic/ Isohyperthermic moisture and temperature regimes, the values are very low in A and Bw horizons (Figure 4). The contribution is also lower in most B horizons of soils found in Udic/Isohyperthermic and Ustic/Thermic regimes.

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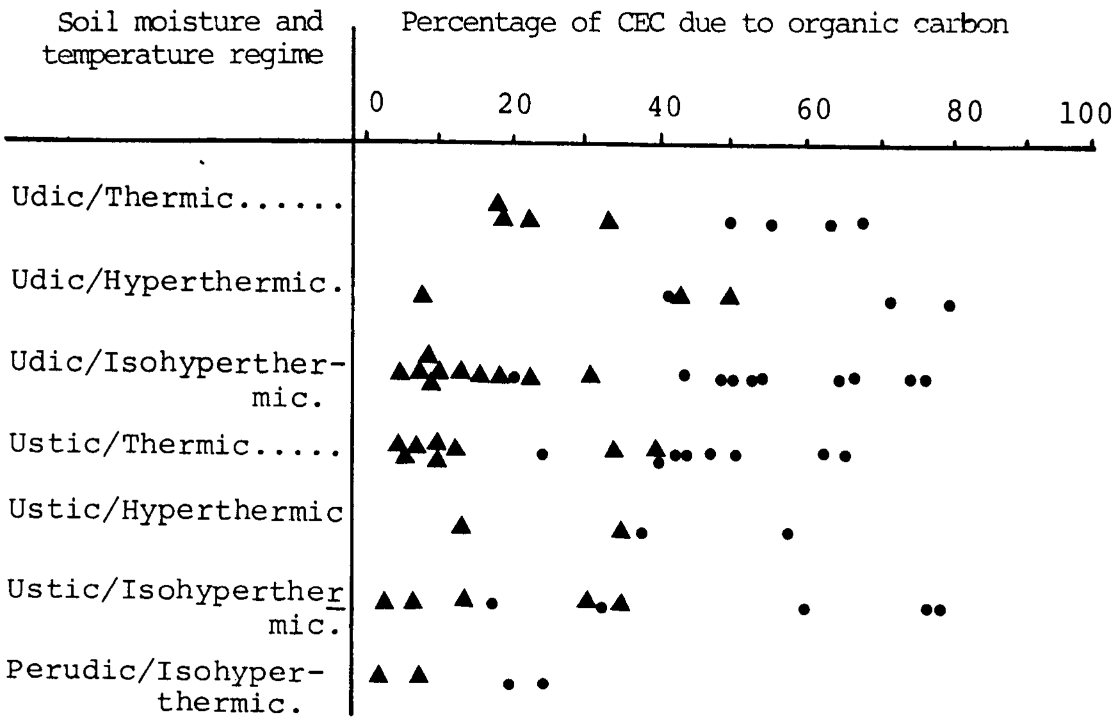

Figure 4. Influence of the moisture and temperatures regimes on the contribution (in %) of organic carbon to the CEC of A (•) and Bw (▲) horizons of Oxisols.

CONCLUSIONS

Oxisols are soils in which one of the main diagnostic characteristic is the presence of an oxic subsurface horizon with a CEC of the fine-earth fraction of 16 me or less per 100 g of clay. This value is generally obtained by calculation:

$$\mathrm{CEC}_{100\ \mathrm{g\ clay}} = \frac{\mathrm{CEC}_{100\ \mathrm{g\ soil}} \cdot 100}{\%\ \mathrm{clay}}$$

which indicates that the contribution of humic substances and inorganic soil constituents are not considered separately.

The contribution of organic matter to the CEC of Oxisols under investigation is very high in the A horizons ($\bar{x}$ = 51%), particularly in Acrustox (44-77%), Acrorthox (49-76%) and Humox (36-67%). This contribution is lower but still significant in the diagnostic subsurface horizon (B_w = $\bar{x}$ = 18%), ranging from 11.5% to 27.7% for different great soil Groups. This indicates that the contribution of organic matter should be considered in determining the CEC_{clay}, as is performed in the Brazilian System of Soil Classification.

The type of vegetation, land use and climatic zones in which Oxisols occur have no major effect on the contribution of organic matter to their CEC. Since there are no clear trends in the distribution of the data obtained, the determination of the contribution of organic matter to the CEC of these soils, has to be done for each profile individually, using the equation or graphical procedure proposed by Bennema (1966) and Bennema and Camargo (1979).

LITERATURE CITED

Bennema, J. 1966. Classification of Brazilian Soils. Report to the Government of Brazil. FAO, Rome, Report no. 2197. 83 p.

Bennema, J. & M.N. Camargo. 1979. Some remarks on Brazilian Latosols in relation to Oxisols of Soil Taxonomyl. 2nd Int. Soil Class. Workshop. Bangkok, Thailand. p. 233-261.

Birch, H.F. & Friend, M.T. 1956. The organic matter and nitrogen status of East African Soils. J. Soil Sci., 7:156-167.

Bohn, H.L. 1976. Estimate of organic carbon in world soils. Soils Sci. Soc. Am. J., 40:468-470.

Bowden, J.W., Posner, A.M. and Quirk, J.P. 1980. Adsorption and charging phenomena in variable charge soils. In: Theng, B.K.G. (ed.). Soils With Variable Charge. New Zealand Soc. Soil Sci. Soil Bureau, Lower Hutt. p. 147-164.

Brams, E.A. 1971. Continuous cultivation of West African Soils: Organic matter diminution and effects of applied lime and phosphorus. Plant Soil, 35:401-414.

Brasil. EMBRAPA. SNLCS. 1981. Bases para leitura de mapas de solos. Rio de Janeiro, SNLCS, Serie Miscelanea, 4:1-89.

Goh, K.M. 1980. Dynamic and stability of organic matter. In: Theng, B.K.G. (ed.). Soils With Variable Charge. New Zealand Soc. Soil Sci. Soil Bureau, Lower Hutt. p. 373-393.

Herbillon, A.J. 1980. Mineralogy of Oxisols and Oxic Materials. In: Theng, B.K. (ed.). Soils With Variable Charge. New Zealand Soc. Soil Sci. Soil Bureau, Lower Hutt, p. 109-123.

Juo, A.S.R. 1980. Mineralogical characteristics of Alfisol and Ultisols. In: Theng, B.K. (ed.). Soil With Variable Charge. New Zealand Soc. Soil Sci. Soil Bureau, Lower Hutt. p. 69-84.

Jenkinson, D.S. & Ayanaba, A. 1977. Decomposition of carbon 14 labeled plant materials under tropical conditions. Soil Sci. Soc. Am. J., 41:912-915.

Keng, J.C.W. & G. Uehara. 1974. Chemistry, mineralogy and taxonomy of Oxisols and Ultisols. Proc. Soil Crop Sci. Soc. Fla., 33-119-126.

Mohr, E.C.J. & Van Baren, F.A. 1954. Tropical Soils. W. van Hoeve, The Hague. p. 498.

Rodrigues, T.E. & E. Klamt. 1978. Mineralogia e genese de uma sequencia de solos do Distrito Federal. R. Bras. Ci. Solo, 2:132-139.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, New York, p. 618.

Tate, K.R. & B.K.G. Theng. 1980. Organic matter and its interactions with inorganic soil constituents. In: Theng, B.K. (ed.). Soils With Variable Charge. New Zealand Soc. Soil Sci. Soil Bureau, Lower Hutt. p. 225-244.

USDA-SCS. 1972. Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Investigation Report no. 1. U.S. Government Printing Office. Washington, D.C. p. 63.

Van Reeuwijk, L.P. 1986. Procedures for Soil Analysis, Technical Paper 9, ISRIC, Wageningen, the Netherlands. p. 106.

Wada, K. 1980. Mineralogical characteristics of Andisols. In: Theng, B.K. (ed.). Soils With Variable Charge. New Zealand Soc. Soil Sci. Soil Bureau, Lower Hutt. p. 87-104.

Young, A. 1976. Tropical soils and soil survey. Cambridge University Press, London. p. 468.