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SOIL CLASSIFICATION AS USED IN BRAZILIAN SOIL SURVEYS

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2 REVIEWS AND ARTICLES

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Contents

1. INTRODUCTION

Brazilian soil science is in its infancy. In studies before 1947 soils were mainly classified in relation to parent material or geomorphological units. In 1947 a national soil science society and survey institution were founded. A programme of reconnaissance soil surveys of Brazil started with the survey of the state of Rio de Janeiro in 1954. At present the entire country has been mapped at the exploratory level, with about 20% at exploratory-reconnaissance level, plus 15% at reconnaissance level and a rather small percentage at more detailed levels.

The former USA soil classification system has been used for the soil map legend and the definition of soil classes (Baldwin et al., 1938; Thorp and Smith, 1949). The great group level was used to refer to the major soils of cartographic units, however, depending on soil variability and distribution patterns also higher or lower taxonomic classes were used.

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2. NATURE OF THE SYSTEM

From the inception of soil surveys in Brazil the concepts of soil classes, their distinction and definition, have been drawn up to serve primarily as units in soil-mapping legends. There has never been a formal soil classification system primarily developed for Brazil, but fragmentary outlines of soil classification elements encompassed in the description of mapping units have been published in various soil survey reports.

By and large, central concepts adopted from the former USA system (Baldwin et al., 1938; Thorp and Smith, 1949) constitute the basis of the soil classification in Brazil. Nevertheless, arising from the experience of soil surveys, changes in the original reference system have taken place. During the numerous soil surveys criteria have been modified, subdivisions created and intergrades recognized. Since the late 1950s, use has been made of principles from the approximations preceeding Soil Taxonomy (Soil Survey Staff, 1975).

The National Soil Survey and Conservation Service (SNLCS-EMBRAPA), successor of the original National Soils Commission, is at present coordinating the development of a new Brazilian system of soil classification. The existing scheme is undergoing thorough reformulation and a formally organized system is under development. Although a 2nd approximation of the system has been completed, it is unsuitable for publication, as it is only a working document. The system is designed to include all known soils of Brazil, but at the same time remaining an open system in which new classes may be incorporated. A multi-categorical and descending system is being developed, the basis of which is morphogenetic, since its organization is keyed to soil horizon characteristics which result from pedogenetic processes. For this purpose, morphological, physical, chemical and mineralogical properties are used.

At the present time an explicit arrangement is sought to serve as a provisional reference base. Such an interim classification is the scope of this paper.

3. DIAGNOSTIC HORIZONS AND DIAGNOSTIC PROPERTIES

Criteria currently applied to soil classification in Brazil by EMBRAPA-SNLCS largely conform with those commonly used by soil scientists in many other countries. They have been drawn from the 7th Approximation (Soil Survey Staff, 1960), from the legend of the Soil Map of the World (FAO-Unesco, 1974) and Soil Taxonomy (Soil Survey Staff, 1975).

Excerpts of the major features of the soil classification criteria contained in a monograph (Carvalho et al., 1986) are given in the following summary.

3.1 Diagnostic horizons

The relatively stable B-horizon was used as a distinctive criterion. An adherence to surface and subsurface diagnostic horizons occurred in the early 1960s, based on the 7th Approximation of the USA (Soil Survey Staff, 1960). However, some of the concepts used in the Brazilian scheme were modified and improved to suit local conditions. The diagnostic horizons currently used in Brazil are compared with the equivalent horizons of the FAO-Unesco Legend (1974) and Soil Taxonomy (Soil Survey Staff, 1975) in Table 1.

3.2 Diagnostic properties

Soil colour correlated with mineral components

In Latosols particularly, the colour of the B horizon was used as an important criterion to distinguish soil classes. At a regional scale colour is linked with other properties, such as iron oxides/hydroxides in the less than 2 mm fraction and the magnetic susceptibility of dry crushed material. It is also associated with behaviour pertaining to agricultural use, and related to soil climatic conditions. However, soil colour *per se* as a high level criterion has not been strongly favoured.

Table 1 - Comparison between diagnostic horizons of FAO, Soil Taxonomy and Brazilian system of soil classification and specific criteria used in Brazil-EMBRAPA-SNLCS

Systems of classification			Specific or additional criteria
FAO	Soil Taxonomy	Brazilian-SNLCS	used in Brazilian system - SNLCS
		- Surface Diagnostic Horizons -	
Mollic A	Mollic Epipedon	Chernozemic A	equivalent definitions
Umbric A	Umbric Epipedon	Prominent A	corresponds to a weakly developed umbric epipedon (thinner and/or less organic carbon content)
---	Anthropic Epipedon	Anthropic A	equivalent definitions
Ochric A (~weak ochric A)	Ochric Epipedon	Moderate A	corresponds to a well-developed ochric epipedon
Ochric A (~very weak ochric A)	---	Weak A	surface horizon with <0.58% organic carbon, light colours with moist values >5 and without development of structure or weak structure; corresponds to a weakly developed ochric epipedon
---	---	Humic A	corresponds to a well developed umbric epipedon (thicker and/or higher organic carbon content)
		- Subsurface diagnostic horizons -	
Argillic B	Argillic horizon	textural B	similar definitions, but textural gradient (ratio of average clay content of B horizon/ A horizon excluding BC) is: >1.5 if A horizon has >40% clay; >1.7 if A horizon has 15 to 40% clay; >1.8 if A horizon has <15% clay. When the B horizon has a blocky or prismatic structure with associated clay skins which exceed few and weak, the former textural gradient is not required

Table 1 - (cont.)

Systems of classification			Specific or additional criteria used in Brazilian system - SNLCS
FAO	Soil Taxonomy	Brazilian-SNLCS	
	- Surface Diagnostic Horizons -		
Natric B	Natric horizon	Natric B	equivalent definitions
Spodic B	Spodic horizon	Spodic B	equivalent definitions
Cambic B	Cambic horizon	Incipient B	similar definitions, but a) to distinguish from latosolic B, it should meet one or more of the following requirements: the 0.05-2 mm fraction contains $\geq 4\%$ weatherable minerals on basis of total fraction < 2 mm; CEC of clay ≥ 13 meq/100 g after correction for organic carbon; or silt/clay ratio 0.7; Ki index (SiO_2/Al_2O_3 molar ratio) ≥ 2.2; or $\geq 5\%$ by volume of rock fragments or saprolite; and b) excluding characteristics from reduction processes and from plinthitization, respectively referred to gley horizon and plinthic horizon
Oxic B	Oxic horizon	Latosolic B	similar definitions, but exclusive of A or AB horizons, and a) meeting all of the following requirements: thickness ≥ 50 cm; CEC after deduction of the contribution of organic carbon < 13 meq/100 g of clay; Ki index ≤ 2.2; silt/clay ratio < 0.7; if present in the 0.05-2 mm fraction, $< 4\%$ weatherable minerals on basis of total fraction < 2 mm; $< 5\%$ by volume of rock fragments or saprolite; strong very fine granular to moderate subangular blocky structure; b) always with clay gradient in the solum insufficient for textural B; and c) additional exclusion of characteristics from reduction processes and from plinthitization, respectively referred to gley horizon and plinthic horizon

Table 1 - (cont.)

Systems of classification			Specific or additional criteria
FAO	Soil Taxonomy	Brazilian-SNLCS	used in Brazilian system - SNLCS
- Surface Diagnostic Horizons -			
---	---	Plinthic horizon	horizon at least 15 cm thick and containing $\geq$15% by volume of plinthite, as defined in Soil Taxonomy
Calcic horizon	Calcic horizon	Calcic horizon	equivalent definitions
---	Petrocalcic horizon	Petrocalcic horizon	equivalent definitions
Sulfuric horizon	Sulfuric horizon	Sulfuric horizon	equivalent definitions
---	Fragipan	Fragipan	equivalent definitions
---	Duripan	Duripan	equivalent definitions
- Surface or Subsurface Diagnostic Horizons -			
Histic A	Histic epipedon	Turfose A	equivalent definitions
Albic E	Albic horizon	Albic E horizon	equivalent definitions
---	---	Gley horizon	hydromorphic properties pro parte as described in the FAO system: 1) dominant neutral (N) hues or bluer than 10Y; and/or 2) saturation of water at some period of the year, or artificially drained, with evidence of reduction processes, or of reduction and segregation of iron reflected by $\geq$20% of mottles of chromas of $\leq$2, otherwise if not mottled, the value being >4, the chroma is >1 and if the value is $\geq$4, chroma $\leq$1
---	Salic horizon	Salic horizon	equivalent definitions

Activity of Clay

This is expressed by the cation exchange capacity (CEC) as determined at pH 7.0, and referred to the fraction less than 0.002 mm and reported as meq per 100 g of clay. It is considered after subtraction of the contribution to the CEC by organic carbon. As a distinctive criterion it applies to the B horizon, or the C for AC soils, or the A horizon in the case of AR soils.

The following equation can be used:

CEC (100 g clay) = (CEC (100 g soil) - (4.5 x %C)) x 100 % of clay

For more precise procedure and especially for Latosols, the graphic method proposed by Bennema (1966) should be used. Two main classes of activity of clay are used:

High activity - soils with CEC $\geq$24 meq/100 g clay, and

Low activity - soils with CEC <24 meq/100 g clay.

Further subdivisions of importance, particularly concerning the Latosols, are indicated by CEC 13 meq, as a requisite for all Latosols, and CEC $\leq$6.5 to separate the mature typical Latosols. A comparison of parameters concerning the CEC used in Brazil with those of Soil Taxonomy (Soil Survey Staff, 1975) is presented in Table 2, according to the correlation developed by Olmos & Paolinelli (1982).

Table 2 - Relationship of CEC limits used in the Brazilian system with those of Soil Taxonomy

Brazilian*	CEC values meq/100 g of clay			Soil Taxonomy**
	Brazilian°		Soil Taxonomy°°	
	- Org. C	+ Org. C	+ Org. C	
High activity/low activity clay	24	27	42	--
Upper limit latosolic B horizon	13	16	24	upper limit oxic subgroups
Upper limit latosolic B horizon of highly weathered kind	6.5	10	16	upper limit oxic horizon

*Distinction intended by the Brazilian system
°CEC values determined according to SNLCS method (pH 7.0)
°°CEC values determined according to Soil Taxonomy method (pH 7.0)
**Distinction intended by the Soil Taxonomy system
- Org. C = Organic Carbon contribution is subtracted from CEC values
+ Org. C = CEC values are not corrected for organic carbon

Silica/Alumina Molar Ratio

The molar ratio SiO_2/Al_2O_3 of the clay fraction is used as an index expressing the degree of weathering. In the tables it is referred to as the Ki index.

High Al saturation (Allic)

The term "Allic" is used to define soil classes with Al saturation $\geq 50\%$ and a minimum of 0.3 meq of extractable Al[1] in the B horizon when present, in the C horizon for AC soils, or in the A horizon for AR soils.

The formula 100.Al/S+Al[1] is used to calculate it.

"Epiallic" designates the presence of allic character in the upper solum.

Base saturation (V)

The same definition is used as in Soil Taxonomy and for the FAO-Unesco Soil Map of the World. Eutrophic refers to a base saturation $\geq 50\%$, and dystrophic $<50\%$ according to CEC at pH 7.0 in the B horizon when present, in the C horizon for AC soils, or in the A horizon for AR soils.

Sodic

Same ESP[2] specifications are used as those required for Natric horizon in Soil Taxonomy and the FAO-Unesco Soil Map of the World.

Solodic

Refers to ESP ≥ 6 and $<15\%$ in the B horizon when present, or in the C horizon for AC soils.

Saline

Refers to the presence of soluble salts, expressed by an ECs[3] 4mS, according to USDA Agricultural Handbook 60 (Richards, 1954).

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1) 1N KCl extractable acidity, in most soils corresponding virtually to A, being expressed as meq of Al/100 g of soil. Details about analytical methods used by the SNLCS are given in Appendix II
2) ESP = Exchangeable Sodium Percentage
3) ECs = electrical conductivity of the saturation extract

Carbonatic

Refers to presence of 15% or more $CaCO_3$, but without a Calcic horizon.

Abrupt textural change (Abruptic)

"Abruptic" denotes a marked increase in clay content from A or E to B horizon, as established in Soil Taxonomy and the FAO-Unesco Soil Map of the World.

Major textural class

This refers to the main denomination of texture in the B horizon or the C for AC soils, or the A for AR soils, as established in Soil Taxonomy viz. very fine clayey $\geq$60% clay; clayey 35-60; medium < 35% clay and >15% sand and exclusive of loamy sand and sand classes; silty <15% sand and < 35% clay; sandy comprising the classes loamy sand and sand. Outstanding textural changes from the upper solum to the B horizon stand as a binomial textural criterion.

Other diagnostic properties

Gilgai, slickensides, clay skins, (para)lithic contact, durinodes, plinthite, sulfidic materials and weatherable minerals, all as defined in Soil Taxonomy or the FAO-Unesco Soil Map of the World, are also used as diagnostic properties. In addition: petroplinthite; the silica/aluminium molecular ratio of the clay fraction; mottling or matrix of reduction colors, i.e. very low chromas or hues bluer than 10Y.

Intergrades

This term refers to the inherent gradation of soil character as between the classes in higher taxonomic categories. Recognized intergrades are: litholic - merging with Litholic soils; cambic - merging with Cambisols; latosolic - merging with Latosols; podzolic - merging with Red Yellow Podzolics; planosolic - merging with Planosols; vertic - with Vertisols; gleyic - with Gleysols; plinthic - with Plinthosols (primary kinds); petroplinthic - merging with concretionary kinds of Plinthosols.

Phases

Most soil surveys in Brazil are medium to small scale reconnaissance surveys or of an exploratory nature. In these circumstances, the appropriate taxonomic soil classes characterizing soil mapping units are rather above the series category, implying a higher abstraction level and a wider taxonomic grouping.

Despite the general nature of these surveys, phases of relief, substratum (for shallow semi-developed soils), primary natural vegetation, stoniness and rockiness have been used as criteria to distinguish mapping units. This has been done in order to provide additional information of interest to soil survey interpretations, especially for agricultual purposes. Criteria currently selected refer to soil and land conditions influencing land use, or which are indicative of pedo-climatic conditions.

Complementary information concerning vegetation phases are found in Appendix 1.

4. SOIL CLASSES AND THEIR DEFINITIONS

Although the system of classification for Brazilian soils has been applied to distinguish and define soil classes, as components of mapping units, thus being implied in the various soil survey reports, there is no special account which deals with the classification itself. Table 3 has been prepared to show in a simplified version the system as it is used by EMBRAPA-SNLCS.

The following publications given in the bibliography form the basis of Table 3: the legend of the 1:5.000.000 scale soil map of Brazil (EMBRAPA-SNLCS, 1981), Bennema & Camargo (1964), Bennema (1966), the proceedings of the 1st Reunião de Classificação de Solos (1979), and Olmos (1981). Other publications used are listed in the bibliography, viz. numbers 2, 5, 11, 12, 13, 14 and 25.

The diagnostic properties for further subdivision of classes at lower levels are given. The system is open ended, and at lower levels incomplete. No formal structure has been established, and no formulated lower class definitions are given.

Some examples are given of how these diagnostic properties are used at lower levels to distinguish soil classes and the phases which are added to characterize mapping units in soil surveys.

<u>Example 1</u>: A soil having a thick, dark organic carbon rich acid surface horizon, followed by a latosolic B horizon, low in iron content and orange colour, with ≥50% aluminium saturation in the subsurface diagnostic horizon, clayey texture, vegetation of tropical humid forest, and found on moderately sloping topography, would be classified as:
<u>Humic-Red Yellow Latosol Allic, clayey; evergreen tropical forest, rolling relief phase</u>.

<u>Example 2</u>: A soil with a not very distinct A horizon, followed by a textural B horizon, with or without an intervening E horizon, with grayish brown colours, ≥50% base saturation, cation exchange capacity after correction for organic carbon ≥24 meq per 100 g of clay, abrupt textural change, medium texture in the A and clayey in the B horizon, vegetation of partially deciduous subtropical forest and slightly sloping topography, would be classified as:
<u>Gray-Brown Podzolic Eutrophic, high clay activity, abruptic moderate A horizon, medium/clayey; semideciduous subtropical forest, gently undulating relief phase</u>.

Example 3: A soil having a thick dark organic carbon rich slight acid to neutral A horizon, friable, clayey texture overlaying soft caliche, and occurring under subxerophytic shrubs and low trees on slightly sloping topography is classified as:
Rendzina, clayey; hipoxerophilous thorn scrub, gently undulating relief phase.

In this particular case, since the type of surface diagnostic horizon (chernozemic A), the high base saturation and high activity of clay are properties implicit in the definition of the soil class, they are unsuited for further subdivisions of classes in lower categorical levels.

Example 4: A soil with a not very distinct A horizon, followed by a textural B of rather bright yellow colours, with $<50\%$ base satuation, and $<50\%$ Aluminium saturation, with only a moderate clay increase from the A to B horizon, with a low weatherable mineral content (but with a somewhat higher weatherable mineral content found in isolated rotten rock remains), cation exchange capacity after correction for organic carbon <24 meq per 100 g of clay, loamy texture in the A and B horizons, vegetation of permanently humid subtropical forest on rather sloping topography, is classified as:
Red Yellow Podzolic Dystrophic Cambic, low clay activity, moderate A horizon, loamy; perudic subtropical forest, hilly relief phase.

Table 3 - Synopsis of high level soil classes established at present and diagnostic properties used for subdivision of classes in lower categorical levels

	Soil classes of high level	Diagnostic properties for further subdivision of classes
1.	Mineral soils, non hydromorphic, with latosolic B horizon following any diagnostic A horizon except turfose (histic). Subdivisions according to type of latosolic B:	- Humic A character for humic Latosol, or presence of high amounts of organic carbon with a light soil colour characteristic for cryptohumic Latosols
1.1	Dusky red to dark reddish brown colours related to very high content of Fe_2O_3 ($\geqslant 36\%$)*, very strong magnetic attraction, Ki index (silica/alumina molar ratio) 0.06-0.9 LATOSSOLO FERRÍFERO (Ferriferous Latosol)	- Base or Al saturation (eutrophic, dystrophic, allic) - Presence of lateritic concretions, thin solum (concretionary, shallow)
1.2	Dusky red to dark reddish brown colours related to high content of Fe_2O_3 (18-40%)*, strong magnetic attraction, Ki index 0.20-2.0 LATOSSOLO ROXO (Dusky Red Latosol)	- Intergradational properties (podzolic, cambic, plinthic), intergrade with Quartzose Sands and intergrades with other kinds of Latosols - Types of A horizon (prominent, moderate ...) - Textural class
1.3	Dark red to dark reddish brown colours related to medium content of Fe_2O_3 (8-18%)*, weak magnetic attraction, Ki index 0.20-2.2 LATOSSOLO VERMELHO-ESCURO (Dark Red Latosol)	- Phases of vegetation and relief
1.4	Red, yellowish red to strong brown colours related to low content of Fe_2O_3 (7-11%)*, virtually no magnetic attraction, Ki index mostly <1.5 LATOSSOLO VERMELHO-AMARELO (Red-Yellow Latosol)	

* Applied to clay content $\geqslant 35\%$ (clayey texture). For loamy soils, values of the Al_2O_3/Fe_2O_3 molar ratio is used as distinctive criterion, e.g. 3.14 is upper limit for Dark Red Latosols.

Table 3 - (cont.)

Soil classes of high level		Diagnostic properties for further subdivision of classes
1.5	Brown, strong brown, yellowish brown to olive brown colours related to very low content of Fe_2O_3 (<7%)*, no magnetic attraction, Ki index 1.5-2.2 LATOSSOLO AMARELO (Yellow Latosol)	
1.6	Dark brown to reddish brown colours related to medium to high content of Fe_2O_3 (>11%)*, virtually no magnetic attraction, Ki index 0.2-2.0 LATOSSOLO VARIAÇÃO UNA (Latosol "Una" Variant)	
1.7	Dark brown to dark yellowish brown colours reddening downward related to medium to high content of Fe_2O_3 (>11%)*, virtually no magnetic attraction, Ki index 0.2-2.2 LATOSSOLO BRUNO (Brown Latosol)	

* Applied to clay content ⩾35% (clayey texture). For loamy soils, values of the Al_2O_3/Fe_2O_3 molecular ratio is used as distinctive criterion, e.g. 3.14 is upper limit for Dark Red Latosols.

Table 3 - (cont.)

Soil classes of high level		Diagnostic properties for further subdivision of classes
2.	Mineral soils, non hydromorphic, clayey, with textural B horizon following any diagnostic A horizon except turfose (histic), low activity clay, only small clay increase A to B horizon, which has moderate to strong blocky or composite prismatic structure, with associated clay skins that are at least common and moderately developed, red or brown colours related to medium to high content of Fe_2O_3. Subdivisions according to type of B horizon:	- Base or Al saturation - Intergradational properties (latosolic, intergrade with Reddish Brunizem) - Type of A horizon: moderate, prominent or humic - Phases of vegetation and relief
2.1	Dark reddish brown, dusky red, reddish brown, dark red to red colours, rather high content of Fe_2O_3 ($\geq$15%) and TiO_2 $\geq$1.50, weak to no magnetic attraction, Ki index 0.90-2.30 TERRA ROXA ESTRUTURADA (Structured Dusky Red Earth)	
2.2	Brown, dark brown, strong brown, reddish brown to yellowish red colours, medium to high content of Fe_2O_3 (>10%), no magnetic attraction, Ki index 1.70-2.10 TERRA BRUNA ESTRUTURADA (Structured Brown Earth)	

Table 3 - (cont.)

Soil classes of high level	Diagnostic properties for further subdivision of classes
3. Mineral soils, non hydromorphic, with non plinthic textural B horizon following any diagnostic E or A horizon except Turfose (histic), with small to large clay increase from A to B horizon and lacking the distinctive features of Planosols. Subdivisions according to B′ horizon:	- High activity clay or low activity clay if applicable - Base or Al saturation - Presence of fragipan, abrupt textural change, thin solum (fragic, abruptic, shallow) - Intergradational properties (latosolic, cambic, plinthic, intergrade with Reddish Brunizem) - Type of A horizon, excluding the combinations: high base saturation (≥50%) + high activity clay + either chernozemic or weak A horizon (cf. 5.2 and 7); high Al saturation + high activity clay + humic A horizon (cf. 6) - Textural class - Phases of vegetation and relief
3.1 Red to dark reddish brown colours coupled to content of $Fe_2O_3 \leq 15\%$ and $TiO_2 \leq 1.70$, often low activity clay PODZÓLICO VERMELHO-ESCURO (Dark Red Podzolic)	
3.2 Red, yellowish red to strong brown colours, content of $Fe_2O_3 \leq 11\%$ PODZÓLICO VERMELHO-AMARELO (Red-Yellow Podzolic)	
3.3 Dark brown to dark yellowish brown upper B horizon often over a lower B horizon with yellowish brown or reddish brown mottling PODZÓLICO BRUNO-ACINZENTADO (Gray-Brown Podzolic)	
3.4 Brown, strong brown, yellowish brown to olive brown colours related to very low content of Fe_2O_3 (<7%), rather low activity clay (CEC <13 meq and Ki index, ≤2.2), low base saturation PODZÓLICO AMARELO (Yellow Podzolic)	

Table 3 - (cont.)

Soil classes of high level	Diagnostic properties for further subdivision of classes
4. Mineral soils with a spodic B horizon following any diagnostic E or A horizon 4.1 Non hydromorphic PODZOL 4.2 Hydromorphic PODZOL HIDROMÓRFICO (Hydromorphic Podzol)	- Base or Al saturation - Presence of fragipan, very thick A + E (albic) horizon, presence of ortstein (fragic, giant, with ortstein) - Intergradational properties (intergrade with Quartzose Marine Sands) - Type of A horizon - Textural class - Phase of vegetation and relief
5. Mineral soils, non hydromorphic, with incipient or textural B horizon, following a chernozemic A horizon, high activity clay, rather high base saturation, lacking the distinctive features of Planosols 5.1 Presence of a neat distinct chernozemic A together with incipient B or dull colour textural B horizon BRUNIZEM 5.2 Modest chernozemic A together with moderate coloured, mostly reddish tinted, textural B horizon BRUNIZEM AVERMELHADO (Reddish Brunizem)	- Presence of calcic, or k horizon in Brunizems, calcium carbonate remains in Reddish Brunizems and Brunizems, abrupt textural change, thin solum (calcic, carbonatic, abruptic, shallow) - Intergradational properties (vertic, planosolic, litholic, intergrade Reddish Brunizem with Terra Roxa Estruturada) - Textural class - Phases of vegetation and relief
6. Mineral soils, non hydromorphic, clayey, with a textural B horizon below a humic A, high activity clay, for the most part reddish colour, moderate to strong prismatic or blocky structure, extremely high Al saturation RUBROZEM	- Intergradational properties (cambic, intergrade with Humic Gley) - Textural class - Phases of vegetation and relief

Table 3 - (cont.)

Soil classes of high level	Diagnostic properties for further subdivision of classes
7. Mineral soils, non hydromorphic with a reddish coloured textural B horizon, strongly contrasting with a usually massive and hard weak and seldom moderate A horizon, high base saturation and relatively high activity clay BRUNO NÃO CÁLCICO (Non Calcic Brown)	- Presence of calcium carbonate remains, slight sodium saturation, abrupt textural change (carbonatic, solodic, abruptic) - Intergradational properties (litholic, planosolic, vertic), intergrade with Reddish Brunizem, intergrade with Red-Yellow Podzolic - Weak or moderate A horizon - Textural class - Phases of vegetation and relief
8. Mineral soils with a textural B horizon, abrupt textural change, and sharp horizon transition, eventually developing when dry a crack between the E or A and the underlying B, which is usually mottled with dull colours PLANOSSOLO (Planosol)	- Activity of clay - Base or Al saturation - Presence of fragipan, calcic or k horizon, calcium carbonate remains, slight sodium saturation (fragic, calcic, carbonatic, solodic) - Intergradational properties (vertic, gleyic, plinthic, intergrade with Brunizem) - Type of A horizon - Textural class - Phases of vegetation and relief
9. Mineral soils with a natric B horizon below any diagnostic E, or moderate or weak A horizon, well contrasting with the natric B usually with faded colours SOLONETZ-SOLODIZADO (Solodized Solonetz)	- Activity of clay - Base saturation - Presence of fragipan, duripan, abrupt textural change, calcium carbonate remains (fragic, duric, abruptic, carbonatic) - Intergradational properties (vertic, plinthic, intergrade with Solonchak) - Weak or moderate A horizon - Textural class - Phases of vegetation and relief

Table 3 - (cont.)

Soil classes of high level		Diagnostic properties for further subdivision of classes
10.	Mineral soils mostly hydromorphic either with a salic horizon, or saline C horizon (Cgz or Cz) following the A horizon	- High E.S.P. ≥15% (sodic) - Weak, moderate A horizon - Phases of vegetation and relief if applicable
10.1	Developed on terrestrial or semiterrestrial landscapes SOLONCHAK	
10.2	Developed on semi-aquatic landscapes SOLOS SALINOS COSTEIROS INDISCRIMINADOS (Undifferentiated Coastal Saline Soils - usually mangrove land)	
11.	Mineral soils usually non hydromorphic, with an incipient B horizon, lacking expressive evidences of gleyzation, non plinthic, following any diagnostic A horizon except turfose (histic) CAMBISSOLO (Cambisol)	- Activity of clay - Base or Al saturation - Presence of calcium carbonate remains, thin solum, over-thick A (carbonatic, shallow, humic) - Intergradational properties (latosolic, gleyic, podzolic, litholic, vertic, plinthic) - Type of A horizon, excluding turfose (histic) and the combination: high base saturation (≥50%) + high activity clay + chernozemic A horizon (cf. 5.1) - Textural class - Phases of vegetation, substratum and relief
12.	Mineral soils with a plinthic horizon, superimposed or not on a textural B, following any E or A diagnostic horizon except turfose (histic)	- Activity of clay - Base or Al saturation

Table 3 - (cont.)

Soil classes of high level	Diagnostic properties for further subdivision of classes
12.1 Lacking or with only rare concretions and nodules from hardening of plinthite (petroplinthite) PLINTOSSOLO (Plinthosol comprises Groundwater Laterite pro-parte and some related soils)	- Abrupt textural change, slight sodium saturation (abruptic, solodic), besides as yet unestablished subdivision according to presence of albic diagnostic horizon - Drainage class - Type of A horizon except turfose (histic)
12.2 Presence of 15% or more by volume of petroplinthite PLINTOSSOLO PÉTRICO (Petroplinthosols)	- Textural class - Phases of vegetation and relief
13. Hydromorphic mineral soils with a gley horizon, superimposed or not on a textural B, in sequence to any A diagnostic horizon except weak, with or without an intervening E horizon	- Activity of clay - Base or Al saturation
13.1 Presence of a gleyic yet textural B horizon preceded or not by an E horizon but anyway lacking an abrupt textural change HIDROMÓRFICO CINZENTO (Gray Hydromorphic Soils)	- Presence of calcium carbonate remains, fragipan, slight sodium saturation (carbonatic, fragic, solodic) - Intergradational properties (vertic, cambic)
13.2 Presence of turfose (histic), humic or prominent diagnostic A horizon followed by a non textural B gley horizon and lacking sulfidic materials or a sulfuric horizon GLEI HÚMICO (Humic Gley)	- Type of A horizon if applicable - Textural class - Phases of vegetation and relief
13.3 As above but with a moderate diagnostic A horizon GLEI POUCO HÚMICO (Low Humic Gley)	
13.4 Presence of sulfidic materials or sulfuric horizon GLEI TIOMÓRFICO (Thiomorphic Gley)	

Table 3 - (cont.)

Soil classes of high level		Diagnostic properties for further subdivision of classes
14.	Mineral soils with 30% or more clay, ill-defined horizonation (AC profiles), relatively high activity clay, having marked changes in volume with moisture variation, as shown by cracks at some period in most years, by intersecting slickensides and eventually wedge-shaped structural aggregates, or gilgai microrelief VERTISSOLO (Vertisol)	- Base saturation - Presence of calcic or Ck horizon, calcium carbonate remains, Cy horizon, thin soil, slight sodium saturation (calcic, carbonatic, gypsic, shallow, solodic) - Intergradational properties (planosolic) - Type of A horizon: weak, moderate, chernozemic - Phases of vegetation and relief
15.	Weakly developed mineral soils, exclusive of Vertisols, without subsurface diagnostic horizon.	
15.1	Non hydromorphic, having AC profile with chernozemic A horizon, formed on calcareous material RENDZINA	- Textural class, phases of vegetation and relief
15.2	Non hydromorphic, shallow to hard bedrock (excluding petroplinthite), having AR profile with or without a thin intervening C horizon SOLOS LITÓLICOS (Litholic Soils)	- Activity of clay, base or Al saturation, type of A horizon, presence of calcic or Ck horizon and calcium carbonate remains (calcic, carbonatic), textural class, phases of vegetation, substratum and relief
15.3	Non hydromorphic, having AC profile, formed on saprolite, pedisediment or other reworked materials carrying weatherable minerals REGOSSOLO (Regosol)	- Base or Al saturation, presence of fragipan (fragic), intergradational properties (cambic), type of A horizon except turfose (histic), textural class and phases of vegetation and relief

Table 3 - (cont.)

Soil classes of high level		Diagnostic properties for further subdivision of classes
15.4	Hydromorphic or not, having AC profile, formed on quartzose sands AREIAS QUARTZOSAS (Quartzose Sands)	- Base or Al saturation, presence of fragipan (fragic), intergradational properties (latosolic, podzolic, intergrade with Podzol) type of A horizon and phases of vegetation and relief
15.5	Mostly non hydromorphic, having AC profile, formed on recent fluvial or lacustrine layered deposits SOLOS ALUVIAIS (Alluvial Soils)	- Activity of clay, evidences of hydromorphism (hydromorphic), base or Al saturation, remains of calcium carbonate, slight sodium saturation (carbonatic, solodic), intergradational properties (cambic, vertic, gleyic), type of A horizon except turfose (histic), textural class and phases of vegetation and relief
16.	Hydromorphic soils consisting of organic materials	
16.1	Lacking sulfidic materials or sulfuric horizon SOLOS ORGÂNICOS NÃO TIOMÓRFICOS (Non-Thiomorphic Organic Soils)	- Base or Al saturation - Slight sodium saturation (solodic)
16.2	Presence of sulfidic materials or sulfuric horizon SOLOS ORGÂNICOS TIOMÓRFICOS (Thiomorphic Organic Soils)	- Phases of vegetation and relief

5. CORRELATION BETWEEN SOIL CLASSES OF BRAZILIAN-SNLCS, FAO AND SOIL TAXONOMY SYSTEMS

A correlation between Brazilian, FAO and Soil Taxonomy soil classification systems has been made, based on about 470 soil profiles described and classified in Brazilian soil survey reports.

In Table 4A results are presented for the first taxonomic level. In Table 4B results are presented for the subclasses of Latosols, as specified in Table 3. The number of actual profiles referred to each FAO unit of second taxonomic level and to each great soil group of Soil Taxonomy varies from two to about twenty.

A reasonable comparison can only be attained for the first taxonomic level (Table 4A). For instance, most of the Latosols of the Brazilian system fit into the Ferralsol unit of FAO World Soil Map legend and into the Oxisol order of Soil Taxonomy.

Comparison on the second taxonomic level is already difficult and confusing (Table 4B). A wide scattering prevails when the Brazilian subclasses of Latosols were correlated to the second level of FAO and to suborder and great groups of Soil Taxonomy. A similar scattering prevails for other classes, including Red-Yellow Podzolic, Terra Roxa Estruturada, Reddish Brunizem and Litholic soils.

This scattering is inevitable as different criteria are used for subdivision on the second or lower levels. For example, colour coupled to iron oxide content is used in the Brazilian system for the Latosols, while presence of plinthite, an umbric A horizon, low CEC and colour are used for Ferralsols in the FAO system. On the other hand, for Oxisols in Soil Taxonomy the moisture regime at the second level and the presence of gibbsite or plinthite, umbric or ochric epipedon, sombric horizon, base saturation and CEC at the third level are used.

Table 4A - Tentative correlation between high level soil classes of the Brazilian system with FAO (FAO-Unesco, 1974) and with Soil Taxonomy (Soil Survey Staff, 1975)°

Brazilian system-SNLCS	FAO World Soil Map legend	Soil Taxonomy
1. Latossolos (Latosols)	Ferralsols pp°°, *Cambisols pp	Oxisols pp°°, *Inceptisols pp
2. Solos Podzólicos (Podzolic Soils)	Acrisols pp, Luvisols pp, Nitosols pp, *Phaeozems pp, *Planosols pp	Ultisols pp, Alfisols pp, *Mollisols pp
3. Terra Roxa Estruturada and Terra Bruna Estruturada (Structured Dusky Red and Brown Earths)	Nitosols pp, *Phaeozems pp	Alfisols pp, Ultisols pp, *Mollisols pp
4. Podzols	Podzols	Spodosols, Entisols pp
5. Brunizems	Phaeozems pp, Chernozems	Mollisols pp
6. Rubrozems	Acrisols pp, Nitosols pp	Ultisols pp
7. Solos Brunos Não Cálcicos (Non-Calcic Brown Soils)	Xerosols, *Planosols pp	Aridisols pp, Alfisols pp
8. Planossolos (Planosols)	Planosols pp, Xerosols pp, *Phaeozems pp	Alfisols pp, Ultisols pp, *Mollisols pp, *Aridisols pp, *Vertisols pp
9 Solonetz-Solodizado (Solodized Solonetz)	Solonetz, *Planosols pp	Alfisols pp, Aridisols pp
10. Solos Salinos (Saline Soils)	Solonchaks, *Fluvisols pp	Aridisols pp, Entisols pp
11. Cambissolos (Cambisol)	Cambisols pp, *Gleysols pp, *Ferralsols pp	Inceptisols pp, *Mollisols pp, *Oxisols pp

°Correspondence should only be sought from the Brazilian to FAO or from the Brazilian to Soil Taxonomy systems. No specific correlation between FAO and S.T. systems and vice-versa is intended.
°°pp = pro-parte
*to a minor extent

Table 4A - (cont.)

Brazilian system-SNLCS	FAO World Soil Map legend	Soil Taxonomy
12. Plintossolos (Plinthosols)	Acrisols pp°°, Arenosols pp, Ferralsols pp, Gleysols pp, Planosols pp, *Luvisols pp	Ultisols pp, Oxisols pp, Inceptisols pp, Entisols pp, *Alfisols pp
13. Gleissolos (Gleysols)	Gleysols pp, *Fluvisols pp	Inceptisols pp, Ultisols pp, *Mollisols pp, *Alfisols pp, *Entisols pp
14. Vertissolos (Vertisols)	Vertisols	Vertisols pp
15.1 Rendzinas	Rendzinas	Mollisols pp
15.2 Solos Litolicos (Litholic Soils)	Lithosols, Rankers, Cambisols pp, Regosols pp, Phaeozems pp, *Histosols pp	Entisols pp, Inceptisols pp, *Mollisols pp, *Histosols pp
15.3 Regossolos (Regosols)	Regosols pp, Arenosols pp, *Planosols pp, *Phaeozems pp	Inceptisols pp, Entisols pp, Aridisols pp, *Mollisols pp
15.4 Areias Quartzosas (Quartzose Sands)	Arenosols pp, *Gleysols pp	Entisols pp, Inceptisols pp
15.5 Solos Aluviais (Alluvial Soils)	Fluvisols pp	Entisols pp
16. Solos Orgânicos (Organic Soils)	Histosols pp	Histosols pp, Entisols pp

°°pp = pro-parte
*to a minor extent

Table 4B - Tentative correlation between second taxonomic level subclasses of Brazilian Latossolos with second level FAO units (FAO-Unesco, 1974) and with great soil groups of Soil Taxonomy (Soil Survey Staff, 1975)

Brazilian system-SNLCS	FAO World Soil Map legend	Soil Taxonomy
1.1 Latossolos Ferríferos (Ferriferous Latosols)	pp Humic Acric-Rhodic Ferralsols	pp Acrohumox
1.2 Latossolos Roxos (Dusky Red Latosols)	pp: Rhodic, Acric-Rhodic, Humic-Rhodic Ferralsols; *Chromic-Ferralic & Chromic-Humic Cambisols	pp: Acr, Hapl, Eutr Orthox & Ustox; *Umbriorthox; Acr & *Hapl Humox; *Dystropepts & rarely Dystrochrepts
1.3 Latossolos Vermelho-Escuro (Dark Red Latosols)	as above	as above, plus rarely Ustropepts
1.4 Latossolos Vermelho-Amarelos (Yellow-Red Latosols)	pp: Orthic, Acric, Humic & *Xanthic Ferralsols; *Ferralic & Humic Cambisols	pp: Acr, Hapl Orthox & Ustox; Umbr & Sombr Orthox; Acr, Sombr & *Hapl Humox; *Eutrustox & Torrox; * Dystr & Ust Tropepts
1.5 Latossolos Amarelos (Yellow Latosols)	pp: Xanthic Ferralsols; *Humic-Xanthic Ferralsols; *Ferralic Cambisols	pp: Hapl, Acr Orthox & Ustox, *Hapl & Acr Humox; *Torrox; *Dystr & Ust Tropepts
1.6 Latossolos Variação Una (Latosols "Una" Variant)	pp: Humic & Acric Ferralsols; rarely Ferralic Cambisols	pp: Acr, Sombr Orthox & *Ustox; *Sombrihumox; rarely Dystropepts
1.7 Latossolos Brunos (Brown Latosols)	pp: Humic Ferralsols; *Humic & Ferralic Cambisols	pp: Acr, Hapl Humox; Sombri, Acr, Umbr Orthox; *Humi & Dystrochrepts

pp = pro-parte
* = to a minor extent

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Appendix 1

PHASES OF ORIGINAL NATURAL VEGETATION

Since the early 1960s, the main types of primary vegetation have been introduced as phase criteria for general soil surveys executed in Brazil (Camargo et al., 1962). The reasoning behind this procedure has been further explained in a soil workshop sponsored by SNLCS-EMBRAPA (Reunião de Classificação, Correlação e Interpretação de Aptidão Agrícola de Solos, 1979) and lately reiterated by Carvalho et al. (1986).

The primary vegetation is determined by climatic and/or edaphic conditions. Areal comparison of climatic divisions with phytogeographic divisions (thermic and hydric indexes versus nature of primary vegetation) shows relationships. Natural soil fertility (oligotrophic or eutrophic status) also influences the character of the primary vegetation.

Field observations of soil climate and especially the soil moisture regime are rare. However, the distinction of phases of primary vegetation allow inferences on climatic conditions and the soil moisture regime to be made. Certainly, besides their pedological significance, the subdivisions carry broader ecological implications, giving further insight into relationships between soil classes, land units and their agricultural capabilities, thus enhancing the utilitarian value of soil surveys.

The main types of original natural vegetation recognized as phases and indicative of pedoclimatic conditions, or sometimes of soil fertility status (Carvalho et al., 1986), are presented in the following Table. Correlations with calculated soil moisture and temperature regimes (Van Wambeke, 1981), as used in Soil Taxonomy (Soil Survey Staff, 1975), are given by comparing the calculated regimes from about 250 meteorological stations with the primary vegetation type or co-existing types (e.g. forest and cerrado; grassland and forest) in the region near the station location. The number of locations referred to each primary vegetation type and corresponding calculated soil moisture and temperature regimes is given between brackets in the table.

Equivalences concerning main phases of primary vegetation* as applied in general soil surveys in Brazil by EMBRAPA-SNLCS versus calculated soil moisture and temperature regimes and classes of tentative subdivisions of moisture regimes

Primary vegetation phases (EMBRAPA-SNLCS)	Calculated soil moisture and temperature regimes (Van Wambeke, 1981)	Tentative subdivisions of moisture regimes (Van Wambeke, 1981)
1. Floresta equatorial (Tropical forest)		
1.1 Perúmida (7) (Perhumid evergreen rain forest)	Perudic Isohyperthermic (7)	Perudic (7)
1.2 Perenifólia (12) (Evergreen rain forest)	Udic Isohyperthermic (9) Ustic Isohyperthermic (3)	Typic Udic (6) Udic Tropustic (3) Dry Tropudic (3)
1.3 Subperenifólia (9) (Semi-evergreen)	Ustic Isohyperthermic (7) Udic Isohyperthermic (2)	Typic Tropustic (4) Udic Tropustic (3) Dry Tropudic (2)
1.4 Subcaducifólia (4) (Semideciduous)	Ustic Isohyperthermic (4)	Udic Tropustic (4)
1.5 Higrófila de várzea (Hygrophilous riverine)	Aquic, at least pro-parte	
1.6 Hidrófila de varzea (Hydrophilous riverine)	Aquic	
2. Floresta tropical (Tropical forest)		
2.1 Perúmida (5) (Perhumid evergreen rain forest)	Perudic Isohyperthermic (5)	Perudic (5)
2.2 Perenifólia (31) (Evergreen rain forest)	Udic Isothermic (14) Udic Isohyperthermic (8) Perudic Isohyperthermic (4) Perudic Hyperthermic (3) Perudic Isothermic (1) Udic Hyperthermic (1)	Typic Udic (23) Perudic (8)
2.3 Subperenifólia (55) (Semi-evergreen)	Udic Isohyperthermic (33) Ustic Isohyperthermic (15) Udic Isothermic (6) Ustic Isothermic (1)	Typic Udic (26) Dry Tropudic (13) Udic Tropustic (11) Typic Tropustic (5)
2.4 Subcaducifólia (31) (Semideciduous)	Ustic Isohyperthermic (18) Udic Isohyperthermic (12) Ustic Isothermic (1)	Typic Tropustic (10) Udic Tropustic (9) Dry Tropudic (8) Typic Udic (4)
2.5 Caducifólia (19) (Deciduous)	Ustic Isohyperthermic (19)	Typic Tropustic (10) Udic Tropustic (9)
2.6 Higrófila de várzea (Hygrophilous riverine)	Aquic, at least pro-parte	Aquic
2.7 Hidrófila de várzea (Hydrophilous riverine)	Aquic	

* A few formation-types of minor extent are omitted in the Table given.

(cont.)

Primary vegetation phases (EMBRAPA-SNLCS)	Calculated soil moisture and temperature regimes (Van Wambeke, 1981)	Tentative subdivisions of moisture regimes (Van Wambeke, 1981)
3. Floresta subtropical (Warm temperate forest)		
3.1 Perúmida (2) (Perhumid evergreen rain forest)	Perudic Isothermic (2)	Perudic (2)
3.2 Perenifólia (8) (Evergreen rain forest)	Perudic thermic (6) Perudic Isothermic (1) Udic Isothermic (1)	Perudic (7) Typic Udic (1)
3.3 Subperenifólia (3) (Semi-evergreen)	Udic Thermic (2) Udic Isothermic (1)	Typic Udic (3)
3.4 Subcaducifólia (2) (Semideciduous woodland)	Udic Thermic (2)	Typic Udic (2)
3.5 Higrófila de várzea (Hygrophilous riverine woodland)	Aquic, at least pro-parte	
3.6 Hidrófila de várzea (Hydrophilous riverine woodland)	Aquic	
4. Vegetação de restinga (Sand bars and coastal sand plains psammophilous vegetation)		
4.1 Floresta mesófila (15) (Mesophyllous forest)	Udic Isohyperthermic (6) Ustic Isohyperthermic (4) Perudic Isohyperthermic (3) Udic Thermic (2)	Typic Udic (6) Perudic (3) Dry Tropudic (2) Udic Tropustic (2) Typic Tropustic (2)
4.2 Floresta hidrófila (Hydrophilous woodland)	Aquic	
4.3 Formação herbácea-arbustiva (Shrub-grassland)	Same conditions as 4.1	
5. Cerrado <u>sensu lato</u> (variously savanna woodland, tree and/or shrub savannas, savanna grassland, all of oligotrophic and scleromorphous nature)		
5.1 Cerrado equatorial subperenifólio (4) (Tropical semi-evergreen tree and/or shrub savannas)	Ustic Isohyperthermic (4)	Dry Tropudic (2) Udic Tropustic (2)
5.2 Campo cerrado equatorial (2) (Tropical savanna grassland)	Udic Isohyperthermic (1) Ustic Isohyperthermic (1)	Dry Tropudic (1) Udic Tropustic (1)

(cont.)

Primary vegetation phases (EMBRAPA-SNLCS)	Calculated soil moisture and temperature regimes (Van Wambeke, 1981)	Tentative subdivisions of moisture regimes. (Van Wambeke, 1981)
5.3 Cerrado e cerradão tropical subperenifólio (16) (Tropical semi-evergreen savanna woodland & tree and/or shrub savannas)	Udic Isohyperthermic (7) Udic Isothermic (7) Ustic Isohyperthermic (2)	Typic Udic (14) Udic Tropustic (2)
5.4 Cerrado e cerradão tropical subcaducifólio (31) (ditto though semideciduous)	Ustic Isohyperthermic (18) Udic Isohyperthermic (11) Ustic Isothermic (1) Udic Isothermic (1)	Udic Tropustic (14) Dry Tropudic (12) Typic Tropustic (5)
5.5 Cerrado e cerradao tropical caducifólio (6) (ditto though deciduous)	Ustic Isohyperthermic (6)	Typic Tropustic (4) Udic Tropustic (2)
5.6 Campo cerrado tropical (3) (Tropical savanna grassland)	Udic Isohyperthermic (2) Udic Isothermic (1)	Typic Udic (3)
6. Caatinga (Thorn scrub)		
6.1 Hipoxerófila (9) (Hypoxerophilous)	Ustic Isohyperthermic (8) Aridic Isohyperthermic (1)	Aridic Tropustic (5) Typic Tropustic (3) Weak Aridic (1)
6.2 Hiperxerófila (8) (Hyperxerophilous)	Ustic Isohyperthermic (5) Aridic Isohyperthermic (3)	Aridic Tropustic (5) Typic Aridic (2) Weak Aridic (1)
7. Vegetação Campestre (Grasslands)		
7.1 Campo tropical higrófilo de várzea (Tropical meadow)	Aquic	
7.2 Campo tropical hidrófilo de várzea (Tropical swamp grassland)	Aquic	
7.3 Campo subtropical perúmido - vegetação altimontana (2) (Subtropical montane grassland - perhumid)	Perudic Isothermic (1) Perudic Isomesic (1)	Perudic (2)
7.4 Campo subtropical úmido (11) (Subtropical mesophyllous grassland)	Perudic Isothermic (5) Perudic Thermic (4) Udic Isothermic (2)	Perudic (9) Typic Udic (2)
7.5 Campo subtropical subúmido (4) (Subtropical subhumid grassland - pampas)	Udic Thermic (4)	Typic Udic (4)
7.6 Campo subtropical higrófilo de várzea (Subtropical meadow)	Aquic	
7.7 Campo subtropical hidrófilo de várzea (Subtropical swamp grassland)	Aquic	

Appendix 2

ANALYTICAL METHODS USED BY THE BRAZILIAN SOIL SURVEY SERVICE - SNLCS

Brief descriptions of analytical methods are given here but full details are available in the "Manual de metodos de analise de solo" (Empresa Brasileira de Pesquisa Agropecuaria - SNLCS, 1979), as indicated by the reference numbers.

Fraction >2 mm (gravel and cobbles) and <2 mm (fine earth) - air-dried whole samples, wood rolling to break clods and sieving through rounded hole 2 mm sieve; volume percentage determined by volumetric measurement of fractions coarser and finer than 2 mm (Method 1,2,2); weight percentage by gravimetric determination (Method 1,2,1).

Particle size distribution - determined in the <2 mm fraction dispersed in water with NaOH or occasionally calgon, high speed stirring, sedimentation; clay measured in supernatant by modified hydrometer method, sands by sieving and silt by difference; no pretreatment to destroy organic matter (Method 1,16,2).

Water dispersible clay - same as above, except no dispersing agent used (Method 1,17,2).

Flocculated clay ratio - derived value based on percentage of clay fraction and percentage of water dispersible clay (Method 1,18).

Bulk density - measured in core samples by volumetric ring (Kopecky) method (Method 1,11,1) or paraffin-coated clods (Method 1,11,3), when applicable - reported on oven dry base.

Particle density - volumetric flask and ethyl alcohol (Method 1,12).

Porosity - derived value based on bulk density and particle density (Method 1,13).

Water content ~1/3 bar - determined in presaturated <2 mm fraction by centrifugation at 2,400 rpm during thirty minutes (Method 1,8).

pH H20 and 1N KCl - measured by glass electrode in a soil-water and soil-1N KCl 1:2.5 suspension contact for no less than thirty minutes, stirring immediately before reading (Methods 2,1,1 and 2,1,2).

Extractable bases - Ca^{++} and Mg^{++} extracted with 1N KCl and titrated with EDTA (Methods 2,9 and 2,10); K^+ and Na^+ extracted with 0.05N HCl + 0.025 N H_2SO_4 and determined by flame photometer (Method 2,12 and 2,13).

Sum of bases - calculated as sum of Ca^{++}, Mg^{++}, K^+ and Na^+ determined as above (Method 2,14).

Extractable acidity - Al^{+++} extracted with 1N KCl, titration of acidity with 0.025N NaOH and bromothymol blue as indicator (Method 2,8); H^+ + Al^{+++} extracted with 1N Ca $(OAC)_2$ pH 7.0, titration of acidity with 0.0606N NaOH and phenolphtalein as indicator (Method 2,15); H^+ calculated by difference from above determinations (Method 2,16).

CEC - sum of cations (at pH 7.0) - calculated by summing extractable bases and extractable acidity as above (Method 2,17).

Base saturation - derived valued based on extractable bases and CEC as above, reported as percentage of CEC (Method 2,18).

Aluminum "saturation" - derived value based on extractable Al^{+++} and extractable bases reported as percentage of summation of these values (Method 2,19).

Extractable P - extracted with 0.05N HCl + 0.025N H_2SO_4 and determined colorimetrically (Method 2,6).

Total P - H2S04 1:1 attack - determined colorimetrically using ascorbic acid (Method 2,28).

Organic carbon - wet oxidation with 0.4N $K_2Cr_2O_7$ and titration with 0.1N $FeSO_4$ (Method 2,2).

Total nitrogen - Kjeldahl - digestion with acid mixture, diffusion and titration of NH_3 with 0.01N HCl (Method 2,4,1).

Attack by H2S04 1:1 and NaOH 0.8% - boiling solubilization of <2 mm size fraction to (1) extract in the filtrate: iron and aluminum - determined complexometrically by titration, reported as Fe_2O_3 and Al_2O_3 (Methods 2,24 and 2,25); titanium, manganese and phosphorus - determined colorimetrically, reported as TiO_2, MnO and P_2O_5 (Methods 2,26; 2,27; 2,28); (2) in the residue of the sulfuric attack, extraction of silicon with NaOH 0.8% and determined colorimetrically, reported as SiO_2 (Method 2,23,3).

Si02/Al203, Si02/R203, Al203/Fe203 ratios* - calculation on molecular basis, derived from above determinations (Methods 2,29 and 2,30).

CBD extractable iron - determined by atomic absorption spectrophotometry, reported as Fe_2O_3 (Method 2,31).

CaC03 equivalent - reaction with HCl 1:1 and gasometric determination of CO_2 evolved (Method 2,43,3).

Electric conductivity of the saturation extract - water extraction of a saturated paste (Method 2,32) and conductimetric determination (Method 2,33).

Total sulfur - Attack by HCl 1:1, precipitation with $BaCl_2$ and determined gravimetrically (Method 2,45).

Mineralogy of sands and fractions >2 mm - identification of mineral particles by optical methods using binocular microscope and polarizing microscope, with occasional complementary chemical microtests; qualitative and semiquantitative determinations of mineralogical species are made and results expressed in approximate percentage (Methods 4,3; 4,4,1; 4,5).

Clay mineralogy - X-ray diffraction and differential thermal analysis.

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* Indexes of overall composition of the secondary mineral constituents plus iron contained in ilmenite.