Chapter 6. SOIL PHYSICAL AND CHEMICAL PROPERTIES

After the soils of the land facets were classified, they were described in terms of their physical and chemical properties. This chapter summarizes these properties.

Summary of the Soil Physical Properties of the Region

Soil physical properties were classified and coded in terms of slope, depth, initial infiltration rate, hydraulic conductivity, drainage, moisture-holding capacity, temperature regime, presence of expanding clays, and texture and presence of coarse materials. Details of their definitions are recorded in the glossary to Part I in Volume 3.

The classification of soils on the basis of physical properties is designed to evaluate their suitability for crop production from a physical standpoint: in the words of F. Hardy (student notes), to study the "root room" of a soil, or its physical characteristics as a growth environment for roots, tubers, and underground stems and tissues of all kinds, including nodules for symbiotic nitrogen fixation. The classification contains the factors necessary to apply the technique developed by Mansfield (I 977) for assessing land capability for crops based on soil physical limitations. It also contains the information necessary to use the soil Fertility Capability Classification (FCC) method of Buol et al. (1975).

Although there are important physical limitations, such as poor drainage, in 2 1 % of the region, severe erosion hazard in 8%, and varying degrees of drought stress all over, the physical properties of the soil in the Land Systems Map can be generally considered favorable.

Soil Texture

Map 12 (see Map Plates) is a computer-based map of soil texture to the 50 cm depth according to the FCC criteria. Table 6-1 shows the tabular data by climatic and topographic subdivision. The most extensive textures are loamy (L) (I 8-35% clay) and loamy over a clayey subsoil (LC). These L and LC classes together account for 55% of the soils. Uniformly clayey (C) profiles account for 26% of the area, the remainder being divided by shallow soils over rock and other textural combinations. Table 6-1 shows that there is a physical barrier to root development at 50 cm or less in 15.8 million ha (2% of the region). Sandy topsoil textures are also important.

Erosion Hazard

Table 6-1 also provides a synthesis of the slope classes of the region. Flat, poorly drained lands cover 2 1 % of the region. Of the well-drained lands, about 61% have level to gentle slopes (O to 8% slopes). Topography is rolling (8 to 30% slopes) in 14% of the region, and steep (more than 30% slopes) in the remaining 4%. The presence of a textural change within 50 cm of the soil surface, such as LC, SL, and SC, makes the soils susceptible to erosion, particularly on steep slopes. Table 6-1 also shows that 64.8 million ha (8% of the region) have soils with a sharp textural (SC, LC) change on slopes greater than 8%, or have shallow soils (LR and CR). The deep soils with textural changes, mostly classified as Ultisols or Alfisols, are generally quite susceptible to erosion unless protected by a plant canopy during periods of heavy rains.

Indiscriminant forest clearing, especially in hilly regions, often leads to serious soil erosion and also increases the rate of flow of water (along with topsoil) away from catchment areas. This, in turn, provokes flooding from rivers, often many miles downstream. It is a particularly serious problem in parts of the sub-Andean foothills where "colonization" is proceeding apace. For example, in Bolivia, the greater frequency and intensity of flooding in recent years, at Trinidad, a city located near the Mamor6 river in the middle of the Mojos Pampas, can be associated with the uncontrolled and excessive forest clearing by settlers in the Chapare district, a major subAndean catchment region of that river (Cochrane, 1973). Such problems can only be avoided by ensuring that colonizers have as little access as possible into the sub-Andean foothills: i.e., that major road systems are located well into the plains areas.

Soil Moisture Relationships

The definition of soil Great Groups and their extent (shown in Table 6-1) permits a calculation of the relative importance of soil-moisture regimes in the region, as defined in Soil Taxonomy (Soil Survey Staff, 1975). About 61% of the region has an udic or perudic soil-moisture regime, indicating that the subsoil is moist during 9 or more months per year. Approximately 21% of the area has an aquic regime, indicating the presence of waterlogged conditions in some parts of the solum during the year. The remaining 18% has an ustic regime, which indicates that the subsoil is dry for more than 90 but less than 180 consecutive days during the year.

The moisture situation is not as clear as these figures suggest because subregion B, which covers a large expanse of the Amazon, includes both udic and ustic soil-moisture regimes in well-drained soils as presently defined (Ranzani, 1978) in detailed soil-water balance studies done near the edge of subregion B (Marabd, Pard), which are classified as welldrained soils in ustic suborders.

Cochrane et al. (198 1) have compared the classification of the main soils in the region at the Great Group level with moisture-regime classes and total wet-season evapotransplration regimes (WSPE) (Table 6-2). There is an approximate relationship, presumably because the definition of moisture re2imes provides for a broad separation of the Great Groups. However, there is the implication that the definition of WSPE reelmes, or an equivalent approximation of "usable energy" reeimes as accorded by annual water balance patterns, could lead to an improved classification of soils in the tropics. The definitions of soil-moisture regimes according to Soil Taxonomv, incidentally, are currently undergoing review because of certain doubts as to the applicability of the present criteria to tropical circumstances (A. van Wambeke, pers. comm., 1980).

Classification considerations aside, it is relevant to point out that most soils in subregion B suffer from temporary moisture stresses during 3 to 4 months of the year; this affects plant growth. The clearly defined dry season in the savannas makes this situation more obvious, especially in the welldrained soils of subregion C and D. Even in the clearly udic soil-moisture regime of subregion A, temporary soil moisture stress occurs sporadically and severely affects crops like upland rice and corn (Bandy, 1977). Thus it appears that shallow-rooted annual plants growing on most well-drained soils in the region can suffer from lack of water during some part of the year.

Niap 13 illustrates the soil moisture-holding capacities of soils throughout the region. More detailed or crop-specific studies must take such capacities into greater account.

Hardened Plinthite or Laterite

It is pertinent to note that the physical properties of most Amazon forest and many savanna soils are generally quite good. The dominance of coarse gravelly topsoils underlain by plinthite in much of West Africa's equivalent to subregion B poses major limitations to the development of permanent agriculture in that vast region (Lal et al., 1975). As noted in Chapter 5, this situation is virtually nonexistent in tropical South America. Hardened plinthite or laterite outcrops do occur, but in geomorphically predictable positions in the landscape, such as on edges of peneplains or plateaus that have been dissected by streams and rivers. These are common in the Guyanian and Brazilian shields, and in the Tertiary surfaces of the Amazon and Orinoco basins. Laterite outcrops occur in the high Llanos of eastern Colombia near Carimagua (see Photo Plate 44), an ICA (Instituto Colombiano Agropecuario) National Agricultural Research Center A-here ICA and CIAT work cooperatively in crop, pasture, and short-term research. These outcrops provide excellent low-cost road-building materials and, consequently, reduce the cost of opening up many hinterland areas. In fact, the lack of laterite in many areas is a definite constraint to road building and construction in general.

Table 6-1. Aereal extent of FCC textural classes of the soils of the central lowlands of tropical South America by climatic subregions (a to e)[a].

FCC texture class	a = Tropical rain forest				b = Semi-evergreen seasonal forest				c = Isohyperthermic savanna				d = Isothermic savanna				e = (Semi-)deciduous forest			
	Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)		
		<8	8-30	>30		<8	8-30	>30		<8	8-30	>30		<8	8-30	>30		<8	8-30	>30
L (loamy)	22.1	19.1	11.0	3.7	26.9	42.5	16.5	3.5	4.6	19.8	7.7	6.0	0.1	5.7	7.1	5.1	6.2	12.2	4.9	3.1
LC (loamy over clayey)	22.5	49.3	14.3	2.8	11.1	46.0	20.4	4.5	14.0	5.2	1.4	0.9	0.6	0.3	0.3	0.2	13.5	10.6	3.5	1.1
C (clayey)	7.1	23.0	13.3	3.8	14.8	60.6	25.4	6.3	8.0	20.7	4.8	1.1	0.2	15.8	4.5	0.3	1.7	2.2	0.5	0.2
S (sandy)	4.6	1.4	-	-	3.2	6.0	0.7	0.1	1.4	15.2	1.8	0.1	-	0.8	0.3	0.6	1.7	30.8	3.3	1.9
SL (sandy over loamy)	6.8	5.0	0.3	-	1.4	2.6	0.7	0.1	1.4	1.1	0.2	-	0.1	0.1	0.1	0.1	0.7	0.3	-	-
LR (loamy over rock)	-	0.5	1.2	1.8	0	0.8	3.8	2.2	0.1	0.4	0.2	0.3	-	0.2	0.2	0.2	-	0.1	0.2	0.4
LS (loamy over sandy)	0.8	0.4	0.3	0.1	0.3	0.5	0.1	-	0.1	1.8	0.8	0.3	-	-	0.3	0.1	0.1	-	-	-
SC (sandy over clayey)	-	-	-	-	0.8	0.1	0.1	-	4.4				-	-	-	-	-	0.1	0.1	0.1
CR (clayey over rock)	-	-			-	0.1	0.2	0.1		0.2	0.8	2.0	-	-	-	-	-	-	-	-
CL (clayey over loamy)	1.2	0.2			0.1	0.1			0.5	0.1				-	-	-	0.7			-

a. Subregions f and g not included due to the relatively small percentage of these soils in the area covered [illegible]

Soil Chemical Properties

Definition of Soil Chemical Properties

Soil chemical properties for both the topsoil (0-20 cm) and subsoil (21-50 cm) were coded and summarized as detailed in the glossary to Part I of Volume 3. Some aspects of this coding and definition merit additional comment.

pH (pH in water, 1: I soil to water ratio). A pH less than 5.3 was considered a realistic level to separate soils with a potential Al toxicity problem. Above pH 5.4, Al is virtually insoluble and not found either in the exchange complex or in the soil solution; below about pH 5.3 the amount of Al in soil solution may be significant. Therefore, pH 5.3 gives a crude critical level for identifying those soils for which the equation developed by Cochrane et al. (1980) for estimating the liming requirements of acid mineral soils might profitably be used. The letter "h" was used to code soils with a pH less than 5.3; this is the same letter used by the FCC system (Buol et al, 1975), and the definition approximates the philosophy of the FCC definition of soil acidity.

Exchangeable Al (Al extracted by IN KCI). The levels used are considered tentative and mainly applicable to soils with a low effective cation-exchange capacity.

Exchangeable Ca, Mg, Na (*IN* KCI extraction). This is a first attempt to equate soil-nutrient levels with crop needs in the sense:

A adequate for most crops
M inadequate for crops requiring high levels of the nutrient
B inadequate for most crops except those tolerant to low levels of the nutrient.

Exchangeable K (I NNH4 Cl extraction). In practice, there does not appear to be much difference between the K levels extracted with NH4CI and NH4OAc. The tentative classification of exchangeable K also qualifies the potash levels according to the FCC criteria. This stipulates as an alternative definition of low K that the soil has less than 10% weatherable minerals in the silt and sand fraction within 50 cm of the soil surface, or that K levels are less than 2% of the sum of the bases, if the sum of the bases is less than 10 meq/100 g soil.

Total exchangeable bases (TEB). This is the sum of the exhangeable Ca, Mg, K, and Na. In some acid mineral soils, Mn and even Fe levels obtained by extraction with IN KCI may be high and contribute to the TEB. Zinc and Cu levels could also be included, but in practice are generally so low as to be insignificant.

Cation-exchange capacity (CEC). This refers to the effective cation-exchange rapacity (ECEC) calculated by the sum of theTEB plus Al (INKCI extraction). The level, less than 4 meq/100 g soil, would correspond approximately to less than 7 meq/100 g soil, if the CEC is determined by the sum of the cations at pH 7.0, and less than 10 when determined by the sum of the cations at pH 8.2 (Buol et al., 1975).

Table 6-2. Comparison (in percentage of total area) of the well-drained Great Group soil classes by WSPE[a] and moisture regime classes.

	WSPE (mm)				Wet months (no.)[c]		
Great Group[b]	>1300	1061-1300	900-1060	<900	>8	6-8	<6
Ustic							
AUSHA, AUSPA, AUSRH, OUSAC, OUSEU, OUSHA, UUSHA, UUSPA, UUSRH	0	2.3	20.1	5.4	0.6	21.6	5.5
Orthic							
OORAC, OOREU OORHA, OORUM	6.7	28.1	1.3	0	14.4	21.7	0
Udic							
AUDHA, UUDPA, UUDPL, UUDRH, UUDTR	15.6	20.4	0	0	17.9	18.2	0
TOTAL	22.3	50.8	21.4	5.4	32.9	61.5	5.5

a. WSPE = Wet-season potential evapotranspiration.
b. A = Alfisol; O = Oxisol; U = Ultisol; US = ustic; OR = orthic; UD = udic; HA = haplic; PA = paleic; RH = rhodic; AC = acric; EU = eutric; UM = umbric; PL = plinthic; TR = tropic.
c. Months with MAI (moisture availability index) > 0.33.

SOURCE: Cochrane et al., 1981.

Table 6-3. Comparison of P levels (ppm) by classification system.

P code		Bray II	Truog	Olsen	"Available P"
A	alto, high	> 7	> 5	> 3	> 7
M	medium	3-7	2-5	1-3	3-7
B	bajo, low	< 3	< 2	< 1	< 3

The classification of TEB and CEC in terms of high, medium, and low clearly has no direct significance with respect to plant nutrient needs. Nevertheless, they are considered convenient groupings to help with the interpretation of the soil's ability to supply nutrients. When considered together with organic matter content and clay mineralogy, they provide an idea of the ability of a soil to retain nutrients and its state of leaching.

Organic matter (OM). The classification has been made to help with the overall interpretation of soil fertility. The percentage of OM is determined by multiplying the organic carbon by 1.7.

Phosphorus. The levels refer to P extracted by the Bray 11 method (Bray and Kurtz, 1945). In very approximate terms, Table 6-3 gives a comparison of P levels extracted by the Bray 11 method, the Truog method (Jackson, 1958), and the "available P" method of Vettori (1969) .

The classifications are also used to equate soil levels with plant requirements.

Phosphorus fixation. Phosphorus fixation is difficult to quantify. The criterion of Buol et al. (1975) was used: soils with a clay content greater than 35'7o and a ratio of free Fe,O, to percentage of clay greater than 0: 15, or those with allophane-dominant clay mineralogy, are classified as potentially high-P fixers. In the absence of more specific information, these parameters give a tentative rating of potential P-fixation problems.

Manganese. The levels refer to Mn extracted with IN KCI, defined as low, satisfactory, and toxic. The definition of Mn toxicity as greater than 35 ppm or greater than 1% saturation of ECEC is provisional, as plants var widely in their ability to withstand high levels of Mn in the soil solution. Furthermore, Mn levels tend to build up, sometimes for relatively short periods, under reducing conditions (Collins and Buol, 1969).

Sulphur. The classifications low, satisfactory, high, and unknown have been made without attempting to define an extraction procedure or limits for soil S; it only reflects what is known about S deficiencies as recorded in the literature.

Zinc (IN KCI extraction). Only the classes low, satisfactory, and unknown have been used. These levels are based on relatively few studies with commercial crops; little is known concerning crop tolerance to different levels of Zn.

Iron *(IN* KCI extraction). The classes low, satisfactory, high, and unknown provide only a rough guide, as they do not take crop tolerance differences into account. At the high level, some crops, e.g. rice, may suffer from excess Fe (Howeler,1973). Like Mn, soil Fe levels vary with the fluctuating oxidation and reduction conditions brought about by different soil-moisture levels. Temporary Fe deficiency sometimes occurs in sugarcane as plant roots grow through wellaerated, unsaturated topsoils (T.T. Cochrane, unpublished data). As the roots penetrate saturated subsoils, the Fe deficiency generally disappears.

Copper (I*N* KCI extract). Little is known about critical Cu levels. Generalized levels have been determined based on experiences from other tropical areas. There is evidence to suggest that they may be correlated with P levels in some acid mineral soils (T.T. Cochrane, unpublished data).

Boron (extraction by refluxing with I OOOC water for 10 minutes). The classes used approximate critical levels for several crops including sugarcane.

Molybdenum (IN KCI extract). Little is known concerning soil Mo levels in the region. The classes used are based mainly on generalized criteria from other parts of the tropics.

Free carbonates. This characteristic refers to carbonates detected simply by dropping 30% HCI onto soil samples taken to a depth of 50 cm and observing CO, effervescence. The presence of calcium and magnesium carbonates detected in this way is also used as an FCC modifier: "b" = basic reaction.

Salinity. This is the salinity of the saturated extract at 24'C of a soil sample taken to a depth of I in. The levels are based on the general values developed by the U.S. Soil Salinity Laboratory Staff (1954) that purport to identify those soils with sufficient salinity to present problems for most crops. It should be noted, however, that some crops are susceptible to a significantly lower level of soil salinity. The 4 mmhos level approximates a 1:2.5 soil-to-water extract conductivity reading of 400 pmhos.

Natric. Sodium levels were given separate mention to identify problem soils. Sodium affects clay dispersion and moisture availability. The levels refer to readings for soil samples taken to a depth of 50 cm and are those limits set by the U.S. Soil Salinity Laboratory (1954).

Cat clay. This identifies the presence of acid sulphate soils (Moorman, 1963). It is identified by the criterion of pH in 1: I soil-to-water extracts less than 3.5 after drying or jarosite mottles with hues 2.5Y or yellower and chromas 6 or more within a depth of 60 cm. It is used with this definition as an FCC modifier: "c" = cat clay.

X-ray amorphous. Greater than 35% clay and pH greater than IO in I*N* NaF, or positive to field NaF test, or is a first attempt to equate soil-nutrient levels with crop needs in the sense: other indirect evidences of allophane in the clay fraction of the surface 20 cm of the soil. This criterion, the definition of the FCC modifier "x," purports to identify soils with allophane-dominated mineralogy; these often have high Pfixing capacity and low rates of mineralization.

Elements of importance mainly to animal nutrition. This evaluation is based purely on specific knowledge about deficiencies and toxicities occurring in a given area. For example, certain soil areas are associated with iodine deficiency in animals.

Examination of Soil Chemical Data

When examining soil chemical data, it is good practice to identify potential soil toxicity factors first, then examine potential deficiencies in the light of what is likely to occur, once corrective measures have been postulated to overcome the soil toxicity problem (see Appendix 2). Such an examination must be preconditioned by the appreciation of climatic and physical conditions.

Historically, Cochrane (1962) examined Ministry of Agriculture files dating to the late 1800s in the Caribbean Island of St. Vincent and found he was. able to detect a hitherto unsuspected relationship between the fertilizer response of cotton varieties and their genetic adaptation to acid, infertile soils. For years it has been assumed that the "best" varieties were those that gave the greater responses to the higher fertilizer treatments.

Appendixes 3 and 4 provide agronomists faced with the task of investigating soil fertility problems for specific crops a more detailed guide as to what may be deduced from existing soil survey and fertility evaluation studies and how agronomic work might be speeded up to provide field-proven answers for farming practice. They use the Llanos Orientales of Colombia (the eastern lowland, well-drained plains) as a case study. Chapter 9 also discusses this topic.

Plant Tolerances to Toxicities and Deficiencies

Clearly, any interpretation of soil chemical data (and certain physical data) must take the tolerances of different crops and varieties or cultivars of those crops into account. It may be noted that several Brazilian wheat varieties have a much greater tolerance to soil Al than those developed in Canada.

Summary of Soil Chemical Properties of the Region

It was concluded that the physical properties of the soils of the central lowlands can generally be considered favorable. The opposite statement can be made as to their chemical properties. The vast majority of the region's soils are acid and infertile in their *undisturbed state.*

From the soil survey classification data, it was noted that only about *507o* of the region has high base status soils with relatively high native fertility. The analytical data indicate that the main chemical soil constraints in the region are soil acidity (Al toxicity), P deficiency, low effective cationexchange capacity, and widespread deficiencies of N, K, S, Ca, and Mg. Toxicities of Mn and Fe are present in some soils as are deficiences of these elements in others. Trace element deficiencies, including B, Zn, and Cu, are commonly seen (Cochrane and Sdnchez, 1982), and Mo deficiency has been identified in the Brazilian Cerrados (CIAT, 1980a). Table 6-4 shows the extent of many of these fertility limitations in the region. Table 6-5 disaggregates the topsoil data according to climatic subregions and topographical positions. Table 6-6 interprets these data in terms of FCC units.

In examining these tables, however, it must be remembered that the figures are largely based on soil-survey information taken under natural vegetation conditions. As shown by Falesi (I 976), in the semi-evergreen forest circumstance with a large biomass content, burning in situ can result in returning to the soil very large quantities of bases, including K and Ca, thus completely changing the chemical characteristics of the topsoil. The subsoil conditions may also be affected as nutrients leach from the topsoil.

Soil acidity. Tables 6-4 and 6-5 show that 75% of the region has soil pH values lower than 5.3, indicating not only an acid reaction but also the presence of potentially toxic levels of exchangeable Al for many crops. The proportion of acid soils is less in the flat, poorly drained topographies (52%). Map 14 is a computer printout composition map of topsoil (0-20) pH levels over the region. Soil acidity is indicated by the "h" modifier in Table 6-6.

Aluminum toxicity in plants is the main consequence of extreme soil acidity. Plant species and cultivars within a species differ in their tolerance to Al; this is expressed in terms of the percentage of Al saturation of their effective cationexchange capacity (ECEC). Some plants sensitive to Al suffer at levels as low as 10% Al saturation. In general, however, when there is 70% Al saturation or more within the top 50 cm, the soil is considered Al toxic. Such soils have been assigned the "a" modifier of the FCC system. Table 6-6 shows that 358 million ha, or 44%, of the soils in the region are potentially Al toxic in their natural state. Map 15 is a computer printout composition mal) of topsoil (0-20 cm) Al saturation levels over the region.

Map 16 shows a computer map of the Al saturation levels in the subsoils (21-50 cm)of the region. It may be noted that there are significant changes in the distribution of the subsoil levels as compared with the topsoil levels. Table 6-5 shows that there is a considerable lowering of subsoil Al saturation levels in subregions C and D, the savanna regions.

Correcting Al toxicity. Al toxicity in soils may be corrected by liming; unfortunately the amounts of lime currently being used by farmers to overcome Al toxicity are usually far in excess of those really needed. Large, unneeded applications of lime have been made in southern Mato Grosso, Brazil, for instance (see Photo Plate 28). Recently, Cochrane et al. (1980) have published an improved liming equation that permits the calculation of the minimal lime requirement for a given acid, mineral soil that will enable the healthy growth of a crop with a known tolerance to Al toxicity. This equation has been recorded in Appendix 2 for the convenience of agronomists.

Table 6-4. Summary of selected fertility parameters in the central lowlands of tropical South America.

		Topsoil (0-20 cm)		Subsoil (21-50 cm)	
Code[a]	Range	Area (million ha)	Percentage of total	Area (million ha)	Percentage of total
pH					
A	> 7.3	0.4	< 0.1	0.6	0.1
M	5.3-7.3	245.8	70.0	203.2	24.9
h	< 5.3	570.8	30.1	613.0	75.0
Organic Matter (%)					
A	> 4.5	145.0	17.8	4.1	0.5
M	1.5-4.5	614.4	75.2	90.5	11.1
B	< 1.5	57.6	7.0	722.4	88.4
Al saturation (%)					
B	0-10	221.5	27.1	243.6	29.8
M	10-40	95.5	11.7	91.3	11.2
H	40-70	141.4	17.3	100.0	12.3
a	>70 (toxic)	358.6	43.9	382.0	46.8
Exchangeable Ca (meq/100 g)					
A	> 4.0	163.7	20.0	68.1	8.3
M	0.4-4.0	338.3	41.4	184.6	22.6
B	< 0.4	315.0	38.6	564.3	69.1
Exchangeable Mg (meq/100 g)					
A	> 0.8	169.6	20.8	63.3	7.8
M	0.2-0.8	410.8	50.3	184.7	22.6
B	< 0.2	236.6	29.0	568.9	69.6
Exchangeable K (meq/100 g)					
A	> 0.3	97.4	12.0	6.3	0.7
M	0.15-0.3	240.8	29.5	105.6	12.9
k	< 0.15	477.1	58.4	705.1	86.3
ECEC[b] (meq/100 g)					
A	8	255.6	31.3	119.6	14.6
M	4-8	319.0	39.0	283.3	34.7
e	4	242.4	29.7	414.1	50.7
P[c] (ppm)					
A	7	97.1	11.9	28.4	3.5
M	3-7	341.5	41.8	89.1	10.9
B	3	378.3	46.3	699.4	85.6
P fixation					
i	> 35% clay and % free Fe_2O_3/ % clay > 0:15	101.2	12.4		
O	low	715.7	87.6		
U	no estimate	< 0.1	< 0.1		

a. a = Al toxic, FCC modifier in topsoil; A and H = high; B = low; h = acid, FCC modifier in topsoil; i = FCC modifier for P fixation; k = K deficient, FCC modifier in topsoil; M = medium.
b. ECEC = effective cation-exchange capacity.
c. By Bray II.

It might be noted that lime per se is not a scarce resource in the region; deposits abound along the eastern foothills of the Andes and the central plateau of Brazil. However, mining and transportation costs are major limiting factors especially for distant frontiers, and the estimation of minimal lime requirements, along with the use of crop cultivars with a certain tolerance to high soil Al levels, are important agrotechnologies for the agricultural development of the region. Consequently, the estimation of a minimal "liming need" can lead to the more effective use of lime and considerable savings in food production.

Phosphorus deficiency. Table 6-4 indicates that 86% of the region's soils have topsoil available P levels lower than 7 ppm, according to the Bray II method. Map 17 (see also Chapter 7) shows the distribution of available P levels in the topsoils over the region, and Map 18 (see Chapter 7) shows the distribution of subsoil P levels. Since the generally recognized adequacy level of this method for annual crops in Oxisols and Ultisols of Brazil is 7 ppm P, it is safe to state that the vast majority of soils in the area are deficient in P for most annual crops. Fortunately, this widespread P deficiency is not accompanied by a widespread high P fixation capacity (see Map 19).

Tables 6-4 and 6-6 show that an estimated 100 million ha, just 12% of the region, have soils with a high P-fixation capacity, as defined by the "i" modifier of FCC. Only those topsoils with more than 35% clay contents and with a high proportion of iron oxides present are considered high P fixers (SAnchez and Uehara, 1980; Sdnchez et al., 1980). This situation is lar ely limited to clayey Oxisols and Ultisols, and, among them, only those having the "Ci" notation in the FCC system. Phosphorus-sorption isotherms, conducted with soil samples of Ultisols from Peru and Brazil by North Carolina State University (1973) and Dynia et al. (1977), show that the fixation capacity is low. Figure 7-3 (Chapter 7) shows the distribution of soils with possible P-fixation problems over the region. Clearly, while P fixation is a possible major constraint of Oxisols in the Cerrados of Brazil and the Llanos of Colombia, it is not a widespread problem in the Amazon, although it is locally important. The use of species and cultivars tolerant to low P levels is a possible alternative to increasing P fertilization in P-deficient soils.

Because of its importance, recent advances in means and ways of correcting P deficiencies are specifically discussed in Chapter 7.

Low potassium reserves. Table 6-5 shows that about 58% of the region (477 million ha) has soils with low K availability. Table 6-6 indicates a lower figure, as soils with “g" (gley) or "d" (dry) modifiers are not taken into account. Although burning native forests increases available K levels, this effect tends to be short-lived, unless rapid recycling takes place. In savanna regions, seasonal burns do little to increase the invariably low levels of the soils. Consequently, this is an important economic constraint in the region. Map 20 illustrates levels of potash in the topsoil throughout the region.

Low calcium and magnesium levels. Table 6-5 shows that *39ulo* of the region (315 million ha) has soils with low Ca levels and 29% (236 million ha) low Mg levels. Burning native forests increases both Ca and Mg levels. In savanna areas, however, Ca and Mg deficiencies must be corrected by fertilization; adding a modest dressing of dolomitic limestone may be a cost-effective means of overcoming these deficiencies. In fact, many soils low in Ca and Mg are potentially Al toxic; in such cases, the addition of dolomitic limestone will solve both the Al toxicity and the Ca- and Mg-deficiency problems. Map 21 illustrates Ca topsoil and Map 22 Ca subsoil levels throughout the region studied.

Low effective cation-exchange capacity. Low ECEC is an important soil constraint because of the susceptibility of K to leaching from the soil profile and the danger of creating serious nutrient imbalances among cations such as K, Ca, and Mg. Tables 6-4 and 6-5 show that approximately 242 million ha (30% of the region) have this condition in the topsoil, and 414 million ha (50%) have it in the subsoil. Low ECEC is more prevalent in subregions B and C and occurs mainly in Oxisols, sandy-textured Ultisols, and all Spodosols.

Rapid leaching losses and serious K-Mg imbalances have been recorded in Ultisols in Peru (Villachica, 1978; Villachica and Sdnchez, 1980).

Sulphur deficiency. McClung (1959) found severe sulphur deficiencies in a greenhouse trial with soils from the state of Goids, Brazil, in soils described as Humic Latosols (Acrustox) and in a sandy Terra Roxa Mixturada (Rhodustalf) in São Paulo. The common occurrence of S deficiency in the soils of Central Brazil has been confirmed by several consequent studies, including the recent greenhouse trials on the Oxisols of Planaltina reported by CIAT (1980a). Although few field-trial results seem to have been recorded, S deficiency is probably a major constraint in many savanna soils where sulphur is lost through burning. Sulphur deficiencies have also been reported by Wang et al. (1976) in rice in *várzeas* (flood plains) along the Jari river in eastern Amazonia.

Deficiencies of other nutrients. The region is a heaven for scientists interested in nutrient deficiencies. In the Ultisols of Yurimaguas, for example, deficiencies of all essential nutrient elements except for Fe and Cl have been recorded in annual crops (Villachica and Sanchez, 1980). In addition to N, P, and K deficiencies, the most widespread ones seem to be Mg, S, and Zn. The limited data base for these parameters impedes a geographic appraisal of where specific deficiencies occur and their relationship to soil properties.

Constraints occurring together. Table 6-6 shows how several of these constraints occur together on the same land units, as defined by the various FCC modifier combinations. Only about 42 million ha (5% of the area) showed no major fertility limitations. The rest showed various combinations of Al toxicity (a), acid but not Al toxic (h), low ECEC (e), low K reserves (k), high P fixation (i), poor drainage (g), and dry season drought stress (d). The most frequent combinations involved Al toxicity, low K reserve, low ECEC, and high P fixation. Clearly the FCC system does not take low or insufficiency levels of phosphorus into account, only potential P fixation. Low levels of P are virtually universal in the Oxisols and Ultisols of the region.

Because of the basic importance of P for crop production throughout the region, recent advances and means or ways of correcting these deficiencies are described in Chapter 7.

Table 6-5. Aereal extent (million ha) of some topsoil (0-20 cm) and subsoil (20-50 cm) chemical properties within the topographic subdivisions of the climatic subregions of central lowland tropical South America.

Parameter and range*	a = Tropical rain forest				b = Semi-evergreen seasonal forest				c = Isohyperthermic savanna				d = Isothermic savanna				e = (Semi-)deciduous forest			
	Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)			Flat, poorly drained	Well-drained (% slope)		
		<8	8-30	>30		<8	8-30	>30		<8	8-30	>30		<8	8-30	>30		<8	8-30	>30
pH																				
Topsoil																				
A >7.3	0.1	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	<0.1	-	-	-
M 5.3-7.3	30.0	15.9	6.0	1.3	30.0	15.9	6.0	1.3	10.1	18.5	6.7	4.7	0.6	2.0	1.7	0.9	17.8	46.3	7.2	3.8
h <5.3	28.5	143.3	61.8	15.6	28.5	143.3	61.8	15.6	24.6	46.0	10.9	6.0	0.3	20.8	11.1	5.5	6.5	9.8	6.0	3.7
Subsoil																				
A >7.3	-	-	-	-	<0.1	1.0	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1	-	-
M 5.3-7.3	28.8	13.1	3.0	0.5	31.9	17.6	4.6	1.0	11.5	8.6	2.3	2.0	0.8	0.4	1.0	0.8	10.1	38.7	5.7	3.0
h >5.3	36.2	85.8	37.4	11.6	26.5	141.5	63.2	15.9	23.2	55.9	15.3	8.7	0.1	22.4	11.7	5.6	14.2	17.4	7.6	4.5
% Organic Matter																				
Topsoil																				
A >4.5	27.3	13.9	4.0	13.6	22.8	18.3	3.9	0.3	19.1	12.2	4.9	4.5	0.9	0.4	0.9	0.3	2.5	2.7	0.9	0.8
M 1.5-4.5	33.3	83.9	35.2	9.1	31.0	124.1	53.1	1.2	15.4	44.0	11.7	2.6	1.0	22.4	11.9	6.1	21.5	53.4	11.9	6.7
b <1.5	4.5	1.1	1.2	1.7	4.8	16.8	10.8	15.3	0.3	8.3	1.0	3.5	-	-	-	-	0.4	0.2	0.4	-
Subsoil																				
A >4.5	<0.1	<0.1	-	-	0.3	0.1	-	-	<0.1	-	-	-	-	-	-	-	-	-	-	-
M 1.5-4.5	21.8	15.4	4.7	1.2	10.2	14.4	4.4	0.6	10.0	4.8	<0.1	<0.1	0.1	-	-	-	0.3	0.7	0.1	-
B <1.5	42.8	83.4	35.6	10.9	45.6	144.2	63.4	16.2	24.5	59.7	17.6	10.7	0.8	22.9	12.8	6.4	24.1	55.7	13.2	7.5
% Al Saturation																				
Topsoil																				
a > 70	24.7	70.2	23.8	6.0	14.3	94.0	42.8	10.3	3.8	20.1	6.2	5.0	0.3	14.8	6.9	2.6	0.4	4.4	4.2	2.7
H 40- 70	7.6	8.9	9.6	4.6	3.3	36.8	13.4	3.4	7.6	10.1	4.1	2.6	0.1	2.6	3.6	2.8	7.1	5.5	1.8	1.2
M 10- 40	5.9	2.1	0.3	0.2	14.0	14.2	6.6	2.4	13.4	19.9	2.1	0.5	0.1	4.1	1.2	0.3	2.2	0.5	0.4	0.5
B < 10	26.8	17.7	6.8	1.2	26.8	14.2	6.0	0.8	9.9	14.4	5.3	2.6	0.4	1.2	1.1	0.8	14.8	46.0	6.8	3.1
Subsoil																				
a > 70	25.9	73.4	23.4	6.0	20.1	115.0	42.8	9.2	3.7	17.6	3.1	3.9	0.1	4.4	1.4	0.2	8.7	10.9	4.7	2.9
H 40- 70	11.1	5.6	7.7	2.1	3.6	17.1	8.0	1.3	-9.4	10.6	3.5	1.0	-	3.4	3.4	1.3	4.0	2.8	1.2	1.0
M 10- 40	0.6	6.5	6.3	3.4	6.4	11.6	8.8	3.5	5.8	14.5	3.0	1.0	0.1	10.4	4.3	1.3	0.3	1.3	1.3	0.2
B < 10	27.6	13.4	3.1	0.6	28.5	16.5	8.2	2.8	15.7	21.8	8.0	4.8	0.8	4.7	3.6	3.6	11.5	41.2	7.0	3.4
Exchangeable K (meq/100 g)																				
Topsoil																				
A > 0.3	22.5	7.2	1.7	1.8	25.3	12.8	5.9	0.9	5.8	2.8	0.1	0.1	-	-	-	-	0.5	2.0	0.9	0.8
M 0.15-0.3	18.9	29.6	11.5	3.3	11.1	46.4	19.3	5.1	17.2	17.5	7.0	5.9	0.6	0.5	2.0	0.5	10.6	11.4	3.6	1.5
k < 0.15	23.6	62.1	27.2	7.0	22.1	100.1	42.6	10.8	11.7	43.8	10.5	4.7	0.3	18.1	10.8	5.8	13.4	43.0	8.7	5.2
Subsoil																				
A > 0.3	0.7	<0.1	-	-	1.1	1.0	-	-	<0.1	-	-	-	-	-	-	-	<0.1	1.9	-	-
M 0.15-0.3	13.3	3.8	1.7	1.8	14.8	9.9	5.3	1.0	10.9	8.4	3.1	2.2	0.4	0.9	0.7	0.2	6.2	4.7	2.9	0.7
k < 0.15	51.0	94.9	38.6	10.3	42.6	148.2	62.5	15.8	23.3	5.6	14.5	8.5	0.5	21.9	12.1	6.2	17.8	49.8	10.4	0.7

Exchangeable Ca (meq/100 g)																				
Topsoil																				
A > 4.0	27.1	19.9	8.2	2.8	23.8	20.4	8.9	3.0	12.4	6.0	32.5	1.9	0.1	0.8	0.5	0.1	3.9	5.4	3.7	1.5
M 0.4-4.0	26.8	61.3	16.3	4.4	20.2	48.8	23.6	6.1	12.3	17.0	4.6	6.2	0.5	6.1	3.2	1.2	17.8	47.7	7.9	5.3
B < 0.4	11.2	27.7	16.9	4.9	14.6	90.0	35.3	7.8	10.0	41.5	9.7	2.7	0.3	16.0	9.0	5.1	2.7	3.2	1.7	0.7
Subsoil																				
A > 4.0	7.5	12.5	6.5	1.2	12.8	6.2	1.2	0.1	6.5	0.6	-	-	0.1	-	-	-	1.8	2.2	0.9	0.8
M 0.4-4.0	36.7	23.4	4.1	1.7	23.5	15.9	9.2	1.5	11.3	10.4	4.5	2.8	0.6	1.0	0.8	0.2	9.6	9.8	4.2	1.9
B < 0.4	20.9	63.0	29.9	9.1	22.2	137.0	57.4	15.3	16.9	53.5	13.1	8.0	0.3	21.9	12.0	6.2	13.1	44.4	8.1	4.8
Exchangeable Mg (meq/100 g)																				
Topsoil																				
A > 0.8	23.0	15.7	7.7	2.8	28.6	25.4	10.8	3.4	11.2	6.9	3.3	1.9	0.1	0.8	0.5	0.1	3.8	5.5	3.7	1.5
M 0-2-0.8	29.8	48.5	11.9	4.2	17.8	83.8	31.0	7.1	15.3	25.3	8.2	4.2	0.5	16.6	9.7	5.1	17.9	47.4	8.2	5.8
B < 0.2	12.3	34.7	20.7	5.1	12.1	50.1	26.0	6.4	8.2	29.2	6.2	4.7	0.3	5.5	2.6	1.2	2.7	3.5	1.4	0.3
Subsoil																				
A > 0.8	5.0	11.3	6.4	1.2	15.6	6.1	1.0	0.1	7.9	1.0	<0.1	<0.1	-	-	-	-	1.7	2.2	0.9	0.8
M 0.2-0.8	24.3	17.4	3.4	1.8	24.0	33.7	14.7	3.7	9.1	10.2	4.3	2.6	0.7	1.4	1.0	0.3	7.6	4.3	3.4	0.9
B < 0.2	35.7	70.2	30.7	9.1	18.9	119.5	52.0	13.0	17.6	53.2	13.3	8.1	0.3	21.5	11.8	6.1	15.1	49.8	9.0	5.8
Effective cation exchange capacity (meq/100 g)																				
Topsoil																				
A > 8	44.0	34.5	8.0	1.3	36.2	5.0	1.6	4.3	16.2	7.4	3.2	2.0	0.2	0.8	0.5	<0.1	5.2	5.6	0.4	1.5
M 4-8	14.8	53.4	27.2	9.9	18.4	62.9	33.4	10.6	9.1	16.1	4.2	4.7	0.4	5.6	3.1	1.2	17.6	16.6	2.1	1.6
e < 4	5.8	10.9	5.2	0.8	3.9	46.5	18.2	1.9	10.3	40.9	10.1	4.1	0.3	16.4	9.1	5.1	1.6	34.1	7.4	4.4
Subsoil																				
A > 8	16.7	18.4	0.7	1.3	25.1	20.8	5.9	<0.6	10.3	1.3	-	-	0.1	-	-	-	<0.1	0.2	0.8	0.9
M 4-8	43.3	41.6	8.6	3.2	22.1	66.8	31.6	9.1	8.2	8.4	4.6	4.4	0.7	1.4	1.0	0.3	8.0	6.1	3.3	5.9
e < 4	5.1	38.9	24.4	7.6	11.3	71.5	30.3	7.3	16.0	54.7	13.0	6.3	0.1	21.5	11.8	6.1	15.9	48.3	9.0	0.7

a. a = Al toxic, FCC modifier in topsoil; A and H = high; B = low; h = acid, FCC modifier in topsoil; i = FCC modifier for P fixation; k = K deficient, FCC modifier in topsoil; M = medium.

Table 6-6. Aereal extent (million ha) of Fertility Capability Classification modifier combinations of the soils of central lowland of tropical South America.

FCC modifier combination[a]	Area	FCC modifier combination[a]	Area
a	63.1	gb	0.7
ae	10.3	gdsn	<0.1
ai	2.0	ga	19.3
ak	145.6	gai	0.5
ake	44.5	gak	13.7
akei	14.8	gake	3.6
aki	16.2	gh	17.6
		ghi	0.2
d	43.3	ghk	16.4
da	1.7	ghke	12.1
dae	0.6	gi	0.6
daei	2.3	gk	11.5
daek	1.0	gke	0.4
daeki	0.3	gkei	1.2
dai	3.1	gs	0.1
dak	1.8		
dake	28.7	h	23.7
dakei	28.5	hc	3.0
daki	1.4	he	2.0
db	0.4	hei	4.3
dei	2.1	hi	1.1
dg	1.1	hix	0.2
dh	6.4	hk	22.0
dhe	0.1	hke	3.4
dhi	3.3	hkei	8.1
dhh	5.4	hki	1.5
dhke	30.8		
dhkei	1.31	i	0.1
di	3.7	ix	1.1
dk	12.6		
dke	39.5	k	6.2
e	<0.1		
g	79.75	Without modifiers	42.4
gak	2.6		
gake	2.1	TOTAL	816.9

a. a = Al toxic, c = cat clay, d = dry, e = low cation exchange capacity (CEC), g = gley, h = acid, i = P fixation, k = K deficient, n = natric, s = salinity, x = X-ray amorphous.

Table 6-7. Average chemical composition of the topsoil (0-20 cm) of an Oxisol under semi-evergreen seasonal forest and ***Panicum maximum*** pastures of different ages in the proximity of Paragominas, Pará, Brazil.

Vegetation type	Clay (%)	OM (%)	N (%)	pH in H_2O	Exchangeable cations (meq/100 g) Ca+Mg	Exchangeable cations (meq/100 g) Al	Available elements (ppm) K	Available elements (ppm) P	Al saturation (%)
Forest	65	2.79	0.16	4.4	1.47	1.8	23	1	53
Pasture (age in no. of years)									
1	50	2.04	0.09	6.5	7.53	0.0	31	10	0
3	60	3.09	0.18	6.9	7.80	0.0	78	11	0
4	55	2.20	0.11	5.4	3.02	0.2	62	2	6
5	50	1.90	0.10	5.7	2.81	0.2	66	3	6
6	51	1.90	0.09	6.0	3.84	0.0	74	7	0
7	48	1.77	0.08	5.7	2.61	0.0	47	1	0
8	52	1.69	0.08	5.4	2.10	0.0	39	1	0
9	50	2.34	0.11	5.9	4.10	0.1	70	2	2
11	45	3.37	0.15	6.0	4.10	0.0	86	1	0
13	62	2.80	0.20	5.6	4.80	0.0	54	1	0

SOURCE: Serrão et al. (1979).