AMAZONIA: A COMPUTERIZED OVERVIEW OF ITS CLIMATE, LANDSCAPE AND SOIL RESOURCES*

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A clear picture of the land resource base of a region is fundamental for an appreciation of its potential and problems. This is particularly important in the case of Amazonia, which according to the FAO-UNESCO Soil Map of the World (1975), the Projeto Radambrasil (1972-1978) studies and others, has extensive areas of very poor soils. Further, there is a legacy of conflicting literature concerning the region. Many authors consider its soil incapable of sustaining agriculture or livestock production after the primary vegetation is removed (Setser, 1967; Reis, 1972; Tosi, 1974; Budowski, 1976; Irion, 1978; Goodland *et al.*, 1978), and just as many present an optimistic future for agriculture (Sanchez, 1977; Alvim, 1978; Serrão *et al.*, 1979; Toledo and Morales, 1979).

In recent years the amount of climatic, landscape, vegetation and soil information on Amazonia has increased substantially, and the advent of satellite and radar imagery enables this information to be collated in an accurate geographical context. A recent survey by Cochrane *et al.* (In Press) sponsored by CIAT ** and National Agencies *** facilitates the evaluation of available information by computerization. The purpose of this paper is to highlight some of the findings from that study, and overview advances in understanding the principles of managing Amazonian land resources.

METHODOLOGY

The methodology used by Cochrane *et at*, is modeled on the land systems approach successfully developed by Christian and Stewart (1953) in assessing the land resources of Northern Australia. It reduces information to a common base, redefining land systems as repetitive patterns of climate, landscape and soils. These are delineated directly onto satellite imagery, taking advantage of radar imagery and following field work and climatic analyses. Vegetation and soils are separately described and coded according to their occurrence on landscape facets that follow the principal topographic sequences within the land systems. The information is computerized to facilitate speedy analysis and thematic map production (Cochrane *et al.*, 1979; Cochrane, 1980).

THE LAND RESOURCES

Poorly drained lands

Figure 1 is a computer produced map which summarizes drainage and topographic data. This information, together with soil classification is put into numerical context in Table I for the Amazon region, which is defined for convenience as lying between the 4º North and 12º South parallels; it covers 484 million hectares. The map illustrates the fact that about 23 percent of the area has either poorly drained soils or lands subject to periodic flooding. The largest single extension of the former is found in the northwest; lands subject to flooding (termed "varzeas" in Brazil), are found along most of the rivers forming the extensive Amazon river watershed. The vast area of poorly drained forested lands provides a natural deterrent to development. On the other hand, it is interesting to note that the minor areas of poorly drained savannas have been preferred since colonial times for cattle raising.

Vegetation and climate

Vegetation throughout Amazonia ranges from Tropical Rain

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Forests to Savannas on both well drained and poorly drained soils. The physiognomic vegetation classes of the well drained soils of Figure 2 are related to total wet season potential evapotranspiration regimes, and information on their dry season lengths and temperature regimes is also recorded. Table II details meteorological data sets for stations located in the vegetation subregions. The climatic input to the computerized study was independently carried out by G. H. Hargreaves and his Utah State University group, who used constant yardsticks for describing meteorological data throughout the region. Comparable meteorological data sets were compiled for over 1000 stations from Central and South America (Hancock *et al.*, 1979).

As found by Cochrane and Jones (1981), natural vegetation patterns on well drained soils can best be discriminated on the basis of total wet season potential evapotranspiration. This is a proxy measurement of the amount of energy plants can use for growth, assuming that there is insufficient soil water during the dry context, for significant growth. In this context, it might be noted that a new equation to calculate osmotic potentials recently published by Cochrane (1983; 1984), would imply that there is a unifying molecular mechanism of water movements throughout biological tissues including plants. As evapotranspiration can be interpreted as a means of accelerating these movements, there would appear to be a sound theoretical basis for this finding.

The close relationship between usable solar energy and natural vegetation would indicate a much more stable climate-vegetation relationship than inferred by many past workers. It would imply that unless substantial climatic changes occur, any fragility in the sense of cleared forest lands not reverting back to forests if left alone, would probably be confined to the transitional areas between forests and savannas. In practice, as emphasized by Hecht (1979), the major problem of clearing forests for pasture establishment is forest regrowth.

The scale of Figure 2 does not permit the subdivision of the vegetation classes to identify areas of more luxurious growth or vice-versa. However, it is clear that soil conditions, particularly variations in water holding capacities and innate fertility conditions that affect root growth, influence the natural vegetation. The Campinas (low vegetation, over infertile white sand), is a case in point, as noted by Schubart and Salati (1982); they are found in northern Amazonia where there is a marginal total wet season potential evapotranspiration for forest growth. In a converse sense, on the central plateau of Brasil, forest formations are found in a characteristically savanna region but only growing on superior soils mainly derived from limestones (Garcia de Freitas *et al.*, 1978). Consequently, it is necessary to examine soil conditions in detail.

TABLE I

DISTRIBUTION OF SOILS IN AMAZONIA

Subregion	Soils	Drainage and Topography			
		Poorly drained	Well drained		
	Orders		<8%	8–30%	> 30%
		..... Million hectares			
Tropical Rain Forest	Oxisol		44.7	18.0	7.0
	Ultisol	11.3	34.0	3.0	0.1
	Entisol	24.0	2.7	2.0	3.8
	Alfisol		0.2		
	Inceptisol	4.2	3.2	0.9	0.2
	Spodosol	8.4			
	Mollisol	0.6	1.4	1.2	0.1
	Vertisol		0.5		
				Total:	171.5
Semi-Evergreen Seasonal Forest	Oxisol	0.9	81.7	42.2	10.8
	Ultisol	7.3	56.4	21.2	4.2
	Entisol	24.8	6.7	0.7	0.2
	Alfisol		4.5	1.7	0.2
	Inceptisol	6.0			
	Spodosol	2.1			
	Mollisol	0.3	0.1		
				Total:	272.0
Well Drained Savannas, Isohyperthermic	Oxisol		16.8	3.7	1.2
	Ultisol		1.1	0.1	
	Entisol		0.9		
	Inceptisol		0.6		
				Total:	24.4
Well Drained Savannas, Isothermic	Note: These soils belong mainly to the Oxisol and Ultisol Orders.				
				Total:	2.5
Poorly Drained Savannas	Ultisol	2.3			
	Entisol	6.8			
	Alfisol	3.3			
	Inceptisol	0.9			
				Total:	13.3
			Grand Total:		483.7

Soils, their topography and distribution

Table I indicates that most Amazonian lands have relatively

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easy topography, the Andean pediments excepted. This would suggest that erosion hazard need not be a limitation to development, always providing that forest clearing is confined to the relatively flat surfaces, and colonization is avoided on the Andean pediments. Unfortunately, as in the Chapare river region of Bolivia, forest clearing on the pediments can result in serious erosion and aggravate flooding of downstream areas.

The distribution of soils is summarized in Figure 3, a computer map of soil Orders the highest category of the United States Department of Agriculture's Soil Taxonomy System (1975). Table I provides additional statistical data. Table III summarizes analytical data from some typical Amazonia soils. Approximately 75 percent of the soils classify as Oxisols and Ultisols, and a lesser 2.2 percent as Spodosols. In these Orders, leached acid mineral soils predominate.

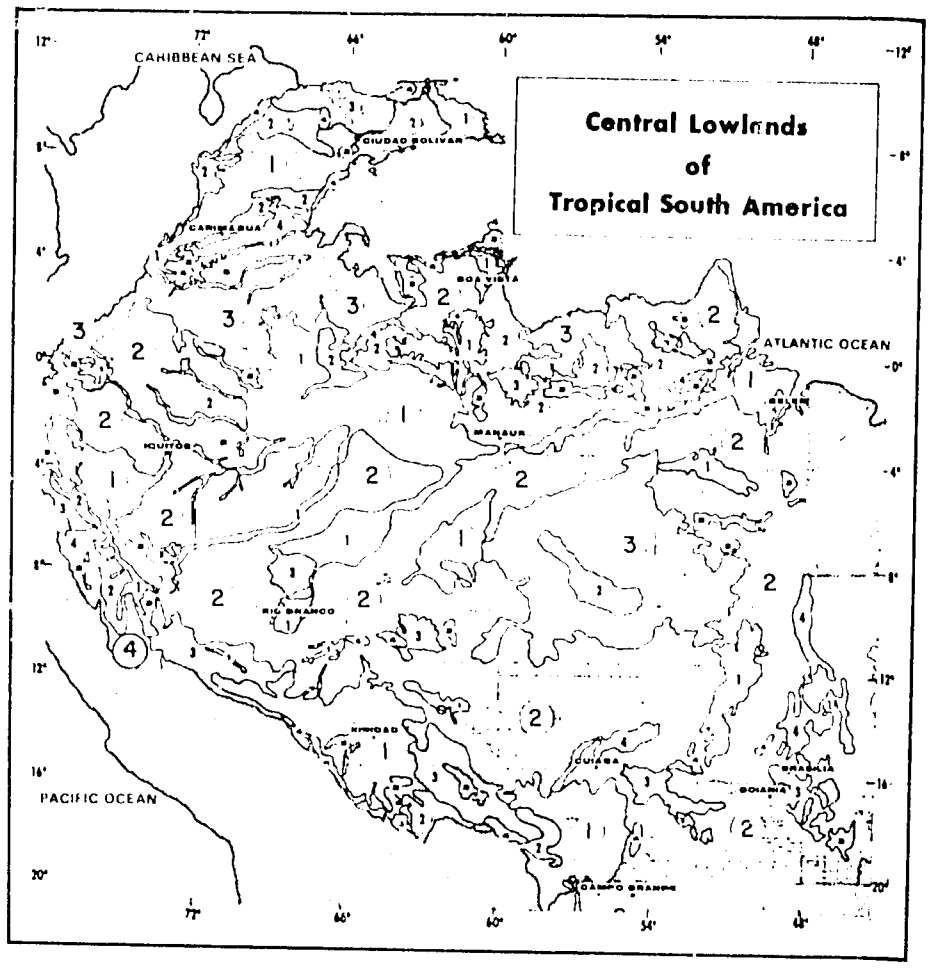


Figure 1. A computer map identifying drainage and topographic classes.

Leached, acid mineral soils

Oxisols are Amazonia's most extensive soils. They are characterized by a subsurface horizon high in sesquioxides. Well drained Oxisols, also known as Ferralsols in the FAO Classification System (1971) and Latosols in Brazil, are found in all the vegetation sub-regions under both native and cleared vegetation. Well granulated clays predominate, but with disproportionately low water holding capacities. Nevertheless their physical properties are generally satisfactory. On the other hand, as may be seen from Table III, their chemical properties are often poor. They have low pH levels, poor ion exchange properties and high aluminium levels. While phosphorus is usually not fixed under forest conditions, the levels are almost universally low. Sulphur, potassium, calcium, magnesium and trace elements especially zinc, are often potentially deficient.

Ultisols, known as Orthic Acrisols and Red Yellow Podzolics in other classification systems, are also extensive, but a higher proportion are found in poorly drained lands. The well drained Ultisols have less favorable physical properties than Oxisols due to their characteristic increase in clay content with depth, which separate these soils from the Oxisols. However, their fertility levels are roughly comparable.

Oxisols and Ultisols are often cited as presenting a laterite hazard; the irreversible transformation of soft plinthite to hard laterite on drying. However, the extent of these soils with plinthite, and only in the subsoil, is limited to three Great Group subclasses, the Plinthaquox, Plinthaquult and the Plinthudult, which account for less than 4 percent of Amazonia (Cochrane and Sanchez, 1982). Further, as most of these soils are found in low-lying poorly drained positions in the landscape, it is difficult to visualize a scenaria of artificial drainage followed by topsoil removal, which would enable the subsoils to dry-out sufficiently for laterite formation.

Spodosols also known as Podzols, Ground-water Podzols and Giant Tropical Podzols are derived from coarse sandy materials, and are well documented in the literature (Klinge, 1965, 1967; and many others), perhaps disproportionately so in relation to their lesser aereal extent. An extensive area is located in the headwaters of the Negro river, and largely accounts for the color of this river, as waters leaching through Spodosols remove organic acids. They are extremely infertile and best left in their natural state.

Well drained fertile soils

Only six percent of Amazonia has well drained, fertile soils. These are limited largely to the Alfisol, Inceptisol and Entisol (some alluvial soils) Orders, and minor areas of Mollisols and Vertisols. Table III has examples of an Alfisol (Terra Roxa Estruturada), and a fertile alluvial soil. Invariably, such soils form on superior soil forming materials, and usually combine good physical properties with high native fertility. Where they occur successful agriculture can be developed

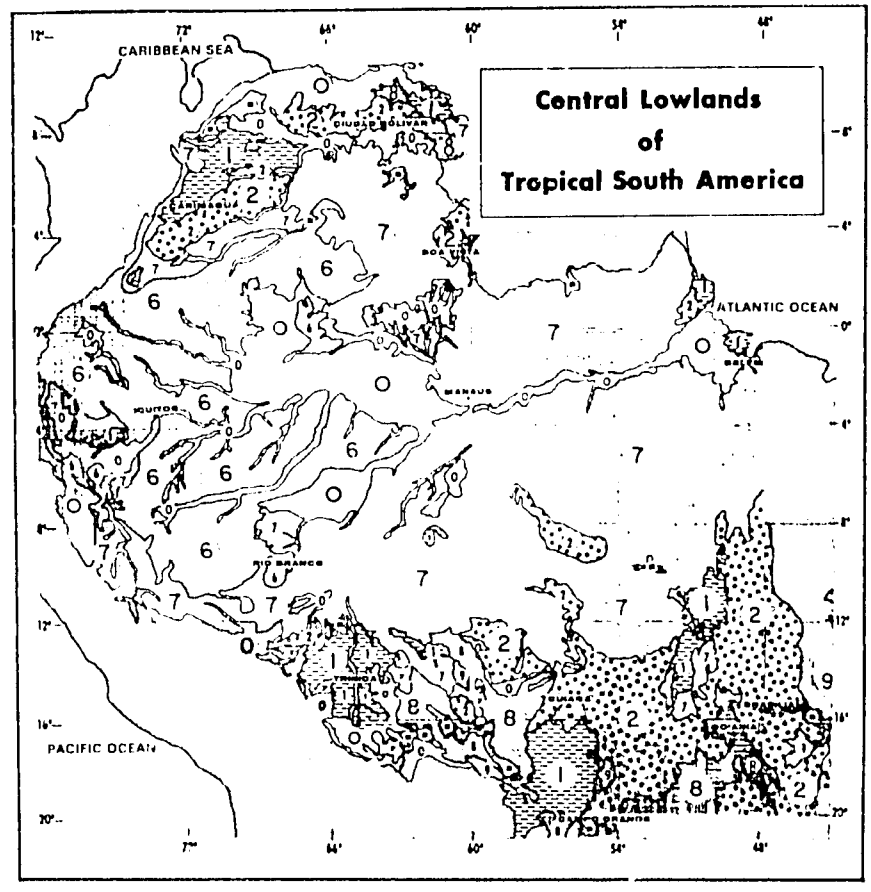
with considerably less skillful management than required for intrinsically infertile soils. In spite of their small total percentage area, they still cover 31 million hectares of terrain, and provide a safe option for expanding agricultural frontiers in Amazonia.

Advances in Soil Fertility Management

Table IV indicates that the common problems in Amazonian soils are low phosphorus levels, very high aluminium saturation, and low potassium, calcium and magnesium levels. Cation exchange capacities are also very low. There is some experimental evidence that sulphur is in poor supply in some soils (Wang *et al.*, 1976), and zinc deficiency symptoms are occasionally seen in crops. Soils with equivalent analyses are described for both forest and savanna soils (Radambrasil, 1972-1978). Nitrogen deficiencies are, of course, an ubiquitous problem.

Phosphorus

Supplemental phosphorus is clearly necessary for effective production on the majority of Amazonian soils. Recent advances in phosphorus management as indicated by Fenster and Leon (1978, 1979), shows that many natural phosphate rock deposits in Central South America can be used effectively either as pure ground rock phosphorus or as partially acidulated rock phosphates. Phosphorus prepared in these forms is much cheaper than the more soluble single and triple superphosphates, and in many circumstances, the cost of correcting phosphorus deficiencies may be significantly reduced.



1. Poorly drained Savannas.
2. Well drained Savannas.
   TWPE* 901-1060 mm, 6-8 months wet season.
   Note: Between the 4° North and 12° South parallels these are mainly isohyperthermic Savannas with WSMT** > 23.5° C. The majority of the Central higland Savannas and Southern Savannas are isothermic with WSMT < 23.5° C.
7. Tropical Semi-evergreen Seasonal Forest.
   TWPE 1061 - 1300 mm, 8-9 months wet season, WSMT >23.5° C.
6. Tropical Rain Forest.
   TWPE > 1.300 mm, > 9 months wet season, WSMT > 23.5° C.
8. Tropical Deciduous and Semi-deciduous forest.
9. Caatinga.
0. Other vegetation classes.
   *Total wet season potential evapotranspiration.
   **Wet season mean temperatures.

Figure 2. A Computer map of vegetation classes which relate to total evapotranspiration regimes.

Aluminum toxicity

Liming is the traditional means of overcoming aluminum deficiency. However, past recommendations based on the equation developed by Mohr (1960) and popularized by Kamprath (1970), result in large doses of lime well in excess of actual needs (Spain, 1976). This problem has recently been solved by Cochrane *et al.*, (1980), who developed an equation that takes into account the tolerance of crops to aluminum, and the exchangeable base levels in soils. Consequently, liming recommendations are now usually only a small fraction of those formerly deemed necessary.

Variable charge characteristics and leaching

In spite of their serious problems, certain common principles are emerging, and substantial practical advances have taken place in managing the fertility of leached, acid mineral soils. Many recent studies including those summarized by Rankin and Churchman (1981), emphasize their very low exchange capacities and variable charge characteristics. In other words, although these soils have a poor ability to retain plant nutrients, they have an ability to retain both nutrient cations and anions, which varies according to soil chemical conditions.

This situation facilitates chemical manipulation. The leaching of calcium down into calcium deficient subsoils in order to encourage root growth as recorded by Ritchie *et al.*, (1980), provides a practical example. The observation that the solubility of calcium in water solution may be increased by introducing chloride ions as recorded by Van Beek and Holt (1973), would suggest that there are promising ways of controlling the rate of movement of calcium and other nutrient ions down the soil profile.

TABLE II

CLIMATIC DATA SETS OF SITES LOCATED IN THE MAJOR VEGETATION SUBREGIONS OF THE AMAZON. *

Subregion Tropical rain forest
CRUZ DO SUL, AC, BRAZIL. LAT. 7° 38'S LONG. 72° 40'W 170 M

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Mean Temp [1]	24.4	24.6	24.4	24.2	24.1	23.4	22.9	23.8	24.5	24.6	24.7	24.6	24.2
MeanR.H. [2]	92.	92.	92.	89.	80.	73.	74.	77.	89.	94.	87.	96.	86.
PCT Sun [3]	30.	30.	31.	36.	50.	57.	56.	53.	36.	28.	40.	23.	39.
Mean Rad. [4]	390.	391.	386.	384.	413.	418.	425.	451.	405.	372.	447.	339.	402.
Precip. [5]	246.	244.	269.	241.	138.	104.	47.	86.	147.	251.	216.	241.	2230.
Pot Et [6]	118.	108.	117.	112.	124.	120.	124.	135.	119.	113.	132.	103.	1426.
Def Prec [7]	-128.	-136.	-152.	-129.	-14.	16.	77.	49.	-28.	-138.	-84.	-138.	-804.
Dep Prec [8]	189.	187.	209.	185.	97.	68.	20.	53.	105.	193.	163.	185.	
Mai [9]	1.60	1.74	1.78	1.65	0.78	0.57	0.16	0.40	0.88	1.71	1.24	1.79	

Subregion Semi-evergreen seasonal forest
MANAUS, AM, BRAZIL. LAT. 3° 8'S LONG. 60° 1'W 48 M

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Mean Temp	25.9	25.8	25.8	25.8	26.4	26.6	26.9	27.5	27.9	27.7	27.3	26.7	26.6
Mean R. H.	88.	89.	89.	88.	81.	74.	71.	63.	67.	76.	78.	85.	79.
PCT Sun	38.	36.	37.	38.	48.	56.	59.	67.	63.	54.	51.	43.	49.
Mean Rad.	420.	415.	418.	404.	426.	441.	462.	525.	541.	509.	491.	443.	458.
Precp.	276.	277.	301.	287.	193.	99.	61.	41.	62.	112.	165.	228.	2102.
Pot Et	132.	118.	131.	123.	135.	136.	149.	172.	173.	167.	155.	142.	1732.
Def Prec	-144.	-160.	-170.	-164.	-58.	37.	88.	131.	111.	55.	-11.	-86.	-370.
Dep Prec	215.	215.	236.	224.	114.	64.	32.	15.	33.	75.	120.	174.	
Mai	1.62	1.83	1.80	182	1.06	0.47	0.22	0.09	0.19	0.45	0.78	1.22	

Subregion Isohyperthermic savannas
CONCEIÇÃO DE ARAGUAIA, PA., BRASIL. LAT. 8° 15'S LONG. 49° 12'W 90 M

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Mean Temp	25.1	24.9	25.2	25.6	25.6	25.1	24.9	26.0	26.7	25.8	25.6	25.2	25.5
Mean R. H.	88.	89.	88.	79.	65.	48.	44.	54.	70.	83.	83.	89.	73.
PCT Sun	38.	37.	38.	50.	66.	79.	82.	74.	60.	46.	45.	36.	54.
Mean Rad.	437.	431.	428.	453.	470.	488.	510.	530.	521.	479.	477.	427.	471.
Precip.	253.	252.	263.	163.	60.	8.	7.	15.	64.	163.	196.	227.	1671.
Pot Et	135.	119.	132.	137.	147.	146.	156.	167.	162.	150.	144.	132.	1727
Def Prec	-118.	-133.	-131.	-36.	87.	138.	149.	152.	98.	-13.	-51.	-95.	56.
Dep Prec	195.	194.	204.	119.	31.	0.	0.	0.	34.	119.	146.	173.	
Mai	1.45	1.63	1.54	0.87	0.21	0.00	0.00	0.00	0.21	0.79	1.01	1.31	

* Source: Hancock *et al.*, (1979).

1. Mean Temp: mean temperature
2. Mean R. H.: mean relative humidity (%)
3. PCT Sun: percent sunshine
4. Mean Rad: mean solar radiation
5. Precip.: mean precipitation (mm)
6. Pot Et: potential evapotranspiration
7. Def Prec: prepicitation deficit
8. Dep Prec: dependable precipitation
9. Mai: moisture availability index

TABLE III

SOIL PROFILE ANALYSES OF SOME TYPICAL AMAZON SOILS

Horizon depth	Clay	Sand	pH	Org. C	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	ECEC	Al Sat.	P
cm	%	%	H_2O	%	..... mec/100 g					%	ppm
OXISOL: Allic Haplorthox (Latosol Vermelho Amarelo Alico) FCC: Ch. 66,8 km from Rio Branco towards Plácido de Castro, Edo. Acre, Brazil [1]											
0-5	39	21	5.1	4.00	1.00	8.22	3.74	0.68	25.70	7	14
5-20	43	22	5.0	1.21	1.60	1.10	1.02	0.17	10.24	41	4
20-70	53	23	4.0	0.81	2.80	0.08	0.12	0.07	6.07	90	1
70-140	62	15	4.9	0.39	2.20	0.03	0.48	0.03	5.35	79	<1
140-170	63	13	5.4	0.27	1.40	0.05	0.20	0.03	3.78	81	<1
ULTISOL: Plinthaquult, Oxic, Allic (Laterita hidromórfica Alica). FCC: Lhakg. Lat. 8°46'S, Long. 61°59'W. Municipio Porto Velho, Brazil [2]											
0-40	28	42	3.8	2.90	5.20	0.15	0.04	0.07	17.62	4	2
40-100	30	52	4.0	2.21	5.20	0.16	0.03	0.07	14.97	95	3
100-130	6	90	4.5	0.16	2.20	0.11	0.01	0.03	3.47	93	1
130-160	20	64	4.5	0.19	5.60	0.11	0.01	0.04	6.47	96	<1
160-200	21	60	4.6	0.18	6.60	0.13	0.01	0.05	7.49	97	<1
ENTISOL: Eutric Tropofluvent (Solo Aluvial Eutrófico). FCC: L. Lat. 1°52'S, Long. 67°41'W. Mun. Japurá, Edo. Amazonas, Brazil [3]											
0-10	17	50	5.5	2.23	5	5.7	1.8	0.59	13.0	5	17
10-80	12	72	5.1	0.66	32	1.7	0.7	0.11	5.7	32	14
80-90	12	72	5.6	0.35	25	2.1	1.0	0.11	6.2	25	16
90-180	10	74	5.3	0.33	24	1.7	0.7	0.09	5.0	24	19
ALFISOL: Tropudalf típico (Terra Roxa Estruturada Eutrófica). FCC: C. km 8 road to Panelas, Altamira, Edo. Pará, Brazil [4]											
0-8	40	44	7.0	2.51	0.01	25.24	2.28	0.28	29.16	3.4	8
8-26	49	28	7.3	0.84	0.11	5.96	0.70	0.27	8.91	1.4	2
26-60	50	24	6.9	0.53	0.01	3.22	0.65	0.10	5.55	0.23	2
60-100	56	23	6.4	0.26	0.11	2.47	0.43	0.09	5.34	0.32	3
100-130 +	55	24	5.5	0.22	0.11	1.29	0.75	0.06	4.86	4.4	3
INCEPTISOL: Udoxic Dystropept. FCC: Cha. Transverse road-Florencia, Mun. Florencia, Caldas, Colombia [5]											
0-16	37	46.3	4.7	2.02	3.2	0.95	0.80	0.23	5.66	61	3.5
16-85	52	29.8	4.7	0.51	6.7	0.22	0.43	0.03	7.74	90	0.9
85-173	49	29.6	4.9	0.22	6.3	0.10	0.47	0.08	7.19	90	0
173-208	28	40.9	4.9	0.15	6.1	0.10	0.41	0.13	7.68	90	0
208-228	20	56.2	4.9	0.08	5.3	0.20	0.56	0.11	7.71	85	0
228-247	28	33.1	4.9	0.09	8.1	0.16	0.63	0.17	9.60	89	0
247-350	21	38.5	4.9	0.07	6.1	0.16	0.53	0.21	7.55	87	0

1. Profile 89 of PROJ. RADAMBRASIL, Vol. 12, 1976
2. Profile 24 of PROJ. RADAMBRASIL, Vol. 16, 1978
3. Profile 39 of PROJ. RADAMBRASIL, Vol. 14, 1977
4. Profile 8 of PROJ. RADAMBRASIL, Vol. [illegible], 1974
5. Profile 9 of BENAVIDES, 1973

In acid mineral soils, as inferred by Nye and Greenland (1965), the nitrate ion is largely responsible for leaching. This observation has a considerable implication in understanding differences between forest and savanna soils.

Savanna soils compared with forest soils

The well drained Savanna soils of Amazonia are almost invariably leached and infertile. In these areas having a marked dry season, there is a rapid build-up of nitrates when soils rewet with the onset of the rainy season. This "nitrogen flush" was originally reported by Hardy (1946), and since substantiated and studied by many workers. With heavy rains, nitrates may leach down the profiles of weakly charged soils very rapidly, carrying along with them nutrient bases. As many Savanna grasses must regrow roots with the onset of the wet season, it is easy to envisage a net loss of soil nutrients and the resulting impoverished conditions of savannas in terms of both soils and total biomass.

In comparison with savannas, whilst the same mechanism of nitrogen build-up takes place in the semi-evergreen seasonal forests at the start of the wet season, the tree roots are still viable, and nitrates along with nutrient bases can be absorbed from the soil and stored in the vegetative biomass. In this sense, the heavy forest biomass can be considered a storehouse of soil nutrients. Although the fertility of forest soils as determined by analyses may be the same as those of savanna soils, the nutrients stored in the biomass may be used to modify these soils by the time honored tradition of felling and burning forests *in situ*.

Restoring fertility to forest soils

Table V illustrates the very substantial contribution of ash to soil fertility in different sites throughout Amazonia. Further, as shown by Falesi (1976) and Serrão *et al.*, (1979), this renewed fertility need not necessary be lost, and can be used for effective pasture growth for many years. Phosphorus was the first nutrient to become deficient.

It is interesting to comment on the problems of fertility with relation to forest regrowth in pastures. Dr. E. Mark Hutton (Personal comm.), has shown in a commercial circumstance in Tabuti (300 Km south of Belém), that the use of the grass *Brachiaria humidicola* together with the legume *Desmodium ovalifolium*, along with moderate fertilization based on phosphates to increase the fertility levels in leached, acid soils (Oxisols) originally supporting Semi-evergreen Seasonal Forest, gave a sufficiently vigorous sward to minimize regrowth. This is a case of ecological control of regrowth supported by increased soil fertility. Clearly a lot remains to be learned concerning the practical management of Amazon soils.

TABLE IV

SUMMARY OF SELECTED FERTILITY PARAMETERS OF THE AMAZON

Parameter and range	Topsoil (0-20 cm) Million ha	Topsoil (0-20 cm) %	Subsoil (21-50 cm) Million ha	Subsoil (21-50 cm) %
Soil pH:				
<5.3	392.2	81	398.9	82
5.3-7.3	91.2	19	84.7	18
% Organic matter:				
> 1.5	43.9	9	405.2	84
1.5-4.5	357.8	74	77.8	16
> 4.5	81.9	17	0.4	—
% Al saturation:				
0-10	81.8	17	96.2	20
10-40	37.9	8	49.8	8
40-70	78.4	16	39.4	8
> 70	285.3	59	298.0	61
Exch. Ca (meq/100 g):				
> 0.4	222.5	46	349.4	72
0.4-4.0	159.7	33	81.3	7
> 4.0	101.2	21	52.8	11
Exch. Mg (meq/100 g):				
> 0.2	185.6	38	356.8	74
0.2-08	185.3	38	84.7	18
> 0.8	112.1	23	42.1	9
Exch. K (meq/100 g):				
> 0.15	298.8	62	439.1	91
0.15-0.30	113.7	24	37.9	8
> 0.30	71.1	15	6.5	1
ECEC (meq/100 g):				
<4	80.0	17	193.4	40
4-8	238.5	49	210.1	44
> 8	165.2	34	80.1	16
Avail. P (ppm)				
<3	276.9	57	414.6	86
3-7	159.1	33	54.6	11
> 7	47.7	10	14.4	3
P fixation				
High (> 35 clay and % Free Fe_2O_3/% clay > 0.15)	77.3	16	—	—
Low	406.3	84	—	—

* From Cochrane and Sanchez, 1982.

Conclusions

As the land resources of Amazonia are becoming better known, many past generalizations should be reconsidered. Almost a quarter of the region is either covered by poorly drained lands or rivers. This provides a natural barrier to development and would buffer possible climatic changes. The close relationship between the physiognomic vegetation classes on the well drained soils and the total wet season potential evapotranspiration regimes, would infer that any fragility in the sense of cleared lands not reverting back to forests if left alone, would probably be confined to transition areas between the well drained Savannas and the Semi-evergreen Seasonal Forests. Notwithstanding, natural vegetation can be strongly influenced by soil conditions.

The soils of Amazonia are becoming better known in terms of their distribution and properties. The pattern of soil variability among the different vegetation subregions and landscapes would serve as the basis for the less hazardous choice of lands for the production of specific crops and pastures.

The study also focuses attention on advances in understanding the principles of improving the fertility of the extensive areas of leached, acid mineral soils. Although these can support pastoral and forestry production, their successful usage depends on the knowledgeable manipulation of soil chemical conditions. Much work is needed to develop technologies appropriate to the range of climates, landscapes and soils in Amazonia to avoid the failures of the past.

A lesser but important acreage of Amazonia has relatively fertile agricultural lands where agricultural frontiers can be expanded with minimal risk. However an adequate infrastructure to market, produce and obtain agricultural inputs at competitive prices, is a necessary pre-requisite for success.

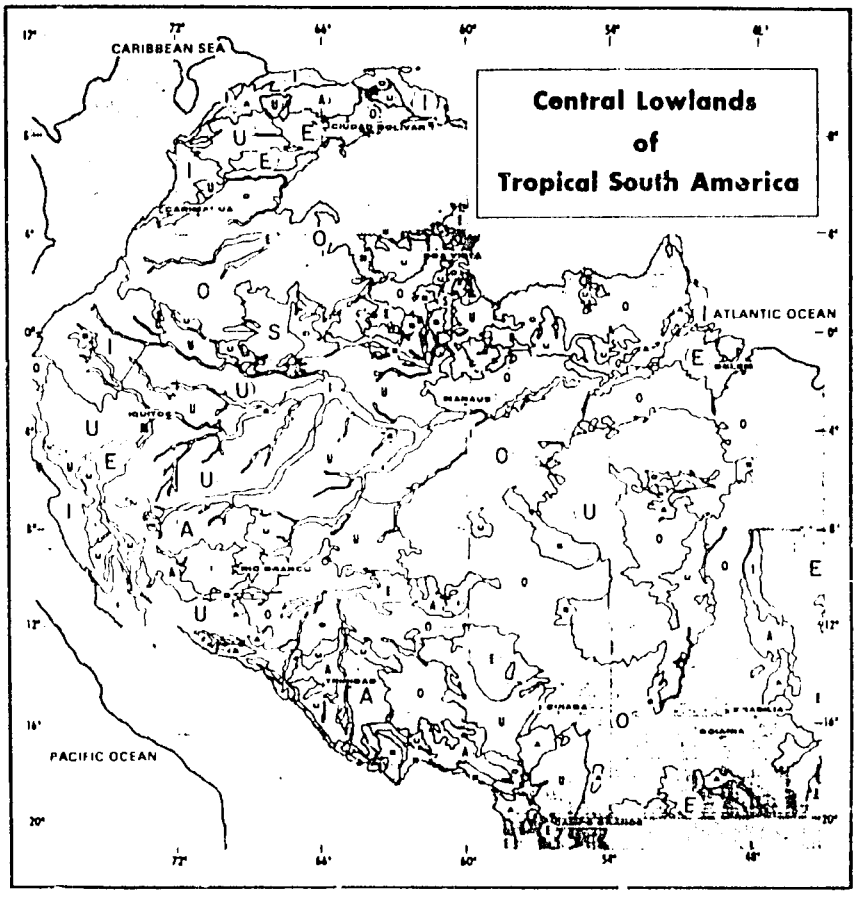


Figure 3. A computer map of soil Order classes.

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TABLE V

SUMMARY OF CHANGES IN TOPSOIL CHEMICAL PROPERTIES BEFORE AND SHORTLY AFTER BURNING TROPICAL FORESTS IN ULTISOLS AND OXISOLS OF THE AMAZON

Soil property	Timing	Yurimaguas [1] (2 sites) I	Yurimaguas [1] (2 sites) II	Manaus [2] ($\bar{X}$ 7 sites)	Belém [3] ($\bar{X}$ 60 sites)
Months after burning:		1	3	0.5	12
pH (in H_2O)	before:	4.0	4.0	3.8	4.8
	After:	4.5	4.8	4.5	4.9
Exch. Ca Mg	Before:	0.41	1.46	0.35	1.03
(meq 100 g)	After:	0.88	4.08	1.25	1.97
	Δ	0.47	2.62	0.90	0.94
Exch. K	Before:	0.10	0.33	0.07	0.12
(meq/100 g)	After:	0.32	0.24	0.22	0.12
	Δ	0.22	(0.07)	0.15	0.00
Exch. Al	Before:	2.27	2.15	1.73	1.62
(meq 100 g)	After:	1.70	0.65	0.70	0.90
	Δ	(0.59)	(1.50)	(1.03)	(0.72)
Al satn.	Before:	81	52	80	58
(%)	After:	59	12	32	30
Avail. P (ppm)	Before:	5	15	—	6.3
(Olsen in Peru,	After:	16	23	—	7.5
NC in Brazil)	Δ	11	8	—	1.2

Calculated from data by:

1 Seubert *et al.*, and Villachica and Sánchez (in press)

2 Brinkmann and Nascimento, 1973

3 Hecht (unpublished data)