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THE MAJOR SOIL ZONES OF COSTA RICA

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Acknowledgements

The authors are indebted to Mr. Jorge Campabadal and his staff at the San José office of the Organization for Tropical Studies, Incorporated for their assistance with the logistics. Financial support was provided by O.T.S.

The Major Soil Zones of Costa Rica by Harris et al.

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Abstract

This paper summarizes the first results of a reconnaissance survey of the soils of Costa Rica based on field and laboratory studies of sections exposed on road cuttings throughout the country.

Seven major soil zones can be recognized:

I. Alfisols (Non-Calcic Brown Soils).

II. Entisols (Lithosols) over ignimbrite in Guanacaste.

III. A complex of Ultisols (Red-Yellow Podzolic Soils) and Alfisols (Non-Calcic Brown Soils) of the Pacific Coastal zone.

IV. Ultisols (Red-Yellow Podzolic Soils) of the Atlantic Coastal Plain.

V. Spodosols (Podsols) of the cloud-forest areas on the north-east slopes of the Cordilleras.

VI. Complexes of Spodosols (Podsols), Inceptisols (Regosols and Andosols) with or without Ultisols (Red-Yellow Podzolic Soils) in mountain areas occupied by recent volcanic deposits.

VII. Mixed Entisols (Alluvial and Low Humic Gley Soils) and Inceptisols (Regosols) with occasional Histosols (Peats and Mucks) on the alluvial plains and coastal flats.

Oxisols (Latosols) may occur in isolated places, but on the whole, the soils are insufficiently weathered to have reached this stage. Leaching is particularly weak in the Guanacaste area where Alfisols (Non-Calcic Brown Soils) are dominant. This

The Major Soil Zones of Costa Rica by Harris et al.

Abstract continued

is presumably due to the fact that the area lies in the rain shadow of the northern Cordillera and to the long dry season.

Ultisols (Red-Yellow Podzolic Soils) occur in a belt centered on the General river valley and they are again widespread on the Atlantic Coastal lowlands. Spodosols (Podsols) occur on the north-eastern slopes of the Meseta Central and the Talamanca Range. They appear to result from the marked increase in cloud cover and relative humidity in these areas. Clubmosses and lichens cover the rocks, tree trunks, and soil surfaces in these regions.

Examples of analyses of typical profiles of each major soil type are given.

Table I. RESULTS OF ANALYSES OF TYPICAL PROFILES OF SOILS REPRESENTING THE MAJOR GREAT GROUPS OF SOILS RECOGNIZED IN THIS STUDY

reat roups.	Profile No.	Horizon	Depth (CM.)	pH 1:25 Aq.	pH 1M NaF	O.M. %.	Mechanical Analysis (%) AmS.	AmSi.	C.	ISi	Texture	Natural Clay %	Index of Structure	Free Iron Oxides %	Water Retention % 15 atmos	1/3 atmos	"Moistur %" at 15 atmos. "clay %" ratio
lfisol or lon-Calcic rown Soil	27	A_1	0-4	6.7	9.6	8.04	54	25	21	15	SCL	2	92	--	--	--	--
		A_3	4-23	6.3	9.6	0.80	19	37	44	23	C	22	50	4.17	22.0	27.3	2.0
		B_{11}	23-35	6.3	9.5	0.54	20	36	44	30	C			3.87	25.5	30.1	0.5
		B_{12}	35-58	6.3	9.5	0.27	19	37	44	31	C	8	81	3.42	25.8	31.6	0.6
		B_2	58-90	6.3	9.5	0.13	21	22	57	15	C	3	95	2.31	25.1	32.6	0.4
		C	90-140	6.2	9.6	0.06	26	38	36	31	CL	14	62	1.97	24.5	33.2	0.7
ltisol or ed Yellow odzolic oil	6	A_1	0-5	4.4	10.0	2.68	37	21	42	15	C	11	71	7.13	--	--	--
		B_2	5-30	4.1	10.2	0.94	30	20	50	15	C	1	98	5.56	--	--	--
		B_{2g}	30-50	4.6	10.2	0.58	29	23	48	17	C	1	98	6.63	--	--	--
		$^{11}C_{g1}$	50-78	4.6	10.2	0.53	25	36	39	17	CL	2	95	7.10	--	--	--
		$^{11}C_{g2}$	78-120	4.6	10.0	0.00	41	37	22	26	L	3	36	7.17	--	--	--
podosol r odsol.	9	1A	0-10	3.9	8.9	24.12	37	50	13	29	L-SiL	3	77	1.81	51.0	102.2	3.9
		11A_3	10-15	3.9	10.0	7.31	37	42	21	33	L	3	36	2.68	43.3	56.6	2.1
		11B_{21}	15-23	3.9	10.0	9.38	34	36	30	25	CL	7	77	4.69	39.7	49.0	1.3
		11Bzir	23-40	4.0	10.9	4.25	39	34	27	22	L-CL	6	78	6.53	30.3	34.4	1.1
		11Cg	40-70	4.0	11.3	1.93	46	36	18	25	L	9	50	4.32	14.5	31.1	0.8
		111Cg	70-75	4.2	11.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

nceptisol or egosol.	18	1A	0-35	5.3	10.2	7.77	30	46	24	37	CL	10	58	6.17	--	--	--
		$1B_1$	35-82	5.7	10.3	6.70	24	50	26	37	SiL-L	12	54	6.17	--	--	--
		$11A_1$	82-130	5.8	10.1	7.35	23	43	34	36	CL	9	73	6.64	--	--	--
		11 (B)	130-150	5.8	10.1	2.95	27	42	31	31	CL	12	61	6.62	--	--	--
nceptisol or ow Humic lay	30	$1A_1$	0-15	6.5	--	6.43	21	49	30	40	CL	10	67	4.22	--	--	--
		1 (B)	15-60	6.4	--	2.55	16	33	31	46	SiCL	0	100	4.13	24.9	35.4	0.8
		$11\ A_1$	60-90	6.3	--	2.01	19	49	32	39	SiCL	1	97	5.02	24.5	35.9	0.8
		11 (B)	90-115	6.3	--	1.21	24	52	24	39	SiL	1	96	5.08	23.8	36.4	1.0
		$111A_1$	115-145	6.3	--	2.01	21	43	36	35	C	1	97	5.89	24.1	36.8	0.7
		111 (B)	145-175	6.4	--	1.07	40	38	22	28	L	0.5	98	4.00	22.6	35.2	1.0

AmS = 2.0 - 0.05 mm

AmSi = 0.05 - 0.002 mm

ISi - 0.02 - 0.002 mm

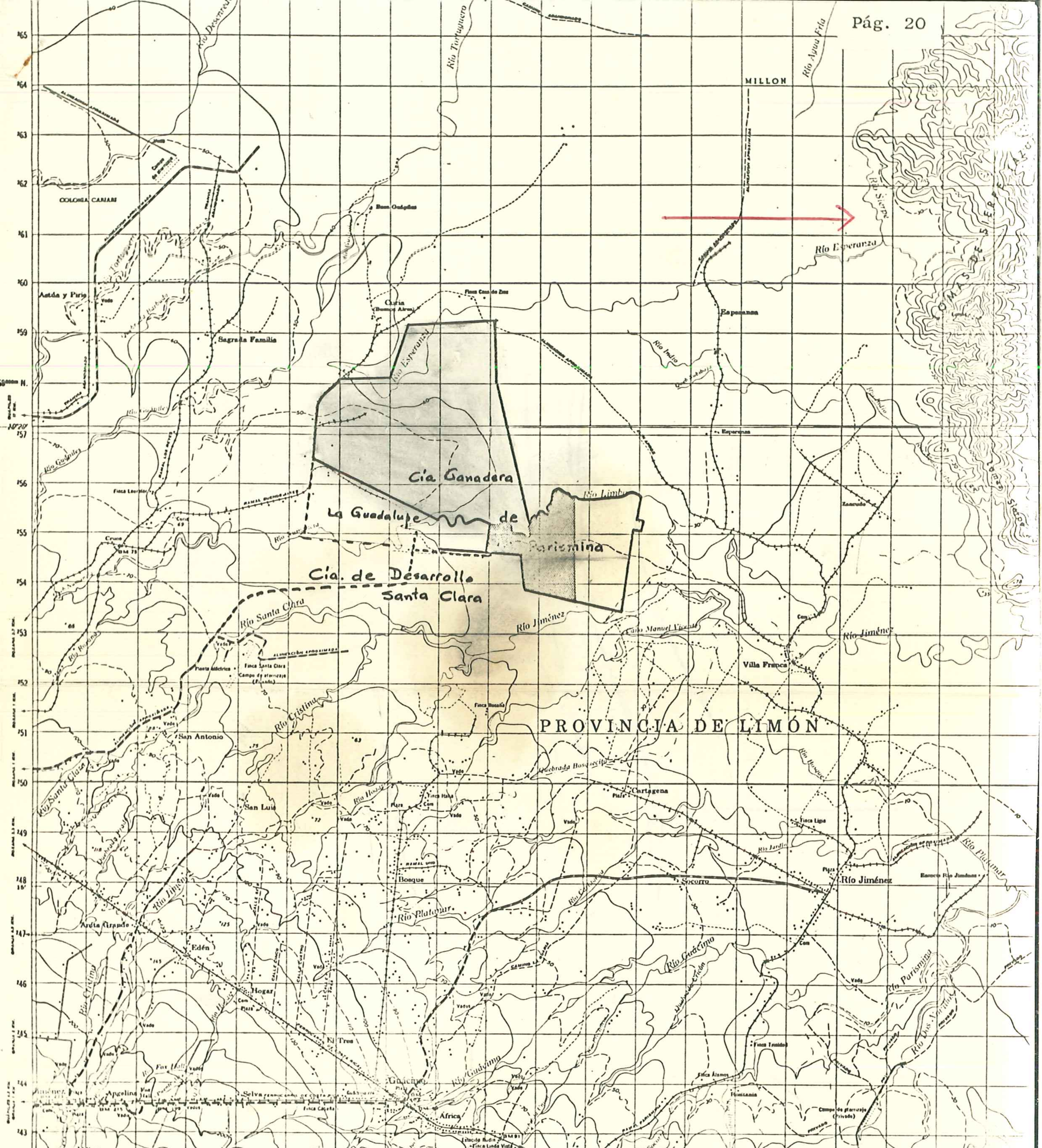
C = 0.002 mm

Table 2. pH of Various Horizons of Spodosols Compared With Those of Some Other Soils from Costa Rica

The pH is for one gram of soil in 50 ml. of 1 M NaF solution after one hour.

Profile Number	Mean pH (NaF) A Horizon	B Horizon	C Horizon	Great Group
9	9.4	10.5	11.3	Spodosol
10	9.2	10.9	11.1	"
11	10.0	10.5	11.3	"
12	7.8	11.3	11.5	"
6	10.0	10.2	10.0	Ultisol
17	9.2	9.3	9.3	"
42	9.7	9.8	9.8	"
41	9 8	9.9	9.9	"
27	9.6	9.5	9.6	Alfisol

Almost all soils are alkaline in reaction by this test. Amorphous material produces unusually alkaline pH values due to the release of [OH]' (Egawa et al., 1960; Huang and Jackson, 1965). Thus normal crystalline mineral soils show pH values by this method between 7.5 and 10. Spodosols show more alkaline values in the B horizons due to the amorphous materials, while Andosols show very alkaline pH values throughout the profile. The above results were obtained using the same batch of NaF, so that variations due to different quantities of silicofluoride will be negligible (See G. Smith in Furkett and Fieldes, 1968, p. 137). The range of variation in pH of the A horizons is due largely to the presence of different amounts of organic matter. The latter tends to produce a more acid reaction than mineral matter.


Cía Ganadera
La Guadalupe de Parismina
Cía. de Desarrollo
Santa Clara
PROVINCIA DE LIMÓN
MILLON
COLONIA CARIARI
Astúa y Pirie
Sagrada Familia
Esperanza
Río Esperanza
Río Jiménez
Río Santa Clara
San Antonio
San Luis
Cartagena
Villa Franca
Río Jiménez
Bosque
Socorro
Edén
Hogar
El Tres
Guácimo
África
Selva
Angelina
Parismina
Iroquois
Mercedes
Bremen
Pocora
Río Parismina
Río Guácimo
Río Platanar
Río Cristina
Río Limbo
LOMAS DE SIERPE
Río Sierpe
Río Tortuguero
Río Agua Fría

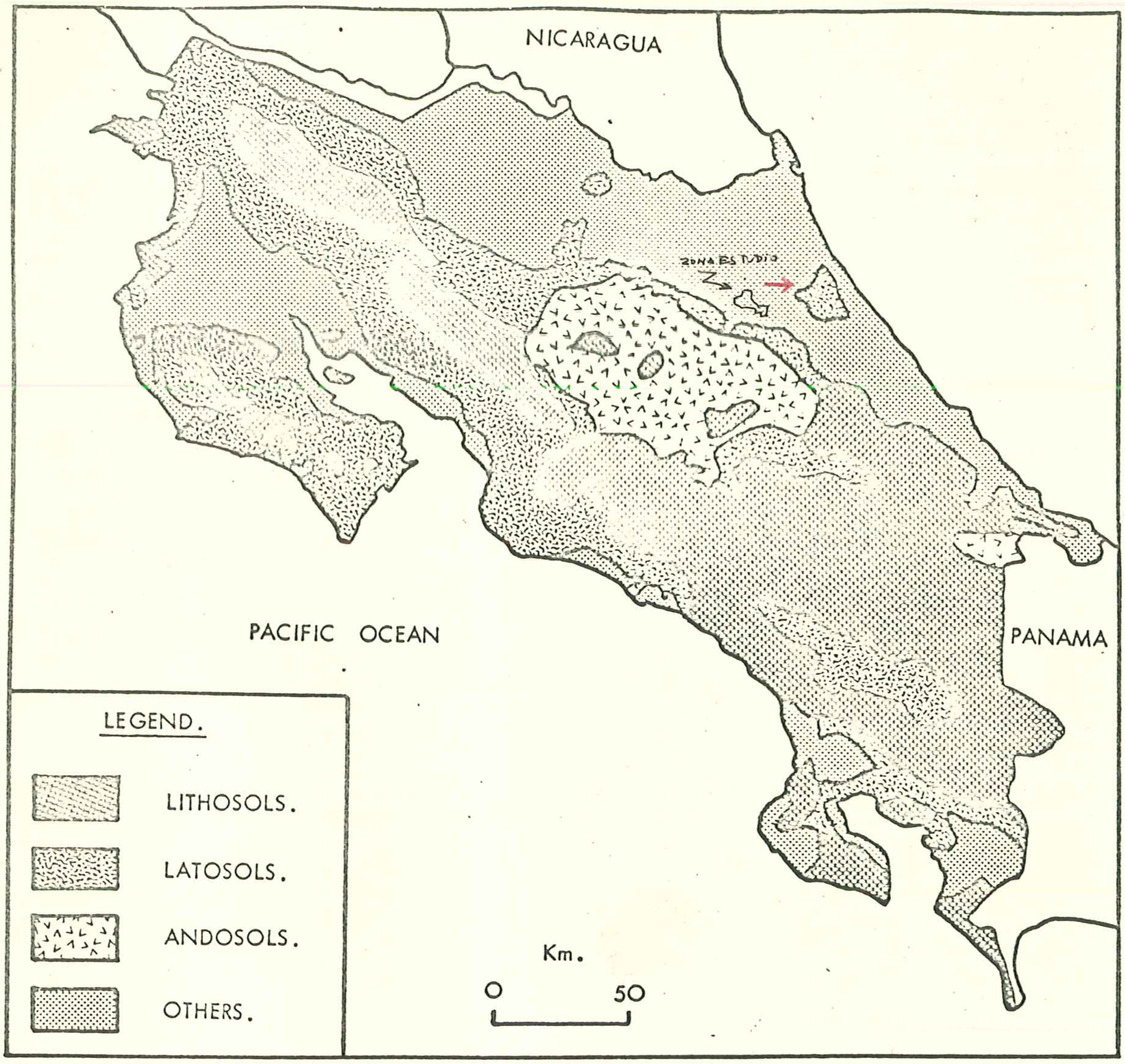


Fig. 1. Soils of Costa Rica, according to A.I.D., 1965.

Soils of Costa Rica by Harris et al.

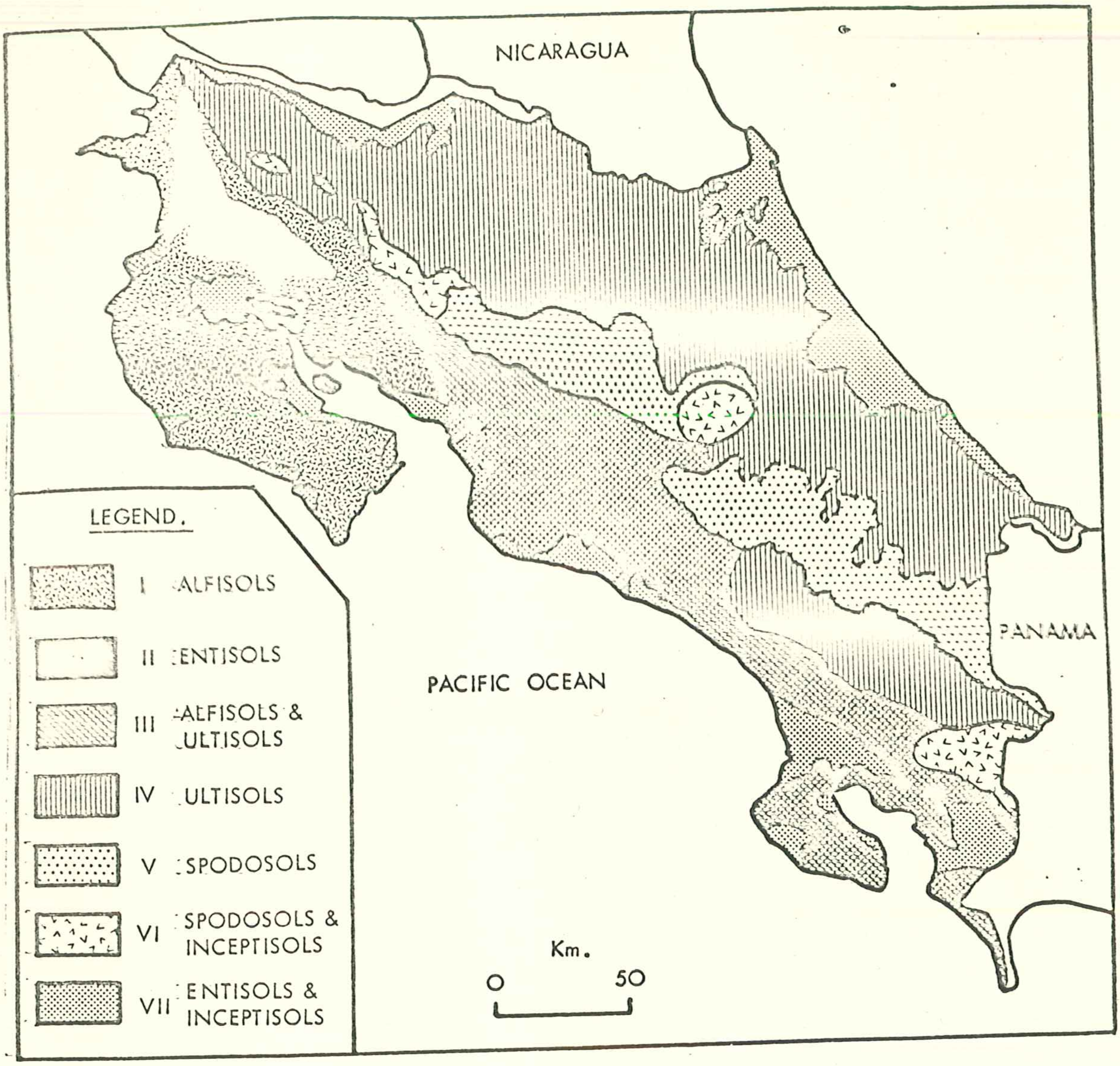


Fig. 2. Major Soil Zones of Costa Rica, based on reconnaissance soil survey along the road network, and also I.T.C.O., 1964; 1967. For further details of the minor soil groups present, see the text.

Soils of Costa Rica by Harris et al.

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Introduction

Until now, the soils of Costa Rica have never been systematically mapped even on a reconnaisance basis. Until five years ago, the only soil surveys that had been carried out were detailed studies of small areas on the Atlantic lowlands for the United Fruit Company and a similar study of part of the Central Valley (Dondoli and Torres, 1954). There were a few isolated observations elsewhere which enabled Stevens (1964, p. 308) to produce a generalized map of the soils of the country at approximately 1 : 10,000,000. The bulk of the country was mapped as being covered by intensely weathered soils, the only exceptions being on the alluvial lowlands and along the chain of active volcanoes in the north of the country. The young volcanic soils were interpreted as being only slightly weathered.

In 1964, there also appeared the first of the reconnaisance soil studies under the auspices of the Instituto de Tierras y Colonizacion of the Upala region of the Atlantic lowlands along the south side of Lake Nicaragua (ITCO, 1964). Oxisols, Entisols, and Inceptisols were recognized, but no soil analyses were given to substantiate this conclusion.

In 1965, the first more detailed compilation of the soils of the country was published, based on the previous works and on any other information (chiefly from A. A. Maroto) which the Agency for International Development could obtain (Map T5, AID, 1965). As in the studies of Stevens and ITCO, the main areas of well drained soils were interpreted as being Latosols, although a large area of Lithosols was mapped in the Talamanca Range (Fig. 1). The soils along the northern Mesetas around the active volcanoes were called Andosols. The map also showed increased differentiation of the soils of the low lying areas near the coast. No soil descriptions or analyses were included.

Since then, there have been several further studies, some using photointerpretation almost exclusively, e.g., Cossio, 1967, and others being based on appreciable field work, e.g., ITCO, 1967. The latter study covered a large region along the Atlantic lowlands stretching from Limon northwards to Nicaragua. The authors summarized the earlier rather inaccessible studies of the United Fruit Company and included some analyses in their report. This time, they chose not to use the Seventh Approximation (USDA, 1960) but instead reverted to the older American system of soil classification (USDA, 1938), with its modifications, The reason for this change was the lack of laboratory data. Once again, the red soils of the lowlands were mapped as being Latosols.

Two other important studies have included the description and analysis of samples from the horizons of approximately forty profiles of soils in the various life zones in the northern half of the country and another compilation of the soils in the form of a map by FAO. The legend used in the case of the latter is an earlier version of the new FAO soil classifiaction system which is being used for the World Soil Map (Dudal, 1967). Unfortunately the results of these studies are not yet generally available.

During the summer of 1967, two of the authors (Harris and Stouse) were teaching a course of Land Use in the Humid Tropics to a group of Geography graduate students in one of the courses offered by the Organization for Tropical Studies, Incorporated. During the field work, descriptions were made of soils at over forty sites throughout

Costa Rica, samples being collected from each soil horizon. These were sent to the University of Kansas for laboratory analysis. The authors were impressed by the lack of correspondence between their field observations and the previous maps of the soils of the country. Accordingly a further study was carried out by the authors of this paper in August and September, 1968, in order to expand their previous work into a reconnaissance study of the major soil types of Costa Rica. Once again, samples were collected along the roads for laboratory analysis in Kansas. At present, the analyses on the latest samples are incomplete, but they are sufficient when combined with the previously published data by other authors to enable us to delimit tentatively the major soil zones of Costa Rica. This paper will summarize the present status of this work.

Methods Used

Costa Rica has one of the best road networks in Central America. By driving along these roads, it is possible to cross all of the major physiographic regions, vegetation zones, and rock types of the country. The only areas which are not accessible in summer are the lower lying areas of the Atlantic Coastal Plain and parts of the eastern side of the Talamanca Range.

During the traverses, typical profiles were described and sampled at well drained sites in convenient road cuttings. Care was taken to sample all of the major soil types observed and to establish any correlations with changes in vegetation, topography, and parent material. More detailed studies were carried out near Quesada and on Finca La Pacifica near Cañas in order to check the variability of soils at different scales of study.

Measurements were made of field moisture content and bulk density by collecting undisturbed samples in cans of known volume for each horizon. These samples were then sealed in polysthene bags. Disturbed samples were also collected from the profiles.

In Kansas, the following analyses have been carried out and are reported here. Mechanical analyses were carried out by the pipette method (Piper, 1950; Kilmer and Alexander, 1949); pH on 1 : 2.5 suspension by glass electrode; pH of 1 gm. of soil in 50 ml. of 1 M NaF solution after one hour (Furkett and Fieldes, 1968); organic matter by the Walkley and Black method (Walkley and Black, 1934); free iron oxides by the dithionate method (Olson, 1965); and water retention at 15 atmospheres and 1/3 rd atmospheres by pressure membrane method using air-dry soil. Natural clay and index of structure were measured by the method of Sombroek (1966).

The soils are classified using both the U.S.D.A. (1938) system and its modifications (Thorp and Smith, 1949; Aomine and Yoshinaga, 1956; Harris, 1963) and the latest version of the Seventh Approximation (U.S.D.A., 1967). For the purposes of this paper, the soils will only be identified at the Great Soil Group or Great Group level. As more data become available, the classification will be completed in more detail.

Major Soils and Soil Zones

Figure 2 shows the major soil zones encountered during the present studies. It will readily be seen that the map is very different to that shown in figure 1. Soil zone 1 is the area of Alfisols (Non-Calcic Brown Soils) of the uplands of the Guanacaste region. Analyses of a typical profile (No. 27) are given in table 1. These soils are characterized by a slightly acid reaction, the presence of an argillic horizon, a low content of organic matter, and a moderate but variable amount of free iron oxides. The bulk density of profiles similar to this varies from 0.70 gm/cc to 1.20 gm/cc. Water retention at 15 atmospheres is around 25% by weight and index of structure is lower than in the other soils of Costa Rica. Ratio of moisture percent at 15 atmospheres to clay (%) is fairly low. These soils commonly contain up to 20% of weatherable heavy minerals in the sand fraction. Parent materials vary enormously from Tertiary and Quaternary volcanics to limestones and sandstones. The high base status of the soils is consistent throughout this area, the extreme redness of certain of these soils meaning little in terms of degree of weathering and leaching.

Soil zone II is found on either side of the Pan American Highway from Cañas northwards almost to the Nicaraguan border. It is a region of very thin soils developed on volcanics that have been recently reclassified as ignimbrites (Dondoli, Malavassi, and Dengo, 1968). These soils consist of A/C profiles with no more than 15 cms of A_1 horizon over bedrock. Locally Alfisols (Non-Calcic Brown Soils) occur where pockets of marine, colluvial, or alluvial sediments have been deposited on the surface of the underlying rock. These Alfisols (Non-Calcic Brown Soils) support a Dry Forest vegetation (Holdridge, 1967) in marked contrast to the very shallow Entisols (Lithosols) which appear to be characterized by a natural savannah type of vegetation.

Soil zone III lies south of this area on the lower slopes of the main Cordilleras, and consists of mixed Ultisols (Red-Yellow Podzolic Soils) and Alfisols (Non-Calcic Brown Soils). The complex extends up to about 2,000 meters in elevation. The Ultisols (Red-Yellow Podzolic Soils) form deep profiles and tend to be found at sites where there is little erosion or where colluvium accumulates. The Alfisols (Non-Calcic Brown Soils) are usually shallower and occupy the steeper slopes and ridge crests where erosion is likely to be proceeding at a greater rate. The profiles of the Alfisols (Non-Calcic Brown Soils) are similar to those found in the Guanacaste area.

Profile 6, table I, shows typical results of analyses of an Ultisol (Red-Yellow Podzolic Soil). In this case, it is developed on colluvium over mudstone. The pH is very acid while organic matter content is low. There is a distinct argillic horizon present and clay skins are usually well developed. The content of iron oxides tends to be higher than in the Alfisols (Non-Calcic Brown Soils). There tend to be fewer weatherable heavy minerals present in the sand fraction, although figures of 20% have been found where the soils are developed on Quaternary volcanics. In the profiles examined so far, the quantity of weatherable heavy minerals never gets so low that oxic horizons could be present. Bulk densities are similar to those of the Alfisols (Non-Calcic Brown Soils).

Two major modifications occur locally in the zones of Alfisols (Non-Calcic Brown Soils) and mixed Alfisols and Ultisols (Non-Calcic Brown and Red-Yellow Podzolic Soils). Where limestone outcrops, Mollisols (Sols Bruns Calcaires) may be found, e.g., about 10 km south of the border with Nicaragua, and again, at the crest of the escarpment on the road to San Vito. The second group of soils are the Inceptisols (Regosols) developed on young volcanic ash around Santa Elena and Monteverde. These soils occupy too small an area to be included as separate mapping units in this study.

Soil zone IV on figure 2 is the area of Ultisols (Red-Yellow Podzolic Soils) occupying the higher parts of the Atlantic lowlands. The same soils are found along the upper Pacific slopes of the northern mountains and also in the General river valley, southeast of San Isidro de General. These acid soils are similar to profile 6, and include the main bauxite deposits of the country. The latter consist of highly weathered material with the typical morphology of Ultisols (Red-Yellow Podzolic Soils). Weathering in these profiles may be up to 20 meters deep, but the solum occupies the upper 2.5 meters.

Soil zone V is the zone of Spodosols (Podsols) of the cloud-forest areas of the north-east slopes of the Cordilleras. Until now, these soils have not been recognized as a distinct group although they appear to cover large areas. Parent material varies from volcanic deposits of various ages to granite. The ground is covered by a thick ($>$ 10 centimeters) layer of acid raw humus with lichens growing on the surface.

Profile 9, table 1, is an example of a soil developed on young volcanic ash at 3,100 meters elevation on the Cerro Muerte, Talamanca Range. The first striking feature is the high acidity of the soil in water. On the other hand, the pH of one gram ofsoil in 50 ml. of 1 M NaF solution at the end of one hour, shows increasing alkalinity in the B_{2ir} and C horizons. Table 2 gives additional data indicating that the results for profile 9 are characteristic of the soils within this zone. It will be noted that the pH values in NaF solution for the A horizons of the Spodosols (Podsols) are similar to those obtained for all horizons in the Ultisols (Red-Yellow Podzolic Soils) and Alfisols (Non-Calcic Brown Soils). Because the pH values in NaF solution are not consistently high throughout the entire profile, these soils do not appear to be Andosols as previously suggested.

Further evidence which supports this interpretation comes from the distribution of free iron oxides, the clay fraction, and the organic matter. These all match the pattern found in the sola of Spodosols (Podsols) , although in this area, movement and accumulation of organic matter does not always take place. In the field, a lighter zone corresponding to the A_2 horizon of the profile is usually apparent. The water retention data is similar to the other soils of Costa Rica bearing in mind the high organic matter content, e.g., profile 27 (the Alfisol) and profile 30 (the Inceptisol). The ratio of moisture content (%) at 15 atmospheres and clay content (%) in the B_2 horizon is similar to that reported from Spodosols (Podsols) elsewhere in the Tropics (Franco, 1968). Heavy mineral determinations of samples of the A horizons of the Spodosols (Podsols) show that all except about 0.5% of the sand fraction is lighter than bromoform (S.G. 2.78) indicating that most of the normally abundant heavy mineral fraction has been destroyed by weathering. The sand and the silt grains in the B horizons are coated with a thick layer of secondary material rich in iron oxides just as in Spodosols (Podsols) of temperate regions.

There appear to be no properties of these soils which indicate the presence of A horizons rich in allophane or some other amorphous materials. This is most interesting since andesitic volcanic ash of this type often weathers to allophane and then, to crystalline halloysite. The relative fertility of these soils of the Central Valley and of the Zarcero environs may well be due to this fact. Likewise Lithosols are rare in this area although some of the Spodosols (Podsols) on the steeper slopes would more correctly be called "Lithosolic".

Soil zone VI is the area of mixed Spodosols (Podsols), Inceptisols (Regosols or possibly Andosols) and sometimes Ultisols (Red-Yellow Podzolic Soils). These are found in the regions of very recent volcanic activity, such as the San Vito area on the Panamanian border, and the Irazu-Turrialba complex of the Meseta Central. In these areas, Spodosols (Podsols) or Ultisols (Red-Yellow Podzolic Soils) are developed on the older ash deposits while Inceptisols (Regosols) mark the zones of fresh ash accumulation. Evidence from C^{14} dates suggests that at an elevation of 2,400 meters, a well developed Spodosol (Podsol) may be produced on these parent materials in a relatively short period of time. Two dates (I-3451 and I-3449) which were obtained from the A_1 horizons of two buried Spodosols (Podsols), one on top of the other, are 17,600 ± 300 years B.P. and 17,650 ± 300 years B.P., respectively.

A typical profile of the Inceptisols (Regosols) is No. 18, table I. The pH values are not as low as in the Spodosols (Podsols) while pH of one gram of soil in 50 ml. of 1 M NaF solution for one hour shows values similar to the Ultisols (Red-Yellow Podzolic Soils) of lowland areas of different parent material. Organic matter contents are intermediate between lowland Ultisols (Red-Yellow Podzolic Soils) and the Spodosols (Podsols) of the uplands, while the soils show only moderate indices of structure. Soil structure apparently improves as soil development proceeds and the values are certainly in accordance with the visual observation on ease of erosion. The fresh ash deposits erode much more easily than the older deposits with well developed soils present. Once again, evidence for the presence of allophane is lacking in the data currently available. Further work is being done on the aspect, since the Irazu ash contains appreciable quantities of volcanic glass.

Soil zone VII consists of the areas of Entisols (Alluvial Soils), Inceptisols (Low Humic Gleys and Saline Marshes), and Histosols (Organic Soils) of the lowland areas along the coasts. Profile 30 is an example of an Inceptisol (Low Humic Gley) from the Nicoya Peninsula near Belén. The soils are typically neutral to slightly acid, with a very good index of structure and a fairly high content of organic matter. Some of the better drained soils, such as profile 30, tend to look similar in color to Vertisols (Grumusols) but they lack the heaving process at present. Heaving must have taken place in some of these soils in the past, judging by the constant textures with depth in certain profiles.

Relationship of the Soil Zones to the Major Soil Forming Factors

In Costa Rica, the most constant of the five major soil forming factors is the parent material. Volcanic ash covers much of the country, while the deposits and soils lying towards the coasts are derived in the main from the volcanic deposits upslope. The greatest variations in soils are found where limestone occurs, but otherwise parent material has limited influence on the soils produced.

The most important factors in soil formation are climate and topography. With chains of mountains rising to over 3,400 meters above sea level, separated by cols and lying athwart the dominant rain-bearing North-east Trade Winds, this is almost inevitable. The mountains cause the air to rise which results in condensation and thus increased cloud cover and precipitation on the north-east slopes, while areas on the leeward side of the mountains lie in the rain shadow.

Poor drainage on the lowlands near the coast produces Entisols (Alluvial Soils) and Inceptisols (Low Humic Gley and Saline Marshes). Topography also influences the duration of time that material remains in situ and the degree of infiltration and run-off at a given site. Slopes of over 100% are commonplace in the higher mountain ranges and inevitably the soils on these slopes are less leached than those at flatter sites.

Surrounding the mountains at an elevation of about 500 meters is a ring of bauxite deposits. These are developed on terrace-like surfaces of marine (Dondoli, et.al., 1968), mudflow (Lahare), or fluvial origin. It seems unlikely that weathering has produced the exceptionally thick regolith. The parent material for these deposits may have been provided by a combination of downslope movement of partly weathered colluvium and mudflows, together with alluvial and occasional marine deposits.

The vegetation of Costa Rica has been classified by Holdridge (1967) and the main vegetation zones agree satisfactorily with the soil zones. However, the mapping units of Holdridge do not identify the areas in which Spodosols (Podsols) occur.

Time is of questionable significance . This is due to the recent emergence and uplift of the land, the widespread distribution of relatively young volcanic ash over considerable areas, the rapidity with which soil formation takes place in the more humid environments, and finally our lack of knowledge of the age of the deposits in general.