Some Aquic Tropudalfs in the Vicinity of Villa Banzer and San Carlitos in Northeastern Bolivia[1]

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ABSTRACT

Several soil profiles were examined near settlements around San Carlitos and Villa Banzer, some 30 and 100 km, respectively, from Trinidad, capital of the Department of Beni, in northeastern Bolivia. In general, the soils appear to be Aquic Tropudalfs. They are very deep; internal drainage varies from moderate to slow; external drainage is slow. Textures are moderately fine to fine with very high (from 42 to 65%) silt content. Clay increases in the B_2 horizon as compared to the A_1. The combined silt and clay content in this horizon ranges from 85 to 96%. Organic matter levels of the surface soils are at least as high as those of other tropical- and temperate-region soils. The soils are strongly acid in the upper layers. CEC seems to be related to organic matter activity in the surface layers and then more to clay content at lower depths. The soils of the areas studied appear suitable for crops such as rice, corn, and cassava. Major problems affecting soil utilization are those related to drainage and irrigation. Liming and fertilization are key factors in developing adequate agricultural programs in the region.

INTRODUCTION

The Department of Beni, with 21 million hectares of land and fewer than 250,000 inhabitants, offers a vast potential for agricultural, industrial and economic development. The great natural resources of Beni, apart from possible mineral resources, are its climate and soils. The vast forestland, of unique timber resources attests to the value of these two assets. Its tropical and subtropical climate would permit continuous year round agricultural production if floods could be controlled during the rainy season, and irrigation provided during the dry season (4, 6), together with judicious liming and fertilization techniques.

The soils, even admitting their serious drainage and fertility handicaps, if properly managed, could be productive and contribute positively to the development of the economy of the region. Definitely, climate and soil resources favor large agricultural development. However, there are other complex problems that adversely affect the development of an efficient agriculture in the region, such as the scarce population and the lack of adequate surface transportation. The situation is more complex because of the low education level of the rural population and the lack of marketing information and techniques. Apart from the large livestock farms, which are underutilized, agriculture is primarily rudimentary, a

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shifting agriculture prevails in which land is temporarily cleared and cropped as long as inherent fertility permits, than allowed to fallow while the peasant farmer moves to another forest patch to start the cycle again. Thus extreme rural poverty persists with its problems of undernourishment, high infant mortality rates, and illiteracy. Public policy grants 50 hectares to each Bolivian who wants to devote his efforts to farming. But the impact of this measure is of doubtful value unless the essential infrastructure of roads and the services for land clearing and preparation (including drainage and irrigation) are provided. The policy is furthermore meaningless if information is not provided. With adequate infrastructure, services and technology, settlers might stay on their land, obtain good crop yields and raise their standard of living.

Livestock, an undertaking of great diversification potential, is limited to beef cattle. The large land holdings devoted to beef cattle are inefficient and contribute to the benefit of only a few, while extreme poverty prevails in the region. Such an extensive livestock raising that requires 5 hectares per animal unit is not geared to contribute substantially towards the economic and social development of Beni.

The general outlook of the current situation at Beni is not bright. However, the potential of its soil and climate resources is encouraging. If government agencies such as CODEBENI,[3] MACA,[4] and particularly IBTA,[5] develop these basic resources by providing infrastructure and services and intensifying the search of a specific technology realistic to the region, the economy and living standards in Beni will improve.

There is enough land in Beni to feed Bolivia better and to feed people far beyond its frontiers, a good part of the outside world. In the meantime, adequate characterization of the soil and climatic resources of Beni should lead to clearer concepts of agricultural planning and management.

This paper reports on the morphology and selected physical and chemical properties of some tropical soils near Villa Banzer, an area now being settled mostly by people displaced from the banks of the large and deep Mamoré River. Other soils studied are those from near San Carlitos, an area where CODEBENI attempts to develop pilot-scale food-crop farms through an experimental-extension type operation.

MATERIALS AND METHODS

Some 30 profiles were observed in the provinces of Mamoré, Itenez, Cercado, Ballivián, Marban and Moxos. Of these, 5 were described in detail following the USDA Soil Conservation Service guidelines. These were located in the general vicinity of Trinidad.[6] Soil samples were taken

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[6] Capital of the Department of Beni with some 18,000 inhabitants.

from each horizon of 2 profiles. Particle-size distribution was determined by the Boyoucos method (5). Organic matter was determined by potassium dichromate titration; pH was determined electrometrically in a 1:5 solution; CEC and exchangeable Ca^{++}, Mg^{++}, Na^{+} and K^{+} by leaching with NH_4OAc and using atomic absorption; exchangeable Al^{+++} by extraction with 1*N* KC 1 and titration (2).

RESULTS AND DISCUSSION

Profiles were examined at Villa Banzer, 100 km from Trinidad and at San Carlitos, 30 km from Trinidad. These areas remain temporarily flooded due to inadequate surface drainage. Slopes are from 0 to 2% and the soils developed from alluvium. The land is under forest cover.

A typical profile of the Villa Banzer series is as follows:

Horizon	*Depth*, cm	*Description*
A_1	0–13	Very dark grayish brown (10YR 4/2) silt loam with few fine faint yellowish brown mottles; moderate medium granular structure; friable, when moist, slightly sticky, slightly plastic; many very fine and fine micropores; many fine and medium roots; strongly acid; wavy boundary.
B_1	13–36	Very dark grayish brown (10YR 4/2) silty clay loam with common, fine distinct yellowish brown mottles; moderate to strong, coarse subangular blocky structure; friable to firm; slightly sticky to sticky, slightly plastic to plastic; many very fine to fine micropores; fine and medium roots; strongly acid, wavy boundary.

Horizon	*Depth*, cm	*Description*
B_{21}	36–63	Dark yellowish brown (10YR 4/4) silty clay; strong medium to coarse angular blocky and prismatic structure; firm to strongly firm, sticky, plastic; common to many very fine micropores; clayfilms; few fine and medium roots; strongly acid; gradual and irregular boundary.

B_{22}	63–88	Brown to dark yellowish-brown (10YR 4/4-4/3) silty clay; medium and coarse angular blocky and prismatic structure; firm to very firm when moist; sticky, plastic; clayfilms; common to many very fine micropores; few fine and medium roots; medium acid wavy boundary.
B_3	88–118	Dark yellowish-brown (10YR 4/4) silty clay loam; moderate medium and coarse subangular blocky structure; firm slightly sticky, slightly plastic; common to many very fine micropores; slightly acid wavy boundary.

Horizon	*Depth*, cm	*Description*
C	118–150	Dark yellowish-brown (7.5YR 4/4) loamy sand with few to common fine faint brown mottles; weak, fine subangular blocky structure; friable; few to common very fine micropores; slightly acid.

A typical profile of the San Carlitos series is as follows:

Horizon	*Depth*, cm	*Description*
A_1	0–18	Very dark gray (10YR 3/1) silt loam with few fine faint brownish yellow mottles; moderate fine and medium granular structure; friable, slightly sticky, slightly plastic, few very fine micropores; very fine micropores; very fine to fine, medium to coarse roots; medium acid; wavy boundary.
A_{12}	18–36	Very dark grayish-brown (10YR 3/2) silt loam; strong coarse, subangular blocky structure; friable; slightly sticky, slightly plastic; many very fine and fine micropores; few fine, medium and coarse roots; strongly acid; gradual and irregular boundary.

Horizon	Depth, cm	Description
B_{21}	36–59	Brown to dark-brown (10YR 4/3) silty clay loam; moderate to strong coarse subangular blocky structure; friable to firm, sticky, plastic; many very fine micropores; few fine and coarse roots; slightly acid; gradual and irregular boundary.
B_{22}	59–80	Yellowish-brown (10YR 5/4) silty clay loam; moderate medium and coarse subangular block stucture; friable to firm; sticky, plastic; common to many very fine micropores; few medium and coarse roots; mildly alkaline; gradual and irregular boundary.
B_{23}	80–107	Yellowish brown to dark yellowish brown (10YR 5/4-4/4) silty clay loam; moderate medium and coarse subangular block structure; friable to firm; slightly sticky to sticky, slightly plastic to plastic; common very fine micropores; moderate alkaline; wavy boundary.

Horizon	Depth, cm	Description
C	107–130	Light olive brown (2.5Y 5/4) silty clay with few fine faint yellowish-brown mottles; moderate medium and coarse subangular blocky structure; friable; slightly sticky to sticky, slightly plastic; moderate alkaline; common very fine micropores.

The Villa Banzer soils are very deep, moderate to moderately well-drained internally, but with slow surface drainage. The control section has a moderately fine to fine texture, blocky over prismatic structure, friable to very firm consistency when moist and color varies from grayish-brown to dark yellowish-brown.

The San Carlitos soils are also very deep. However, both internal and surface drainage are slow. The control section has a moderately fine texture, blocky structure and is of friable to firm consistency when moist.

Variations in morphology between these two and the other profiles examined were minimal, mostly in depth of the various horizons.

Table 1 gives data on particle-size distribution of the various horizons of the Villa Banzer and San Carlitos profiles. The high silt content (from almost 42 to 65%) is a salient feature througout all layers. Clay content increases in the B: From 19 in the A_1 of Villa Banzer to 43% in the B_{22}; from 18.6 in the A_1 of San Carlitos to 37.6% in the B_{21}. The combined silt and clay contents in the B_2 in the two profiles range from 85 to 96%. This might explain the slow to moderate drainage of these soils.

Table 2 gives data on selected chemical properties of the soils. Organic matter levels at the surface 36 cm are as high as reported from tropical soils at other locations (8) and from soils of the temperate region (11). All the soils are strongly acid in the upper layers, but pH increases with

TABLE 1.—*Particle-size distribution of typical Alfisols of northeastern Bolivia*

Series	Horizon	Depth	Sand	Silt	Clay
		Cm		%	
Villa Banzer	A_1	0–13	28.0	53.0	19.0
	B_1	13–36	17.6	49.8	32.6
	B_{21}	36–63	15.8	41.6	42.6
	B_{22}	63–88	15.2	41.6	43.2
	B_3	88–118	17.8	48.4	33.8
	C	118–150	56.2	27.2	16.6
San Carlitos	A_{11}	0–18	16.4	65.0	18.6
	A_{12}	18–36	25.6	58.0	16.4
	B_{21}	36–59	4.4	58.0	37.6
	B_{22}	59–80	4.4	62.0	33.6
	B_{23}	80–107	16.4	52.0	31.6
	C	107–130	5.0	50.6	44.4

depth. In general, CEC values are low to moderately low and increase with depth ranging from 6.46 in the surface 18 cm to almost 15 meq in the 63-88 cm layer of the Villa Banzer soil. In this case the CEC values appear to be related to clay content (table 1). In the San Carlitos profile, the highest CEC value of the surface soils can probably be attributed to the activity of the soil organic matter (1). At greater depth CEC values seem to be directly related to clay content. In general, the soils are low in exchangeable Mg^{++}, K^{+} and Na^{+}. They are moderately low in exchangeable Ca^{++} The few values on exchangeable Al^{+++} suggest a 15 to 20% saturation in the upper layers. These soils are probably Alfisols as suggested by high base saturation levels and the presence of an argillic horizon. Furthermore, most of the hue values are around the 10YR level, indicative of less leaching of bases and less weathering than is normal for

Ultisols. This indicates a higher inherent fertility. The evidence indicates that they are Typic Tropudalfs.

Soils and climate of the Villa Banzer and San Carlitos areas seem to be well suited for the production of rice, corn, soybeans, cassava, cotton, bananas and probably citrus fruits. However, due to flooding during half of the year and dryness during the other half, drainage and irrigation must be established for intensive cultivation of these soils.

At the San Carlitos Demonstration farm, over 7000 kg/ha of rain-fed rice has been obtained from December to April. Other crops under observation are tomatoes, cabbage, cauliflower, peas, beans, lettuce and sweet peppers. Pineapples (Smooth Cayenne) are also grown under

TABLE 2.—*Selected chemical properties of typical Alfisols of northeastern Bolivia*

Series	Horizon	Depth	Organic matter	pH	CEC	Exchangeable bases				Al^{+++}
						Ca^{++}	Mg^{++}	Na^{+}	K^{+}	
		Cm	%				*Meq*			
Villa Banzer	A_1	0–13	3.1	5.4	6.46	4.8	1.0	0.20	0.26	
	B_1	13–16	1.7	5.2	7.54	3.6	1.7	.20	.14	1.5
	B_{21}	36–63		5.4	10.87	5.8	4.0	.28	.19	
	B_{22}	63–88		5.9	14.99	8.2	6.2	.28	.21	
	B_3	88–118		6.2	10.07	5.6	4.0	.21	.16	
	C	118–150		6.2	7.11	3.8	2.7	.22	.19	
San Carlitos	A_{11}	0–18	3.8	5.6	14.34	12.2	1.2	1.34	.40	
	A_{12}	18–36	1.9	5.5	4.72	2.6	.5	.46	.16	.7
	B_{21}	36–59		6.2	13.07	7.6	3.3	1.42	.25	
	B_{22}	59–80		7.4	14.66	9.0	3.6	1.71	.25	
	B_{23}	80–107		8.1	15.88	9.6	4.0	2.00	.28	
	C	107–130		8.2	18.03	9.6	5.4	2.72	.31	

experimental conditions as well as sugarcane (for forage), sorghum and *Brachyaria decumbens*.

The major problem of the soils of the area is the very low or low hydraulic conductivity (3). Also, the subsoil is usually heavy, dense, with angular blocky structural units, and very fine micropores.

In general, the soils of Beni, except those of the Riberalta-Guayaramerín region (8), show slow initial infiltration and hydraulic conductivity that is probably decreasing along the years with increase of sediments from yearly floodings. To maximize their yield potential, it is, therefore, essential to provide the necessary drainage facilities and irrigation techniques based on a sound knowledge of the physical and chemical properties of the soils and their constraints.

Beyond doubt, the problems of poor drainage observed are caused by an unfavorable soil structure.

This is further complicated by yearly overflows of rivers carrying enormous amounts of silt and colloidal clay sediments, which are deposited over the soil. These additions of fine material make the soil profile more compact and less permeable.

In the lowlands or "bajíos", and even on some of the grasslands at the intermediate positions which comprise the central hydromorphic zone of the region, the possibilities of more intensive livestock grazing are scarce as long as flooding prevails. The prospect of improving the quality of the grasses is also limited as long as the ratio between graminaceous to arboreal species remains low. The latter can withstand flooding better, because of their greater ability to develop adventitious roots over water. It may be added that the annual burning of pastures in the hydromorphic areas does not appear to be efficient. On the other hand, fencing might result in trapping the cattle during the flooding period.

Some other 970,000 ha of savannah and forests at higher positions offer greater possibilities of more intensive grazing and cropping under proper management. Their texture varies from silty clay to almost loamy sands near the river beds. Their main management requirement is to get rid of excess water with surface drains, before serious problems of inadequate soil aeration arise and, consequently, soil nutrients availability is affected.

Root respiration is a natural and essential process for water and mineral uptake. It is the equivalent to respiration in leaves as a reaction to photosynthesis. In both, molecular oxygen consumption is required. If water saturates the soil voids, giving way to anaerobic conditions, growth and root activity are markedly suppressed as microbial activity competes for the limited oxygen. Crops, however, vary in their tolerance to low oxygen diffusion rates, and on the basis of the soil environment, plants usually undergo a natural selection process.

When the soil pores are saturated with water, moisture uptake is drastically reduced. This is not only due to the low oxygen diffusion, but also to the toxicity induced by high CO_2 concentrations under anaerobic conditions.

Adverse changes in the composition of the soil atmosphere are not the only factors interfering with root growth and development. As a result of the extended soil-water saturation periods, and/or of the soil compaction that the silt and clay fractions rearrangement in the soil profile may provoke, both typical in the savannah, mineral reduction also becomes an adverse condition. Toxic concentrations of ferrous and sulfide compounds develop in the soil medium. In addition, organic compounds, such as methane, are formed. It is also known that hydrogen sulfide has been found to inhibit P and K uptake (9). It could be suggested here, from a theoretical standpoint, that the use of animal manures, green manures, crop residues, and other amendments could be recommended to improve soil structure. However, these measures are perhaps not practical under conditions of large scale farming at Beni. It would be an unrealistic recommendation. To improve structure in the compact soils, very little can be done. Soils must be fully utilized with awareness of this particular limitation and surface drains provided if economically feasible. Perhaps the action of deep rooting crops, grasses and weeds would help improve soil structure more effectively than other treatments. Soil structure could also be improved mechanically through land preparation techniques including deep plowing. Under natural conditions, the normal processes of alternate wetting and drying that occur in Beni may be an important factor in improving soil structure, especially if by mechanical means, drains could improve infiltration and deeper percolation.

The dramatic effect on soil structure and crop production of irrigation adequately managed was observed at the San Carlitos area on the CODEBENI farm. Obviously, the supply and control of water is a primary factor limiting the productive potential of these soils.

Liming and fertilization, including S, are perhaps, after adequate supply and management of water, the most important factors affecting crop production in the area. In the Oxisols of the Brazilian savannahs (cerrados) marked responses to fertilizer P have been obtained (6). Evidence has been recently obtained indicating that S deficiencies can occur even more frequently than K deficiencies in tropical soils (10). This is true in spite of the fact that the S requirements of most crops is relatively low. In areas where N fertilizers such as urea and ammonium sulfate are used, as well as superphosphate, these S deficiencies are not evident since these fertilizers contain S. Such a situation might well arise in the Alfisols of Beni. The deficiency can probably be corrected with applications of 10 to 40 kg/ha of S. In Brazil, the application of S to coffee is a generalized practice.

RESUMEN

Varios perfiles de suelos se examinaron cerca de los desarrollos de colonización en los alrededores de Villa Banzer y San Carlitos, a 30 y 100 Km, respectivamente, de Trinidad, capital del Departamento de Beni, en el noreste de Bolivia. En general, los suelos paracen ser Aquic Tropudalfs. Son muy profundos, y su desagüe interno varía de moderado a lento; el externo es lento. Las texturas son de moderadamente finas a finas con un alto contenido de limo (42 a 65%). La arcilla aumenta más en el horizonte B en que el A_1. El contenido combinado de arcilla y limo fluctúa entre 85 y 96%. Los niveles de materia orgánica de los horizontes superficiales son, por lo menos, tan altos como los de otros suelos de

zonas tropicales y templadas. Los suelos son fuertemente ácidos en la superficie. La capacidad de cambio de cationes parece estar relacionada con la activadad de la materia orgánica en las capas superiores y con el contenido de arcilla a mayores profundidades. Los suelos de las áreas estudiadas parecen ser aptos para la producción de cosechas, tales como arroz, maíz, yuca y quizás otras. Los problemas de mayor envergadura que necesitan solución son los relacionados con el riego y el desagüe. El uso de cal y abonos es esencial para lograr un desarrollo agrícola adecuado en la región.

LITERATURE CITED

1. Abruña, F. and Vicente-Chandler, J., 1955. Organic matter activity of some typical soils of Puerto Rico, J. Agri. Univ. P.R. 42 (2):65–76.
2. Black, C.A., (Ed), 1965. Methods of soil analysis, Part 2, Chemical and microbiological properties, No. 9 in the series Agronomy, Amer. Soc. Agron.
3. Capiel, M., 1978. Análisis y recomendaciones sobre riego y drenaje en la región Nor-oriental de Bolivia: Enfoques hacia el programa de investigación. Informe sometido al Instituto Boliviano de Technología Agropecuaria.
4. Codebeni, 1977. Proyecto Ganadero del Beni, Parte 2, Tomo 4.
5. Kilmer, U.J. and Alexander J.T., 1949. Methods of making mechanical analyses of soils, Soil Sci. 68:15–24.
6. Lugo-López, M.A., 1978. Potential of the soil resources of Beni, Report to the Instituto Boliviano de Technología Agropecuaria.
7. Lugo-López, M.A., Abruña, F. and Pérez-Escolar, R., 1981. The role of crop and industrial residues on erosion control, properties and productivity of some tropical soils of Puerto Rico, Agri. Exp. Stn. Univ. P.R. Bull. 266.
8. Lugo-López, M.A., Carrera-Murillo, W. and Bauzá-Salas, J., 1980. Tropeptic Haplustox: Major soils of the plains of Riberalta-Guayaramerín in northeastern Bolivia, J. Agri. Univ. P.R. 64 (4):391–9.
9. Luthin, J.N., 1957. Drainage of agricultural lands, On Chapter 5 III, p. 531. Am. Soc. Agron. Monogr., Madison, Wis.
10. Sánchez, P., 1974. Manejo de suelos tropicales, CIAT, Cali, Colombia.
11. Smith, R.M., Samuels, G. and Cernuda, C.F., 1951. Organic matter and nitrogen build-ups in some Puerto Rican soil profiles, Soil Sci. 72 (6): 409–27.