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PRELIMINARY SURVEY OF SOME SOILS FROM CHILEAN ALTIPLANO NEAR IQUIQUE

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ABSTRACT

In the Altiplano of the Iquique Province, Chile, a study was carried out for the purpose of advancing in the knowledge of the soils in the zone, to determine the soil moisture and soil temperature regimes, and to establish its taxonomic classification. In one area, at the base of the slopes of the *Irruputuncu* volcano, where the occurrence of lahars and the presence of moraine deposits is described, 5 soil profiles were examined morphologically and some of their chemical and physical properties were determined. Moreover, the degree of pedogenic evolution of the volcanic parent materials was assessed. The depth of the solum did not exceed 0.40 m, and the low organic carbon content, combined with the dominance of the sand fraction, determined a low water holding capacity, which hampers the development of vegetation. It was determined that the soil temperature regime is frigid and its moisture regime is ustic. None of the soils showed andic soil properties. Hence, given the limited pedogenic development it was proposed to classify them as Ustorthents (Entisols, USDA, 2010).

Key words: High altitude soils, Ustic moisture regime, Andic properties, Entisols.

INTRODUCTION

Soil studies in altiplano zones of Chile are very scarce and lack detail (Luzio *et al*., 2002), due to the difficult accessibility and low potential for agricultural and forestry use. IREN (1976 and 1979) indicated that the area show a high sensitivity to erosion processes. No recent soil surveys have been made on the area, so it is considered important to advance in the knowledge of its edaphic characteristics. A limited soil survey was made by Luzio *et al*. (2002) in the northern sector of the Chilean Altiplano, Province of Parinacota, where the volcanic materials showed a poor degree of evolution, attributed to the low water availability and the almost permanent low temperatures, which would impede pedogenic development (Brady and Weil, 1996).

Luzio *et al*. (2010) indicate that in the Altiplano the soil moisture regime would be ustic, since there would be a slight excess of moisture during the months of higher temperatures. Also, they deem that the soil temperature regime would be frigid, considering the mean annual soil temperature is below 8ºC and the temperature difference between summer and winter is above 5ºC. However, since no records have documented soil temperatures in the highlands, these reports cannot be confirmed. Therefore, the objectives of this paper are:

- To advance in the knowledge of soils in the Andes highlands (Altiplano).
- To determine the moisture and temperature regimes of the soils in the study area.
- To determine if the soils present andic properties.
- To establish a taxonomic classification for some pedons.

MATERIALS AND METHODS

The area of the study is about 150 hectares, located at 20º44 S and 68º34 W and between 4,200 a 4,500 m.a.s.l. Five edaphic units were distinguished on the basis of the local geomorphological configuration and the observation of surface materials. Five pedons were described.

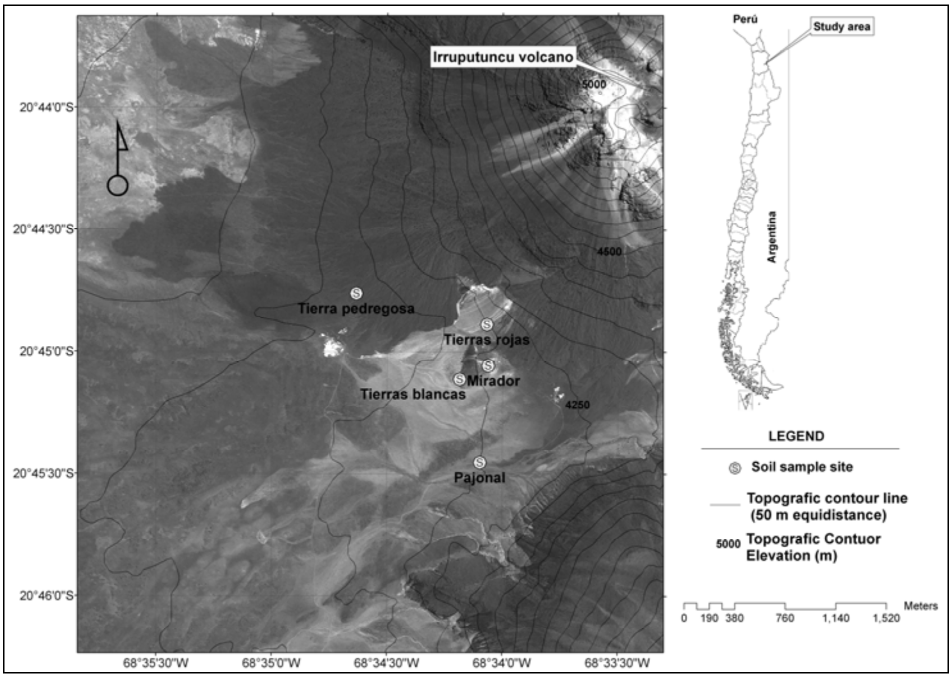

Figure 1. General location of the zone under study and distribution of sites.

The selected sites were:

- Mirador: 2 to 5 % slope; tolar and queñoal vegetation unit; abundant fragments and rockiness; volcanic deposit, tephra.
- Pajonal: 2 to 5 % slope; high altitude grassland vegetation unit, dense; volcanic deposit, tephra.
- Tierras blancas; 5 to 8 % slope; without vegetation; volcanic deposit, tephra.
- Tierras rojas: 30% slope; high altitude grassland vegetation unit, open; volcanic deposit , tephra and rill erosion.
- Tierra pedregrosa: 2 to 5 % slope; without vegetation; volcanic deposit, lahar.

Each one of the 5 representative pedons was described according to Schoeneberger *et al.*, (2002), obtaining reference samples from the A horizon (Schoeneberger *et al.*, 2002), because, for the purpose of identifying the existence of andic soil properties, their presence is required only within the 60 cm of mineral soil (SSS, 2010). In the laboratory, the samples were air-dried and sifted at 2 mm. The following analysis were made (Sadzawka *et al.*, 2004): granulometry by the Bouyoucus method; water content at 33 and 1,500 kPa, using pressure cooker and plate; organic carbon by acid digestion with potassium dichromate and determination by potentiometric titration; pH in water in 1:2.5 ratio; pH in KCl in 1:1 ratio; interchangeable Ca, Mg, K, and Na by extraction with ammonium acetate solution of 1 mol/L at pH 7.0; the cation exchange capacity by saturation with 1M sodium acetate at pH 8.2 and displacement of adsorbed sodium with 1M ammonium acetate at pH 7.0; P retention; iron and aluminum extractable with oxalic acid-oxalate; $CaCO_3$ and $CaSO_4$ content. The cation exchange capacity (CEC), base saturation (BS), and electrical conductivity (EC) were also analyzed. The soil temperature and moisture was measured, on site, at 40 cm of depth by means of a capacitance sensor, for a period of 16 months. The information obtained was subsequently analyzed following the Soil Taxonomy guidelines (SSS, 2010).

RESULTS

In all soils abundant surface rockiness, of volcanic origin, were measured, ranging from 5 to 50%, from fine gravel to sub-angular pebbles in size~~,~~ The morphology of the soils (Table 1), indicates a sandy textural class, a surface horizon up to 30 cm over a C horizon with abundant presence of gravel and cobbles. Lack of structure is common, except for the thick, although very weak, laminar structure in the A horizon of the Mirador soil. The colors vary from dark brown (7.5YR3/2) to light brown (10YR6/3) in the A horizons, and very light brown (10 YR 8/2) to Brown (7.5 YR 4/3) in the C horizons.

The majority of roots are found between 12 and 30 cm depth. The exception occurs in those soils with abundant presence of fragments on the surface, where roots were observed underneath them. This distribution of roots is related to the moisture conditions of the soil profiles, that indicate a dry surface strata, a moist subsurface layer, and a dry underlying strata.

Physical analyses are presented in Table 2. According to the particle size distribution, the dominant textures are sandy-loam and sandy. There is no description of textural discontinuities in the profiles and, therefore, the existence of one single agent of sediment transport and deposition is assumed. However, the existence of different deposition processes is notable between the A and C horizons corresponding to eolian deposits and mantle flow action in the surface horizon and colluvial deposits in the subsurface.

The water retention at 33 kPa, range from 6.2 to 12.7 %, while at 1,500 kPa vary from 2.2 and 7.7 %. So that the available moisture content goes from 1.5 to 9.8%, meaning a much reduced available water for plants.

Chemical analyses (Table 3) indicate the pH vary from extremely acid to slightly acid, with values from 4.15 to 6.00. The delta pH varies between -0.4 and -1.55, so that it presents a negative electrical charge. The Cation Exchange Capacity (CEC) is very low in all soils, varying between 6 and 10 $\text{cmol}^{(+)}$ kg^{-1} with equally low exchangeable cation contents. The dispersion values of Base Saturation (BS) should be highlighted, which varies between 94% and 21%. The Organic Matter (OM) content is variable but do not exceed 2.3%, being very low in some sectors, along with the scarce vegetation cover observed in the field.

The soils are non-saline, with EC less than 1 dS m^{-1}, without the presence of $CaCO_3$ and low contents of N, P, and K. The exception occurs for EC and K in the Mirador soil, with values of 3.49 dS m^{-1} and 260 mg kg^{-1} respectively. In Table 4 Andic soil properties are described. P retention varies between 24 and 25%, and the sum of the $\text{Al}_{\text{(ox)}} + 1/2\text{Fe}_{\text{(ox)}}$, is greater than 0.4 in all samples.

Figure 2 shows the monthly average water content and soil temperature, measured at 40 cm depth, between March 2009 and July 2010. It is observed that the water content in the soil is higher during the summer months, at the same time with the highest temperatures and precipitation. The mean soil temperature varied between 2.5 and 12.8°C, remaining at above 10°C for nearly six months.

DISCUSSION

The soils showed very limited pedogenic development, the solum does not exceed 0.40 m depth, and with an A-C horizons sequence. The “few” and “very few” roots described correlates with the low water retention capacity of the soil, low rainfall and high evaporation rates from the soil surface. All of these conditions make it difficult to establish vegetation in these soils, explaining the low organic matter content, and making them more susceptible to erosive processes (Nearing *et al*., 2005).

The difference between the texture findings in the field and in the laboratory may be due to the formation of micro-aggregates, which are mostly destroyed in the laboratory procedures. A similar process was described by Luzio *et al*. (2002) in altiplano soils from the Parinacota Province.

The pH values, always lower than 6, are mainly due to the mineralogical composition of parent material and its incipient pedogenesis. The pH values below 5 may also constitute a hindrance to the normal development of plants not adapted to these conditions (Troeh and Thompson, 2005). On the other hand, since the pH in KCl is always lower than 5, the presence of non-crystalline silicates in these soils are discarded. Sadzawka and Carrasco (1985) upon correlating the pH in KCl, the absolute value of the delta pH, and the CO content in volcanic soils from central and southern Chile, indicate that there is a predominance of non-crystalline silicates in the soils when the pH (KCl) >5.0; the absolute value of the delta pH <1.0, and the CO (%) <10. On the contrary the crystalline silicates would predominate. These results are consistent

Table 1. Summary of the morphological descriptions.

Soils	Horizon Depth (cm)	Color	Textural Class	Structure	Roots	Observations
Mirador	A1 0 - 2	10 YR 5/3	a	Thick laminar	no roots	Linear limit, abrupt
	A2 2 - 12	7.5 YR 5/3	a	very weak	vf, f 1	Linear limit, abrupt
	A3 12 – 24	7.5 YR 5/4	a f	no structure	co 2; vf ,f 3	Undulated limit, abrupt
	2C 24 - 85	10 YR 8/2	-	no structure	f 1	Presents slight hydrophobia
Pajonal	A1 0 – 12	7.5 YR 4/3	a	no structure	vf 1	Linear limit, clear
	A2 12 – 27	7.5 YR 4/3	a g	no structure	vf, f 3	Linear limit, clear
	C1 27 – 46	7.5 YR 5/4	a g	no structure	vf 1	Linear limit, clear
	C2 46 – 70	10 YR 6/3	A	no structure	vf 1	Angular gravel by 40%
Tierras Blancas	A1 0 – 13	7.5 YR 6/2	a g	no structure	f 1	Linear limit, clear
	A2 13 – 30	7.5 YR 4/3	A	no structure	vf , f, m 3	Undulated limit, clear
	C 30 and more	7.5 YR 4/3	a g	no structure	f ,m 2	
Tierras Rojas	A1 0 - 5	7.5 YR 5/5	a g	no structure	f , vf 1	Linear limit, abrupt
	A2 5 - 32	7.5 YR 5/4	a g	no structure	f ,vf 3	Undulated limit, abrupt
	C 32 - 59	7.5 YR 5/4	a g	no structure	vf 1	Gravel and abundant angular fragments
Tierra pedregosa	A 0 - 20	7.5 YR 3/2	a	no structure	vf, f 3	Undulated limit, abrupt
	2C 20 - 38	Variegated	a	no structure	vf, f 3	Undulated limit, abrupt
	3C 38 - 50	Variegated	a	no structure	no roots	

Texture	**Size of roots**	**Quantity of roots**
F=loam	vf = very fine	1 = scarce
A=clay	f = fine ;	2 = common
a=sand	m = medium ;	3 = abundant
L=silt	co = thick	
g = gravelly		

Table 2. Physical analysis of the soils.

Identification	Granulometry (%)			Texture (USDA)	Water Retention (kPa)	
	Clay	**Silt**	**Sand**		**33**	**1500**
Mirador	7.5	9.5	83.0	Loamy sand	9.3	7.7
Pajonal	7.4	6.4	86.1	Loamy sand	6.2	2.8
Tierras blancas	5.5	3.4	91.1	Sandy	7.3	3.5
Tierras rojas	8.0	7.6	84.4	Loamy sand	12.7	6.3
Tierra pedregosa	6.8	14.1	79.1	Loamy sand	12.0	2.2

Table 3. Results of chemical analyses of soils.

Soil	pH		EC	OM	N inorganic	P-Olsen	K available	CEC	Extractable Cations					$CaCO_3$
	H_2O (1:2,5)	**KCl (1:1)**							**Ca**	**Mg**	**K**	**Na**	**Sum**	
			dS m^{-1}	%	--------mg kg^{-1} -----------			--------------- $cmol^{(+)}$ kg^{-1} --------------						%
Mirador	4.40	4.00	3.49	2.08	26	13	260	10	6.8	0.88	0.77	0.93	9.4	0.0
Pajonal	6.00	4.45	0.18	0.30	24	17	129	6	2.5	0.36	0.19	0.31	3.4	0.0
Tierras Blancas	4.70	3.90	0.26	0.57	23	19	141	6	1.4	0.21	0.24	0.38	2.2	0.0
Tierras Rojas	4.80	4.00	0.16	1.05	30	12	120	8	1.4	0.19	0.17	0.40	2.2	0.0
Tierra Pedregosa	4.15	3.40	0.33	2.28	30	180	130	9	1.2	0.17	0.21	0.29	1.9	0.0

Table 4. Andic properties (Fe(ox) and Al(ox) and P retention).

Soil	$Fe_{(ox)}$ (%)	$Al_{(ox)}$ (%)	$Al_{(ox)}$ +1/2 $Fe_{(ox)}$ (%)	P Retention (%)
Mirador	0.36	0.35	0.53	24
Pajonal	0.30	0.29	0.44	24
Tierras Blancas	0.40	0.59	0.79	25
Tierras Rojas	0.46	0.81	1.04	24
Tierra Pedregosa	0.31	0.70	0.85	24

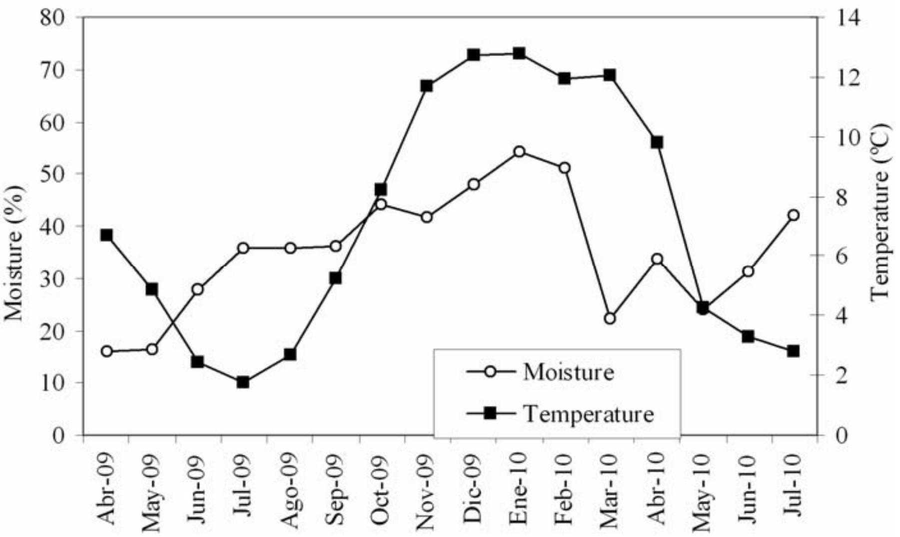

Figure 2. Temperature and moisture content of soil at 40 cm of depth.

with those that Luzio *et al*., (2002) obtained in mineral soils from the Parinacota Altiplano.

Base Saturation varies from 21% to 56% in the soils, and only reaches up to 94% in the Mirador sector. These values could be an indication of a limited weathering and a scarce soils development. Due to the low specific surface of the particles and the excessive drainage of the soils, it is possible that the weathering products are easily leached out by the occasional but heavy rainfalls. So that, the high Electrical Conductivity values in the Mirador soil, may indicates a relatively lower incidence of translocation processes in that sector.

According to Soil Taxonomy (SSS, 2010) none of the soils have developed andic soil properties. These results are consistent with those obtained by Luzio *et al*. (2002), in Parinacota Province soils, which would indicate that it is a common condition in the soils of the Altiplano.

Luzio *et al*. (2002) after a generalized soil survey in the high plateau area between Visviri and the Surire saltpan, concluded that for most of the Altiplano regions the soil moisture regime was aridic and soil temperature regimes was cryic. This proposal was based on the idea that the soil control section was dry more than half the time (cumulative days per year) when the soil temperature was above 5 º C. With regards to soil temperature regimes, it was assumed that the mean annual soil temperature (MAST) ranged between 0 and 8 º C, without permafrost. The inference of an aridic soil moisture regime was based on the idea that in the Altiplano Zones periods of precipitation are insufficient to maintain the control section wet due to low water holding capacity of soils and high evapotranspiration rates. Subsequently, the data provided by Houston and Hartley (2003) allowed to define, in a general manner, the soil moisture regimes for the sector, establishing an imaginary line in a NW – SE direction, so that the areas to the west of this line would have a combination of aridic - thermic regimes and to the east of the line, the dominant regimes would be ustic- thermic. Taking this information into consideration, Luzio *et al*. (2010) defined ustic soil moisture regimes for the Chilean Altiplano, however, they settled on a frigid soil temperature regime, since a thermic soil moisture regime would imply that the MAST would fluctuate between 15º and 22ºC, temperatures, which were considered excessive for the highland sector.

In this study, it was possible to measure both, the temperature of the soil and its water content, both measurements taken at 40 cm depth. The average temperature during the months of June, July, and August (winter) is 2.3ºC and the average temperature for the months of December, January, and February (summer) is 12.5ºC, that is, there is a 10.2ºC difference. At the same time the MAST, is lower than 8ºC. Therefore, both parameters determine a frigid soil temperature regime. The precipitation and soil moisture data allowed identifying the moisture regime as ustic. This implies that soil moisture is limited, but is present when conditions are suitable for plant growth. In particular, tropical climates with summer rainfall, such as this area (Luebert and Pliscoff, 2006), require a rainy season of three consecutive months (SSS, 2010), a common condition for extensive sectors of the Altiplano.

Finally, the taxonomic classification of the soils at Great Group level (Keys to Soil Taxonomy, SSS, 2010) was considered. According to the chemical and physical analytical data, the profile descriptions, the soil moisture and temperature regimes and the very low profile development, the 5 soils tested were considered as Ustorthents (Entisols).

CONCLUSIONS

The soils in the Altiplano of the Province of Iquique are subjected to a more severe moisture regime than soils of the Altiplano further north, due to a lower amount of rainfall, which coupled with a poor water holding capacity due to its sandy texture, implies a limited available water for plants throughout the year. The measurements of soil moisture and soil temperature carried out for a period exceeding one year, allow a better estimation of the identification of moisture and temperature regimes of soils. In this way, it can be confirmed, based on available data, that the soil moisture regime is ustic and the temperature regime is frigid.

Data on andic soil properties confirm that stated by Luzio *et al*. (2002) and Luzio *et al*. (2010) since, in spite of the fact that the soils derive from volcanic origin parent materials, their pedogenic development is limited by the environmental conditions, not giving rise to the formation of short-range order minerals. Given that the soils studied are found under the limit of andic properties, it is considered that the best taxonomic estimation is to associate the soil to the Great Group of Ustorthents (Entisols).

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