Soil salinization processes in small-lake Ballestera wetland ecosystem (La Lantejuela, Seville, Spain)

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Salinization processes in soils with thermo-mediterranean-semiarid conditions within a confined environment (basin closed) are studied in Natural Reserve Ballestera small-lake ecosystems (Seville, Spain). Methodologically it is carried out a geopedological catena integrated by five drilling-profiles with depths between 0.20 and 1.50 m. A total of 21 pedo-sedimentary samples have been characterized through pH, electric conductivity, carbonates contents, magnetic susceptibility and texture determinations. The results show the presence of two different phases in the geopedological evolution of the ecosystem: one of them is previous to the geomorphological constitution of the existing wetland, characterized by carbonates and salts lateral lixiviation processes (vertisolization-tirsification processes determinant of a special black color in the soil), and the second one, later and current, distinguishing processes of salt accumulation (saline brines) and surface crust formations (saltcrete) of halite and gypsum with high value of electric conductivity (salinization and hydromorphic processes).

Keywords: thermo-mediterranean environment; salinization; tirsification; Ballestera wetland ecosystem; Spain

Introduction

In the area adjacent to the Natural Reserve Ballestera small-lake belonging to the marsh area of La Lantejuela (Seville, Spain), Diaz del Olmo and Recio Espejo (1990 and 1991) identified in its surrounding zone the formation of haplic and calcium Vertisols (FAO, 1989) (equivalents to typic eutric and chromic Vertisols, Soil Taxonomy, 1975) with clear decarbonation, desalination and blackening processes. In this tirsified area the presence of salts on the surface was very low (1.33 mhs / cm) and 7 mhs at 85 cm depth, and the carbonates ranged between 8.6% on the surface and 29% on the deep horizons.

Similarly, the drilling carried out in the central zone of its bottom showed high concentration of salts (103 mhs / cm in surface), and 40% of carbonates from 30 cm of depth. Its matrix was constituted by 80–96% of fine particles (silts and clays) and showed a very little detrital nature with values of 3.56% of sands at 30–45 cm depth. The salt crust formed in the summer season was constituted by halite and gypsum, leafy nature and slight presence of carbonates (Diaz del Olmo and Recio Espejo, 1990).

This ecosystem has an extension of 25 ha and a drainage basin of 155.63 hectares (CMAJA, 2002), and is located on quaternary materials composed mainly of marls, clays and sands on a triassic substrate in the relations between the Guadalquivir river depression and the alocitone units of the subbetic alpine mountains in south part of iberian peninsula (IGME, 1976).

According to CMAJA (2005) its current hydrological functioning system is of epigenetic type, although other authors relate its saline character with the contributions coming from the aquifer (Beltrán et al., 2012). The salts washing from the different lithologies present in its hydrological basin would constitute the main contribution of saline compounds in the small-lake, crystallized in the surface by the evapotranspiration effect.

The present work focuses on the physical-chemical study of the bottoms of this ecosystem, especially in the processes of salinization and decarbonation that affects them from a catena of five soundings between 0.90 and 1.50 m, arranged from the center of the wetland (BLL-1) to one soil profile open at the base of the slope at its NW extreme (BLL-5) (Fig. 1).

Materials and methods

The sediments and soil has been described and classified according to FAO (1977 and 1989). Its physicochemical and mineralogical characterization has been carried out following the usual methodology of our laboratory: chroma (Munsell, 1990), pH (Guitián and Carballas, 1976), wet and organic matter by calcinations (MAPA, 1986), electric conductivity by USDA (1973), total carbonates (Duchaufour, 1975), magnetic
susceptibility (Dearing, 1999) and texture by Soil Survey England and Wales laboratory methods (1982). Field works and use of geological and topographical maps, satellite images and aerial photographs have completed the used materials.

Results and discussion

A total of 21 pedo-sedimentary samples have been characterized physico-chemically in the laboratory. The results are shown in Table 1.

This shows the results obtained for the different drilling carried out, surface saline-crust and pedological profile studied uniformized by depths in order to make comparisons between them. Table 2 shows the average values calculated for two depths (0–30 and 30–90 cm), and Table 3 the values for the 10 cm more superficial in order to evaluate the processes of capillary rise of salts and carbonates (ratio capillarity ascent).

In the interior the pH of the upper 30 cm is above 8.0 and somewhat lower (7.8–7.9) in the lower 30–90 cm. The crust is very saline with values of 135 mhos/cm and a dry residue of 458–462 g/l. The C.E. it decreases clearly from the central zone (BALL-1) towards the edge (BALL-4) depending on its greater or lesser annual extension that reaches, and in depth it shows very high values up to 90 cm. where the water table was cut. The mineralogical analysis studied indicates the presence of halite and gypsum, with the former predominating in BALL-1, in line with the previous data.

The carbonates show a more significant evolution to know the genesis of this wetland, since the upper 30 cm are sensibly decarbonated compared to the lower layers that present very uniformly contents of 41–48% for all surveys conducted. The values of magnetic susceptibility (SM), although very low, also mean this differentiation, as well as humidity (Table 1).

The color, both in dry and wet, gray chromatic samples coinciding with hydromorphic environments (5Y), and organic matter (MO) shows low values (1.18–1.64%) in surface and null in depth, indicative of its non-accumulation and rapid mineralization.

Table 1
Physical-chemical characterization of soil-sediments in Ballestera bottom ecosystem

| Samples | pH | E.C./F. | CO2- | O.M. | Mg, Sr. | Wet | Colour (Munsell) | Sand | Silt | Clay | Fines |
|---------|----|---------|------|------|---------|-----|------------------|------|------|------|-------|
| Ref.    | (H2O)| (mhos/cm)| (%)  | (%)  | (m²/kg) | (%) | (Laboratory) | (%)  | (%)  | (%)  | (%)   |
| G.00-0.10 | 8.6 | 81 | 12 | 1.65 | 13 | 16 | 5Y 4/2 | 5Y 4/1 | - | - | - |
| BALL-1 | 8.0 | 69 | 24 | 0.54 | 7 | 15 | 5Y 7/1 | 5Y 7/2 | - | - | - |
| 0.30-0.60 | 7.9 | 64 | 65 | inap | 20 | 11 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| G.60-0.90 | 7.6 | 78 | 61 | inap | 80 | 11 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| Crust | 6 | 135/462 | 6 | - | - | - | - | - | - | - | - |
| G.00-0.10 | 7.8 | 53 | 14 | 1.54 | 11 | 15 | 5Y 6/3 | 5Y 5/2 | - | - | - |
| BALL-1 | 6.3 | 28 | 22 | inap | 10 | 13 | 5W 3/1 | 5W 5/2 | - | - | - |
| 0.30-0.60 | 7.0 | 22 | 48 | inap | 26 | 10 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| G.60-0.90 | 7.6 | 54 | 45 | inap | 31 | 9 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| G.00-0.10 | 8.5 | 12 | 8 | inap | 0 | 10 | 5Y 6/2 | 5Y 5/2 | - | - | - |
| BALL-1 | 7.8 | 94 | 10 | 1.4 | 8 | 10 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| 0.30-0.60 | 8 | 51 | 47 | inap | 24 | 11 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| G.60-0.90 | 7.7 | 70 | 49 | 5.17 | 21 | 9 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| Crust | 7.5 | 134/453 | 6 | - | - | - | - | - | - | - | - |
| BALL-4 | 7.0 | 6 | 22 | 1.12 | 10 | 11 | 5Y 7/1 | 5Y 6/2 | - | - | - |
| 0.00-0.15 | 7.6 | 3 | 29 | inap | 101 | 5 | 2Y 7/6 | 5Y 4/1 | 20 | 65 | 15 | 80 |
| BALL-4 | 7.7 | 8 | 82 | inap | 28 | 5 | 5Y 6/1 | 5Y 4/1 | 18.8 | 38.1 | 4.4 | 38.1 |
| G.60-0.90 | 7.7 | 6 | 82 | inap | 17 | 5 | 5Y 6/1 | 5Y 5/2 | 10.5 | - | - | 85.5 |
| G.90-3.20 | 7.6 | 5 | 35 | inap | 94 | 5 | 5Y 6/1 | 5Y 5/2 | 14.35 | 35.15 | 52.5 | 85.65 |
| L.20-3.50 | 7.6 | 0 | 50 | inap | 101 | 0 | 5Y 7/1 | 5Y 5/2 | 15.55 | 31.95 | 52.5 | 84.45 |

Fig. 1. Geographical location of La Ballestera small-lake ecosystem, and satellite image
The high presence of salts and particulate gypsum in the different fractions of diameter prevents the textural analysis in the laboratory, although the fine fractions (clays and silts) are clearly the predominant ones, in particular the former, compared to a scarce or null presence of sand-sized particles of detrital character. These same gray chromas are present throughout the exterior floor profile (BALL-5), and its low salt content (5–6 mhs/cm) if it has allowed the distribution of particles showing fines levels above 80% (maximum value of 89.70%) and presence of low levels in detrital sands.

### Table 2
**Physical-chemical characterization and average values**

| Samples | Ref. | Depth (m) | pH (H2O) | E.C./D.R. (mhs/cm) | CO3= (%) | Magn. Susc. (m3∙kg−1∙109) | Wet (%) |
|---------|------|-----------|----------|-------------------|----------|--------------------------|--------|
| BALL-1  | 0.00-0.30 | 8.4 | 75 | 18 | 7 | 15,5 |
|         | 0.30-0.90 | 7.9 | 69 | 43 | 25 | 11 |
|         | Medium   | 8.1 | 72 | 30 | 17,5 | 13,2 |
|         | Ratio rise | 1.08 | 0.41 | | | |
| BALL-2  | 0.00-0.30 | 8 | 28 | 18 | 10 | 13,5 |
|         | 0.30-0.90 | 7.9 | 28 | 46 | 28 | 9 |
|         | Medium   | 7.9 | 28 | 32 | 19 | 11,2 |
|         | Ratio rise | 1 | 0.39 | | | |
| BALL-3  | 0.00-0.30 | 8.3 | 33 | 11 | 1,5 | 17 |
|         | 0.30-0.90 | 7.9 | 60 | 48 | 22,5 | 10 |
|         | Medium   | 8.1 | 46 | 29 | 12 | 11,5 |
|         | Ratio rise | 0.55 | 0.22 | | | |
| BALL-4  | 0.00-0.10 | 7.9 | 9 | 24 | 19 | 11 |
| BALL-5  | 0.00-0.30 | 7.6 | 6 | 38 | 49 | 6 |
|         | Medium   | 7.6 | 4,5 | 34 | 71 | 5,5 |
|         | Ratio rise | 0.55 | 0.78 | | | |

### Table 3
**Physical-chemical characterization of 10 cm higher**

| Samples | Ref. | Depth (m) | pH (H2O) | E.C./D.R. (mhs/cm) | CO3= (%) | Magn. Susc. (m3∙kg−1∙109) | Wet (%) |
|---------|------|-----------|----------|-------------------|----------|--------------------------|--------|
| BALL-1  | 0.00-0.03 | 8.5 | 107 | 19 | 27 | 14 |
|         | 0.03-0.10 | 8.7 | 55 | 6 | 0 | 18 |
|         | Ratio rise | 1.94 | 3,16 | | | |
| BALL-2  | 0.00-0.05 | 7.7 | 46 | 21 | 18 | 14 |
|         | 0.05-0.10 | 8 | 20 | 8 | 5 | 17 |
|         | Ratio rise | 2,3 | 2,62 | | | |
| BALL-3  | 0.00-0.10 | 8.3 | 12 | 8 | 0 | 18 |
| BALL-4  | 0.00-0.03 | 7.8 | 4 | 25 | 21 | 9 |
|         | 0.03-0.05 | 8.2 | 13 | 12 | 5 | 14 |
|         | 0.05-0.10 | 7.8 | 10 | 35 | 31 | 10 |
|         | Ratio rise | 0.3 | 2,08 | | | |
| BALL-5  | 0.00-0.15 | 7.6 | 3 | 29 | 101 | 5 |

The pH is always below 8.0, the M.O. it is negligible and the carbonates are present on the surface at higher levels than those found in the interior soundings, except at the depth of 30–90 cm which are similar to the previous ones (35–42%). The magnetic susceptibility values, although higher, reach their lowest value coinciding with this same level of depth.

To mean these differences and help to evaluate the processes of capillary rise of salts Table II shows the average values of these parameters for these two differentiated levels. Based on them, no rise in salts or even carbonates is detected, becoming more evident towards the outer areas of its bucket (BALL-3), and always decarbonated the surface area of 30 cm uppers.

However, these processes are clearly revealed when considering only the most superficial 10 cm (Table 3), in which the most soluble salts double at the surface, with the carbonates reaching three times higher levels as a result of this pumping by evaporation.

In view of these results, several considerations could be made. The greater annual extension that the small-lake reaches in function of the precipitations is well represented in the values of maximum salinity found in its central part. The existing brine floods the entire mass of sediments and makes it difficult to obtain data in the laboratory (organic matter by ignition and texture). The decarbonation that presents the upper 30 cm of its mantle/glacis, and subsidence subsequently originating the current cuvette, causing a significant change in the hydrological regime and of the area of a climato-geomorphological nature. The similarity existing at the same depth with the outer profile, together with the hydromorphic chromas that it presents, helps to think of the presence of a previous mantle/glacis, and subsidence subsequently originating the current cuvette, causing a significant change in the hydrological regime and of the area of a climato-geomorphological nature.

This previous cumulative glacis would previously have been tirsified in the entire adjacent area of the small-lake, as it seems to indicate the decarbonation that presents on the surface, recently mitigated by the subsequent processes of capillary ascent.
All this would contribute without any doubt to the knowledge of the genesis of this type of ecosystems so frequent in our region, to the evolution of the establishment of the conditions of current climatic semi-aridity and hydrological regime, and of the coexistence of the processes of tirsification and endorreism/basin closed phenomenon.

Conclusion

The existence of two pedogenetic processes existing in the soil-sediments of the Ballestera ecosystems are proposed: first one of decarbonation of superficial horizons under a regimen of vertisolization-tirsification and subactual chronology, and a later one where the evaporite accumulation processes predominate subjected to pumping to the surface by capillary ascent from the lower levels, more accentuated in the center of the small-lake and less towards the shores.

This double process should be interpreted as two pedological episodes superimposed over time, the first prior to the geomorphological constitution of the current wetland and the second that would have destructured the initial vertic horizons.

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