Reclamation of Saline Soils in Portugal

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Halomorphic soils occurring in Portugal are saline soils, which contain enough salts so distributed in the profile as to interfere with the growth of most crops. They may be either saline non sodic soils or saline-sodic soils and correlate well with Solonchaks (chloride or sulphate-chloride or chloride-sulphate solonchaks) [10]. (In a very few spots sulphate-soda solonchaks and soda solonchaks have been found.)

In the Soils Map of Portugal (made at a scale of 1 : 25,000 and published at 1 : 50,000) they are subdivided into two soil groups: saline soils of medium salinity (soluble salts less than 0.2%) and saline soils of high salinity (soluble salts above 0.2%). Each group is subdivided into subgroups and families according to the nature of the parent material, presence or absence of carbonates, texture, etc. Several soil phases are shown on the map [9].

Most of the saline soils occur on marine alluvium, covering about 22,700 hectares. They are found in estuaries or lagoons separated from the sea by sandy strips and are commonly named "sapais". Their nature is determined by local conditions such as tides, flow volume of streams, transported sediments, salinity, etc. [14].

Analytical data of 3 profiles are shown in Table 1, representing different typical cases of these soils [9]. They may present, in some cases, layers comparatively high in organic matter, sulphur compounds — acid sulphate soils or thiosols [13] — or sea-shells, all of them over sands [14]. Clay mineralogical analyses have shown a dominance of illite, the presence of kaolinite and some quartz [7].

Experimental fields

Saline soils on marine alluvium are being studied for reclamation by the Pedology Department of the "Estação Agronómica Nacional". They were inventoried and mapped and then reclamation experiments were conducted.

Four experimental fields were set up, two for dry farming conditions (Faro and Tavira) and two for irrigated crops (Sado and Alvor).

Analytical data for some soil units of the experimental fields are shown in Table 2 [4].

There is a predominance at the Faro, Tavira and Alvor fields of silty clay soils which are 1–2 m deep over sand; calcium carbonate is often found and acid layers or "Katteklei" occur sometimes either down in the profile or near the surface of the soil. In the Sado region soils are clayey to 3 meters, have no calcium carbonate and show acid reaction. Typical colours of thiosols

Table 1

Analytical data of three characteristic, salt affected soils

	Profile n°. 112					Profile n°. 323			Profile n°. 403	
Horizon	Ap	C_1	C_2	C_3	C_4	Ap	C_1	C_2	Ap	C_1
Depth (cm)	0—30	30—50	50—80	80—95	95—110	0—20	20—40	40—80	0—25	25—70
Coarse sand (%)	1.0	0.3	0.2	0.7	2.4	0.8	0.8	1.7	1.6	2.4
Fine sand (%)	7.7	3.3	21.7	26.1	35.4	21.4	18.2	21.9	38.7	20.1
Silt (%)	21.3	22.2	20.5	19.6	18.4	44.8	43.4	41.4	23.7	39.5
Clay (%)	70.0	74.2	57.6	53.6	43.8	33.0	37.6	35.0	36.0	38.0
Organic Matter (%)	2.49	1.71	0.65			5.44			2.76	
Total N (%)	0.150		0.067			0.200			0.130	
Carbonates (%)	4.0	0.8	Traces	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Salinity (% NaCl)	0.04	0.016	0.20	0.65	>1.00	0.30	0.55	>1.00	>1.00	1.00
pH (Water)	8.6	8.7	8.2	7.7	5.6	6.2	5.7	4.2	7.6	7.4
Total exchangeable cations (me./100 g):										
Ca^{2+}	5.90	1.80	3.00	2.70	0.80	7.40	5.70	3.70	8.10	9.30
Mg^{2+}	7.60	10.00	9.00	7.30	2.58	5.10	3.98	3.96	9.00	23.10
K^+	0.57	4.35	8.20	7.63	2.00	2.20	2.54	3.04	9.60	11.90
Na^+	3.50	20.00	21.00	35.90	32.30	6.40	13.30	23.60	172.00	200.50
H	0.00	0.00	0.00	0.00	3.00	2.15	2.70	7.00	0.00	0.08
Exchangeable cations in the sat. ext. (me./100 g):										
Ca^{2+}	0.38	0.37	0.57	0.78	0.60	0.51	0.50	0.76	2.56	1.85
Mg^{2+}	0.17	0.48	0.45	1.29	0.50	4.96	3.87	2.10	6.26	5.18
K^+	0.17	0.75	0.75	2.29	1.61	1.33	1.50	2.70	8.62	6.32
Na^+	0.25	1.91	2.33	8.60	15.45	3.65	7.38	15.95	35.30	28.20
Cond. of the sat. ext. (mmhos/cm)	1.00	5.11	5.14	16.73	36.79	8.29	17.41	30.67	64.28	60.03
Water in the sat. paste (%)	55.3	55.5	65.0	60.4	59.2	56.6	53.6	59.3	59.0	66.6
Exchangeable cations in the soil (me./100 g):										
Ca^{2+}	5.52	1.43	2.43	1.92	0.20	6.89	5.20	2.94	5.54	7.45
Mg^{2+}	7.43	9.52	8.55	6.01	2.08	0.14	0.11	1.86	2.74	17.92
K^+	0.40	3.60	7.45	5.34	0.39	0.87	1.04	0.34	0.98	5.58
Na^+	3.25	18.09	18.67	27.30	16.85	2.75	5.92	7.65	136.70	172.30
H	0.00	0.00	0.00	0.00	3.00	2.15	2.70	7.00	0.00	0.08
S — Value (me./100 g)	16.60	33.64	37.10	40.57	19.52	10.65	12.27	12.79	145.96	203.25
T — Value (me./100.g)	16.60	32.64	37.10	40.57	22.52	12.80	14.97	19.79	145.96	203.33
V — Value (%)	100.0	100.0	100.0	100.0	86.7	83.2	81.9	89.9	100.0	99.9
Exchangeable cations (%):										
Ca^{2+}	33.3	4.4	6.5	4.7	0.9	53.8	34.7	14.9	3.8	3.7
Mg^{2+}	44.8	29.2	23.0	14.8	9.2	1.1	0.7	9.4	1.9	8.8
K^+	2.4	11.0	20.1	13.2	1.7	6.8	6.9	1.7	0.7	2.7
Na^+	19.5	55.4	50.4	67.3	74.8	21.5	39.5	38.7	93.6	84.7

have not developed because of continuous rice cultivation. In a few cases, accumulations of organic matter have been found in some layers [4].

In the experimental field at Faro, protected from tides for more than 40 years, trials have been conducted using calcium carbonate, calcium oxide and calcium sulphate as amendments and a crop adaptation study has been carried out along with periodic soil analyses of the experimental plots [4].

In the Tavira experimental field, protected from tides since 1962, drainage practices, amendment applications, deep liming for correction of excess of acidity, and sand mulch have been under investigation [3].

In the Alvor experimental field, trials on drainage, leaching, deep plowing, applications of several amendments, organic and mineral fertilization, and crop rotation under intensive irrigation (with and without rice) are being conducted [3].

In the experimental field at Sado trials deal with reclamation in relation to rice cultivation [4].

Some results

Soil-vegetation and microrelief

Studies at the experimental field of Tavira before and after protection from tides have shown that *Spartina stricta*, *Atropis convoluta* and *Arthroeneum perenne* had the most active role on sediment fixation and on microrelief formation before reclamation started. *Spartina stricta* showed very good adaptation to all microrelief conditions, and certain types of vegetation cover of this species seems to be a good indicator of a further development of very acid soil surface layers [2].

Possibility of reclaiming saline soils on marine alluvium without irrigation

In the experimental field at Faro, non-irrigated winter crops have been grown successfully for several years. This seems to confirm the initial hypothesis that it is possible to reclaim these soils without irrigation. This is particularly important for those areas where there is a shortage of water.

The hydrological balance, estimated by the Thornthwaite-Mather's method, for an available water capacity of 150 mm and average rainfall (423 mm) and temperature (17.8 °C) for thirty years, indicates a water deficit from April to October with no month of the year showing a water surplus. This would imply the indispensability of the use of irrigation for salt removal from the layers explored by roots [4]. However, in those years of heavy rainfall the salts are apparently leached. For instance, in 1959 and 1960, water surpluses were registered in March (59 mm) and February—March (77 mm + 58 mm), respectively, with a consequent lowering of the salinity levels of the Faro experimental field [1, 6]. In the Tavira experimental field, yields of wheat and barley of about 3000 kg/ha were obtained in 1966 (second year of trials) under non-irrigated conditions of reclamation. Good yields seem to depend largely on spring rains, particularly in April [4].

Drainage

In dry-farming reclamation experiments results have shown that a drainage system established at a 1 meter depth is generally adequate [1].

Table 2

Analytical data for some of the soils being studied

Experimental field	Faro							Tavira					
Profile n°.	29				220			3			18		
Deth (cm)	0—15	15—35	35—65	65—85	0—10	10—30	30—100	0—5	5—24	24—100	0—12	12—40	40—100
Coarse sand (%)	1.3	0.1	0.3	4.3	1.6	1.6	—	0.5	2.0	5.4	1.4	2.9	2.0
Fine sand (%)	8.7	6.1	18.0	41.4	10.1	9.6	—	12.8	20.6	25.4	13.7	25.9	22.6
Silt (%)	40.5	35.4	31.9	21.8	34.9	30.4	50.0	39.0	38.2	31.3	40.3	35.4	39.0
Clay (%)	49.5	58.4	49.8	32.5	53.4	58.4	20.6	47.7	39.2	38.0	44.6	35.8	36.4
N (%)	0.18	0.10	0.18	0.07	0.17	0.17	0.13	0.22	0.18	0.14	0.14	0.13	0.17
C (%)	2.20	1.04	1.26	1.45	1.79	1.37	2.58	3.53	1.49	1.85	1.52	1.26	3.26
pH	7.9	6.7	7.3	7.9	4.0	3.6	3.1	7.4	7.8	8.0	5.9	7.3	7.4
SP (%)*	86.6	68.8	65.3	62.1	49.5	74.1	41.9	66.6	61.2	61.3	71.2	61.4	78.2
EC (mmho/cm)**	3.6	13.2	18.0	12.2	4.4	5.5	25.9	41.8	39.0	51.0	52.0	38.5	64.0
Cations (me./l):***													
Ca^{2+}	7.30	17.30	53.00	53.05	5.55	0.81	6.20	57.8	53.4	55.6	70.4	50.7	55.1
Mg^{2+}	9.00	41.56	49.31	31.40	1.21	1.08	114.55	104.6	96.6	116.4	167.6	79.3	238.9
K^+	0.92	2.47	3.06	2.25	1.01	0.94	0.23	6.5	11.9	7.9	9.1	7.1	16.9
Na^+	22.17	100.00	115.31	81.64	16.56	26.58	117.56	315.5	302.5	417.5	767.5	232.5	627.5
Anions (me./l):***													
Cl^-	—	174.20	234.20	130.10	24.20	37.00	180.00	440.0	350.0	510.0	668.8	395.0	853.6
SO_4^{2-}	18.93	21.40	52.70	57.10	5.14	—	542.70	91.7	95.1	126.4	91.0	93.2	171.6
CO_3^{2-}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	—	—	—	—	—	—
HCO_3^-	2.80	0.68	1.13	1.17	0.00	0.00	0.00	—	—	—	—	—	—

* Saturation percentage (Agr. Handb. n°. 60. USDA).
** Electrical conductivity of saturation extract.
*** In the saturation extract.

Coarse sand (%)	—	—	—	0.2	0.1	0.1	1.3	0.3	0.2
Fine sand (%)	—	—	—	2.0	—	1.5	1.9	1.3	2.2
Silt (%)	—	—	—	26.8	39.5	36.8	28.3	24.6	38.3
Clay (%)	—	—	—	71.0	46.9	61.6	68.5	73.8	59.3
N (%)	0.14	0.16	0.18	—	—	—	—	—	—
C (%)	1.68	1.60	3.57	—	—	—	—	—	—
pH	6.0	6.0	2.7	6.0	5.5	5.6	3.8	3.4	5.8
SP (%)*	—	—	—	103.0	183.0	115.7	92.9	104.4	102.9
EC (mmho/cm)**	21.0	30.0	100.0	6.2	25.0	22.0	17.4	17.7	42.9
Cations (me./l):***									
Ca^{2+}	12.88	12.88	33.12	2.25	8.55	5.65	4.25	4.00	9.75
Mg^{2+}	32.12	41.12	153.88	11.20	—	35.80	38.20	—	152.90
K^+	4.00	5.25	14.75	1.73	4.97	4.97	3.79	4.80	13.90
Na^+	167.50	275.00	1300.00	48.10	162.30	132.96	64.10	113.00	356.80
Anions (me./l):***									
Cl^-	177.50	262.50	1350.00	46.90	180.70	156.30	61.60	83.00	371.30
SO_4^{2-}	35.90	65.98	254.47	24.84	81.91	31.55	86.53	104.10	151.74
CO_3^{2-}	—	—	—	0.00	0.00	0.00	0.00	0.00	0.00
HCO_3^-	—	—	—	—	—	—	0.00	—	—

* Saturation percentage (Agr. Handb. n°. 60.USDA).
** Electrical conductivity of saturation extract.
*** In the saturation extract.

Under irrigation those results do not seem to apply. Studies made at the Sado Experimental field, using a quick field method of determining electrical conductivity of the soil [12], have shown that covered drains placed at a depth of 90 cm, either at 12.5 m or 20 m intervals, had a marked influence on lowering the salinity of the surface 25 cm-layer of the soil in a 3 m wide band on each side of the drain, but it decreases rapidly till 5 m, being nul from there on [4, 12].

Responses of some crops to salinity and acidity

In the Faro experimental field, where salinity is moderate in the surface soil horizons, the following non-irrigated crops have been tried: barley, wheat, oats, rye, maize, sorghum, broad beans, beets, tomatoes, potatoes, onions, garlic, *Lolium multiflorum*, *Melilotus segetalis*, *Vicia atropurpurea*, *Lathyrus ochrus* and *Lathyrus clymenum*. All crops showed good growth on those soils which had calcium carbonates, and yields as high as 2700 kg/ha for wheat, 1600 kg/ha for broad beans, and 30 000 kg/ha for forage crops, were obtained, depending on the quantity of spring rainfall [6, 14].

Almost all crops, especially *Melilotus segetalis*, barley and beets, were very sensitive to "cat clay" acidity, while *Lolium multiflorum*, rye and oats showed tolerance to these conditions [4, 14].

Irrigated rice has been the main crop tested in the Sado experimental field. Its adaptation has been successful, with yields as high as 7000 kg/ha, provided enough flooding water was applied at frequent intervals. Under the poor drainage conditions desalinization is very slow, as it is carried on mainly by salt diffusion in the flooding water [4, 14], and may be reversed if irrigation stops, due to the high capillary conductivity of the saturated soil [4].

Efficiency of lime treatment in reclaiming Thiosols

Thiosols [13] occur in the experimental fields of Faro, Tavira and Alvor· Lime requirements of these soils are very high, and increase rapidly with increased acidity. For a soil of pH 5.0 it is about 5 ton/ha of calcium carbonate per centimeter thickness of the acid layer, about of 9 ton/ha for pH 4.0, 12 ton/ha for pH 3.5 and 26 ton/ha for pH 3.0 [5].

Nevertheless, an application of 10 ton/ha of CaO in the upper 25 cm-layer of a soil of pH 4.0 on the experimental field at Faro gave good results. Crops such as barley, which could not be grown before the amendment, showed good initial response, although in the final stages rooting difficulties in the deeper acid layers seemed evident [4, 14]. Crops with shallower root systems (onions, garlic), some forage crops of shorter growing cycle (oats, *Vicia atropurpurea*, *Lolium multiflorum*), and crops of higher acidity-tolerance (rye, potatoes) give good yields after amendment [4]. Lime plowed under to a depth of 50 cm at the rate of 25 tons/ha of CaO greatly improved the growth and yield of barley [4, 14].

Sand mulch

At the Tavira experimental field a 10 cm-thick mulch of sand (90% of the particles with a diameter of 0.2 – 1 mm) increased the water content of the upper 15 cm of the soil, reduced salinity of the same layer, and increased the yield of tomatoes [11]. The cost of the mulch application varied from about $ 800 to $ 3000 US dollars per hectare [8].

Economic aspects of reclamation

Studies made at the Tavira and Alvor experimental fields have shown that the cost of reclamation of saline soils on marine alluvium is about $ 1200 US dollars per hectare with no irrigation, and $ 2400 with irrigation (15).

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