SOLUTE TRANSPORT, SWELLING AND SHRINKING IN SALT-AFFECTED SOILS

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Abstract: *Soil containing high concentrations of soluble salts and exchangeable sodium frequently produce distinct agricultural and management problems. Soluble salts in the Low Plain Aranca arise from the upward movement by capillarity from a high saline water table. Three mechanisms operate to transport solutes in soils: advection, diffusion and dispersion. Flow through the vadose zone requires study of saturated and unsaturated flow through variably saturated media. Solutes can interact strongly with soil surfaces and their transport can be appreciably slowed in a process known as retardation. Soils with high smectite content may also swell considerably more in the presence of high sodium and/or low salt concentrations. The study is based on a detailed soil survey effectuated in the hydrographical basin Aranca in order to achieve soil map and to take soil samples for the laboratory studies about solute transport and swelling-shrinking in salt-affected soils. There were studied 79 main soil profiles, from which 36 profiles are Fluvisols, 31 profiles are Vertisols, 8 profiles are Chernozems and Phaeozems, 2 profiles are Solonetz and 2 profiles are Gleysols. Because of their coarse or medium texture, in the case of Fluvisols, Chernozems, Phaeozems and Gleysols, solute transport was easily and the soluble salts are concentrated in the upper part of soil profile. A different situation is in Vertisols, which is a deep clayey soils, dominated by clay minerals such as smectites, that expand upon wetting and shrink upon drying. They form wide cracks from the soil surface when drying out. The water potential Φ in swelling systems is the sum of the gravitational potential with capillary and overburden potential. The overburden potential is related to the civil engineers' effective stress. Soil-solution-soil-matrix physicochemical interactions enhanced by dilute soil solution with relatively high sodium to calcium ratios, can affect the flow parameters considerably. The retardation caused by Na/Ca exchange increases with increasing SAR and decreasing C and h, especially in relatively fine-textured soils.*

Key words**:** *soluble salt, clay, water, soil, transport*

INTRODUCTION

Soils containing high concentrations of undesirable salts, such as sodium, frequently produce distinct agricultural and management problems. Salts are found in the soil solution and linked with the clay particles. There is a continuous interchange or exchange of salt as ions between these two sites, to establish an equilibrium situation. High concentrations of soluble salts can be toxic and by increasing the solute suction, reduce the availability of soil water to plants. High concentrations of exchangeable sodium produce a soil structure breakdown which reduces permeability, aeration, infiltration rate and soil workability. Soluble salts can arise from the upward movement of salt by capillarity from a high saline water table, or surface deposition from saline irrigation or flood water, or wind-borne salt.

Three mechanisms operate to transport solutes in soils and aquifers. Advection refers to the movement of chemicals with soil fluids and groundwater. Diffusion is the omnidirectional spreading of a chemical that result from thermal motion of the fluid and solute molecules. Dispersion results primarily from variations in fluid velocity that occurs at all scales. Dispersion is anisotropic and enhanced in the overall direction of flow (T. FERRE and A. WARRICK). Flow through the vadose zone requires study of saturated and unsaturated flow through variably saturated media. Both saturated and unsaturated flow problems may be steady-state or transient. Solutes can interact strongly with soil surfaces by physical or chemical adsorbtion and their transport can be appreciably slowed in a process known as retardation. Repulsion or exclusion of solutes from soil surfaces can result in transport more rapid than that of the carrier fluid. Water movement in soils that change volume with water content is not well understood, and management of swelling soils remains problematic. Difficulties arise because volume change complicates measurement of material balance and both the liquid and the solid phases must be considered. Swelling or shrinking accompanying soil water content change results in vertical displacement of the wet soil which involves gravitational work and contributes an overburden component to the total potential of the soil water. In addition, the total flux of the water has a component advected with the moving solid as well as the water potential-driven, darcian flux relative to the solid. Finally, many swelling soils crack and the network of cracks provides alternative, preferential pathways for rapid flow of water which prejudice application of theory simply based on darcian flow. Soils with high smectite content may also swell considerably more in the presence of high sodium and/or low salt concentrations (D. RUSSO).

MATERIAL AND METHODS

The study is based on a detailed soil survey effectuated in the years 1967-2007 in the hydrographical basin Aranca, especially of the Cenad territory, and also were used scientifically studies with similar themes conducted by other researchers. The objective were to achieve soil map at large scale in order to know the soil cover and their characteristics, and to take soil samples for the laboratory studies about solute transport and swelling-shrinking in salt affected soils.

RESULTS AND DISCUSSIONS

The environmental conditions in Aranca plain are dominated by the stratified parent material, a landscapes governed by microrelief, water logging at the surface salinity in the profile and in the groundwater. In a large area the parent material is rich in smectite clay. During the soil survey was studied 79 main profiles, which consisted of:

- Fluvisols (Aluviosol-SRTS) – 36 profiles;
- Vertisols (Vertosol-Pelosol-SRTS) – 31 profiles;
- Chernozems and Phaeozems (Cernoziom and Faeoziom) – 8 profiles;
- Solonetz – 2 profiles;
- Gleysols – 2 profiles.

All the soil types can be grouped in two categories, in accordance with particle size distribution: a first group with coarse-medium texture, for Fluvisols, Chernozems, Phaeozems and Gleysols and the second group with fine texture and sodium, for Vertisols and Solonetz.

Fluvisols are young soils and the stratification is the major characteristic used to distinguish these soils from other soils. In many cases stratification may be easily detected through the occurrence of layers showing different particle-size distribution and organic matter content. Fluvisols are soils that receive fresh materials (fluviatile, marine and lacustrine sediments) at regular intervals, or have received them in the recent past. Physically, Fluvisols may be wet through the presence of groundwater, soil salinity and high sodium levels may be a problem (table 1 and 2).

Salic Fluvisols from table 1 is a loamy type, porous, with a high hydraulic conductivity and moderate salinity in all horizons between topsoil and horizon C, below 78 cm.

Table 1

Aluviosol salinic – Salic Fluvisols, profile 175

Horizon	Apk	Aok	ACk	I Ck
Depth, cm	0-12	-40	-68	-78
Coarse Sand, % Fine Sand Silt Clay	1,4 39,6 26,0 33,0	1,7 35,3 28,1 34,9	3,2 44,1 31,1 21,6	54,4 40,0 4,1 1,5
Air Porosity, %	28,25	9,38	15,18	-
Hydraulic Conductivity, mm/h	20,0	3,2	7,0	50
pH	8,09	8,29	8,20	8,69
Humus, %	2,82	2.42	1,82	-
ESP, %	0,24	0,98	0,90	0,77
CECs, me/100g	89,2	34,8	35,1	33,5
Soluble Salt, mg/100g	240,8	194,9	138,8	128,4

Table 2

Aluviosol salinic-sodic – Salic –SodicFluvisols, profile 204

Horizon	Ap	Aok	I Ck	II Ck
Depth, cm	0-24	-36	-47	-57
Coarse Sand, % Fine Sand Silt Clay	0,2 47,2 21,8 30,8	0,2 44,5 24,0 31,3	0,5 75,5 14,3 9,7	0,5 91,5 5,3 2,7
Air Porosity, %	13,36	13,77	6,81	-
Hydraulic Conductivity, mm/h	3,8	4,0	13	40
pH	8,55	8,62	8,54	8,59
Humus, %	2,73	2,42	0,62	
ESP, %	7,15	0,56	-	
CECs, me/100g	31,33	28,70	-	
Soluble Salt, mg/100g	546,7	48,3		

Salic-sodic Fluvisols (table 2) has a coarse texture below 36 cm, and the value of ESP 7,15 in Ap horizon. In the same horizon, at surface were concentrated the soluble salts (546,7 mg/100g). It can be noticed that the Salic-Sodic Fluvisols has comparatively with Saline Fluvisols, a small value of hydraulic conductivity. Most of Fluvisols (91,6%) have the soluble salts in the first 50 cm from the surface.

Table 3

Cernoziom salinic-sodic – Hyposalic-Hyposodic Chernozems, profile 1

Horizon	Ap	Atp	Am	ACk	Cca
Depth, cm	0-20	-34	-61	-72	-120
Coarse Sand, % Fine Sand Silt Clay	6,6 47,5 15,8 30,1	7,1 35,6 22,5 34,8	4,9 36,0 17,8 41,3	1,6 45,4 18,0 35,0	4,3 59,3 16,2 20,2
Air Porosity, %	-2,51	3,59	-1,29		
Hydraulic Conductivity, mm/h	0,9	1,2	0,7	0,4	
pH	6,67	8,30	9,19	9,40	8,89
Humus, %	3,35	3,28	2,73		
ESP, %	-	10,08	13,29	8,85	8,50
CECs, me/100g	31,20	30,45	32,20	28,32	21,76
Soluble Salt, mg/100g		102,3	180,2	247,4	

Chernozems (table 3) and Phaeozems (table 4) have a deep humus rich mollic horizon with a well developed crumb structure resulting from a high annual biomass production and a very high biological activity in the soil. Concentrations of soft powdery lime occur in the lower part of the soil profile as a main diagnostic property, separating the Chernozems from the Phaeozems. Downward percolation in spring leaches nutrients from the topsoil and lime accumulates in the subsoil. In the wetter areas at the boundary of steppe and deciduous forest, clay may also accumulate to form an argic horizon in the subsoil. The favorable physical and chemical properties, especially the high porosity and available water capacity, the high levels of organic matter and nutrients make these soils very fertile. In the territory of Cenad, 75% from soil profiles have had the soluble salts in the first 50 cm subsurface.

Table 4

Faeoziom gleic – Gleyic Phaeozems, profil 28

Horizon	Ap	Am	AC	Cg_2
Depth, cm	0-21	-46	-87	-115
Coarse Sand, % Fine Sand Silt Clay	4,8 33,9 27,0 34,3	3,6 38,3 22,8 35,3	2,2 47,7 22,2 27,9	1,1 50,9 22,3 25,7
Air Porosity, %	34,43	23,58	14,00	-
Hydraulic Conductivity, mm/h	22	8	8	-
pH	7,09	7,55	8,29	8,17
Humus, %	3,28	3,04	1,82	-
ESP, %				
CECs, me/100g	30,2	29,3	33,07	26,4
Soluble Salt, mg/100g	-	-	21,99	

Vertisols (fig.1 and table 5 and 6) are deep clayey soils (>45% clay) dominated by clay minerals such as smectites, that expand upon wetting and shrink upon drying. They form wide cracks from the soil surface down to at least 50 cm depth when drying out. The upper part of soil commonly consists of strong and prism-like blocks. At the suface a linear frecquency of microknolls and depressions may occur, collectively known as "gilgai" microrelief. Gilgai is a consequence of churning of soil material as a result of swelling and shrinking. Although they have a relatively high water holding capacity shallow rooting crops may suffer from drought stress.

Table 5

Vertosol salinic-sodic – Salic-sodic Vertisols, profil 45

Horizon	Ay	Ayw	AyGoyC	GrK	CnGr
Depth, cm	0-25	-61	-95	-175	-210
Coarse Sand, % Fine Sand Silt Clay	0,7 17,0 17,9 64,4	0,6 13,4 21,3 64,7	0,6 15,1 18,3 66,4	0,7 8,7 22,8 67,8	12,3 38,6 17,1 32,0
Air Porosity, %	1,9	-0,91	1,98	-2,47	-
Hydraulic Conductivity, mm/h	0,26	0,10	008	005	001
pH	6,97	7,41	8,01	8,35	8,89
Humus, %	3,35	2,73	2,28	-	-
ESP, %	-	-	0,5	7,7	10,3
CECs, me/100g	31,01	30,05	51,5	61,8	26,7
Soluble Salt, mg/100g			311,4	142,6	95,1

The most important physical characteristics of Vertisols are a low hydraulic conductivity and stickness when wet and a high flow of water through the cracks when dry. Because of the very fine pores, which are dominant, the solute transport is very slow and the soluble salts are concentrated at the bottom of the soil profile in most cases (71%).

Figure 1: Microrelief with “gilgai” in Cenad territory on a Vertisols

Table 6

Vertosol salinic-sodic – Salic-sodic Vertisols, profil 148

Horizon	Ap	Ay	ABy	ByC
Depth, cm	0-17	-44	-76	-124
Coarse Sand, %	0,8	0,7	1,0	0,5
Fine Sand	27,7	28,1	31,8	42,4
Silt	22,2	19,9	20,7	20,6
Clay	49,3	51,3	46,5	36,5
Air Porosity, %	16,21	12,64	8,40	-
Hydraulic Conductivity, mm/h	2,2	1,5	0,7	1,2
pH	7,56	8,57	8,21	8,99
Humus, %	3,47	3,28	1,92	-
ESP, %	12,31	21,37	24,56	23,73
CECs, me/100g	37,23	37,87	43,52	32,20
Soluble Salt, mg/100g	-	278,1	1219,4	540,8

Solonetz (table 7). Dry conditions and inherent salinity of soils, parent materials and groundwater are conducive to the formation of Solonetz. Salt accumulation takes place in the middle or lower parts of the soil, with an upward movement during the summer (dry) season and downward movement during the winter (rainy) season. Solonetz are developed under the influence of such salts as $NaHCO_3$, Na_2CO_3, $MgCO_3$ and Na_2SiO_3.

The natric horizon and saline subsoils is characteristic for Solonetz. The natric horizon is a dense subsurface horizon which has greater clay content than the overlying horizons and a high amount of exchangeable sodium and/or magnesium. The dominant physical features of Solonetz are the poor aggregate stability, the impermeability under wet conditions and the hardness of the nitric horizon when dry. The main chemical characteristics are the high amounts of sodium at the adsorbtion complex and the high pH which is frequently more than 9,0. In the case of Salic Solonetz, the high salt accumulation limits plant growth to salt tolerant plants, because either it is toxic, limit growth because nutrients are proportionally less available, or it creates physiological drought as a consequence of high osmotic pressure of the soil solution.

Table 7

Solonet salinic – Salic Solonetz, profil 182

Horizon	Btnasc	Btnasc	BCksc
Depth, cm	4-21	-40	-104
Coarse Sand, %	0,6	0,1	0,1
Fine Sand	42,4	31,3	30,5
Silt	23,7	27,8	23,9
Clay	33,3	40,8	45,5
Air Porosity, %	-0,55	-9,30	-12,08
Hydraulic Conductivity, mm/h	1,8	0,45	0,43
pH	9,82	9,99	9,99
Humus, %	2,97	2,73	1,92
ESP, %	35,6	48,5	37,1
CECs, me/100g	29,6	37,4	26,9
Soluble Salt, mg/100g	176,6	240,8	172,0

Material balance in Swelling Systems

Water flow in unsaturated nonswelling soils is described by combining the Darcy law with an equation of continuity that accounts for the water in the system during steady and unsteady flow; the Richards equation results (T.Ferre, A. Warrick). One-dimensional flow of water in a swelling system requires material balance equations for both the aqueous and solid phases:

$$\frac{\partial \theta w}{\partial t} = -\frac{\partial Fw}{\partial z} \quad (1)$$

$$\frac{\partial \theta s}{\partial t} = -\frac{\partial Fs}{\partial z} \quad (2)$$

where z is a distance coordinate, t is the time, Fw and Fs are the volume flux densities of the water and of the solid (cubic meters per square meter per second) relative to the observer, and θw and θs are the volume fractions of the water and solid. The volume fractions are defined per unit area of horizontal cross section of the soil and the reference volume includes the cracks (D.SMILES, P.RAATS).

The water potential Φ in swelling systems is the sum of:

1. the gravitational potential, z;
2. the capillary potential, ψ;

3. the overburden potential, Ω, representing vertical displacement of the wet soil accompanying unit change in water content at z.

$$\Phi = z + p_w = z + \psi + \Omega = z + \psi + \alpha\left(\int_z^T + \gamma \cdot dz + P\right) \tag{3}$$

The unloaded capillary potential Ψ is the potential a tensiometer would measure at the existing moisture ratio in the absence of overburden. In Eqn (3), γ is the wet specific gravity of soil, P is any static load on the soil surface, and α reflects the degree to which the soil is elevated by unit change in water content.

The overburden, Ω, is related to the civil engineers' effective stress according to the equation

$$\Omega = \alpha\delta = \delta^{'} + p_w \tag{4}$$

in which δ is the total normal stress and δ' is the effective or interparticle stress.

Soil-solution-soil-matrix physicochemical interactions enhanced by dilute soil solution with relatively high sodium-to-calcium ratios, can affect the flow parameters considerably. In other words, soil-solution-soil-matrix physicochemical interactions may affect both water flow and solute transport. For a given soil, the retardation of the water movement by the matrix-soil solution interaction will increase as either the initial soil solution SAR or the SAR of the applied water increases, as either the initial soil-solution concentration or the solution concentration of the applied water decreases, and as the surface water application rate increases. The retardation effect because of Na/Ca exchange is given by the retardation factor, Rf:

$$Rf(h,R,C_o) = 1 + \frac{[R+1]\Gamma_{Na}(h,R,C_o)FA_{ad}\,p_b}{Z_{Na}RC_o\theta(h)} \tag{5}$$

where F is the Faraday constant, A_{ad} is the specific adsorbtion surface area of the soil, and Γ_{Na} is the quantity of sodium ionic charges per unit area of the charged surface. The retardation caused by Na/Ca exchange (expressed in terms of R_f) increases with increasing SAR and decreasing C and h, especially in relatively fine-textured soils. Applying the Boltzmann distribution law for the Na/Ca-Cl system considered here, the amount of excluded chloride per unit surface area is calculated from:

$$Ef(h,R,C_o) = 1 - \frac{[R+1]\Gamma_{Cl}(h,R,C_o)A_{ex}\,p_b}{|Z_{Cl}|C_o[R+2]\theta(h)} \tag{6}$$

where Ef, the elution factor and A_{ex} is the specific exclusion surface area. It is worthwhile emphasizing that the theoretical finding discussed here are relevant to soils whos clay fraction is dominated by smectite minerals (e.g. montmorillonite), with solutions containing Na, Ca and Cl ions only. Furthermore, the model of the hydraulic functions in salt-affected soils is based on a simplified description of the porous medium, and of the physicochemical interactions between the soil solution and the soil matrix, when the soil ESP exceed a critical value.

CONCLUSIONS

The Low Plain Aranca, with accumulative relief and slow bent and an obvious subsidence is covered with fluvio-lacustrine deposits with various granulometries, from gravel and sand, until smectite clays. The phreatic water is mineralized with the dominance of Na+K over Ca+Mg and a ratio Ca/Mg $\leq$ 1. In the droughty years it reaches to the soil solution concentration and sodium ions reach into the colloidal complex and destroy the soil structure and heavily increase the pH. Solute can interact strongly with soil surfaces and their transport can be appreciably slowed in a process known as retardation. The main types soil are Fluvisol and Vertisol, with a diametrically behaviour concerning solute transport. In the Fluvisols, the soluble salts, like in Chernozems and Phaeozems, are concentrated in the first 50 cm of the soil profile, while in the Vertisols the most soluble salts are concentrated at the bottom of the profile. Water flow and solute transport in swelling soils is described within a macroscopic, one-dimensional theory because field volume change, in the large, is vertical. The theory identifies an overburden component of the water potential in addition to those due to gravity and capillarity.

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