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Classification and Mitigation of Soil Salinization

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Summary and Keywords

Soil salinity has been causing problems for agriculturists for millennia, primarily in irrigated lands. The importance of salinity issues is increasing, since large areas are affected by irrigation-induced salt accumulation. A wide knowledge base has been collected to better understand the major processes of salt accumulation and choose the right method of mitigation. There are two major types of soil salinity that are distinguished because of different properties and mitigation requirements. The first is caused mostly by the large salt concentration and is called saline soil, typically corresponding to Solonchak soils. The second is caused mainly by the dominance of sodium in the soil solution or on the soil exchange complex. This latter type is called "sodic" soil, corresponding to Solonetz soils. Saline soils have homogeneous soil profiles with relatively good soil structure, and their appropriate mitigation measure is leaching. Naturally sodic soils have markedly different horizons and unfavorable physical properties, such as low permeability, swelling, plasticity when wet, and hardness when dry, and their limitation for agriculture is mitigated typically by applying gypsum. Salinity and sodicity need to be chemically quantified before deciding on the proper management strategy. The most complex management and mitigation of salinized irrigated lands involves modern engineering including calculations of irrigation water rates and reclamation materials, provisions for drainage, and drainage disposal. Mapping-oriented soil classification was developed for naturally saline and sodic soils and inherited the first soil categories introduced more than a century ago, such as Solonchak and Solonetz in most of the total of 24 soil classification systems used currently. USDA Soil Taxonomy is one exception, which uses names composed of formative elements.

Keywords: Sodium Adsorption Ratio, Exchangeable Sodium Percent, salt accumulation, Solonetz, Solonchak, Solod, irrigation, leaching, drainage

Salt-affected soils are widespread, covering nearly 10% of continental surfaces (Szabolcs, 1989). Salinity and alkalinity are present in every climate zone but are most prominent in arid, semiarid, and subhumid zones, where evaporation brings salts close to the surface and into the root-zone, thereby causing problems for agriculture. There are two kinds of areas affected by salinity: (1) drylands, or naturally salt-affected areas, and (2) the salt-affected areas as a result of irrigation. Since 40% of all food is produced on irrigated land worldwide, which consumes some 90% of all utilized water (Döll and Siebert, 2002), irrigation related salt accumulation is in the focus of agricultural studies. These soils pose severe limitations for their management, firstly in agriculture. Since there is a wide variety of salt-affected soils, as described below, each of those have their particular handicaps. Most often, the problems of salinity and/or sodicity are quite noticeable. Salinity causes stunted growth of plants, sodicity causes problems in cultivation, irrigation, traffic. Besides several other modifying factors, the three most important chemical indicators of salt-affected soils are salinity, sodicity, and alkalinity.

Salinity

The damage caused by salts has been known for thousands of years (see the legendary salting of Carthage, which was probably a myth coined on the example of Shechem as mentioned in Book of Judges [9:45]). Salts, to a large extent visible on the surface, reduce plants' ability to take up water. In normal soils, the driving force of water uptake through the plant is the potential difference between the atmosphere and the soil. Due to the under-saturation of air by vapor, its diffusion through the stomata results in a tension in the xylem, reaching down to the roots. The tension difference between roots and soil will extract water from the soil. In contrast to non-saline soils, tension is not necessarily greater in roots in saline soils: this is because of the osmotic effect of salt in the soil solution. In such soils water availability is limited for the plants. Consequently, plants require special mechanisms to extract water from saline soils.

The chemical definition of soil salinity is the dry mass of salts in unit mass of dry soil, expressed in units such as percent or ppm. For the exact measurement, all salts should be removed from the soils by leaching and be evaporated and measured, which is a lengthy process. In practice, the assessment of soil salinity is done not by complete leaching but by using extracts prepared at different soil/water ratios; additionally, there is no mass weighing of evaporated salts: this is done by a proxy, which is the electrical conductivity of the extract. The most useful and probably the most widely used indicator of soil salinity is the conductivity of saturated soil extract (EC_e) expressed in deciSiemens (or dS) m^{-1}. There are two reasons for its practicality.

Firstly, it is measured in the saturation extract in which water is removed from a soil that has been saturated previously (so that it cannot hold more water) and not in a fixed soil:water extract, such as 1:5 or 1:10 used in some cases. The water needed to reach soil saturation or the soil saturation percentage, is closely dependent on the moisture range of the given soil (Richards, 1954). More clayey soils will have higher saturation percentage (SP) values; typical ranges are sand <25, sandy loam 25–37.5, loam 37.5–50, loamy clay 50–75, clay >75 (Lesch et al., 1995). However the effect of higher SP values is automatically considered by the method, because SP is about four times as high as the permanent wilting percentage (the minimal soil moisture content under which the plants wilt) and two times as high as the field capacity (Richards, 1954, p. 8), the typical soil moisture content to which the soils drain down after complete wetting of the soil.

Secondly, electrical conductivity is directly related to the concentration and mobility of ions, as shown by the following equation for a two-component system of an anion and a cation:

$$\kappa=\alpha^* c_e{}^*(F^*U_c+F^*U_a)$$

κ = specific conductivity, reciprocal of specific resistivity ≡ electrical conductivity of 1 cm cube, if the current flows perpendicular to one pair of sides

α = degree of dissociation

c_e = concentration in gram-equivalent/cm^3

F = electrical charge of one gram-equivalent ion

U = absolute mobility of anion and cation, which is proportional to ionic charge and inversely proportional to mass of ions

The conductivity of soil solutions with similar ion composition will therefore mostly depend on the concentration.

Sodicity

Some salt-affected soils have low salinity and are characterized by a barely visible high sodium ion concentration in the soil solution or on the surface of the soil colloids. Sodicity typically causes high water retention (i.e., the capacity of soil to absorb water), strong swelling of the soil (i.e., volume increase when soil is wet, decrease when soil is dry), and a resulting low hydraulic conductivity (i.e., ability of water to move across soil pores). For a farmer, the symptoms are presented as slow infiltration of rain/irrigation water, and a short period is available for plowing after snowmelt: the soil quickly turns from being completely wet and plastic to being dry with massive soil structure due to quick drying.

“Sodicity” is a term used for the description of the problems caused by exchangeable sodium (Na_{ex}) (i.e., the amount of sodium ions bound by adsorption on the surface of colloids). When the Na_{ex} content is low, (because mostly Ca occupies most of the binding sites of the soil colloids), the particles flocculate (i.e., form larger aggregates), and the conditions are favorable for the formation of stable soil aggregates (i.e., soil particles bound to each other strongly) and contribute to good soil structure: meaning the aggregates are not too small or great and there is enough pore space to facilitate the movement of air and water. If a cation with small ionic charge and large hydration shell (such as sodium but also potassium) occupies a large proportion of exchange sites on the clay mineral complex, the clay disperses, and the soil structure becomes unstable. In order to express the magnitude of sodicity, exchangeable sodium is related to the Cation Exchange Capacity (CEC) (e.g., the capacity of the soil to hold cations on the dominantly negatively charged surface of its particles), expressed as cmol(+) kg^{-1} and expressed as percentage. This indicator is called Exchangeable Sodium Percentage (ESP). There is an alternative indicator of sodicity, the Sodium Adsorption Ratio (or SAR) value, determined from the soil solution (in fact, the saturated paste extract), being in equilibrium with the soil:

$$SAR=Na/[(Ca+Mg)/2]^{0.5}$$

In this equation the chemical symbols represent soluble ionic concentrations in milliequivalent/liter or millimoles of charge/liter, of the relevant cations. There are several thresholds used for judging the sodicity of soils. ESP 15 is the traditional threshold value, which is equivalent to SAR 13 (see Richards, 1954, p. 103). ESP 6 is also used in Australia (Sumner and Naidu, 1998) and for the delineation of less favored areas in the European Union (Van Orshoven et al., 2014). The damage related to sodicity depends on several soil properties, as is shown below.

Alkalinity

High soil alkalinity occurs in the presence of constituents characterized with alkaline hydrolysis, such as carbonates of calcium, magnesium, and sodium. The major factors determining the degree of alkalinity of salt-affected soils are salt concentration and composition, the sodium saturation of soil colloids, as well as the CO_2 partial pressure (Filep, 1999).

The alkalinity of soils is measured typically by glass electrodes in the saturation extract or soil slurry at the ratio of 1:5 or 1:10 soil:water. The threshold value of sodic soils is pH 8.5 measured in the saturation extract.

Relationship between Chemical Indicators of Salt-affected Soils

Saline soils may have varying salinity with near neutral pH values. In sodic soils salinity, sodicity and alkalinity are often closely correlated, as will be illustrated below. This behavior is related to the alkaline hydrolysis of sodium bicarbonate. This compound has low solubility, and as it is slowly dissolved, more and more sodium and carbonate ions appear in the soil solution increasing salinity, sodicity, and alkalinity at the same time.

Hydrophysical properties of Salt-affected Soils

This topic has been extensively studied and several recent summaries exist (e.g., Blaskó, 2011A, 2011B). There is a pronounced difference between the hydrophysical properties of saline and sodic soils; the consequential differences in water adsorption and hydraulic conductivity are derived from swelling and dispersion (Blaskó, 2011A). These are more apparent in fine textured soils, since most underlying processes, such as swelling and dispersion, are unique characteristics of clay minerals. Consequently, high sodicity is not such a serious problem in soils with a coarser texture. The problems presented by sodic soils for land management are not caused by the salts or sodium directly but are more closely related to the secondary (i.e., the sodicity-related) physical properties (Suarez at al., 1984; Várallyay, 1977). The overall relevance of physical properties for sodic soils is demonstrated by the fact that soil swelling kinetics are the main criteria in the Russian soil classification for Solonetz soils (Krasilnikov, 2009).

One of the most characteristic features of salt-affected soils is described by the so-called Quirk-Schofield diagram (Quirk and Schofield, 1955). As Figure 1 shows, for a given soil there is a clear relationship between the soil permeability and salinity versus sodicity.

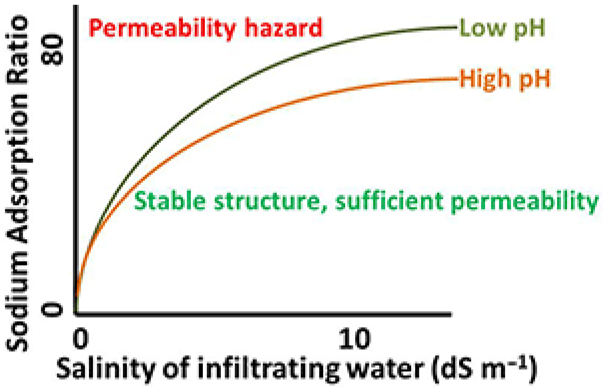

Figure 1. Idealized Quirk-Schofield diagram showing the relationship of salinity, sodicity, alkalinity, and soil structure.

Low sodicity (i.e., dominance of divalent cations) and greater salinity favors aggregation of soil particles and results in a well-structured soil. But high sodicity and low salinity results in low permeability because of dispersion of soil aggregates. As it is expressed by experienced irrigators, “Hard water makes soft land and soft water makes hard land” (Mays, 2007). This means that the dominance of divalent cations, such as calcium and magnesium (responsible for the formation of scale in hard water), will cause a shift in the direction of lower SAR values in Figure 1, and the soil will be soft, permeable, and well structured. Further, the high pH of infiltrating water will result in a requirement for higher salinity to attain favorable soil permeability. This diagram is crucial for deciding on the optimum composition of irrigation water and the need to provide gypsum for reclamation to improve soil permeability.

Classification of Salt-affected Soils

Ever since the beginning of agriculture, farmers used simple classes of soils in planning land management. In ancient times and even recently, farmers’ efforts were based on their own local experiences (Barrera-Bassols and Zinck, 2003). Consequently, different terminology had been used to characterize soil salinization all over the world. Without formalized knowledge communication (such as schools) the damages of salinization and related processes occurred repeatedly all over the world. Therefore the first specific classifications of salt-affected soils were developed where these caused large problems, such as in ancient Mesopotamia, Indus Valley, and Central America (Dennis, 2012).

Mapping of Salt-affected Soils

In soil science, soil classification is an indispensable precondition for soil mapping. Soil mapping is necessary for the spatial planning of land management. Being a natural body with three-dimensional extent, soil must be represented in space for every management decision. Spatial representation of soils (i.e., soil maps) are prepared at different scales. For everyday crop farming practice the scales of 1:1,000 to 20,000 are typical. The United Nations' Food and Agricultural Organization presented the world map of soils in 1988 (FAO, 1988) at the scale of 1:5,000,000. Every map has a legend to explain the graphical/color delineations, and the soil maps have soil categories as legends. Every soil survey (the US Soil Survey uses scales between 1:12,000 and 1:24,000, but the 1:2500 scale was used for specific territories [Durana, 2008]) has a detailed description of the categories presented on map sheets. Due to the wide range of possible scales used in soil mapping the detail level of the categories in the maps is markedly different. Passing from the highest spatial resolution (plot/field scale) to global soil maps, the series of the categories of the soil maps at different scales correspond to the hierarchical levels of the soil classification systems from the most to the least detailed (i.e., from many low-level categories at the bottom to a few main categories at the top).

For planning management, application of reclaiming materials, the status (severity) of salinity/sodicity/alkalinity must be assessed or mapped in the plots that must be reclaimed. There are several approaches to this planning (see Figure 2).

PRECONDITIONING FACTOR	MAIN VARIABLES	CONSEQUENTIAL VARIABLES
Relief	**Salinity↔Sodicity↔Alkalinity (pH)**	*Surface discoloration*
Hydrology	↓	*Mechanical properties*
Other soil forming factors	**Electrical conductivity**	Hydrophysical properties
		Extent of plant cover/biomass
		Species composition/abundance

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Figure 2. Schematic representation of the relationship of some factors that facilitate the mapping of salt-affected soils. Bold character = main variable to map. Underlined character = observable by remote/proximal sensing. Italic character = covariable.

Based on the existing land use of the plot, either the vegetation cover (see Figure 8 below) or the color of the bare soil are proxies for estimating the degree of salinity/sodicity/alkalinity. But the major factors of formation, such as relief and hydrology also provide subsidiary variables for mapping these properties. Often remote sensing techniques are used, based on the high reflectance of salt efflorescences, or dispersed surface particles in sodic plots.

A special characteristic of salt-affected soils is that the main chemical limitations can be mapped with isoline (contour) maps, which can be directly utilized for management and reclamation. The most commonly determined parameter, the electrical conductivity of bulk soil is easily and quickly measurable in the field with handheld, tractor-towed, or airplane/satellite-carried sensors (by remote sensing), providing a means of creating maps at several spatial scales.

Interested readers can look up salt-affected soils at the two extreme mapping scales. At the global scale, the Harmonized World Soil database contains information such as the map of excess salt concentration in the soils (FAO, ISRIC, & JRC, 2009). In the United States, the distribution of saline and sodic soils at local scale is best presented by the national large-scale soil surveys, such as the Web Soil Survey (United States Department of Agriculture, Natural Resources Conservation Service, 2016).

Based on Durana (2008) the history of soil classification in the United States has been through a series of important stages. After the initiation of soil survey early in 1898 the need for classifying the soils rose immediately. Soil texture, soil moisture, soil temperature, and concentration of soluble salts were the characteristics noted in the field. Already in the first years, electrical resistivity measurements to estimate salinity in the field were used. Early surveys contributed to the development of irrigated agriculture in the western states. Despite the fact that local land users requested them, the surveys demonstrating presence of salinity and sodicity were often kept secret or even destroyed (Durana & Helms, 2008, pp285-6.) in order to keep land prices high. The naming convention then required a location and texture category for composing a “soil type,” such as Miami silt loam. In 1903 the “soil series” concept was established (such as the Miami series), in which Miami silt loam, Miami loam, Miami gravelly loam (altogether 15 textural phases) were listed in Michigan only (Michigan Board of Geological Survey, 1908). From 1904 color and organic matter content begin to be considered as criteria for defining a soil series. From 1905 most other soil characteristics presently used for mapping were incorporated into soil description. In 1911 soil provinces (i.e., homogeneous geographical regions) were introduced into the soil classification. By 1912 the number of soil types was 1650 in 534 soil series.

Broader soil categorization was suggested by C. Marbut, reflecting the Russian Dokuchaev school. In the 1938 map “Soil Associations of the United States” Marbut’s classification was applied, and there was also a category labeled “Solonchak and Solonetz Soils.”

In the map “Distribution of Principal Kinds of Soils: Orders, Suborders and Great Groups of the National Atlas” (National Atlas of the United States, 1970, pp. 86–87), the precursor of the present Soil Taxonomy, National Cooperative Soil Survey Classification (also known as the Seventh Approximation) was presented. The mapped categories present a correlation between the earlier Marbut/Dokuchaev categories and the newly introduced Seventh Approximation. Based on the formative element "Na" the following groups were distinguishable at the scale of 1:7,500,000: Natraqualfs, Natrargids, Natriborolls, Natrustolls. All were essentially Solonetz soils. Great Groups containing the formative elements Sal or Hal, indicating the presence of salic horizon of Soil Taxonomy, were not presented on this map presumably because of the small size of the patches occupied by these soils.

Besides the systematic pedological soil classifications, practical approaches were developed for saline and sodic soils to have distinguished classes to keep up profitability. The most widely used agronomy-oriented classification of salt-affected soils is presented in Table 1.

Table 1. Agronomy-oriented classification of salt-affected soils based on parameters measured in saturation extract (Hayward & Wadleigh, 1949, p. 4., Kelley, 1951, p. 8.). The original term was "alkali," but nowadays "sodic" is the accepted term.

Soil	**EC_e**	**ESP**	**pH_e**
Non-saline	<4 dS m^{-1}	< 15	< 8.5
Alkali (=Sodic)	<4 dS m^{-1}	> 15	> 8.5
Alkali (=Sodic) saline	>4 dS m^{-1}	> 15	< 8.5
Saline	>4 dS m^{-1}	< 15	< 8.5

This classification is used to make decisions on the management of the topsoil in a given area, typically not deeper than 30 cm. Bulk soil sample (from several subsamples) is collected in a zigzag pattern from different locations of the management unit, or several points are sampled (Richards, 1954, p. 7). Although the approaches of the practical versus scientific soil classifications are different, they have common points when classifying salt-affected soils. Each threshold value in Table 1 appears in international and national classifications.

The evolution of Solonetz soils through various phases of salinization, alkalinization, desalinization, degradation, and regradation is incorporated into the classification system of de Sigmond (1938). These phases are clearly identified soil variants in his Soil Order 12, equivalent to Sodic soils, which have the main types listed in Table 2.

Table 2. Salt-affected soil types in the “Soil order 12. Sodium soils” of de Sigmond (1938).

Main types	Interpretive name based on the Russian names
1: Saline soils	Solonchak
2: Saline alkali soils	Solonchak-Solonetz
3: Leached alkali soils	Solonetz
4: Degraded alkali soils	Solod
5: Regraded alkali soils	Soil salinized again

The concept of temporal development of salt-affected soil types is linked to the changes of water table level. Solonchak soils develop with a shallow saline water table. Solonchak profiles do not show large profile development, but have the maximum of salinity close to the surface; and there is no substantial leaching in the profile. “Solonchak-Solonetz” soils are intergrades between Solonchak and Solonetz soils. Solonetz soils have a deeper saline water table than the previous ones and have distinct near surface eluvial horizon and immediately below an often strikingly different illuvial horizon (in terms of salinity, sodicity, alkalinity, clay content, color, structure), as shown in Figure 3.

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Figure 3. Solonetz soil in Hortobágy, Hungary. Note the typical variation of several properties with depth above and under the sharp transition of eluvial and illuvial natric horizon at 8 cm. The most important feature is the columnar structure starting at 8 cm, best visible on the right-hand side wall. Below 50 cm the yellowish calcareous parent material is seen in this shallow profile.

There is leaching in the profile. Solod soils show strong features of leaching above an even deeper water table, which is manifested by a pale-colored eluvial horizon. If saline water table becomes shallower, the process of salinization will form a saline soil again.

Classification of Salt-affected Soils All Over the World

Solonetz (based on the original Russian terminology) is used in the following soil classification systems following its first use in Russia (Krasilnikov, 2009): World Reference Base (WRB, see IUSS, 2015), France, Canada, Germany, Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Russia, and Ghana. Solonetz are potentially equivalent to the following classes in the established soil classification systems. In Soil Taxonomy at the level of Great Groups, Natraqualf, Natrudalf, Natrustalf, Natrixeralf, Natriargid, Natridurid, Natrigypsid, Natrialboll, Natraquoll, Natricryoll, Natrudoll, Natrustoll, Natrixeroll are distinguished. Alkalic Halosol is used in the Chinese classification, Suelo Sodico in Cuba, Sodosol in Australia, Solonetzic Semiarid Soils in New Zealand.

Solonchak (based on the original Russian terminology) is used in the following soil classification systems as it was first used (Krasilnikov, 2009): WRB, France, Germany, Poland, Czech Republic, Slovakia Hungary, Romania, Bulgaria, Russia, Israel, and Ghana. Solonchak corresponds, among others, to the following names in the established soil classification systems. In Soil Taxonomy at the level of Suborders Salid, at the level of Great Groups Salicryid, Halaquept are distinguished. Orthic Halosol is used in China, Suelo Salino in Cuba, Gleissolos Sálicos Órticos in Brazil, and Salic Hydrosol and Hypersalic Hydrosol in Australia.

Solod, solodized soil (based on the original Russian terminology) is used in the following soil classification systems as it was first used (Krasilnikov, 2009): Canada, France, Russia. Solod corresponds among others to the following names in the established soil classification systems. The term Planossolos Nátricos is used in Brazil, Subnatric Black Sodosols and Mottled-Subnatric Black Sodosols are used in Australia. Solods are not identifiable in either the World Reference Base (2015) (they were represented in 1974 and 2006 as Solodic Planosol), or Soil Taxonomy.

Field Soil Description and Classification of Salt-affected Soils: Two Examples

Soil classification is performed in excavated soil pits, which are called "profiles" by soil scientists. The location of the pits is crucial for the success of the classification and the related mapping. It is opened at characteristic locations, therefore represents a point sample, in contrast to the agronomy-oriented classification of plots (Table 1). Natural vegetation is a good indicator of the homogeneity of the site. In croplands, surface features such as color, structure, and plant cover help to find a representative location for the pit. One strictly vertical wall of the pit is smoothed, and visual and manual observations (which make up the "profile description") are made there, among other things. The methods used for the characterization, laboratory analysis, and classification are diverse in distinct soil classification systems but have common points. For each of the 24 classification systems in current use described by Krasilnikov (2009) there is a specific set of methods used to describe and classify soils.

On the profile wall the distinct horizontal layers, known as "horizons" in soil science, are separated as A, B, C or 1, 2, 3. Each such layer is described one after the other, from top to bottom. The most important characteristics are color (with a color chart), structure and "texture" (the size distribution from the smallest [clay] to the largest [sand] single particles of the soil), but several other characteristics are used for identifying soils.

The profile description of the soil is often not sufficient for classifying the soil and analytical parameters necessary for that are determined in the field or in the laboratory.

Two profile photographs with the horizons distinguished in them are presented. The description of the profiles shown in Figure 4 is presented in Table 3, and the corresponding analytical results are in Table 4.

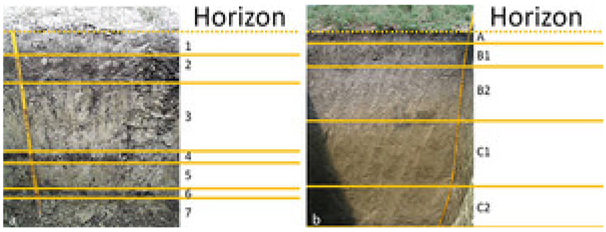

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Figure 4. The horizon sequence of the (a) Sarrod and (b) Apaj soil profiles. (**a.**) Sarród profile (In the local, Hungarian classification at the level of subtype Sarród profile is a "Sulphatic Solonchak," which has at least 50% sulphates among the anions.) (**b.)** Apaj profile (In the local, Hungarian classification at the level of subtype the Apaj profile is a "Crusty Meadow Solonetz," that is a Solonetz (type is Meadow Solonetz, a solonetz directly linked to watertable) with shallow leached eluvial horizon).

Table 3a. Characteristics of the soil horizons as described at the soil profile using the method of Jahn et al. (2006) and Munsell (1975).

Horizon	Depth	Color (Munsell code)	Texture	Structure
Code	Cm			
1	0–10	Grayish Yellow Brown (10YR5/2)	SandyLoam	Angular blocky
2	10–18	Brownish Black (10YR3/2)	Clay	Angular blocky
3	18–52	Light Yellow (2.5Y7/3)	ClayLoam	Angular blocky
4	52–54	Dull Yellowish Brown (10YR4/3)	LoamySand	Single grained
5	54–75	Light Gray (2.5Y7/2)	ClayLoam	Angular blocky
6	75–78	Dark Brown	Sand	Single grained
7	77–82	Light Gray	Clay	Angular blocky

3a. Settlement: Sarród, Hungary

Date: 2001 March 28

Land use: Grazed grassland

Geographic coordinates: Northern 47º 39.253“ Eastern 16º 48.764”

Elevation: 118 m

Native plants: *Salicornea europea, Suaeda salsa, Plantago maritima*

Groundwater depth: 190 cm, EC 6 dS m^{-1}, pH 7.7

Table 3b. Characteristics of the soil horizons as described at the soil profile using the method of Jahn et al. (2006) and Munsell (1975).

Horizon	**Depth**	**Color**	**Texture**	**Structure**
code	**Cm**			
A/E	0–4	Brownish-Gray	Loam	Subangular blocky
B1	4–20	Gray	ClayLoam	Prismatic/Columnar
B2	20–58	Pale Gray	ClayLoam	Blocky
C1	58–104	Gray Yellow	Loam	Blocky
C2	104–140	Yellowish Gray	Clay Loam	Blocky
C3	140–170	Yellowish Gray	Sand	Single grained

3b. Settlement: Apaj, Hungary

Date: 2003 August 5

Land use: Grazed grassland

Geographic coordinates: Northern 47º 05.228’ Eastern 19º 05.903’

Elevation: 92 m

Native plants: *Festuca pseudovina. Artemisia santonicum*

Groundwater depth: 175 cm, EC 5.8 dS m^{-1}, pH 8.7

Table 4. Characteristics of the soil samples collected in the different horizons of the profiles described in Table 3.

Site	**Horizon**	**Depth**	**pH_e**	**OM**	**$CaCO_3$**	**Clay**	**EC_e**	**SAR**
	code	**cm**		**%**	**%**	**%**	**dS m^{-1}**	
a.)	**Sarród**							
Sarród	1	0–10	7.78	0.89	22.1	15	27	45.1
Sarród	2	10–18	7.54	0.93	33.7	38	16.2	33.5
Sarród	3	18–52	7.31	0.56	57.9	45	15.3	30.8
Sarród	4	52–54	7.34	0.48	26.6	18	11.2	26.5
Sarród	5	54–75	7.19	0.42	53.7	37	11.6	26.2
Sarród	6	75–77	7.12	0.26	21.9	Nd	11.3	25.2
Sarród	7	77–82	7.15	0.37	52.2	38	9.4	25.3
b.)	**Apaj**							

Apaj	A/E	0–4	8.21	3.50	8.3	16	1.1	5.1
Apaj	B1	4–20	8.39	0.83	16.6	28	2.5	32.8
Apaj	B2	20–58	9.62	0.43	37.1	40	5.5	99.7
Apaj	C1	58–104	9.60	0.34	28.9	19	4.7	80.4
Apaj	C2	104–140	9.04	0.26	31.5	13	3.0	58.7
Apaj	C3	140–170	8.82	0.30	26.9	1	2.4	50.0

Note: In Table 4 samples are identified by horizon depth (cm). pH_e is pH value of saturation extract, *OM* organic matter %, $CaCO_3$ shows carbonates %,, *Clay* shows clay %, EC_e shows electric conductivity of the soil saturation extract (dS m^{-1}), *SAR* is sodium adsorption ratio of the saturation extract.

When using the WRB (IUSS, 2015) first the diagnostic horizons, properties and materials (which can be overlapping) are to be identified in the soil profile. As a second step the Reference Soil Group and the qualifiers must be found based on the WRB Key (IUSS, 2015, pp. 85–116).

Examples of Using World Reference Base

Classification of Sarród Profile with WRB

A salic horizon was found between the surface and 52 cm, which has the following definition.

“1. at some time during the year an electrical conductivity of the saturation extract (EC_e) at 25 °C of

a. ≥15 dS m^{-1}; or

b. ≥8 dS m^{-1} if the pH of the saturation extract is ≥ 8.5; and

2. at some time during the year a product of thickness (in centimetres) and EC_e at 25 °C (in dS m^{-1}) of ≥ 450; and

3. a thickness of ≥ 15 cm.” according to IUSS, 2015 pp. 53–54.

Since Table 4 shows more than 15 dS m^{-1} EC_e values for some depths, the Sarród profile meets Criterion 1, now the product of thickness and EC_e for those horizons that meet Criterion 1 are checked and the result is 27 dS m^{-1} * 10 cm +16.2 dS m^{-1} * 8 cm +15.3 dS m^{-1} * 34 cm = 919.8 dS m^{-1} * cm, the 0–52 cm layers meet Criterion 2 and since these together are thicker than 15 cm also Criterion 3 is met. It can be concluded that there is a salic horizon in this profile.

Now using the Key to the Reference Soil Groups (IUSS, 2015), with lists of principal and supplementary qualifiers, the key must be followed and arrive at Solonchaks. See page 92:

“Other soils having:

1. a *salic* horizon starting ≤ 50 cm from the soil surface; and

2. no *thionic* horizon starting ≤ 50 cm from the soil surface; and

3. not permanently submerged by water and not located below the line affected by tidal water (i.e., not located below the line of mean high water springs).”

The Sarród profile meets 1, 2, and 3 and is classified as Solonchak.

Now a principal qualifier must be chosen, each of which are defined in the IUSS (2015). The principal qualifiers are Stagnic Sodic Calcic Fluvic (in that order) and there are supplementary qualifiers, which render the final name as Fluvic Calcic Sodic Stagnic Solonchak (Alkalic, Calcaric, Evapocrustic).

The profile photo indicates that this soil was formed on alluvial, more exactly lacustrine sediments. Darker layers (see horizons 4 and 6) with contrasting calcium carbonate content and texture can be distinguished indicating the deposition of lake sediments at this lakeside location.

Classification of Apaj Profile with WRB

There was a natric horizon, which has the following definition according to IUSS (2015):

“Diagnostic criteria

A natric horizon consists of *mineral* material and:

1. has a texture class of loamy sand or finer and ≥ 8% clay; and
2. one or both of the following:
a. has an overlying coarser textured horizon with all of the following:
i. the coarser textured horizon is not separated from the natric horizon by a *lithic discontinuity*; ***and***
ii. if the coarser textured horizon directly overlies the natric horizon, its lowermost subhorizon does not form part of a plough layer; and
iii. if the coarser textured horizon does not directly overlie the natric horizon, the transitional horizon between the coarser textured horizon and the natric horizon has a thickness of ≤ 15 cm; ***and***
iv. if the coarser textured horizon has < 10% clay in the fine earth fraction, the natric horizon has ≥ 4% (absolute) more clay; and
v. if the coarser textured horizon has ≥ 10 and < 50% clay in the fine earth fraction, the ratio of clay in the natric horizon to that of the coarser textured horizon is ≥ 1.4; and
vi. if the coarser textured horizon has ≥ 50% clay in the fine earth fraction, the natric horizon has ≥ 20% (absolute) more clay; or
b. has evidence of illuvial clay in one or more of the following forms:
i. oriented clay bridging ≥ 5% of the sand grains; or

ii. clay coatings lining ≥ 5% of the surfaces in pores; or

iii. clay coatings covering ≥ 5% of the vertical and ≥ 5% of the horizontal surfaces of soil aggregates; ***or***

iv. in thin sections, oriented clay bodies that constitute ≥ 1% of the section; ***or***

v. a COLE (Coefficient of Linear Extensibility is the proportion of shrinkage based on the measurement of swollen length of moist soil clods compared to the shrinked dried soil clod) of ≥ 0.04 (cm/cm, meaning 4% swelling of soil when wet) and a ratio of fine clay to total clay in the natric horizon greater by ≥ 1.2 times than the ratio in the overlying coarser textured horizon; and

3. has one or more of the following:

a. a columnar or prismatic structure in some part of the horizon; or

b. both of the following:

i. a blocky structure; and

ii. penetrations of an overlying coarser textured horizon in which there are uncoated silt or sand grains, extending ≥ 2.5 cm into the natric horizon; and

4. has one of the following:

a. an exchangeable Na percentage (ESP) of ≥ 15 throughout the entire natric horizon or its upper 40 cm, whichever is thinner; or

b. both of the following,

i. more exchangeable Mg plus Na than Ca plus exchange acidity (at pH 8.2) throughout the entire natric horizon or its upper 40 cm, whichever is thinner; and

ii. an exchangeable Na percentage (ESP) of ≥ 15 in some subhorizon starting ≤ 50 cm below the upper limit of the natric horizon; and

5. has a thickness of one-tenth or more of the thickness of the overlying *mineral* material, if present, and one of the following:

a. ≥ 7.5 cm (combined thickness if composed of lamellae) if the natric horizon has a texture class of sandy loam or finer; or

b. ≥ 15 cm (combined thickness if composed of lamellae).

The B1+B2 horizons (4-58 cm) are classified as natric horizons in the Apaj soil. These horizons meet Criterion 1 by having a clay loam texture, Criterion 2a by the difference of clay content (28 is more than 40% greater than 16, see Table 4), Criterion 2b by the presence of clay coating, Criterion 3 by having columnar structure, Criterion 4 proven by SAR values of Table 4 and Criterion 5 by being 13.5 times as thick as (54÷4 cm, see Table 4) the overlying horizon."

Based on the presence of a natric horizon in to the Reference Soil Groups (IUSS, 2015) Solonetz (p. 90) is selected: “Other soils having a *natric* horizon starting ≤ 100 cm from the soil surface.” The final name of the soil will be Calcic Mollic Solonetz (Columnic, Cutanic).

Examples of Using Soil Taxonomy

Classification of Sarród Profile with Soil Taxonomy

In the Sarród profile, the salic horizon does not meet the required criteria since Soil Taxonomy has twice as strict a threshold value for salinity (Soil Survey Staff, 2014) compared to WRB as

“A salic horizon is a horizon of accumulation of salts that are more soluble than gypsum in cold water.

Required Characteristics

A salic horizon is 15 cm or more thick and has, for 90 consecutive days or more in normal years:

1. An electrical conductivity (EC) equal to or greater than 30 dS/m in the water extracted from a saturated paste; *and*
2. A product of the EC, in dS/m, and thickness, in cm, equal to 900 or more.”

The Sarród soil horizons do not meet Criterion 1.

There are two diagnostic horizons in this profile according to Soil Taxonomy. There is an ochric epipedon, which does not meet the requirements of other epipedons (i.e., surface horizons) because it is not thick, wet, dark, or structurally developed enough. In the Sarród soil there is also a cambic horizon, which by definition shows physical and/or chemical modifications.

Based on these observations the soil is classified as Aeric Halaquept. It is an Inceptisol (ending with ~ept, indicating the soil order of not very developed soils) because there is no other horizon except the cambic horizon. It is inside the Suborder of Aquepts because there is SAR > 13 close to the surface. It belongs to the Great Group of Halaquepts for the same reason. Its Subgroup is Aeric Halaquept due to its light color in the near surface layers.

Classification of Apaj Profile with Soil Taxonomy

There was a natric horizon, which has the following definition according to Soil Survey Staff (2014):

“A natric horizon is an illuvial horizon that is normally present in the subsurface and as a significantly higher percentage of silicate clay than the overlying horizons. It shows evidence of clay illuviation that has been accelerated by the dispersive properties of sodium.

Required characteristics of

the natric horizon in Soil Taxonomy:

1. Meets *one* of the following thickness requirements:

a. If the horizon meets the particle-size class criteria for coarse-loamy, fine-loamy, coarse-silty, fine-silty, fine, or very-fine or is loamy or clayey, including skeletal counterparts, it must be at least 7.5 cm thick or at least one tenth as thick as the sum of the thickness of all overlying horizons, whichever is greater; *or*

b. If the horizon meets sandy or sandy-skeletal particle-size class criteria, it must be at least 15 cm thick; *or*

c. If the horizon is composed entirely of lamellae, the combined thickness of the lamellae that are 0.5 cm or more thick must be 15 cm or more; *and*

2. Has evidence of clay illuviation in at least *one* of the following forms:

a. Oriented clay bridging the sand grains; *or*

b. Clay films lining pores; *or*

c. Clay films on both vertical and horizontal surfaces of peds; *or*

d. Thin sections with oriented clay bodies that are more than 1% of the section; *or*

e. If the coefficient of linear extensibility (COLE) is 0.04 or higher and the soil has distinct wet and dry seasons, then the ratio of fine clay to total clay in the illuvial horizon is greater by 1.2 times or more than the ratio in the eluvial horizon; *and*

3. If an eluvial horizon remains and there is no lithologic discontinuity between it and the illuvial horizon and no plow layer directly above the illuvial horizon, then the illuvial horizon must contain more total clay than the eluvial horizon within a vertical distance of 30 cm or less, as follows:

a. If any part of the eluvial horizon has less than 15% total clay in the fine-earth fraction, the illuvial horizon must contain at least 3% (absolute) more clay (10% versus 13%, for example); *or*

b. If the eluvial horizon has 15 to 40% total clay in the fine-earth fraction, the illuvial horizon must have at least 1.2 times more clay than the eluvial horizon; *or*

c. If the eluvial horizon has 40% or more total clay in the fine-earth fraction, the illuvial horizon must contain at least 8% (absolute) more clay (42% versus 50%, for example); *and*

4. Has *either:*

a. Columnar or prismatic structure in some part (generally the upper part), which may part to blocky structure; *or*

b. Both blocky structure and eluvial materials, which contain uncoated silt or sand grains and extend more than 2.5
cm into the horizon; *and*

5. Has *either:*

a. An exchangeable sodium percentage (ESP) of 15% or more (or a sodium adsorption ratio [SAR] of 13 or more) in one or more horizons within 40 cm of its upper boundary;
or

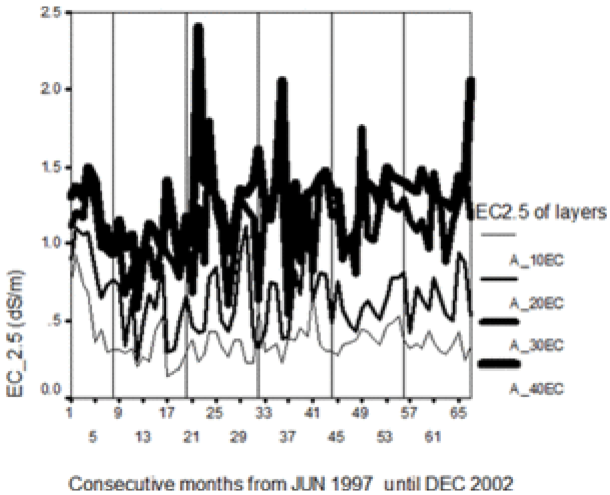
b. More exchangeable magnesium plus sodium than calcium plus extractable acidity (at pH 8.2) in one or more horizons within 40 cm of its upper boundary *and* the ESP is 15 or more (or the SAR is 13 or more) in one or more horizons within 200 cm of the mineral soil surface."

This definition is similar to the IUSS (2015) definition. The WRB Criteria no. 2, 3, 4, 5 correspond to Criteria no. 3 (broadly), 2, 4, 5, 1 (latter four strictly) of Soil Taxonomy. Criterion 1 of WRB's natric horizon is unique.

Based on the presence of an ochric epipedon and a natric subsurface horizon, the Apaj profile belongs to the Alfisol Order (ending with ~alfs—or soils with clay illuviation), Ustalf (i.e., not humid, not arid soils) Natrustalf (i.e., soils with natric horizon), Great Group, and Typic Natrustalf Subgroup.

Temporal Dynamics of Soil Salinity

The soluble salts in the soil profile move rapidly in the soil together with water. Consequently, there can be quick changes in the salinity status of soils especially under irrigation. Figure 5 shows the fluctuation of soil salinity in the Apaj profile (Figure 4B) during a period of 6.5 years. Electrical conductivity measured in 1:2.5 soil:water suspension is shown, which is suitable for the simple monitoring of changes.

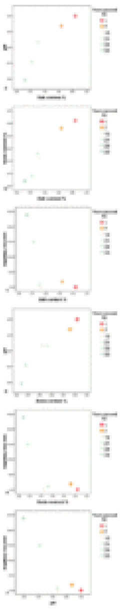


Click to view larger

Figure 5. Changes of soil salinity at Apaj profile from June 1997 to December 2002 in four depth increments, 10, 20, 30, 40 indicates 0–10 cm, 10–20, 20–30, 30–40 cm layers.

Figure 5 shows salinity increasing with increasing depth and demonstrates strong fluctuation. Evidently during summer months, such as months 1–3, 13–15, 25–27, 37–39, 49–51, 61–63, there are higher values because of upward evaporative shift of saline soil solutions in warm months.

Figure 6 shows the consequences of a sinking water table at a plot close (circa 5 km) to the Apaj profile between 1953 and 1988.

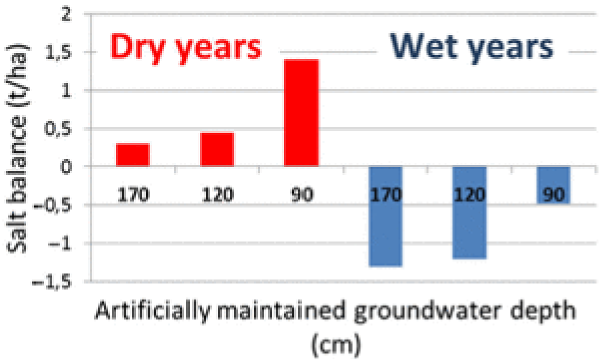


Click to view larger

Figure 6. Relationships (scattergram) between soil salinity (%) and pH (measured in 1:2, 5 suspension after waiting 12 hours) (a), soil salinity and soda content (%) (b), soil salinity and capillary rise (mm) (c), soda content and pH (d), soda content and capillary rise (e), and pH and capillary rise (f) of samples taken from the 0-20 cm layer of a cultivated saline land during 33 years of observation according to Harmati, 2003. Year 1 is 1953.

At the beginning of the experimental work the soil was characterized by high salinity, sodicity as expressed by the soda (i.e., sodium carbonate), Na_2CO_3 content, and high pH value. As the water table dropped and its salinity decreased, the previously classified Solonchak soil (see Table 2 for the sequence of changes) turned into a Solonchak-Solonetz through leaching, and later Solonetz, a stage corresponding to the described and classified Apaj profile (Table 4). The scattergrams of Figure 6 support the observations on the close correlation between salinity/sodicity/alkalinity and soil physical properties. Figure 6A shows the relationship between salinity and alkalinity. Figure 6B shows that most of the salts are actually soda. Other soluble salts are chlorides and sulfates in this area. Figure 6C shows that capillary rise of sodic soils (measured as the height of the rising wetting front after 20 hours in vertical glass columns inserted into water) is zero due to swelling of the soil and therefore blocking the movement of water (see also “Permeability hazard” region of Figure 1). As salinity/sodicity/alkalinity decreases, soil conditions shift into the “Stable structure” region of Figure 1, and the 20 hour soil capillary rise increases because of decreasing swelling and dispersion in the leached soil. Figure 6D and Figure 6E support the fact that soda is the dominant salt in this layer. Figure 6F shows that below pH 9 the values of capillary rise changes. Indeed this pH value is used in the Hungarian soil classification (Jassó, 1989).

Since the shallow water table is often the most important factor of salt accumulation, its depth and salt content are the most crucial elements in soil salinization. Figure 7 shows how unchanging water table levels affect salinization in subhumid conditions in which rainfall promotes leaching (negative salt balance) but lack of precipitation increases soil salinity (positive salt balance). The experimental lysimeters (vessels used for the study of water balance), were filled with 2m-deep soil columns and the artificial water table level was stabilized with local saline groundwater. The extent of yearly salt accumulation depends on the groundwater depth (see Figure 7).



Click to view larger

Figure 7. Average salt balance in the dry year of 1989 and the wet year of 1991 in lysimeter vessels with groundwater stabilized at different depths based on Karuczka, 1999.

In dry years, the shallower the groundwater table, the greater the salt accumulation is—accumulating (positive salt balance) between 0.3 and 1.4 tons of salts per hectare of land. In wet years, the deeper the groundwater table, the greater the leaching of salts is, which decreases the accumulated amount of salts by 0.4 to 1.3 tons per hectare.

Spatial Variability of Salt-affected Soils

Salt-affected lands occur in the lowest topographical positions, where the water table gets close to the surface. These soils are most often formed on alluvial sediments, where the riverine topography (system of fluvial terraces) is inherited by the soils. Erosion of the top eluvial horizons results in clayey saline horizons at the surface and adds to the variability, posing a challenge for mapping of these soils as described above. The variability is expressed at several spatial scales, from river basin (10^2 km) to river channel (10^{-1} km) (see Fig 8), to microerosional mounds (10^{-3} km).

Click to view larger

Figure 8. The native vegetation of a sodic grassland in Hortobágy, Hungary, 3 June 2005, crossing an area that used to be a river bed, not far (ca. 2 km) from the profile shown in Figure 3. The different hues of color indicate separate vegetation types reflecting distinct soil variants of Solonetz. The elevation difference between the highest pinkish zone of *Festuca pseudovina-Artemisia santonicum* (most leached) and the lowest deep green zone of *Bolboschoenus maritimus* (most affected by stagnant and groundwater) are not more than 30 cm. Hues and height of vegetation clearly reflect variability in both soil conditions and water availability. More than five vegetation types occur in a distance of 100 m.

Larger salinity of irrigation water and finer soil texture were found to increase the patchiness (larger spatial variability) of soils in Rajasthan (Joshi et al., 2006).

Soil Reclamation

The reclamation of salt-affected soils is costly and focuses on evident limitations of cropping. There are simple and more complex solutions as well, all depending on the soil characteristics, hydrology, irrigation, and cropping pattern.

Ideally all the conditions necessary for the successful reclamation of salt-affected soils (as listed by Filep, 2001) must be met, such as the following: (1) stopping the effect of sodic surface/ground/irrigation waters on salt-accumulation/Na-adsorption (stopping saline water irrigation, sinking saline water table), (2) providing means for Na-ions and soluble Na-salts to leave the root zone (field drainage), (3) exchange of Na-ion adsorbed on the colloids with Ca provided by sufficiently soluble reclamation material.

The exhaustive measures of field drainage (see 1–3 as listed in previous paragraph) are rarely taken because of financial considerations, except where specialized irrigation agriculture is highly profitable, such as California, Israel, Spain, among others. Where subsistence farming is practiced (Africa, India, etc.) only the most accessible elements of the full spectrum of reclamation, chemical reclamation and surface drainage, are applied.

The simplest measure is the application of reclaiming material to replace sodium with calcium, the most easily available soluble divalent cation (in Figure 1 moving toward lower Sodium Adsorption Ratio values) in order to improve the physical conditions of a salt-affected soil or preventing structure deterioration when using inappropriate (too sodic) irrigation water. Several materials are used, most frequently gypsum ($CaSO_4 \cdot 2H_2O$), in some regions lime ($CaCO_3$). The chemical properties and the planned depth of reclamation of a soil, or the composition and amount of irrigation water applied will determine which material to use and in what dosage it should be applied. For acidic soil surface layers, liming materials can be applied, but gypsum is applied on alkaline soils. The dosage must be determined in such a way that it replaces all the deleterious sodium ions. There are many possible methods; typically, for the calculation of dosages simple balance equations are used. For example, in order to replace x moles of adsorbed Na, x/2 moles of Ca is required, and so on.

Irrigation and Leaching in Saline Conditions

If the salt added to the soil by the irrigation water is not leached out, but the irrigation water is evaporated/transpired and the added salt is accumulated, soon surface soils become excessively saline. Therefore, if there is considerable salt in the irrigation water, not only is the physiological water requirement of the plants required, but also more water is needed to leach the surplus salt from the root zone. Leaching is part of the reclamation of salt-affected soils as it was described in the previous chapter, it is step 2 of Filep (2001).

Saline soil solution or saline surplus irrigation water is leached from the soil where there is (1) natural leaching, such as deep groundwater (characteristic in arid zones where irrigation water is taken from deep wells with continuously sinking water levels due to extraction) or (2) where there is an artificial drainage system installed (Keren & Miyamoto, 1990). When soil leaching is planned, provisions must be made that (1) salts will be dissolved, (2) the water will pass through the soil (top 45–60 cm soil) and (3) that salts will be removed from the root zone to a sufficient degree (to the threshold tolerance of the crop).

The portion of the water that must pass through the root zone in order to keep salinity under a given threshold, is called “leaching requirement” (Richards, 1954) and is expressed as:

Leaching Requirement = $EC_{irrigation\ water}/EC_{drainage\ water}$

Taking an example of $EC_{irrigation\ water}$ = 1 dS m^{-1} and $EC_{drainage\ water}$ = 5 dS m^{-1}

The leaching requirement is 20%, but it is 50% (2.5/5) for $EC_{irrigation\ water}$ = 2.5 dS m^{-1}. If the better-quality water with 1 dS m^{-1} conductivity is used, out of 100 mm irrigation water 20 mm water must be designated for washing the surplus salts from the soil. When the conductivity of the irrigation water is 2.5 then 50% of irrigation water is needed to wash the salts down.

The leaching requirement concept is widely used, but other concepts have also been developed. Hoffman and Van Genuchten (1983) suggested an approach to estimate $EC_{drainage\ water}$ and presented a graphical solution to calculate leaching requirement (see their Figure 6 on p. 83) from $EC_{irrigation\ water}$ and the salt tolerance threshold value of the particular crop. A recent review of this topic (Letey et al., 2011) found that the application of leaching requirement is too strict and overestimates the risk of irrigation-induced salt accumulation.

There are several methods used for leaching salts from the soil rooting zone. Continuous ponding is the shortest and most economic approach, but this requires a levelled dry plot. Intermittent ponding is used in fields with tile drains. As the ponding goes on, evaporation increases, but mulching can help to reduce evaporation when low drainage rates and shallow water table occur. Sprinkle irrigation does not require leveled fields, but on windy and hot days evaporation can be disproportionally high. Alternate row or border leaching causes salts to move into unirrigated furrows, from which salts will be removed when the groundwater table has been lowered. For maintaining high yields, there is a cost of irrigation and also increasing cost of drainage water disposal (Wallender & Tanji, 2011). There are concerns about the toxicity of irrigation and drainage waters (e.g., in California selenium, arsenic and boron are mentioned most often as elements of concern) (Chang & Silva, 2013). Prior to discharging such waters into surface watercourses, the concentration of toxic elements must first be reduced below hazardous levels.

Utilization of Saline Lands Without Mitigation

There are growing areas under agricultural practices where soil salinity is not leached but rather where salt-tolerant plants, adapted to such environment, are cropped (Rozema & Flowers, 2008). There are immense advantages of saline agriculture, the single most important being the unlimited availability of seawater. Halophyte, that is salt-loving crops to be consumed as vegetable, and for fuel and fiber were tested on a large scale at the end of the 20th century. *Salicornia* is the plant genus that has delivered most of the success stories so far. Saline discharge waters are also used for growing salt tolerant fodder crops (Wallender & Tanji, 2011).

Conclusion

Soil salinity, the related sodicity and consequential occasional high alkalinity pose a problem for agriculture since ancient times. Farming practice has adapted to such conditions, and empirical management practices were developed to cope with this kind of degradation.

Since the late 19th century, systematic institutional research has been initiated for classifying, mapping, and reclaiming soils with much emphasis on salt-affected soils in the affected countries such as the United States, Russia, India, Australia, and China. The techniques of assessment and reclamation of salinization have developed much and new concepts are appearing from time to time. Nevertheless, the basic concepts of salinization are valid worldwide.

Based on the breadth of data collected so far, the most critical issues of managing salinization are the following:

- selection of proper land use type, such as grassland, cropland, paddy, fishpond, forest
- selection of a suitable crop for the particular soil conditions
- preliminary evaluation of the drainage conditions of the area where irrigation is planned
- selection of the optimal irrigation technique, water quality and drainage of the plots
- proper disposal of drainage effluents.

The characterization and mitigation of salinization is complex, as it involves physical, physicochemical, chemical, and biological factors as well. Human-designed (i.e., non-natural) processes to reduce the impact of salinity on agriculture should be looked at as engineering decisions that have environmental consequences and thus should be designed and executed carefully. Salinization, being closely related to water regime, is typically not a local but a regional problem. Local salinization or mitigation of it might result in off-site effects several kilometers away.

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