Classification of Soils According to Their Chemistry and Degree of Salinization

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The classification of saline soils according to their chemistry and degree of salinization is well known [2, 5, 6, 9, 11, 16, 17]. We suggest a refined classification involving 9 types of chemistry and 4 degrees of salinization (Table 1).

The chemistry of salinity is determined by the anion ratio and the type of cations. In defining the type of salinity only those anions are included, that constitute more than 20 per cent of the total anion content, except with CO_3 and HCO_3. With these latter anions, if they exceed 0.03 and 1.40 per cent, respectively, the words "with soda participation" are added to the definition. However it is necessary to calculate hypothetic salts (ions are combined as hypothetical salts in the following sequence: carbonates, sulphates, chlorides, CO_3 with Na, then with Mg; if HCO_3 content is more than 1.4 meq. with Ca, Mg, Na; if it is below 1.4 meq. with Ca — not more than 0.6 meq—, then 2/3 of the rest of HCO_3 with Na and 1/3 with Mg [2, 3]) and to make sure of the presence of soda (sodium carbonate or bicarbonate).

While making chloride-sulphate or sulphate salinity subdivisions in soils with a low and a significant gypsum content (< 1 % and > 1 % respectively) not only the SO_4 anions are taken into account, but also the Ca content of the water extracts. In the first case the Ca content is usually lower than 12.5 meq., while in the second it is above 12.5 meq. because of gypsum solubility in the presence of sodium or magnesium sulphates.

If the chemical composition of salts does not vary strongly in the soil profile, the salinity type is defined on the basis of the mean values for a one-meter depth of soil. If variations are considerable, the first upper saline horizon is responsible for the name of the chemistry type of the deeper horizons.

In evaluating the degree of salinity many classifications have been suggested [4, 5, 7, 19, 13, 14, 15, 16, 17 etc.].

A review of the existing literature shows:

1. Considerable variations of both total soluble salts and separate anion contents for equal degrees of salinization and the same salinity types;

2. Non-equivalent indexes for the same salinity degree in soils with similar types of chemistry (e.g. for the same salinization degree, alongside the same Cl index rather different values for the SO_4 ions are supplied);

3. Absence of a strict correlation between the types of soil chemistry and Cl and SO_4 indexes.

4. A frequent discrepancy between the total soluble salt content values and ion indexes, though there must be a strict correspondence between them

when ions are expressed as salts, taking into account the possible presence of other salts.

5. Incompatibility of data on the degree of salinity owing to different depths of soil considered by different authors.

These problems suggested the need of a soil classification based on the degree of salinity where all of the indexes (total salt content, ion content, type of chemistry) would be adequately considered.

The same quantities of soluble salts in soils may give rise to different degrees of salinity due to salt composition and the different toxicity of certain salts and ions. The limit of salt toxicity depends also on moisture content and some other soil properties (texture, physical properties, etc.) as well as on climatic conditions, plant species, physiological conditions, agrotechnical measures, etc. Based on data concerning the salt-resistance of medium salt-resistant crops (cereals and cotton) it seems possible to suggest a tentative scale of ion toxicity limits. Considered in this paper is a loamy soil with a moisture content equal to 0.7 of the field-capacity and a bulk density of the upper horizons of 1.1—1.2 g/cm³, that of subsoil 1.3—1.4 g/cm³.

Supposing that only toxic salts are present in the solution, the following limits of toxicity are accepted %/meq.:

$$CO_3 = \frac{0.001}{0,03}\ ;\ HCO_3 = \frac{0.06}{0.8}\quad [1,\ 2,\ 8,\ 10,\ 14],$$

$$Cl = \frac{0.01^{++}}{0.3}\ (12,\ 17];\ SO_4 = \frac{0.08}{1.7}$$ ([7, 15] and experimental data of ANTIPOV-KARATAEV, personal communication).

Some authors [9] suggest a lower toxic limit for Cl^- 0.005%, others [5], on the contrary, prefer a higher one — 0.03%.

However, alongside the toxic salts, the non-toxic ones [$Ca(HCO_3)_2$, $CaSO_4$] are always present in the soil. Therefore, the HCO_3 and SO_4 ion contents in water extracts will always be higher than the suggested toxic values.

$CaCO_3$ solubility is restricted in the presence of sodium and magnesium carbonates and bicarbonates. With a HCO_3 content equal to 0.8 meq. bound with Na or Mg and a CO_3 content of about 0.03 meq. (with a total alkalinity of HCO_3 equal to 0.8 meq., due to the presence of alkalis, CO_3 ions usually appear in the solution [3]) the $Ca(HCO_3)_2$ content of the solution cannot surpass 0.6 meq. If gypsum is present ($CaSO_4 > 1\%$) not more than 0.6 meq. of $CaCO_3$ can be dissolved. Consequently, with 0.8 meq. HCO_3 being toxic, its total amount in the water extract, corresponding to the toxic limit is 1.4 meq. (0.8 + 0.6).

A SO_4 anion content corresponding to the toxic limit $\left(\frac{0.08}{1.7}\right)$ is only possible in case of soda-sulphate and sulphate salinities. In other salinity types the admissible SO_4 ion content, corresponding to the toxic limit, is restricted by correlations with other anions responsible for salinity. For example, chloride salinity can not have a SO_4 content higher than $\frac{0.006\ \%}{0.12\ \text{meq.}}$ because $\frac{Cl}{SO_4}$ ratio of this salinity type must be over 2.5, with the Cl toxicity limit being accepted as $\frac{0.01}{0.3}$. In the case of the soda-sulphate salinity only toxic sulphates are present in the soil. Therefore, the SO_4 ion content for this salinity type corresponds to the SO_4 toxic limit $\left(\frac{0.08}{1.7}\right)$. In the case of sulphate salinity with a low gypsum content (< 1%) SO_4 ions of the toxic salts (1.7 meq.) are present in the water extract together with the SO_4 of gypsum. The minimal SO_4 ion content of gypsum approximates $\frac{0.08}{1.7}$ giving a total of $\frac{0.16\%}{3.4\ \text{meq.}}$ (correlation between SO_4 ions of toxic and non-toxic salts by sulphate salinity with a low and considerable gypsum content has been found empirically [3]).

This value changes with the gypsum content of the soil. The amount of SO_4 ions of gypsum in the presence of sodium and magnesium sulphates may rise to 12.5 meq. In this case the total amount of SO_4 ions is in agreement with the toxic limit, and proves to be 14.2 meq. The latter value results from $\frac{0.6\%}{12.5\ \text{meq.}}$ of non-toxic salts plus $\frac{0.08\%}{1.7\ \text{meq.}}$ of the toxic ones.

These considerations allow us to state the following approximate figures for the contents of toxic and non-toxic ions in water extracts, corresponding to the toxic limits of toxic salts only $\left(\frac{\%}{\text{meq.}}\right)$.

$$CO_3 - \frac{0.001}{0.03}\text{; } HCO_3 - \frac{0.08}{1.4}\text{; } Cl - \frac{0.01}{0.3}\text{; } SO_4 - \frac{0.08}{1.7} \text{ to } \frac{0.68}{14.2}.$$

The proposed classification of soils, according to degrees of salinity, is based on the values of the toxic limits of the ions responsible for the salinity type. We give the summarised indexes both for toxic and non-toxic ions present in the water extracts (Table 1).

Variability of the indexes is governed by the range of the accepted ratios of ions determining the salinity types; regional peculiarities of soil chemistry especially for soda salinity types, i.e. by participation of chlorides and sulphates in various proportions together with soda; variations in gypsum content; dynamics of carbonate equilibriums causing changes in the HCO_3 and CO_3 ion contents in relation to temperature, CO_2 partial pressure, etc.

If the results of water extract analyses do not correspond to all the criteria (Table 1) accepted for each salinity degree, it seems reasonable to define the degree of salinity by the highest amounts of certain ions in the water extract.

A simpler method of determining the degree of soil salinity based on calculations of the "total effect" of toxic ions on plants is possible. Different ions have different degrees of toxicity and the "total

Table 1

Soil classification according to the degree of salinity in relation to salt composition % me.

Salinity type	Degree of salinity				
	Non saline	Weakly saline	Moderately saline	Strongly saline	Extremely saline (solonchaks)
Chloride					
$Cl : SO_4 > 2.5$					
Total salts	<0.05	0.05—0.15	0.15—0.3	0.3 —0.7	>0.7
Cl^-	$<\frac{0.01}{0\ 0.30}$	$\frac{0.01-0.03}{0.3-1.0}$	$\frac{0.03-0.1}{1.0-3.0}$	$\frac{0.10-0.25}{3.0-7.0}$	$>\frac{0.25}{7.0}$
SO_4^{2-}	$<\frac{0.006}{0.12}$	$\frac{0.006-0.02}{0.12-0.4}$	$\frac{0.02-0.06}{0.4-0.2}$	$\frac{0.06-0.13}{1.2-2.8}$	$>\frac{0.13}{2.8}$
Sulphate-chloride					
$Cl : SO_4 = 1 - 2.5$					
Total salts	<0.1	0.1 —0.2	0.2 —0.4	0.4 —0.8	>0.8
Cl^-	$<\frac{0.01}{0.30}$	$\frac{0.01-0.03}{0.3-0.9}$	$\frac{0.03-0.10}{0.9-2.8}$	$\frac{0.10-0.23}{2.8-6.5}$	$>\frac{0.23}{6.5}$
SO_4^{2-}	$<\frac{0.014}{0.30}$	$\frac{0.014-0.04}{0.3-0.9}$	$\frac{0.04-0.12}{0.9-2.5}$	$\frac{0.12-0.26}{2.5-5.5}$	$>\frac{0.26}{5.5}$
Chloride-sulphate					
$Cl : SO_4 = 0.2 - 1$					
With a low gypsum content					
Total salts	<0.2	0.2 —0.4(0.6)	0.4(0.6)—0.6(0.9)	0.6(0.9)—0.9(1.4)	$>0.9(1.4)$
Cl^-	$<\frac{0.01}{0.3}$	$\frac{0.01-0.03}{0.3-0.8}$	$\frac{0.03-0.1}{0.8-2.7}$	$\frac{0.1-0.23}{2.7-6.4}$	$>\frac{0.23}{6.4}$
SO_4^{2-} Toxic	$<\frac{0.05}{1.0}$	$\frac{0.05-0.11}{1.0-2.2}$	$\frac{0.11-0.14}{2.2-3.0}$	$\frac{0.14-0.22}{3.0-4.5}$	$>\frac{0.22}{4.5}$
SO_4^{2-} Total	$<\frac{0.07}{1.5}$	$\frac{0.07-0.19}{1.5-4.0}$	$\frac{0.19-0.34}{4.0-7.0}$	$\frac{0.34-0.48}{7.0-10.0}$	$>\frac{0.48}{10.0}$

With a high gypsum content Total salts Cl^- SO_4^{2-} Toxic Total		Does not occur			
Sulphate $Cl : SO_4 < 0.2$ *With a low gypsum content* Total salts	<0 30(1.0)	0.3(1.0)—0.4(1.1)	0.4(1.1)—0.8(1.4)	0.8(1.4)—1.2(2.0)	>1.2(2.0)
Cl^-	$<\frac{0.01}{0.30}$	$<\frac{0.02}{0.6}$	$<\frac{0.07}{2.0}$	$<\frac{0.12}{3.5}$	$>\frac{0.12}{3.5}$
Toxic	$<\frac{0.08}{1.70}$	$\frac{0.08-0.14}{1.7-3.0}$	$\frac{0.14-0.34}{3.0-7.0}$	$\frac{0.34-0.86}{7.0-18.0}$	$>\frac{0.86}{18.0}$
SO_4^{2-} Total	$<\frac{0.16(0.68)}{3.40(14.0)}$	$>\frac{0.16(0.68)-0.19(0.74)}{3.4(14)-4.0(15.5)}$	$>\frac{0.19(0.74)-0.48(0.9)}{4.0(15.5)-10(19.0)}$	$>\frac{0.48(0.19)-0.86(1.44)}{10(19)-18(30)}$	$>\frac{0.86(1.44)}{18(30)}$
With a high gypsum content Total salts	<1.0	1.0 —1.2	1.2 —1.5	1.5 —2.0	>2.0
Cl^-	$<\frac{0.01}{0.30}$	$\frac{0.02}{0.6}$	$\frac{0.07}{2.0}$	$\frac{0.12}{3.5}$	$>\frac{0.12}{3.5}$
Toxic	$<\frac{0.08}{1.70}$	$\frac{0.08-0.14}{1.7-3.0}$	$\frac{0.14-0.34}{3.0-7.0}$	$\frac{0.34-0.86}{7.0-18.0}$	$>\frac{0.86}{18}$
SO_4^{2-} Total	$<\frac{0.68}{14.0}$	$\frac{0.68-0.82}{14.0-17.0}$	$\frac{0.82-0.96}{17-20}$	$\frac{0.96-1.44}{20-30}$	$>\frac{1.44}{30}$
Soda-chloride $Cl : SO_4 > 1$; $HCO_3 : Cl < 1$; $HCO_3 > Ca + Mg$; $Na > Mg$; $Na > Ca$ Total salts	Does not occur			0.2 —0.5	>0.5
Cl^-				$\frac{0.05-0.11}{1.5-3.1}$	$>\frac{0.11}{3.1}$
CO_3^{2-}				$\frac{0.001-0.01}{0.03-0.4}$	$>\frac{0.01}{0.4}$
HCO_3^-				$\frac{0.08-0.18}{1.4-30}$	$>\frac{0.18}{3.0}$

Salinity type	Degree of salinity				
	Non saline	Weakly saline	Moderately saline	Strongly saline	Extremely saline (solonchaks)
Soda-sulphate Cl : SO_4 < 1; HCO_3 : SO_4 < 1; HCO_3 > Ca + Mg; Na > Mg; Na > Ca					
Total salts	Does not occur		0.25 —0.4	0.4 —0.6	>0.6
SO_4^{2-}			0.08—0.12 / 1.7 —2.5	0.12 —0.19 / 2.5 —4.0	> 0.19 / 4.0
CO_3^{2-}			0.001—0.006 / 0.03 —0.2	0.006—0.01 / 0.2 —0.5	> 0.01 / 0.5
HCO_3^-			0.08—0.12 / 1.4 —2.0	0.12 —0.21 / 2.0 —3.5	> 0.21 / 3.5
Chloride-soda Cl : SO_4 > 1; HCO_3 : Cl > 1; HCO_3 > Ca + Mg; Na > Mg; Na > Mg; Na > Ca					
Total salts	<0.10	0.1 —0.2	0.2 —0.3	0.3 —0.5	>0.5
Cl^-	< 0.01 / 0.3	0.01 —0.02 / 0.3 —0.7	< 0.07 / 2.0	< 0.10 / 3.0	> 0.10 / 3.0
CO_3^{2-}	< 0.001 / 0.03	0.001—0.002 / 0.03 —0.07	0.002—0.006 / 0.07 —0.2	0.006—0.01 / 0.2 —0.4	> 0.01 / 0.4
HCO_3^-	< 0.08 / 1.4	≈ 0.08 / 1.4	1.4 —2.0	0.12 —0.18 / 2.0 —3.0	> 0.18 / 3.0
Sulphate-soda Cl : SO_4 < 1; HCO_3 : SO_4 > 1; HCO_3 > Ca + Mg; Na > Mg; Na > Ca					
Total salts	<0.15	0.15 —0.25	0.25 —0.4	0.4 —0.6	>0.6
SO_4^{2-}	< 0.02 / 0.5	0.02 —0.07 / 0.5 —1.4	< 0.10 / 2.0	< 0.14 / 3.0	> 0.14 / 3.0
CO_3^{2-}	< 0.001 / 0.03	0.001—0.002 / 0.03 —0.08	0.002—0.009 / 0.08 —0.3	0.009—0.015 / 0.3 —0.5	> 0.015 / 0.5
HCO_3^-	< 0.08 / 1.0	≈ 0.08 / 1.40	0.08 —0.15 / 1.4 —2.5	0.15 —0.21 / 2.5 —3.5	> 0.21 / 3.5

Sulphate or chloride-hydrocarbonate $HCO_3 > Cl$; $HCO_3 > SO_4$; $Na < Ca$; $Na < Mg$: $HCO_3 > Na$				
Total salts	<0.2	$0.2-0.4$	$0.4-0.5$	Does not occur
SO_4^{2-}	$<\frac{0.04}{0.9}$	$<\frac{0.10}{2.0}$	$<\frac{0.10}{2.0}$	
Cl^-	$<\frac{0.01}{0.3}$	$<\frac{0.03}{1.0}$	$<\frac{0.07}{2.0}$	
HCO_3	$<\frac{0.08}{1.4}$	$<\frac{0.12}{2.0}$	$<\frac{0.15}{2.4}$	

effect" of toxic ions may be expressed in Cl equivalents. The following approximate relations may be accepted: $1\ Cl = 0.1\ CO_3 = 2.5-3.0\ HCO_3 = 5.0-6.0\ SO_4$. Only toxic ions (calculation of toxic salts and ions is based on combining ions into hypothetical salts) are considered. Then the degree of soil salinity may be determined from Table 2.

If salinization has been caused by one salt, the lowest index of the "total effect" should be used. In case of multisalt salinity and the presence of gypsum in particular, it is necessary to make use of the highest ones.

The degree of salinity of solonchakous soils is determined by the "total effect" of the toxic ions in the 0–30 cm layer. We distinguish extremely saline, strongly, moderately and weakly saline solonchakous soils. If there is a very strong salinity in the 0–30 cm layer, the soil is classed as solonchak. Virgin soils should be called solonchaks if their upper genetic horizon, even thinner than 30 cm, is characterized by extreme salinity.

The degree of salinity of shallow solonchakous soils is calculated according to the mean content of salts in the 30–50 cm layer; that of the solonchakous soils in the 50–100 cm layer; and of deeply solonchakous in the 100–150 cm layer. Consequently, extremely saline, strongly, moderately and weakly saline shallow solonchakous, solonchakous and deeply solonchakous soils are distinguished.

For soils greatly differing in water-physical properties (first of all in bulk density) of certain genetic horizons (peaty-meadow soils, solonetz) values of total salt and anion contents are multiplied by special corrective coefficients calculated for each horizon. A corrective coefficient is a ratio of the bulk density of a certain genetic horizon to a conventional bulk density, equal to 1.2 g/cm³.

By combining these three criteria: chemical composition of salts, degree of salinization and depth of the upper saline horizon, one can make a complete appraisal of soil salinity.

Table 2

Soil classification according to the type of salinity taking into account the "Total Effect" of toxic ions

Salinity degree	„Total Effect" of toxic ions (CO_3, HCO_3, Cl, SO_4) expressed in meq.
1. Non-saline	<0.3
2. Weakly saline	0.3 —1.0 (1.5)
3. Moderately saline	1.0 (1.5)—3.0 (3.5)
4. Strongly saline	3.0 (3.5)—7.0 (7.5)
5. Extremely saline	>7.5

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