Salt Balance in Sustainable Irrigated Farming

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Introduction

The aim of sustainable farming is the maintenance or increase of soil fertility. To achieve this, technical, agrotechnical and agronomical measures, and their simultaneous application have to be determined accordingly. A change in any of these factors must be followed by a reconsideration of the whole system and by adjusting the different components of the new technology.

A knowledge of the water and salt regimes of soils and their regulation is of basic interest when using lands affected by salinity (SZABOLCS, 1989).

The preconditions for the development of soil salinity are:

- a connection between the soil and salt sources,
- the presence of salts, and
- the prevalence of accumulation over leaching processes.

Changes in the salt content and in factors influencing it, should be expressed as the salt balance of the soil.

The salt balance of soils described in the literature using different relationships has validity for territories of different extent. It is possible to set up the salt balance of a large area, for instance of a river valley, but the information obtained by this method would be much more concrete if a smaller area, such as an irrigated field, were considered.

The factors in the general form of the salt balance can be given as follows:

$$\Delta S = (W + P + R + G + Y + F) - (lp + r + g + li + u) \qquad (1)$$

where:

Δ S = change in the salt content of the soil at a given depth and over a given period;
W = salts derived from local weathering products;
P = salts derived from the atmosphere (air-borne salts, rainfall, wind action, etc.);
R = horizontal inflow of salts transported by surface waters;

G = horizontal inflow of salts transported by subsurface waters;
Y = quantity of salts added with irrigation water;
F = salts added as chemical amendments;
lp = salts leached out by precipitation;
r = horizontal outflow of salts transported by surface waters;
g = horizontal outflow of salts transported by subsurface waters;
li= quantity of salts leached out by irrigation waters;
u = salts assimilated by plants and transported from the area with the yield.

The resultant effect of factors determining the soil salt balance is measured by the change in the salt content of the soil layer during the period of observation:

$$d = b - a \tag{2}$$

where:
b = the salt content of the soil to the depth given at the end of the observation;
a = the salt content of the soil at the beginning of the observation;
d = the salt balance or salt regime coefficient of the soil.

b-a is the difference between the amount of salts accumulated in the soil from different sources and the salts leached out. This difference is indicated as the salt regime coefficient (d).

One or another factor of the salt balance may dominate and, depending on the conditions, may result in long-term effects (salts derived from local weathering products) or short-term effects (salts added with irrigation water). A change in any factor, however, leads to a change in the whole salt balance. In Hungary, for example, a surface water drainage system was built up in the last century, which shifted the water and salt regimes of soils towards leaching processes on the territories affected (SZABOLCS, 1960).

Three types of salt balance can be distinguished:

- Stable salt balance: the salt content of the soil to the depth given does not change during the period of observation.
- Accumulation: the salt balance is positive and the total salt content of the soil to the depth of observation increases during the period considered.
- Leaching: the salt balance is negative and the salt content in the soil layer under observation decreases during the period considered.

The salt balance equation makes it possible to consider one or more factors influencing the salt accumulation and leaching separately (SZABOLCS, DARAB & VÁRALLYAY, 1969).

The method of salt balance has been used on the Hungarian Plain for decades to determine the maximum permissible concentration of the irrigation water and to fix limit values for the permissible salt concentration (SZABOLCS

& DARAB, 1968). The method has been applied for the planning of sustainable irrigation in the Tisza river valley and to indicate regions of potential soil salinity (SZABOLCS, DARAB & VÁRALLYAY, 1969). In these calculations of salt balance average values for *d* have been used generally. It is more exact, however, when data are available for the given territory and calculations are carried out with measured *d* values. Furthermore, the maximum and minimum depths of the groundwater, the soil texture, the layering, and the degree of salinity and sodicity of the soil to be irrigated are considered when calculating salt balances.

Computation Model, Case Studies

A computation model was developed to predict the conditions for irrigation, taking into account the depth of the groundwater at a stable salt balance (critical depth) and the use of irrigation waters with different salinity on the soils of the Hungarian Plain. The model was applied to soils where the regime of soil compounds and the factors affecting it were known, and their relevant data had been used previously to determine limit values for irrigation water (DARAB & FERENCZ, 1969). Case studies were carried out for three characteristic regions in the Tisza valley.

Case study No. 1 (Szarvas)

The groundwater table is lower than the average for the Plain, because there is a river backwater nearby, where the volume of reserved water varies to a wide extent. In summer, this water is used for irrigation. From autumn to spring the backwater collects seepage waters, acting as a drainage canal (Figure 1). The salt content and salt chemistry in the backwater also varies widely, depending on the origin and volume of the water reserved (Table 1). The salt content and chemistry of the groundwater in this area are also given in Table 1.

The salt balance was calculated for a 1.4 - 1.5 m thick soil layer, where studies had shown salt accumulation to take place.

The annual salt balance and the ion balance can be characterized by a slight decrease in the average salt content and by a decrease in the Na^+ and SO_4^{2-} ion contents when comparing the data obtained at the beginning and end of the year of observation (Table 1).

The salt reserves of the soil and its yearly changes are influenced mainly by the water level of the Körös river backwater and by the level of the water reserved in the backwater. At the beginning of the observation, when the water level was relatively high, the salt reserves in the soil were as high as 0.85 g/ /100 g (Table 1). Between January and March this value decreased with the de-

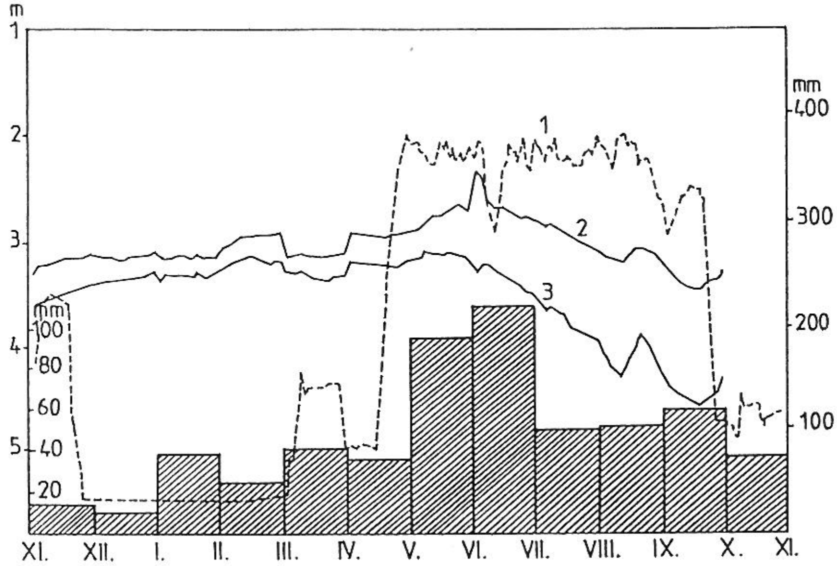


Figure 1

Some hydrological and meteorological factors influencing the salt balance of the soil (Szarvas) 1. water level in the backwater; 2 and 3:. groundwater levels (in two wells). Block diagram: monthly distribution of the precipitation

crease in the water level and the simultaneously increasing drainage effect and reached a more or less constant value. In April, the backwater was filled up with river water. This caused not only the dilution of the reserved water, but also a decrease in the salt reserves of the soil. Between April and September, salt accumulation prevailed over leaching. Irrigation at the end of July led to a temporary fluctuation in the salt reserves.

Case study No 2 (Hortobágy)

On this area, the annual distribution of precipitation is nearly the same as in the former case (Figure 1), at most, small local changes occur. The hydrological conditions are more disadvantageous than in the Szarvas area. Accumulation in most cases prevails over leaching processes.

The infiltration and the capillary zone are in contact, consequently salt accumulation occurs, and even irrigation does not change the situation (SZABOLCS, 1960).

In the case of a deeper groundwater level, which is probable between May and June, slight leaching occurs due to irrigation. Based on monthly data of the

Table 1

Monthly data of the total dissolved salts (TDS) and ions in irrigation water, groundwater and soil-water extract Szarvas, Hungary

Month	Irrigation water*				Soil-water extract**				Groundwater			
	TDS mg/l	Na^+	Cl^-	SO_4^{2-}	TDS g/100g	Na^+	Cl^-	SO_4^{2-}	TDS mg/l	Na^+	Cl^-	SO_4^{2-}
		meq/l				meq/100g				meq/l		
Nov.					0.86	12.4	0.18	13.7	0.88	5.7	1.30	6.2
Dec.					0.74	4.3	0.48	10.0	1.00	5.2	1.36	8.1
Jan.					0.65	6.4	0.24	8.3	1.04	4.9	1.37	4.2
Febr.					-	-	no data	-	1.06	5.1	1.40	8.3
March	1.17	2.34	0.80	1.66	0.65	7.3	1.00	9.34	1.18	5.6	1.38	8.3
April	0.49	3.44	1.03	1.51	0.37	5.0	0.18	4.14	1.05	6.6	1.45	6.9
May	0.13	1.06	0.27	0.97	0.59	5.3	0.15	6.87	1.12	6.2	1.70	7.0
June	0.19	1.66	0.35	0.89	0.58	5.0	0.11	7.14	1.47	7.7	2.50	6.7
July	0.25	2.06	0.48	0.29	0.63	7.7	0.10	9.71	1.39	7.4	2.40	7.0
August	0.27	2.32	0.44	2.26	0.38	5.6	0.13	5.30	1.16	6.1	1.70	7.0
Sept.	0.28	1.58	0.59	2.13	0.69	8.0	0.16	9.12	1.16	3.1	1.70	7.1
Oct.	0.37	1.66	0.60	3.00	0.60	7.8	0.17	8.36	1.13	5.4	1.40	7.0

** there was no water in the backwater in November, December, January and February; ** averages in the soil between 0-140 cm* average salt content and Cl^-, SO_4^{2-} and Na^+ ion concentrations in the soil solution, different periods in the salt regime can be distinguished (Table 2).

Case study No. 3 (Kopáncs)

On a salt-affected rice field with poor drainage conditions investigations were carried out from the end of the leaching period in spring (April) till the harvest time of rice (October) (Table 3). During this short period, if the salt content is taken into account, salt accumulation takes place. The salt balance shows that more salts were applied with the irrigation water, than salts could be leached out from the soils.

The data show clearly that the intensity of accumulation and leaching processes is influenced in the investigated regions mainly by hydrological factors, that is:

1. the accumulation and leaching of salts originating from irrigation water;
2. an increase in the level of the groundwater table connected with:

a) the transport of the groundwater salt content into the affected layers,
b) the upward movement of salts from deeper soil layers towards the surface or surface layers;
c) the limitation of the leaching of salts due to a rise in the groundwater table.

In the calculation of the salt balance, the following factors were taken as variables:

a) the volume of irrigation water;
b) the salt concentration of the irrigation water;
c) the average salt content of the soil between the surface and the groundwater table;
d) the salt regime coefficient;
e) soil water properties (texture, bulk density, thickness of the capillary zone, etc.);
f) the salt concentration of the groundwater

The computation model consists of the calculation of the salt regime coefficient of non-irrigated soil, and the calculation of the salt balance after the separate estimation of its components: salt accumulation from irrigation water, salts transported from the groundwater, average original salt content of the soil, redistribution of salts along the soil profile.

Based on the salt balance, to predict the possibility of irrigation or the necessity of drainage, further calculations have to be carried out to determine the depth of the groundwater table where a stable salt balance is assured (critical depth), and the maximum permissible concentration and/or volume of irrigation waters with different chemical characteristics.

Table 2

Weighted averages of the content of salts and different ions on an irrigated field in the soil between 0-140 cm (Hortobágy, Hungary) (measured in the soil solution)

Month	Soil moisture, %	Total dissolved salts g/100g	Na^+		Cl^-		SO_4^{2-}	
			meq/l	meq/100g	meq/l	meq/100g	meq/l	meq/100g
May	17.9	0.21	160.4	2.87	76.0	1.40	119.6	2.14
June	23.2	0.16	84.3	1.96	17.7	0.41	83.0	1.93
July	22.9	0.22	156.6	3.60	37.0	0.85	137.5	3.15
September	25.2	0.24	128.2	3.20	18.3	0.46	11.3	2.81

Table 3

Weighted averages of the content of salts and different ions on a rice field (flooded in May) in the soil between 0-140 cm (Kopáncs, Hungary) (measured in the soil solution)

Month	Soil moisture, %	Total dissolved salts g/100g	Na^+		Cl^-		SO_4^{2+}	
			meq/l	meq/100g	meq/l	meq/100g	meq/l	meq/100g
April	22.85	0.08	61.8	1.4	33.7	0.77	17.0	0.4
May	24.6	0.12	88.7	2.2	46.9	1.15	12.6	0.3
June	33.9	0.35	144.7	4.9	82.9	2.81	75.4	2.6
August	30.5	0.37	122.5	3.7	103.8	3.5	107.4	3.3
October	25.4	0.18	106.7	2.7	69.3	1.7	70.0	1.7

The flow chart of the computation model for determining the possibility of irrigation is given in Table 4.

The computation consists of three steps:

I. Calculation of the salt balance coefficient or the annual salt balance of the soil (d)

The salt balance coefficient calculated from the data of non-irrigated soil gives information on the conditions and possibilities of irrigation.

- When the d value is < 0, principally the possibility of irrigation exists.
- In cases, when the d value is > 0, thus salt accumulation takes place, the prevalence of leaching processes must be assured before irrigation.

II. The calculation of factors influencing the salt balance of the irrigated soil is carried out (Table 4) according to the following equation:

$$b_i = a + x + z + d \tag{3}$$

where:

b_i = the average salt content of the soil after the investigated period of irrigation,

a = the average original salt content of the soil (between the surface and the water table).

d = the change in salt resources, i.e. the difference between the amount of salts entering the soil from other sources than salts accumulated from the groundwater and irrigation water, and the amount leached out from the irrigated soil. The input data of the computation model are the a and d values.

z = the amount of salts transported from the groundwater. For the calculation of this parameter, further input data are:

- the field capacity
- the actual depth of the groundwater
- the thickness of the capillary zone
- the volume of moisture transported from the capillary zone to the upper layers.

x = the amount of salts accumulated from the irrigation water. For the calculation of this parameter the salt concentration and the volume of irrigation water applied in the given period must be known.

According to the calculated salt balance of the soil, three cases can be distinguished.

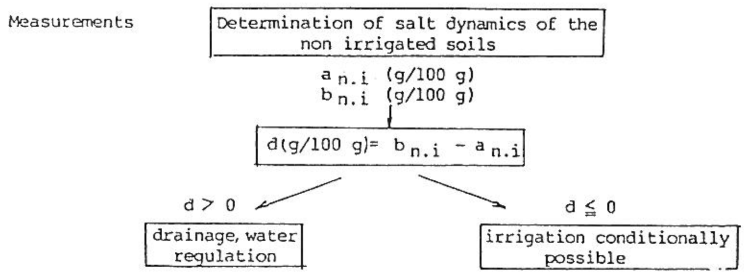
Case 1: $b_i > a$ and $d \geq 0$. Amelioration is necessary, which includes the regulation of the groundwater table and improvement in the possibility of leaching.

Case 2: $b_i > a$ and $d < 0$. The conditions for the possibility of irrigation must be further investigated, including (Step 1) the determination of the maximum permissible concentration of the irrigation water (when $b_i = a$ is taken into account as a limiting condition) and (Step 2) the determination of the

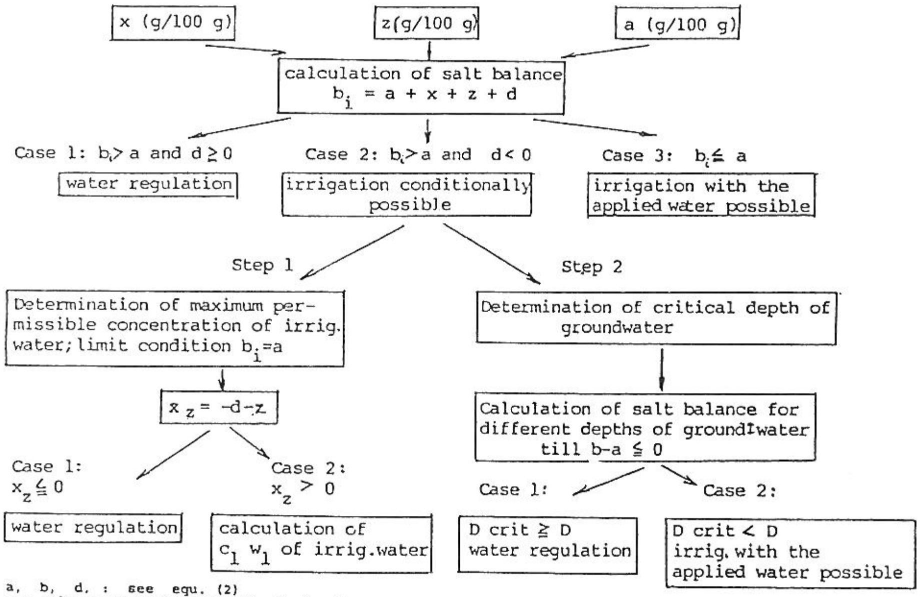
Table 4

Flow Chart of the computation model for determining the possibility of irrigation

I. Calculation of the salt balance coefficient (d) of the non irrigated soil

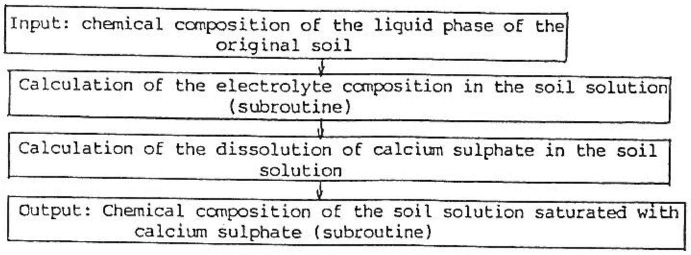


II. Determination of factors influencing the salt balance of irrigated soils



a, b, d. : see equ. (2)
x = salts accumulated from the irrigation water
z = salts transported from the groundwater

III. Model computing the dissolution of calcium sulphate in the soil solution



groundwater table assuring a stable salt balance (critical depth of the groundwater).

Case 3: $b_i \leq a$, and $d \leq 0$. The salt balance of the irrigated soil is negative, leaching prevails over accumulation in soils under irrigation. The use of irrigation water with the available concentration and with the application of the given irrigation technique is possible.

III. The computation of the dissolution of calcium sulphate in the soil solution.
The amount of dissolved gypsum can be calculated based on the ion concentration of the soil solution.

Results and Discussion

For the determination of the possibility of irrigating larger territories, the expected change in the salt balance can be estimated if the territorial average values for *d* are taken into account. Such calculations characterize territories where irrigation can be carried out without any danger of salinization and where a stable salt balance can be assured under the given hydrological conditions with the given irrigation technology. On these territores the salt regime coefficient is < 0 in every case.

At the same time, by calculating salt balances it is possible to indicate regions where progressive salt accumulation from the groundwater takes place, and irrigation is possible only after previous amelioration measures, and after assuring the prevalence of leaching processes over accumulation.

Ameliorative measures, especially the enlargement of the drainage and irrigation system always cause a change in the salt balance of the soil and, at the same time, in the value of the salt regime coefficient.

To check the applicability of the model, the relationship between the salt regime coefficient and the depth of the (critical) groundwater table assuring a stable salt balance was studied at four salinity levels (Figure 2). Calculations show clearly that, with the increase in the value of the salt regime coefficient, the critical groundwater table at the stable salt balance decreases. For example, in the case of curve No 4 in Figure 2, the critical depth of the groundwater decreases from 4.5 to 1.5 m with an increase in the salt regime coefficient from 0.03 to 0.17.

Curves having the same pattern are obtained when differences in the values of other factors influencing the salt balance (irrigation water concentration, groundwater concentration, actual groundwater table) are taken into account.

When calculations are carried out for a given area, changes in the salt regime coefficient value can be obtained due to irrigation and drainage. As a control, the factors of the salt regime coefficient were calculated for the three irrigated fields investigated.

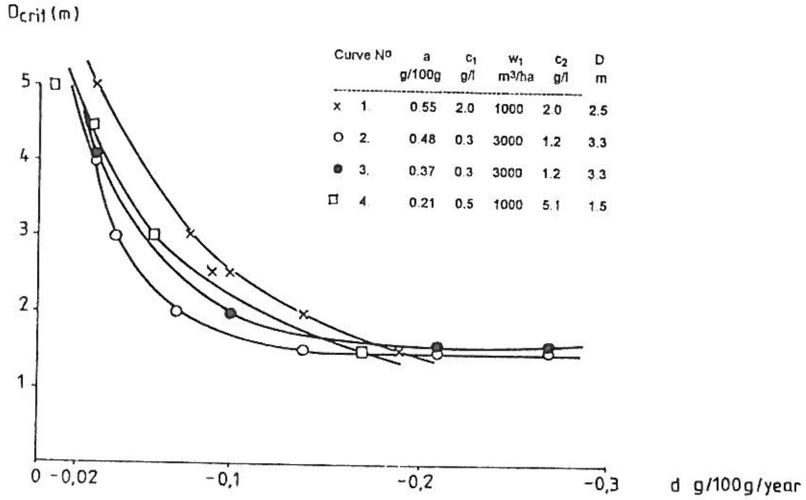


Figure 2
Relationships between the salt regime coefficient and the critical depth of the groundwater

- In the case of the Szarvas area, (case study No. 1) in spite of irrigation, a nearly stable or slightly negative salt balance was found when the average salt content measured in winter or early spring was taken as the beginning of observation. Irrigation in July with 1200 m³/ha irrigation water having a 0.26 g/l salt concentration, 1.1 g/l average groundwater concentration and 2.0 m groundwater depth were taken into account. A value of -0.17 g/100 g/year was calculated for the salt regime coefficient. Calculations based on the computation model (Table 5) show that the depth of the groundwater is equal to the critical depth, the salt balance is negative and irrigation with the applied water is possible.

- In the case of soils on the Hortobágy rice field (case study No. 2), flooding with 5000 m³/ha water having 0.65 g/l salt concentration, 6.0 g/l average groundwater concentration, and 1.5 m groundwater depth were taken into account. The *d* value was calculated to be -0.08. According to the calculations (Table 5), the main source of salts is the groundwater. This suggests the dominance of salt accumulation over leaching (salt balance = +0.03g/100g) and D_{crit} >D. Irrigation can be carried out only after amelioration measures (water regulation).

- Rice production was in progress in case study No. 3 (Kopáncs). During the vegetation period, the volume of irrigation water was 15,000 m³/ha, the salt concentration 0.96 g/l, and the groundwater salt concentration 6.4 g/l.

Table 5

The determination of the possibility and conditions of irrigation at stable salt balance

	Case study		
	No. 1 Szarvas	**No. 2 Hortobágy**	**No. 3 Kopáncs**
Input data			
Texture of soil	clay	clay	clay
Concentration of irrigation water (c_1), g/l	0.26	0.65	0.96
Volume of irrigation water (W_1), m³/ha	1200	5000	15000
Depth of groundwater (D), m	2.0	1.5	1.5
Concentration of groundwater (c_2), g/l	1.1	6.0	6.4
Salt regime coefficient (d) g/100g/year	-0.17	-0.08	-0.07
Average original salt content of the soil (a), g/100 g	0.65	0.21	0.08
Output			
1. Salt balance			
Salts accumulated from the irrigation water (x), g/100 g	0.002	0.003	0.124
Salts transported from groundwater (z). g/100 g	0.12	0.079	0.043
Average salt content of the soil after the investigated period of irrigation (b_i), g/100 g	0.60	0.24	0.18
Salt balance (b_i-a), g/100g	-0.048	0.03	0.102
2. Possibility and conditions of irrigation	$b_i - a < 0$	$b_i - a > 0$ *and* $d < 0$	$b_i - a > 0$ *and* $d < 0$
	Irrigation is possible with the applied water	Irrigation is conditionally possible	Irrigation is conditionally possible
Groundwater depth at stable salt balance(D_{crit}), m	2.0	2.5	3.5
	$D_{crit} = D$ higher volume and/or concentration of irrigation water permitted	$D_{crit} > D$ irrigation only after previous amelioration (water regulation)	$D_{crit} > D$ irrigation only with low volume and/or concentration of irrigation water

According to the salt balance calculations, the main source of salt accumulation was the irrigation water, and only to a lesser degree the groundwater. A decrease in the salt accumulation can be achieved if, instead of rice, less water-consumptive cultures are produced.

For characterizing salt balances, the use of Cl^- ion concentrations (in meq/ /100 g or g/100 g soil), determined from any kind of soil-water extracts, is also recommended. The data of Cl^- ion balances (Table 6) show higher leaching than the data on the balance of total dissolved salts (Table 5). The reason for this is that the chemistry of the irrigation water is reflected in the salt chemistry of the soil. Consequently, the possibility of using the Cl^- ion balance as the indicator of salt balance exists if chemical reactions between the irrigation water and the soil are simultaneously followed up. This concerns not only the anion composition, but also the ratio between uni- and divalent cations (for example, the SAR value) in the liquid phase of the soil (DARAB, RÉDLY & CSILLAG, 1992).

Table 6

Chloride balance of the investigated area

	Case study No. 1.	**Case study No. 2**	**Case study No. 3**
*Input data**			
Texture of the soil	clay	clay	clay
c_{1Cl}, g/l	0.02	0.26	0.15
W_1, m^3/ha	1200	5000	15000
D, m	2.0	1.5	1.5
$c_{2Cl,}$, g/l	0.11	1.6	2.8
d_{Cl}, g/100g/year	-0.0018	-0.06	-0.042
a_{Cl}, g/100 g	0.006	0.048	0.033
Output: Balance of chloride*			
x_{Cl}, g/100 g	0.00013	0.0114	0.0194
z_{Cl}, g/100 g	0.0013	0.0187	0.0177
b_i, g/100 g	0.0059	0.016	0.0281
Chloride balance,(b_i - a) g/100 g	-0.0005	-0.032	-0.0049

* *For abbreviations: See Table 5*

This is particularly pronounced in irrigated, gypsum-containing soils, where the continuous dissolution of gypsum assures a constant Ca concentration in the soil solution. In this case both the decrease in the Na^+ ion concentration (leaching) due to irrigation and the dissolution of gypsum have an influence on the decrease in the SAR value of the soil solution. This is proved by the data of

Table 7

Cation concentrations and SAR values measured in extracts with different soil-water ratios

w%	Na^+, meq/l	Ca^{2+}, meq/l	Mg^{2+}, meq/l	SAR
A. In soil containing gypsum				
32.2	137.67	30.72	56.49	20.9
75.0 (SP)	68.48	22.56	36.18	12.6
100	54.70	14.70	27.50	11.9
200	48.00	14.10	19.10	11.8
500	35.10	14.70	11.60	9.7
B. In soil without gypsum content				
14.8	73.44	2.50	1.46	81.0
17.9	67.39	0.91	1.00	69.0
18.6	63.39	0.81	0.96	66.2
22.2	55.21	0.79	0.75	62.9
64.0 (SP)	28.61	0.31	0.78	39.2
100	19.78	0.96	0.08	27.4
200	15.04	0.41	1.50	15.4
500	18.69	0.50	4.33	12.0

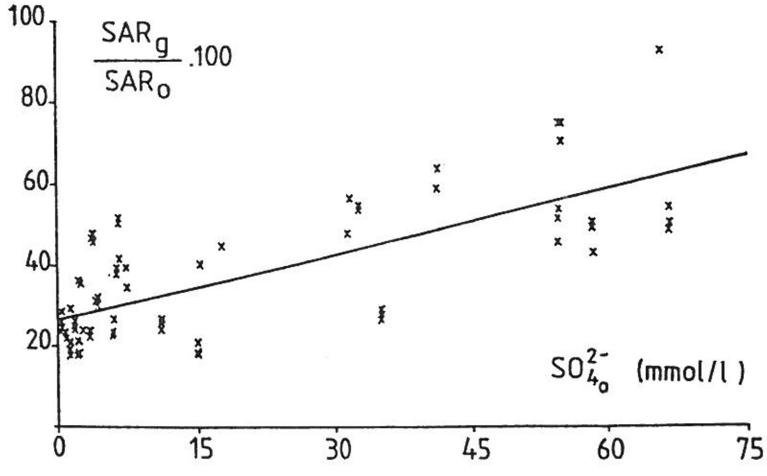


Figure 3

SAR values of soil saturation extracts after treatment with calcium sulphate in the percentage of their original SAR values, as a function of the SO_4^{2-} concentration of the original solutions. o: measured in original, untreated solutions; g: measured in soil extracts saturated with calcium sulphate extracts with different soil-water ratios (Table 7). A significant difference in the decrease in the SAR value with dilution can be observed between the data of gypsum-containing and non-gypsum containing soils.

The data in Figure 3 also illustrate the necessity of taking into account both the dilution of the soil solution and the continuous disssolution of gypsum when determining the possibility of irrigation. The calculations in the 3rd part of the computation model (Table 4) can be used for the above purpose.

Table 8

Relationship between the amount of dissolved gypsum and the anionic composition of the irrigation water

Anionic composition of the irrigation water	**$Ca^{2+}g$ meq/l**	**ΔCa^{2+} meq/l**	**$\Delta CaSO_4.2H_2O$ kg/m³**	**Volume of irrigation water,* m³/ha**
Hydrocarbonatic	35.0-36.6	31.5-32.8	2.7-2.8	420-410
Hydrocarbonate-sulphatic	31.6-34.4	28.9-30.4	2.5-2.6	470-440
Sulphate-hydrocarbonatic	33.2-31.0	21.3-29.6	1.8-206	450
Sulphatic	25.2	16.4	1.4	600

$Ca^{2+}g$: saturation Ca^{2+} concentration of the waters; ΔCa^{2+}: increase in Ca^{2+} concentration due to saturation with gypsum (calculated values); $\Delta CaSO_4.2H_2O$: quantity of dissolved gypsum necessary for the saturation of the waters; * quantity of irrigation water necessary for the exchange of 1 meq/100g adsorbed Na^+ in the top 10 cm layer of the soil

In this part of the model, the ion concentration data in the liquid phase of the soil serve as input, and by applying a successive approximation procedure the dissolved quantity of $CaSO_4$ is computed taking into account the ion and ion pair concentrations in the soil solution (Table 8) (DARAB, RÉDLY & CSILLAG, 1989).

Conclusion

Based on mathematical models including the given parameters of the water and salt regimes of the area, the chemistry of the salts, the electrolyte properties of the soil solution, soil properties and known relationships, the possibility of irrigation with the applied water can be determined with the use of a computer programme.

The models elaborated make it possible to proceed from giving limit values for irrigation (irrigation waters) to the determination of the possibility of irrigation by taking into account the natural conditions of a given area.

Summary

Calculations were carried out to predict the conditions required for irrigation, taking into account the critical depth of the groundwater and the use of water with different salinity on the soils of the Hungarian Plain. Data on salinity, its annual dynamics and the chemistry of the salts were collected from water extract and soil solution analyses of the horizons of a great number of soil profiles of non-irrigated and irrigated territories. Available data on water physical soil properties and sodicity, on hydrological conditions, and on groundwater and irrigation water chemistry were`also used.

The computation model consists of the calculation of the salt regime coefficient of non-irrigated soil, and the calculation of the salt balance after the separate estimation of its components: salt accumulation from irrigation water, salts transported from the groundwater, and the average original salt content of the soil. Based on the salt balance, further calculations were carried out to predict the possibility of irrigation or necessity of drainage and to determine the maximum permissible concentration and/or volume of irrigation waters with different chemistry, assuring a stable salt balance. To evaluate the sodicity of irrigation waters, the change in the SAR value of the soil solution and the ESP of the soil during irrigation and leaching processes were predicted by the application of a successive approximation procedure.

To check the applicability of the model, case studies were carried out on three irrigated territories in the Tisza river valley.

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