Effects of Chemical Amelioration and Soil Moisture Regulation on Various Types of Salt Affected Soils

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In Hungary a wide variety of salt affected soils may be found. In a considerable area of the Hungarian Plain the soils are under the influence of highly saline groundwater, and this has led to their deterioration. The correlation between the depth of the water table and the different types of alkali soils in the Trans-Tisza region may be seen in Fig. 1. This Figure clearly demonstrates the unfavourable effect of saline groundwaters on the soil forming processes.

The amelioration of these soils cannot be achieved without the regulation of soil moisture conditions [4]. So far, however, very little scientific and practical knowledge has been available on the applicability of soil moisture regulation methods for the reclamation of the alkali soils and the meadow soils saline in deeper layers in the Trans-Tisza region [1, 2, 3]. These soils are compact, heavy-textured, have a high clay content, their field capacity and permeability are very low.

In order to study the possibilities of amelioration, a complex emperiment was launched conjointly by the Karcag Research Institute of the Debrecen University of Agrarian Sciences and the Technical Development Institute of the Research Centre for Water Resources Development in 1977.

Detailed investigations were made on how subsurface drainage installed with different drain-spacings at an average depth of 0.8 m, surface drainage and sprinkler irrigation, as well as chemical amelioration and deep loosening to a depth of 0.2 and 0.45 m — separately or in various combinations — affect

— the fluctuations of the water table;

— the chemical, physical and water regime properties of the soil profile above subsurface drainage pipes, with special regard to changes in the moisture content, salt movement, salt balance and the after-effect of deep loosening;

— the development of field crops, the quantity and quality of yields, yield stability, as well as the nutrient and water supply of plants.

Hydrological, pedological and climatic conditions of the experimental site

The experimental site was set up at Karcagpuszta in late 1977.

According to the results of soil-borings to a depth of 23—25 m on the experimental site, the soil has a high clay content and is very compacted, its water conductivity is poor. Natural drainage and vertical moisture movement within the soil are not satisfactory. The groundwaters are generally under pressure to some extent. Their equilibrium water level (pressure level) is 1—1.5 m below the surface. The groundwater contains hydrocarbonates and sulphates. The relative quantity of sodium salts exceeds 65 percent, while the quantity of dissolved salts is more than 2000 mg/l. The thickness of the capillary zone varies between 1—1.5 m. The exchangeable and water soluble salt content of the soil to a depth of 2.8—5.7 m is very high. Accordingly, to this depth the soil can be classified as salt affected. Below this depth the total water soluble salt content of the soil layers is much smaller (0.01—0.08 %).

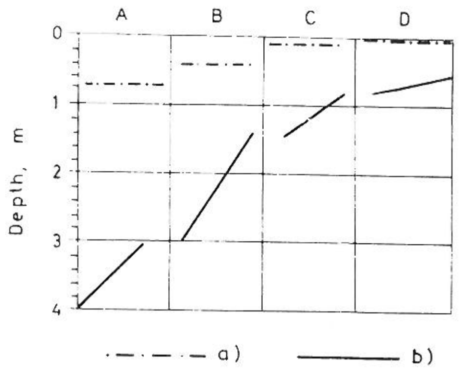

Fig. 1

Correlation between the depth of the water table and the development of different types of salt affected soils. A) Meadow solonetz turning into steppe formation. B) Meadow solonetz. C) Solonchak-solonetz. D) Solonchak. a) level of maximum salt accumulation; b) range of the fluctuation of the water table

70 percent of the experimental site is covered with solonetz soils (mostly medium but also deep and crusty solonetzes), 25 percent with solonchak-like, crusty meadow solonetz soils solodized in spots, and about 5 percent with solonetz soils having a medium thick humous layer and meadow soils saline in deeper layers. In the soil profiles the B horizon — an accumulation layer with unfavourable chemical and physical properties — can be easily identified.

From among the harmful soil processes the most frequent are: a breakdown of the colloid complexes of the soil, the decomposition of clay minerals, and the accumulation of amorphous silicic acid (SiO_2), that is, degradation, solodization, which has led to the reduction and discolouration of the organic and inorganic colloid materials in the 15—20 cm thick top layer.

The aqueous extract of the soil contains — besides a considerable quantity (some tenth of one percent) of water soluble salts — large quantities of cations (mostly Na^+ and Mg^{2+}) and anions (mostly Cl^-, SO_4^{2-} and HCO_3^-). The unfavourable physical and moisture and air regime properties are caused by the dispersed or peptized state of organic and inorganic colloid materials which — in turn — results from the large relative amounts of adsorbed Na^+ ions.

The infiltration capacity of the soil varies between 0—20 mm/hour, water permeability between 0—35 mm/hour. The water: air ratio of 95 : 5 (measured at field capacity) indicates that the aeration of the soil is unsatisfactory. The analytical data of a characteristic soil profile from the experimental site are given in Table 1.

Before 1977 the natural plant cover of the area consisted of the following plants: *Festuca pseudovina, Alopecurus pratensis, Hordeum hystrix, Plantago tenuiflora, Artemisia maritima* ssp. *salina, Matricaria chamomilla, Achillea millefolium* ssp. *collina, Statice gmelini*, etc.

The experimental site is situated within the geographical region of Nagykunság, which is the warmest, the most continental part of the Hungarian Plain, though its temperature fluctuations are the most extreme according to the national meteorological observations. Annual precipitation amounts to 520 – 560 mm. June is the rainiest month, the winter is very dry; precipitation is usually slightly more in autumn than in spring (KOKAS [3]).

Layout of the experimental site and system of measurements

The experiment is of the large-plot, long-term, model type (CSAPLÁR [1]). The treatments and their layout are shown in Fig. 2. Size of plots: 40 m × 100 m = 0.4 ha.

The physical and chemical amelioration of the B horizon was carried out using a TLC type plough constructed at the Karcag Research Institute of the Debrecen University of Agrarian Sciences (the amendment was mixed into the soil with a fraise) and with a VIMA-2 deep loosener (the amendment was placed in vertical strips). Depending on the chemical soil properties, limestone powder and phosphor gypsum were applied as amendments.

The drain pipes were laid down at an average depth of 0.80 – 0.90 m. They consist of flexible plastic pipes 0.05 m in diameter. The suction drains are 100 m long, with a min. slope of 1‰ and a max. slope of 3‰. The closed collector drain consists of a plastic pipe 0.05 m in diameter (FEHÉR [2]). The suction drains were installed using a ditch-opening technique. 0.55 m below the surface a sandy gravel layer was spread on the bottom of the ditches.

The indicator plants used in the experiment were:
– 1977/78: winter wheat (Var. *Bezostaya 1)*
– 1978/79: winter wheat (Var. *Bezostaya 1)*
– 1980: lucerne (Var. *Szarvasi 1)*.

Soil cultivation was carried out uniformly and simultaneously. After determining the readily soluble nutrient content of the soil, fertilizers were applied according to the directives on mineral fertilization published by the Centre for Plant Protection and Agrochemistry of the Hungarian Ministry for Agriculture and Food.

Hydrological, hydrometeorological and pedological data are regularly collected on the site and the water quality is also tested (Fig. 3).

Results of soil moisture regulations

The investigations were carried out in the upper 60 cm thick soil layer, that is, to the depth of mechanical and chemical amelioration, because it is the condition of this layer which influences the velocity of horizontal and vertical water movements in the soil.

The absolute moisture content was determined (in volume %), then, on the basis of the pore volume of the various layers, the relative moisture content was calculated in order to study the changes in the water : air ratio in the various soil layers, because it is very important from the point of view of plant production. On the basis of the findings special attention was paid to investigating the development and length of permanence of an 80 : 20 water : air ratio,

Table 1

Physical and chemical characteristics of a representative soil profile

Depth, cm	Horizon	Water soluble salt content, %	Particle size distribution, % 0.25—0.05 mm	0.05—0.01 mm	0.01—0.005 mm	0.005—0.001 mm	0.001—0.0001 mm	Bulk density, g/cm³	pF values, vol. % 0	0.4	1.5	2.5	Humus %	$CaCO_3$ %	pH H_2O	pH KCl
0— 5	$A - A_0$	0.13	3.0	39.7	11.7	20.5	25.1	1.21	54.2	51.3	45.3	41.4	4.34	—	5.90	5.09
5— 15	A_1	0.12	0	28.2	12.1	18.9	42.0	1.41	51.9	50.2	49.6	46.7	3.44	—	6.30	5.22
15— 40	$B - B_1$	0.31	0	23.9	9.0	18.3	50.6	1.45	58.4	55.7	55.2	52.6	2.18	—	7.27	6.15
40— 70	B_2	0.56	0	19.6	12.4	16.5	52.1	1.47	59.6	56.9	56.3	54.5	1.15	0.5	8.30	7.12
70—100	B_3	0.47	3.6	19.5	15.5	24.8	36.6	1.47	53.5	50.4	49.5	46.9	0.48	14.1	8.63	7.70
100—140	C	0.48	4.0	34.2	7.8	14.7	39.3	—	—	—	—	—	0.31	5.2	8.90	7.85

Depth, cm	Exchangeable cations, me/100 g Ca^{2+}	Mg^{2+}	K^+	Na^+	Aqueous extract (1 : 5) Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}
0— 5	15.0	4.6	0.5	4.2	0.09	0.03	1.60	0.03	0.54	0.38	0.33
5— 15	17.0	7.7	0.8	4.2	0.24	0.09	0.55	0.05	0.42	0.24	0.27
15— 40	15.2	9.1	0.7	11.2	0.63	0.25	0.65	0.05	0.51	0.34	0.74
40— 70	12.8	10.1	0.7	17.0	1.06	0.37	0.95	0.06	0.30	0.44	1.55
70—100	11.4	7.7	0.4	14.0	0.38	0.12	0.68	0.03	0.60	0.12	0.44
100—140	6.8	8.5	0.4	17.0	1.15	0.75	4.70	0.04	0.58	0.30	5.58

which meets the requirements of the plants (80% moisture content) in these soils.

The distribution of precipitation during the two years investigated was also reflected in the changes in the moisture content of the soils in the different treatments (Fig. 4).

In the soils without water regulation, which were only deep loosened and chemically ameliorated in the A and B_1 horizons, detrimentally high moisture content lasting for a longer period of time could not be observed in 1978.

From Dec. 1978 until April 1979 the moisture content in the upper layers of soils without subsurface drainage exceeded 80%, and it damaged both the soils and the plants. A decrease in the moisture content of water saturated

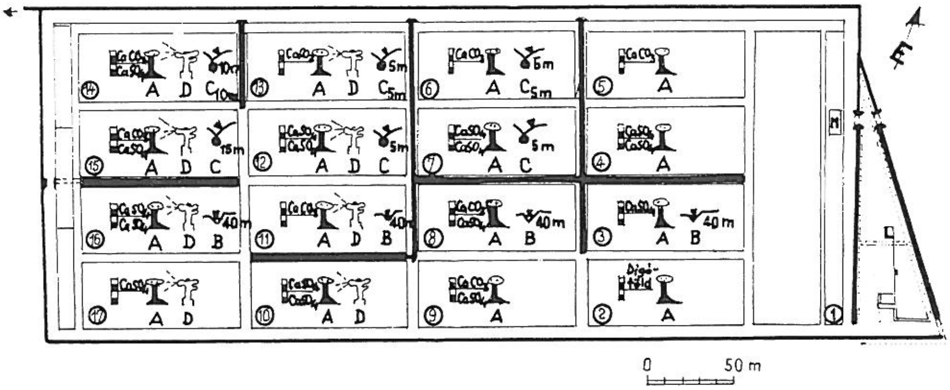

Fig. 2

Treatment applied at the amelioration model site. Legends: ▬ = Drainage ditch or trough; $CaCO_3/CaSO_4$ = amendment used in chemical amelioration (one scale = 10 cm); A = deep loosening to 0.6 m depth; B = Surface drainage at 40 m spacing; C = subsurface drainage with drain spacing indicated; D = irrigated area; M = hydrometeorological instrumental observation station

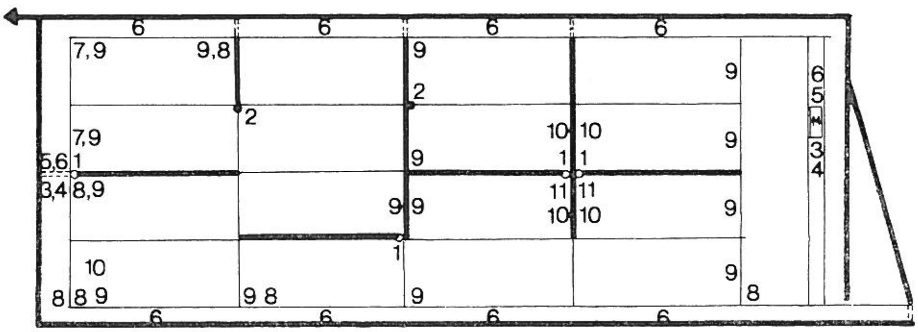

Fig. 3

Observation system at the amelioration model site. 1: Observation of surface discharge and water quality; 2: Observation of drainage discharge and water quality; 3: Precipitation gauge; 4: Recording precipitation gauge; 5: Groundwater well; 6: Piezometer; 7: Row of piezometer wells; 8: Nuclear soil moisture measurement; 9: Electric moisture measurement; 10: Series of soil thermometers; 11: Electric salt probe; M: Hydrometeorological instrumental observation station soils could only take place from above. In a case like this, when the lower soil layers are saturated, the already relatively dry upper layer may become rapidly saturated again even by a light precipitation, and water-logging may occur.

The second treatment in Fig. 4 is the water regulation of the surface: part of the excess water was removed by forming a suitable slope on the surface. The maximum length of water movement was 40 m. The treatment also included deep loosening and the chemical amelioration of the A horizon (0–20 cm).

The moisture regulating effect of subsurface drainage may be seen in Fig. 4/C. It can be observed that the moisture content is regulated and stratified; from the surface downwards the individual layers contain more and more moisture.

Naturally, anomalies in the stratification may occur in the case of a big water load (for instance: a sudden thawing of snow, cloud-bursts, etc.), when the upper soil layer becomes completely saturated, but only for a short period of time. Then a depression is produced in the upper layer by the suction effect of subsurface drainage, which exerts its influence only in the two-phase state of the soil. In the case of a bigger water load (60–80 mm precipitation within 1–2 days) a non-permanent state occurs for 1–2 days and once the drain activity begins the three-phase state is quickly restored in the upper layer. Water-logging does not develop even in this case; in fact the upper 10–15 cm thick layer is still practically in the three-phase state, though the water : air

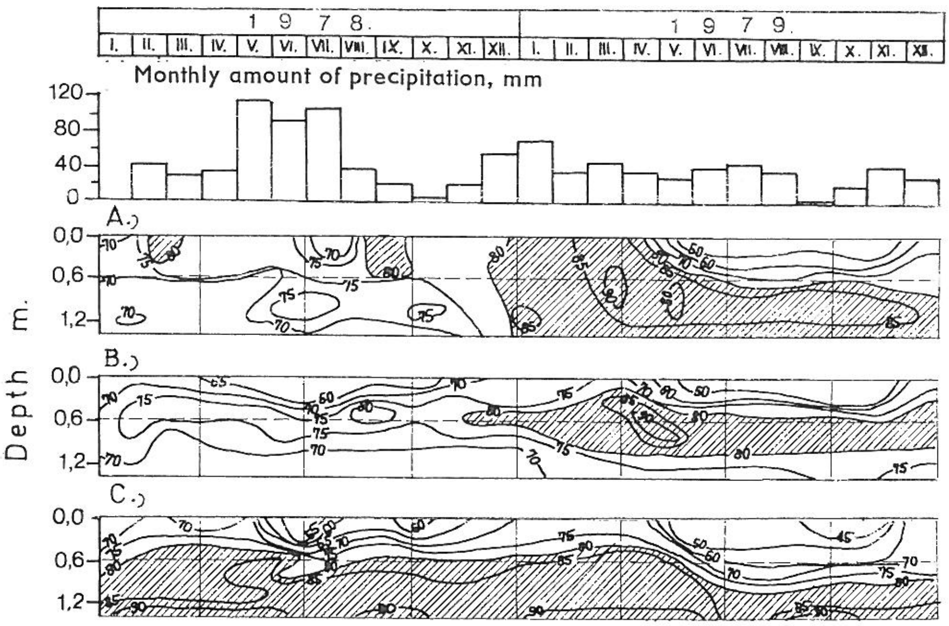

Fig. 4

Moisture content of soils as affected by various treatments. A) Plot without water regulation; the soil was deep loosened and the A and B_1 horizons ameliorated chemically. B) Water regulation on the surface, the topsoil was ameliorated chemically. C) Subsurface drainage (drain distance: 5 m), the topsoil was ameliorated chemically ratio deteriorates because of the tension. These phenomena were observed only in rows of wells placed perpendicularly to the suction drains in the loosened layer, but they could not be registered by soil moisture measurements.

The moisture values which can be seen in Fig. 4 were measured at places halfway between two suction drains (i.e. in the least favourable position for drainage). When studying the data for 1978 of soils provided with subsurface drainage and comparing them with those obtained in the other two treatments, it can be seen that the infiltration was more intensive and the moisture reserves of the soil were considerably greater in the deeper layer. Over a longer period of time the water : air ratio in the ploughed layer (25—30 cm) was always satisfactory.

Fig. 4 shows that subsurface drainage produced a considerably more balanced moisture content in the soil. Compared with the other two treatments,

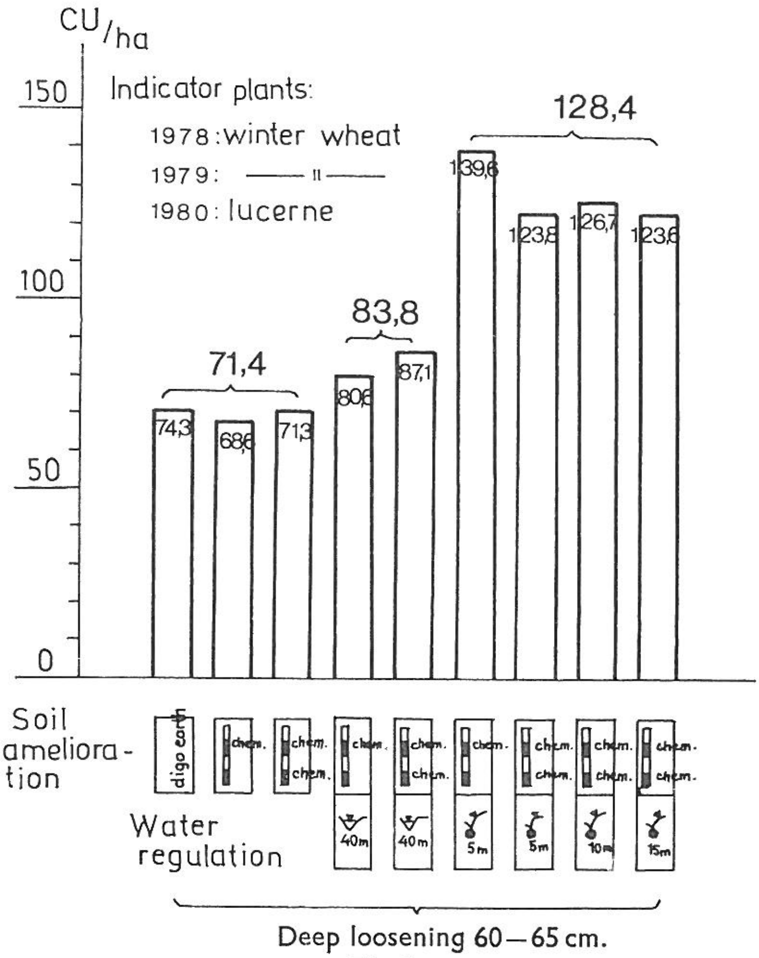

Fig. 5

Effect of agro- and hydromeliorative methods on three-year-yields of indicator plants on alkali soil. Vertical axis: Cereal unit the different effects of the relatively drier year (1978) and the wetter year (1979) cannot be observed here: the moisture distribution is balanced throughout, and the soil profile has ample moisture reserves. Consequently, the drainage system is capable of regulating the moisture content of deep loosened soil layers. On the area provided with subsurface drainage all the precipitation infiltrates into the soil, so the moisture reserves of the soil profile are constantly replenished. At the same time the excess moisture is always removed by the drainage system, thus preventing the saturation of the loosened layer.

On the basis of the trend in soil moisture content on the area provided with subsurface drainage system, the following conclusions can be drawn:

— The water movement towards the suction drains takes place mainly in the loosened layer.

— Deep loosening combined with subsurface drainage promotes drain activity and ensures the removal of harmful excess moisture from the soil profile above the drain pipes.

— With the help of chemical and physical amelioration and subsurface drainage the moisture content of the upper (deep loosened) 60 cm thick soil layer can be regulated in such a way that a water: air ratio worse than 80 : 20, which is considered critical from the point of view of plant production, cannot develop even in extreme cases.

Yield results

The yield increasing effect of treatments can be seen in Fig. 5. for different indicator plants. The data clearly prove that soil moisture regulation and the elimination of detrimental soil compactness are of fundamental importance in increasing the fertility of these soils.

Summary

In the course of research conducted in a complex amelioration model area established on various types of salt affected soils, a system of subsurface drainage and deep loosening was elaborated which has made it possible — even in extremely compacted alkaline soils saline in deeper layers and having a high clay content — to lower the water table or to keep it at a suitable level, and to improve the soil structure by loosening the layers above the tile drains, thus creating proper conditions for crop production.

It has been observed that when deep loosening is accompanied by subsurface drainage, a more lasting after-effect of deep loosening can be expected.

Drainage has exerted a very favourable influence on soil properties, and, consequently, on crop yields. The agrotechnical advantages of this method are particularly noteworthy from the point of view of regional amelioration.

It has been found that the drainage of excess surface waters in itself increases yield stability, so it should be a minimum requirement of complex amelioration. The experimental results also indicate that chemical amelioration of the soil does not significantly influence the effectiveness of the moisture regulation methods used on the experimental site. Therefore it seems to be advisable to revise the present norms of chemical amelioration and to modify the pedological and agrochemical parameters with respect to soil moisture regulation. Also, new norms should be elaborated concerning the applicability of various amelioration methods.

References

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Discussion

GIRDHAR, I. K.
It is very interesting to see that by only deep ploughing the hydraulic conductivity was improved from practically zero to 0.4 m/day. May I know the reason for such a highly significant change? Because even very good chernozem soils with high clay content do not have such a high H. C. as you got in highly deteriorated alkali soil with high clay content. According to your data it means that you have converted the highly sodic soil to good soil. Please comment.
FEHÉR, F.
We created this high value of the hydraulic conductivity with mechanical intervention (i.e. deep loosening). This can be achieved on heavy soils independently from their chemical properties. The condition of stabilizing the high hydraulic conductivity is continuous drainage, lasting saturation of the soil with water must not take place.
YADAV, J. S. P.
(1) When the soil is highly clayey alkali soil and has about zero hydraulic conductivity, it is of interest to know the subsurface drainage is effective?
(2) The author has advocated the benefit of deep loosening (60—65 cm) in improving the water and air movement in the alkali clayey soil. I would like to know how long the beneficial effect of deep loosening on hydraulic conductivity of such soils can last?
(3) When the depth of drainage system is only 80—100 cm, is it adequate to maintain the water table below the critical level?
FEHÉR, F.
(1) The drainage system can work only when deep loosening is carried out. Then the hydraulic conductivity of the topsoil will substantially increase.
(2) It is commonly held that the effect of deep loosening lasts for about 2—3 years. According to our observations, however, hydraulic conductivity has not decreased significantly in the experimental plots even after 4 years. We estimate that the effect of deep loosening lasts for 6—10 years when the soil is provided with adequate drainage.
(3) Due to the effects of drainage and deep loosening, the water table is kept at about 60 cm below the soil surface. This is far above the so-called "critical depth" which is about 1—1,5 m in these soils. In our opinion, however, the "critical depth" of the water table cannot be interpreted in the traditional way if it is ensured that the downward water movements dominate in the cultivated topsoil layer. According to our experimental results the shallow drainage has positive effects and brings about soil improvement.