The Effect of Multi-Layer Reclamation on Meadow Solonetz Soils Turning into Steppe Formation

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The amelioration of salt affected soils has a two-century tradition in Hungary. The problem of how to increase the fertility of these soils, covering several hundred thousands of hectares in the eastern part of the country, has been of high concern, that is why nearly all the researchers working in the field of soil science have dealt with it [2].

Hungarian scientists were not only engaged in studying and describing salt affected soils, but they also advised farmers on how to alter the undesirable properties of the soils.

It was characteristic of the many-sided activity of one of the most outstanding Hungarian soil scientists, ALEXIUS A. J. DE 'SIGMOND (1873 – 1939) that besides investigating the properties and the genesis of salt affected soils, and establishing a scientific basis for their classification, he also studied the theoretical and practical problems of their reclamation.

He grouped the reclamation methods according to those properties of the soils which required amelioration [10]. He ranged "digózás" (i.e. the application of digó-earth — which means that material from deeper subsoil horizons rich in calcium carbonate and devoid of harmful salts is spread on the surface in a 6 – 8 cm thick layer and is mixed with the soil of the plough-layer) as well as the different methods of protection against evaporation among the "physical reclamation" methods. Shadowing the soil surface with opulent leaves aims at reducing evaporation from the soil, thus preventing the ascent of harmful salts to the surface. A sand layer of a few cm in thickness, straw, or any other locally available material can also be used for this purpose.

For the desalinization of salt affected soils 'SIGMOND proposed the following measures:

1. Sweeping the salts from the surface;
2. Leaching the salts down into the subsoil;
3. Removing the salts by thorough leaching.

For the chemical reclamation of these soils he proposed, in the first place, to apply gypsum but he approved of the application of calcium chloride and calcium nitrate, too.

'SIGMOND studied the role that different halophytic plants play in the desalinization of soils. He gave practical advice on the utilization of natural vegetation (mostly grasses) on salt affected soils under irrigated conditions.

The contribution of the junior colleagues and followers of 'SIGMOND to the improvement of reclamation methods was also significant.

The present system of the reclamation and agricultural utilization of salt-affected soils has evolved from the theoretical and practical work of HERKE, ARANY, DI GLÉRIA, PRETTENHOFFER, and others [1, 7, 8, 9].

The depth of the water table, the thickness of the A horizon, the degree of soil alkalinity and salinity, the quality and quantity of salts, all are important factors determining the possibility of the agricultural utilization of salt-affected soils. Naturally, the question of rentability is to be considered as well, since the appropriate reclamation method chosen in view of the properties of the soil necessitates considerable investments.

Of the salt-affected soils chernozem and meadow-chernozem soils salty in deeper horizons, solonetzic meadow soils, meadow solonetzes turning into steppe formation, and meadow solonetzes having an at least 15 cm thick A horizon may be utilized as arable land. Reclamation is necessary also in these cases to ensure the optimum biological conditions for the plants.

By now reclamation has been carried out on about 40% of the 600 thousand hectares of salt-affected soils in agricultural use in Hungary.

Depending on the soil properties chemical ameliorants containing calcium carbonate or calcium sulphate have been used. On territories where soil layers rich in calcium carbonate or gypsum and devoid of salts harmful for plants can be found not deeper than 2–3 meters, reclamation is achieved by "digózás". This technique has been applied in Hungary for almost 200 years.

Since the solubility of these chemical ameliorants is very low, the changes they bring about in the soil properties are slight. In many cases, 8–10 years are needed for the recovery of reclamation expenses [3]. Thus, Hungarian literature on the reclamation of salt-affected soils includes numerous works dealing with the increase of the efficiency of chemical ameliorants. The majority of soil scientists were of the opinion that calcium carbonate could only be applied simultaneously with manuring, since farmyard manure highly increases the solubility of the ameliorant [9].

With the progress in agriculture and industry, however, the amounts of available manure are decreasing, whereas the production of fertilizers has been considerably increased. This calls for a new solution of the problem.

The results of the experiments carried out in the past decade have shown that the favourable effect of manure primarily lays in ensuring the satisfactory nutrient supply of plants. This goal, however, can be reached by appropriate artificial fertilizers, too. In experiments investigating the possibilities of increasing the solubility of ameliorants, the application of sulphuric acid resin — a by-product of oil purification — has proved highly efficient [4, 5].

The above described processes aim at improving the upper 15–20 cm layer of the soil. In this layer, however, the conditions necessary to achieve high crop yields cannot be provided for. That is why the reclamation of the B horizon of undesirable chemical and physical properties is none the less important. Subsoiling is a partial solution of the problem. Based on experimental results, by now subsoiling is widely used in solonetz soils. It gives, however, only a temporary increase of the yields, the chemical soil properties remain unchanged, thus, subsoiling must be repeated every 3–4 years [6, 9, 11].

In the Research Institute for Soil Management at Karcag trials have been carried out for ten years now, aiming at a radical improvement of the unfavourable chemical and physical properties of the B horizon.

Natural conditions of the experimental area

A field experiment was conducted at the research station at Karcag in the Nagykunság area of Hungary, on a meadow solonetz soil turning into steppe formation.

The Nagykunság is situated in the Carpathian basin, at 87–88 m above sea-level. Some centuries ago a considerable part of this territory was permanently or temporarily water-logged. In those parts where the surface- and groundwaters determined the periodically alternating downward and upward movements of the soil moisture, if other factors were suitable, meadow solonetzes were formed. This development was facilitated by the geological conditions, that is to say, by the presence of calcareous clayey loess sediments (from the upper pleistocene period) forming the parent material.

In the past two centuries, however, wide-scale drainage works in the Trans-Tisza-River region have brought about radical changes in the hydrological conditions of this territory. No seasonal water-loggings occur any more and due to the lowering of the water table, the overwhelming influence of water on soil formation has decreased. This started a process of turning the meadow solonetzes into steppes, thus improving the undesirable properties of the soils to some extent.

Apart from the above factors, continental climate has also influenced the development of the soil conditions in the region. Characteristic data of the climatic conditions have been recorded for 50 years. The annual mean temperature is 10.5 °C, the annual average fluctuation of temperature is 24.5 °C; the number of hours of sunshine amounts to 2080, the number of days of freeze is 109.6 per year. The monthly distribution of annual precipitation is given in Table 1.

Evaluation of the precipitation conditions indicates, first of all, that the wet and the dry years, as compared to the average, have varied periodically. Out of the 8 years of the survey period 5 years were more rainy and three years less rainy than the past 50 years' average. In the first half of the survey period the amount of precipitation surpassed the average, while in the second half rainless years were prevailing.

Due to the disadvantageous water regime of the soil, extreme precipitation conditions caused either water-logging or drought on the studied area. This has raised the question of the better utilization of precipitation water.

Tables 2, 3 and 4 present the most important analytical data of the soil of the experimental field. The data in Table 2 indicate that the 15 cm thick A horizon of the soil has a slightly acidic reaction. As to the macro-nutrients, it is well supplied with potassium, poor in nitrogen and the phosphorus supply is medium. The B horizon is situated in a depth of 15–72 cm. This horizon has

Table 1

Distribution of precipitation, in mm (Karcag, 1963—71)

Months	1963	1964	1965	1966	1967	1968	1969	1970	1971	Average of 9 years
January	55.6	2.9	49.3	58.9	34.0	23.8	8.4	58.7	33.2	24.0
February	54.5	13.0	11.8	35.2	20.9	34.4	74.0	39.6	6.8	27.0
March	35.0	50.7	46.2	31.6	14.4	15.8	26.2	41.8	11.0	32.0
April	28.1	34.1	43.1	36.9	46.7	32.9	12.5	38.1	40.8	43.0
May	66.8	55.0	65.6	67.2	73.2	17.7	22.1	93.9	34.8	54.0
June	77.2	98.9	117.6	55.2	71.5	49.3	102.7	69.7	50.1	68.0
July	49.0	34.8	93.9	65.1	31.6	42.1	52.1	34.1	31.4	56.0
August	55.7	53.6	67.3	82.2	87.4	98.3	66.8	122.1	16.1	52.0
September	53.0	57.4	14.9	29.4	64.5	83.4	17.3	4.2	45.0	42.0
October	29.8	87.0	0.6	69.3	16.8	1.8	14.2	7.3	25.2	48.0
November	10.5	17.3	112.4	81.7	11.7	63.3	41.6	55.2	32.6	45.0
December	53.7	82.5	50.6	71.7	26.9	20.4	97.5	50.9	15.4	36.0
Yearly total	568.9	587.2	673.3	684.4	499.6	482.7	536.9	615.6	362.4	527.0

Table 2

Chemical data of the soil

Horizons and sampling depth, cm		pH_{H_2O}	pH_{KCl}	Hydr. acidity	$CaCO_3$ %	Nutrient content			
						Humus	Total N	P_2O_5	K_2O
						%		mg/100 g	
A	(0 – 15)								
	0 – 15	6.3	5.3	13.3		3.7	0.16	7.0	28.0
B_1	(15 – 42)								
	15 – 28	8.2	6.8			2.8	0.15	5.3	22.1
	28 – 42	8.6	7.4			2.0	0.13	4.8	14.0
B_2	(42 – 72)								
	42 – 57	8.8	7.7						
	57 – 72	8.9	7.8	2.3	2.3				
B/C	(72 – 120)								
	90 – 100	9.2	7.8	11.8	11.8				
C	(120 – 150)								
	140 – 150	9.2	7.9	16.7	16.7				

alkaline reaction, and it contains calcium carbonate already at a depth of 52 cm.

Table 3 gives information on the mechanical composition of the soil. It was found to be of heavy texture. These data indicate a solonetz horizon.

The data in Table 4 clearly show that the amount of exchangeable K + + Na-ions constitute 1/5 of the exchangeable cation content, and in the B horizon their quantity amounts to 1/2 of the total.

Table 3

Mechanical composition of the soil, in %

Sampling depth, cm	Hygroscopic water	Loss of acid	Mechanical fraction, in mm						Physical sand	Physical clay
			1.0—0.05	0.25—0.01	0.05—0.005	0.01—0.001	0.005—0.001	<0.001		
	%								%	
0—15	6.10	3.20	0.73	2.96	29.13	9.55	19.30	35.13	32.82	63.98
15—28	9.17	2.75	0.25	1.14	19.55	8.06	18.28	49.97	20.94	76.31
28—42	8.94	2.70	0.06	1.84	17.09	8.92	18.26	51.13	18.99	78.31
42—57	7.62	2.92	0.07	3.70	15.20	13.48	16.85	47.48	18.97	78.11
57—72	6.75	5.23	0.04	2.15	18.16	12.67	18.43	43.32	20.35	74.42
90—100	6.05	14.37	0.09	3.24	16.86	11.19	16.13	38.12	21.19	65.44
140—150	4.25	19.51	0.06	0.26	18.47	16.33	17.21	28.16	18.79	51.70

According to the analytical data the soil in question is a meadow solonetz turning into steppe formation, and this is also proved by the morphological description of the soil profile.

Materials and methods

Starting from the fact that the non-recurrent application of either method known so far does not bring about definite and profound changes in the properties of solonetz soils, in the course of our experiments reclamation was divided into several stages, i.e. certain operations were repeated at definite intervals. Since the impact of subsoiling, which plays an important role in improving the fertility of solonetz soils, lasts for about 4 years, the length of the intervals was fixed in 4 years.

Table 4

Exchangeable cations of the soil

Sampling depth, cm	Ca^{2+}	Mg^{2+}	$K^+ + Na^+$	S	T	Ca^{2+}	Mg^{2+}	$K^+ + Na^+$
	me/100 g soil					in per cent of S-value		
0—15	14.2	7.4	5.3	26.9	33.1	52.8	27.5	19.7
15—28	15.0	7.3	12.5	34.8	37.7	43.1	21.0	35.9
28—42	17.1	8.1	19.3	44.5	45.1	38.4	18.3	43.3
42—57	17.4	7.8	19.4	44.6	45.6	38.8	17.7	43.5

For the chemical improvement of the 15 cm thick surface layer of the soil ground limestone was applied. The required amount of the ameliorant was determined on the basis of the amount of $CaCO_3$ needed for the neutralization of hydrolytic acidity, as well as for the replacement of the exchangeable Na^+ content by Ca^{2+}. This amount was as much as 20 tons of ground limestone per hectare. In some treatments only 1/4 of that quantity was applied but in that case the application of the lower amount was repeated every 4 years.

Table 5

Average yield increases of winter wheat (W)

Treatment: Reclaiming agent for the A horizon	Treatment: Reclaiming agent for the B horizon	Average, 1st four-year period: FYM W	FYM S	Mineral fertilizer W	Mineral fertilizer S
				A. Due to 1 kg	
Limestone, 5 + 5 t/ha	—	2.3	5.2	5.6	7.7
Limestone, 20 t/ha	—	4.6	4.7	6.0	0.2
—	Subsoiling	1.0	0.5	5.4	4.4
—	Subsoiling and 5 + 5 t/ha gypsum	3.5	6.6	3.9	7.2
Limestone, 5 + 5 t/ha	Subsoiling	2.2	6.1	5.2	8.7
Limestone, 5 + 5 t/ha	Subsoiling and 5 + 5 t/ha gypsum	2.9	2.2	4.0	9.3
Limestone, 20 t/ha	Subsoiling	0.0	2.4	3.5	9.8
Limestone, 20 t/ha	Subsoiling and 5 + 5 t/ha gypsum	2.1	6.1	2.1	13.8
$LSD_{5\%}$		1.4	5.5	1.4	5.5
			B. Due to multi-layer reclamation		
Limestone, 5 + 5 t/ha	—	7.2	20.8	12.1	26.6
Limestone, 20 t/ha	—	14.7	29.6	16.3	26.8
—	Subsoiling	13.8	40.1	20.3	48.7
—	Subsoiling and 5 + 5 t/ha gypsum	19.2	50.7	20.5	52.5
Limestone, 5 + 5 t/ha	Subsoiling	16.2	54.7	23.0	60.7
Limestone, 5 + 5 t/ha	Subsoiling and 5 + 5 t/ha gypsum	20.7	58.8	22.3	74.7
Limestone, 20 t/ha	Subsoiling	17.7	47.8	23.0	64.1
Limestone, 20 t/ha	Subsoiling and 5 + 5 t/ha gypsum	23.0	61.3	23.0	73.4
$LSD_{5\%}$		6.2	32.9	6.2	32.9

For the chemical improvement of the B horizon of the soil gypsum was used. 5 ton/ha gypsum spread at the bottom of the furrow was mixed into the B horizon by means of a subsoiler chisel fitted in front of the plough, penetrating the soil 10 – 12 cm deeper than usual. The 5 t/ha of gypsum was applied every 4 years.

The unfavourable water regime of the B horizon of the soil was improved by subsoiling to a depth of 60 cm, with 60 cm row distance. This operation was also carried out every 4 years.

Two kinds of fertilizers were used: farmyard manure and mineral fertilizers. 30 ton/ha manure was applied in one portion at the beginning of the 4-year periods, while the NPK fertilizers of the same nutritional value were applied in stages during the 4 years, in a decreasing percentage of 40, 30, 20 and 10.

The rest of the agrotechnical factors were identical in all treatments. In the test period sorghum and winter wheat *(Bezohstaya)* were grown in yearly alternation, the first crop in each 4-year-period, however, was sorghum.

and of the green matter of sorghum (S)

of the				Average of 8 years			
2nd four-year period							
FYM		Mineral fertilizer		FYM		Mineral fertilizer	
W	S	W	S	W	S	W	S
of NPK nutrient (kg/ha)							
0.1	7.2	1.6	4.4	1.2	6.2	3.6	6.0
1.1	13.6	2.2	11.6	2.8	9.1	4.1	5.7
1.3	17.6	1.1	17.3	1.2	9.0	3.2	10.8
1.6	5.4	0.8	4.3	2.5	6.0	2.3	5.7
1.4	11.9	0.8	11.4	1.8	9.0	3.0	10.0
2.9	5.1	1.4	4.1	2.9	3.6	2.7	6.7
1.0	20.2	0.6	17.5	0.5	11.3	2.0	13.6
1.5	20.0	0.7	10.8	1.8	13.0	1.4	17.3
1.3	8.6	1.3	8.6	1.4	7.1	1.4	7.1
of the soil and fertilizing (q/ha)							
7.3	39.3	9.5	32.9	7.2	30.0	10.8	29.7
6.8	44.5	8.6	39.7	10.7	35.7	12.4	33.2
11.7	65.5	11.4	69.9	12.7	52.8	15.8	54.3
12.8	86.9	11.6	85.0	16.0	68.8	16.0	68.7
13.7	82.1	12.6	76.1	16.0	68.4	17.8	68.8
17.3	104.0	15.1	102.3	19.0	81.4	18.7	88.5
13.9	89.2	13.2	83.8	15.8	68.5	18.1	73.9
15.8	116.1	14.6	95.4	19.4	88.7	18.8	84.4
2.1	19.4	2.1	19.4	4.2	26.1	4.2	26.1

Results and discussion

In the last decade, experiments testing the possibilities of multi-layer soil reclamation have gained increased importance in improving the fertility of solonetz soils in Hungary. The results of a field experiment, started in 1963, are used as the basis for comparing the effects of the chemical amelioration of the soil surface and of multi-layer reclamation. The results also provide an answer to the question put earlier, i.e. whether farmyard manure should be used or not with ground limestone for chemical reclamation.

We examined these questions with agricultural practice in view, i.e. we intended to develop a reclamation method more practicable and more efficient than those applied before. Thus, when drawing the conclusions, in addition to the rate of yield increase, the rentability of this increase was also seriously taken into account.

Table 5 demonstrates the figures on the efficiency of farmyard manure and mineral fertilizers. In the first four-year period, in all cases the efficiency of mineral fertilizers substantially exceeded that of manure. In the case of surface chemical amelioration, this difference was somewhat decreasing, yet, even here, the efficiency of manure was less than that of mineral fertilizers.

In the second four-year period the specific effectiveness of farmyard manure was somewhat higher than that of the mineral fertilizers at plots where multi-layer reclamation was performed. In the case of surface chemical amelioration, however, just like in the previous stage, mineral fertilizers produced a much greater increase in the yields than manure.

In the average of the eight years of the experiment the efficiency of manure exceeded that of mineral fertilizers only if in multi-layer reclamation a large amount of ground limestone was applied. The difference, however, was not significant even then.

Based on the experimental data the conclusion may be drawn that, in the average of eight years, the yield increasing effect of mineral fertilizers surpassed that of manure containing an equivalent amount of NPK active agent. This difference was of particularly great importance if the chemical agent was added in small dosage, yet periodically.

These conclusions are confirmed by the data in Table 5. The average yield increase in treatments with mineral fertilizers was generally higher than with manuring. If the soil properties allow the chemical amelioration of solonetz soils with limestone, the application of organic manure becomes dispensable.

Data concerning the efficiency of multi-layer reclamation of meadow solonetzes turning into steppe formation are also given in Table 6.

For a correct evaluation of the increase of yields brought about by reclamation, we must bear in mind that the plots where no reclamation and no fertilizing were effected (absolute control plots) in the first four-year-period the average yield of wheat was 19.8, in the second 12.9, and the average yield of the green matter of sorghum amounted to 112.7 and 100.2 quintals per hectare, respectively. In the years 1968 – 71 the effect of the unfavourable precipitation conditions was thus reflected also in the amount of yields.

Should we consider the average yield increases of the eight years, we can establish that large doses of ground limestone proved to be more efficient than smaller ones. If this fact alone were taken into account when evaluating the difference between the efficiencies of the two dosages of ground limestone, we might draw erroneous conclusions.

We wish to emphasize that during the period from 1964 to 1967 the whole amount of ground limestone required, i.e. 20 tons/ha, was applied at once for the chemical reclamation of the surface in one treatment while in the other only 5 tons/ha was given. Thus it is understandable that in the course of the first four-year period of the experiment larger yield increases were obtained with the higher dose of ground limestone than with the lower one.

At the beginning of the period 1967 – 71 the low dose treatment was repeated on the plots that had received 5 tons/ha limestone. As a result, the difference experienced before completely disappeared. Accordingly, the difference in the average yield increases of the eight years was the remainder of the first four-year period. We assume that during the third, subsequent period the effect of the small dosage will exceed that of ground limestone applied in one, large dose.

Another important fact that the results of the experiment indicate is that the yield increasing effect of subsoiling greatly exceeds the effect of chemical amelioration carried out on the surface only. It must be remarked that subsoiling was repeated every four years.

Based upon the experimental data, it can also be stated that the yield increasing effect of reclamation carried out in the B horizon was approaching the effectiveness of surface chemical amelioration. The results achieved should be all the more appreciated as the chemical amelioration of the B horizon in this experiment could be performed only by using a primitive technique.

Finally, the results of the experiment prove that our opinion concerning the multi-layer reclamation of the soil was correct. With the joint application of the above-mentioned amelioration methods, the fertility of the soil was doubled. In some cases, the average yield increase of wheat exceeded 18–19, and that of the green matter of sorghum about 100 quintals per hectare.

These results have encouraged us to improve the reclamation techniques used for improving the B horizon. This necessitated a study into the rentability of the increase of yields.

When comparing the costs of the various treatments and the obtained yield increases it became evident that from the economic point of view the best way to increase the fertility of meadow solonetz soils turning into steppe formation is by multi-layer reclamation, provided mineral fertilizers are used.

Summary

For the time being in Hungary the reclamation of meadow solonetz soils turning into steppe formation means the chemical reclamation of the upper, 15–20 cm thick soil layer. For this purpose substances containing $CaCO_3$ are applied. In order to increase the efficiency of the ameliorant, the application of lime is combined with manuring.

In the Research Institute for Soil Management at Karcag, we have sought to improve the fertility of solonetz meadow soils turning into steppe formation by performing subsoiling in the B horizon of the soil, as well as by chemical amelioration with gypsum from the early sixties. The process of reclamation was divided into four-year periods. The chemical amelioration of the surface layers of the soil was carried out with a smaller dose of ground limestone and this treatment was repeated every four years. The same method and subsoiling were applied for the amelioration of the B horizon. We also compared the efficiency of farmyard manure and that of mineral fertilizers, in order to check whether liming should be accompanied by manuring or not.

The other agrotechnical factors were identical in all the treatments. On the experimental field, sorghum and winter wheat were grown in alternating years.

The present paper contains the data on the yields of two four-year-periods (1964–67 and 1968–71).

On the basis of the experimental data, the following conclusions may be drawn:

1. The yield-increasing effect of mineral fertilizers surpassed that of farmyard manure of the same nutritional value. This difference was particularly significant when the chemical ameliorant was applied in reduced portions, yet periodically. The application of mineral fertilizers, in each case, involved smaller expenses.

2. The greatest relative increase of yields at the lowest cost was brought about by the multi-layer reclamation of the soil, since chemical amelioration with smaller doses of ameliorants, as well as subsoiling are inexpensive, as compared to surface chemical amelioration.

3. Relying upon the experiences gained during the eight years of the experiment, we have elaborated the techniques for the chemical amelioration of the B horizon. The equipment developed for this purpose is being tested. We hope that by the application of the improved technique the fertility of meadow solonetz soils turning into steppe formation can be increased to an even higher extent than described above.

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