Amelioration and Utilization of Solonetzes in the Region East of the River Tisza

I. PRETTENHOFFER
Research Institute for Soil Cultivation, Karcag (Hungary)

In the region east of the river Tisza the amelioration of the non-calcareous solonetzes both with liming and with the application of "digó-earth" has been carried on for decades. Both methods have proved to be effective. The extent of the ameliorated solonetz soils is more than 120 000 ha. The fundamental findings of 'SIGMOND on the physico-chemical processes of the formation of salt affected soils made it possible to start the research on the possibilities of their amelioration and provided a good scientific basis for the investigations. Based on his initiatives and proposals, the Ministry of Agriculture adopted the first official measures to ameliorate the non-calcareous solonetz soils in the year 1928. The small landowners received state support for the improvement of these solonetzes.

1/1. The main characteristics of non-calcareous solonetzes (meadow solonetz soils turning into steppe formation) are the extremely unfavourable physical properties. The upper layer of the soil profile is non-calcareous. The total salt and exchangeable Na content of the A horizon is generally low, soil reaction is slightly acidic or about neutral. Under this mouse-grey horizon a compact accumulation horizon (B) darker in colour can be found. As a rule, it has columnar structure and relatively high salt and exchangeable Na content. The possibilities of the agricultural utilization of solonetz soils are determined, first of all, by the thickness of this upper, non-calcareous, slightly saline A horizon. The thicker this layer, the higher is the soil's fertility because the underlying B horizon has very unfavourable agronomic properties.

The classification of salt affected soils, worked out by 'SIGMOND, was widely used all over the world and it served also as a basis for the grouping of salt affected soils according to the possibilities of their amelioration. These grouping systems are summarized in Table 1. They are based on the reaction of the topsoil, on the genetic soil type and on the methods of amelioration most suitable for the different types or varieties.

In this grouping the thickness of the non-calcareous topsoil decreases, while soil salinity and alkalinity increase with increasing serial numbers.

The large-scale mechanized amelioration of non-calcareous solonetzes was started in 1947. For the effective and economic amelioration of solonetzes on a large-scale mainly two methods were used: liming and the application of "digó-earth" (calcareous soil from deeper horizons, the so-called "digó-earth", is spread on the surface of solonetzes in a 6—8 cm thick layer, and then mixed with the ploughed layer). It was necessary to determine that to what

Table 1

Classification and grouping of salt affected soils in Hungary based on the possibilities of their amelioration

Serial number	Classification according to SIGMOND	Genetic classification	Grouping for amelioration purposes		Methods for amelioration (according to PRETTENHOFFER)
			original	revised	
1	leached and degraded alkali soils	Deep meadow solonetz turning into steppe formation	Non-calcareous	Non-calcareous, slightly acidic	*a)* Liming* *b)* Application of "digó-earth" (calcareous subsoil)*
2	leached alkali soils	Deep and medium meadow solonetz turning into steppe formation	Non-calcareous	Non-calcareous, about neutral	
3	leached and regraded alkali soils	Medium meadow solonetz turning into steppe formation and deep and medium meadow solonetz	Transitional	Non-calcareous, slightly alkaline	*a)* Combined application of lime and gypsum* *b)* Combined application of humus containing, non-calcareous, slightly acidic topsoil "underspreading" and "digó-earth". Application of gypsum containing "digó-earth"
4	alkali soils	Medium and shallow meadow solonetz	Calcareous, soda-containing	Alkaline, calcareous, with structural B horizon	Gypsum and gypsum by-products, lignite dust; $CaCl_2$, H_2SO_4 HCl containing- and other acidic by-products*
5	salty alkali soils	Solonchak-solonetz	Calcareous, soda-containing	Highly alkaline, calcareous, signs of a structural B horizon	

* Subsoiling to a depth of 55 – 60 cm is also necessary

extent the effectiveness of these techniques depended on the soil properties. The optimum quantity of the reclaiming material (ground limestone, lime sludge from sugar factories and other lime byproducts) that could be used economically, had to be determined just as the permissible Mg content of the amendments, and the permissible salt and Na_2CO_3 content of the subsoil to be used. These problems were studied in a great number of long-term field experiments (lasting for 12 – 20 years) conducted on different varieties of solonetz soils (Kelemenzug, Hortobágy, etc.).

On the basis of the results of these long-term field experiments it can be stated that liming is effective only on those non-calcareous solonetzes, where the pH of the topsoil is slightly acidic or neutral (Table 2). If the reaction is alkaline the efficiency of liming is significantly lessened because the solubility of $CaCO_3$ sharply decreases, the Ca^{2+} ion concentration in the soil solution becomes much lower and. consequently, the possibilities of $Na^+ - Ca^{2+}$ ion exchange are very limited.

Table 2

Some characteristic data of the experimental fields' soils

Sampling depth, cm	pH_{H_2O}	pH_{KCl}	Hydrolytic acidity Y_1	Total salt content %	Alkalinity against phenolphtalein (expressed as soda content) %	$CaCO_3$ %	Sticky point according to ARANY	Height of capillary rise after 5 hours
Non-calcareous solonetz (slightly acidic) (Kelemenzug, Lukács-telep)								
0 – 10	6.0	5.4	7.5	0.04	—	—	42	80
10 – 20	6.3	5.6	6.0	0.04	—	—	43	65
20 – 30	6.6	6.1		0.05	—	—	42	50
30 – 40	7.3	6.8		0.07	—	—	48	40
40 – 50	7.5	6.9		0.10	—	—	64	30
50 – 60	7.6	7.0		0.16	traces	traces	64	45
60 – 70	8.2	7.2		0.23	traces	1.8	65	30
70 – 80	8.5	7.6		0.23	traces	6.8	65	40
80 – 90	8.6	7.7		0.27	traces	10.9	64	60
90 – 100	8.6	7.7		0.28	traces	14.0	62	90
Non-calcareous solonetz (neutral) (Kelemenzug, Lukács-telep)								
0 – 10	7.0	6.2	5.8	0.06	—	—	44	70
10 – 20	7.2	6.4	4.8	0.07	—	—	48	40
20 – 30	7.3	6.3		0.11	—	—	54	70
30 – 40	8.1	6.6		0.12	traces	traces	62	55
40 – 50	8.3	6.9		0.19	traces	2.5	69	50
50 – 60	8.5	7.0		0.24	traces	6.8	65	65
60 – 70	8.6	7.3		0.30	traces	12.4	66	110
70 – 80	8.6	7.4		0.34	0.02	11.7	69	80
80 – 90	8.7	7.6		0.34	0.02	17.5	56	90
90 – 100	8.7	7.5		0.38	0.12	12.8	57	85
Non-calcareous slightly alkaline solonetz, salty in deeper layers (Kelemenzug)								
0 – 10	7.7	6.2	4.2	0.14	—	—	49	
10 – 20	7.8	6.2	3.2	0.20	—	—	50	
20 – 30	8.0	6.5		0.30	—	—	68	
30 – 40	8.0	6.6		0.61	traces	—	73	
40 – 50	8.1	6.8		0.80	traces	traces	84	
50 – 60	8.2	7.4		1.02	0.08	2.2	75	
60 – 70	8.4	7.6		0.90	0.08	9.1	77	
70 – 80	8.3	7.6		0.90	0.05	13.4	64	
80 – 90	8.9	7.8		0.61	0.15	17.1	78	
90 – 100	8.9	7.8		0.48	0.15	15.9	77	
Non-calcareous slightly alkaline solonetz, containing Na_2CO_3 in deeper layers (Szelevény)								
0 – 10	7.8	6.8	3.2	0.10	traces	—	39	
10 – 20	8.2	7.0	3.1	0.19	traces	—	46	
20 – 30	8.4	7.2	—	0.18	traces	—	44	
30 – 40	9.0	7.5		0.19	0.06	traces	92	
40 – 50	9.3	7.9		0.19	0.15	1.4	86	
50 – 60	9.3	8.0		0.23	0.15	5.8	97	
60 – 70	9.4	8.0		0.19	0.16	6.1	96	
70 – 80	9.4	8.0		0.20	0.19	12.1	81	
80 – 90	9.4	8.0		0.19	0.23	11.8	84	
90 – 100	9.4	8.0		0.20	0.24	14.0	98	

The effect of liming materials depends not only on their $CaCO_3$ content but also on their particle size distribution and on the favourable and/or unfavourable accessory materials in them. The best liming material is lime sludge from sugar factories because of its very fine (mostly colloidal) particle size and considerable plant nutrient (P, N) content. The field experiments performed with liming materials of various $MgCO_3$ content proved that even if the amendment contains up to 18–20% of that compound, it influences the quantity of exchangeable Mg^{2+} in the soil only slightly, if at all.

Reclamation with "digó-earth" can be effective if the maximum quantity of neutral Na-salts does not exceed 0.5–0.8% in it, because in this case these salts are leached out of the topsoil after amelioration. If the "digó-earth" contains Na_2CO_3, the applicability of this method depends on the reaction of the upper layers of the solonetz.

Due to the effect of amelioration performed either by liming or by the application of "digó-earth", the extremely disadvantageous physical properties of the solonetz soil change favourably, the soil becomes crumbling and loose, more permeable to water, easier to till and, consequently, crop yield increases considerably.

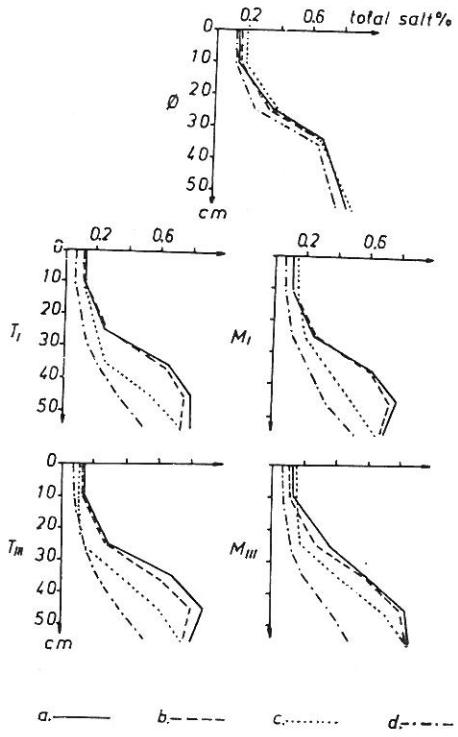

Fig. 1
The changes in the salt profiles of soils in the long-term field experiment. Treatments: Ø — control; T_I — 260 m³/ha; T_{III} — 780 m³/ha calcareous subsoil; M_I — 260 q/ha; M_{III} — 780 q/ha sugar factory lime sludge. a. before amelioration; b. after 2 years; c. after 4 years; d. after 13 years

The crop yields obtained in long-term (20 years) experiments on solonetz soils ameliorated either with liming or with the application of "digó-earth", are presented in Table 3. The data show that the crop yield increase was 10–11.5 q/ha (in terms of wheat units). Similar crop yield increases were measured in long-term experiments performed on other varieties of non-calcareous solonetz soils.

The crop yields and the changes in some soil characteristics show that there is no difference in the effects of small and high dosages of the amendments in case of normal tillage practice (20 cm deep ploughing). In case of deeper tillage (25–30 cm) — which can be permitted on deep solonetzes — probably also the medium dosage is efficient.

The increase of crop yields is brought about not only by better nutrient supply, but, first of all, by the improved chemical and physical properties of the soils. The regular analysis of the soil profiles during the experiment indicated the rela-

tionships between the changes in the soil properties and the crop yield increases. Especially the decrease of exchangeable Na^+ is remarkable. According to the investigations carried out in the 13th year of the experiment, a further decrease of exchangeable sodium could be measured together with a further increase of crop yields. The thickness of the A horizon increases (Fig. 1), the total water soluble salt content gradually decreases (Fig. 2).

Table 2 shows that the two methods are almost equally effective for the amelioration of non-calcareous solonetzes. Salt regime studies and the measured changes in the exchangeable cation composition clearly indicate that the effect of liming or "digó-earth" is not limited to the top horizons, but slowly and gradually the lower layers are improved as well. It means that on solonetzes with deep water table the effect of amelioration can be regarded practically as permanent.

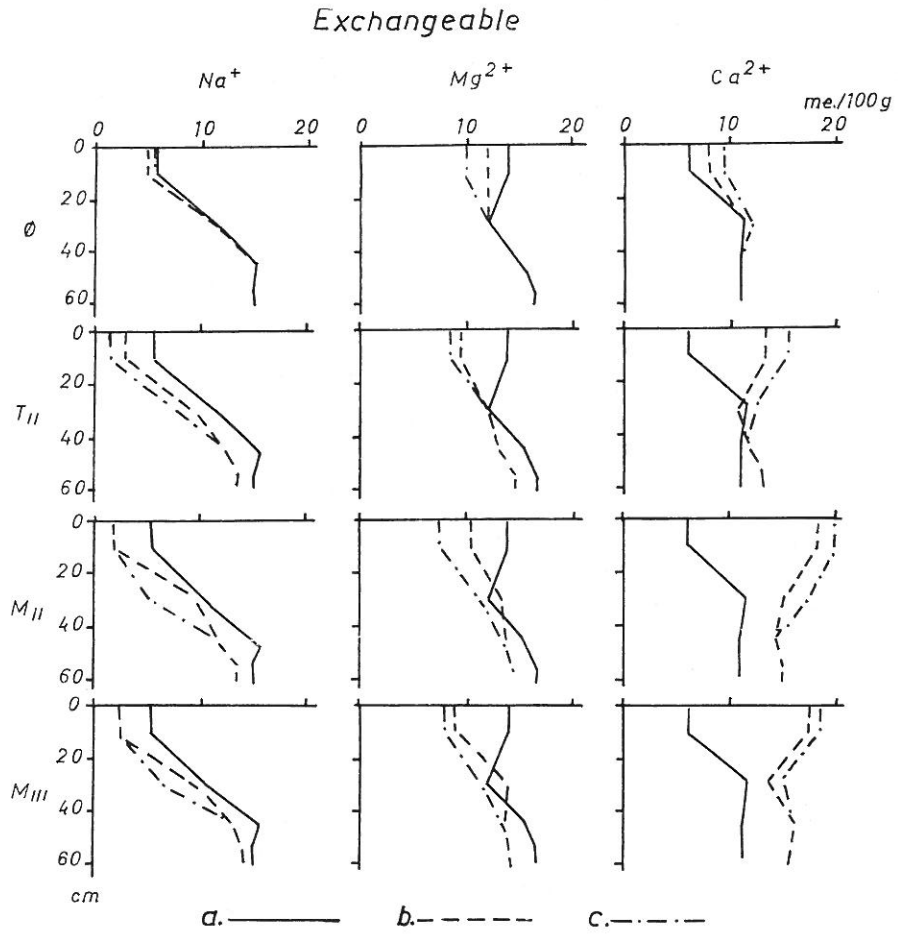

Fig. 2.

The changes in the exchangeable cation profiles of soils in the long-term field experiment. Ø — control; T_{II} — 520 m³/ha calcareous subsoil; M_{II} — 520 q/ha; M_{III} — 780 q/ha sugar factory lime sludge. a. before amelioration; b. after 4 years; c. after 13 years

Concerning the economical aspect of large-scale soil amelioration it can be stated that the surplus of crop yields due to liming or to the application of "digó-earth" is about 9.5 q/ha wheat units, which means that the expenses of amelioration are recovered in about 3 years. After amelioration not only cereals can be grown successfully but various other crops, including alfalfa, too.

To obtain "digó-earth" previously the so-called "ditch-system" was used, involving heavy manual labour. "Digó-earth" was taken from the ditches. At present only the so-called "mine-system" is used. "Digó-earth" of good quality (high $CaCO_3$ content, low salinity and alkalinity) is excavated from a large pit, the so-called "digó-mine". In large-scale agriculture only this system can be used properly. The old manual method of amelioration (using tumbrels and hand harrows) was first replaced by excavators and now by scrapers.

1/2. For the amelioration of the worst, slightly alkaline solonetz spots or patches, occurring among the non-calcareous solonetzes, neither liming nor the "digó-method" can be used successfully. If the upper soil layer is alkaline (pH over 7.5) the solubility of $CaCO_3$ is sharply reduced, therefore the result of the amelioration is not satisfactory. For the amelioration of these soils the author elaborated the following methods:

a) Application of lime + gypsum;

b) Spreading "digó-earth" over a previously applied layer of black earth;

c) Spreading gypsum containing subsoil.

ad *a)* In case of the combined application of lime and gypsum, soil alkalinity is reduced by the added small amount of gypsum, thus the solubility of $CaCO_3$ increases.

ad *b)* First, the black, humous, non-calcareous, slightly acidic top layer of the "digó-mine" is spread on the surface of the salt affected soil and the "digó-earth" is applied on the surface of this black soil cover. The role of this understratified black earth is similar to that of gypsum, it decreases alkalinity and so increases the solubility of the $CaCO_3$ content of "digó-earth".

ad *c)* If the "digó-earth" contains, in addition to $CaCO_3$, 1—2% gypsum, too, it can be used for the amelioration of slightly alkaline solonetzes, as well.

The experimental results prove that with these methods a yield increase amounting to 15—40% may be obtained.

Both on non-calcareous, slightly alkaline and soda solonetzes the $CaCl_2$ containing materials are the most effective according to the results of long-term experiments carried out with various acid substances and acidic industrial by-products. Next in effectiveness follow the different sludges from sulfuric acid factories and the varieties of gypsum sludge. Lignite dust was effective on soda solonetzes but on non-calcareous solonetz it has only negligible effect, because of the lack of calcium. After amelioration with $CaCl_2$ the Cl^- ions were practically leached out of the solonetz soils of lighter texture within a year, therefore it had no harmful effect.

The amelioration was based on detailed soil survey and laboratory analysis (large-scale soil maps and cartograms, analytical data, etc.). The spreading of the ameliorating materials and mixing them with the upper layer were fully mechanized.

The results of long-term field experiments carried out on various kinds of non-calcareous solonetzes proved that deep plowing of these soils was not

Table 3

Average crop yields in the long-term field experiment on the amelioration of non-calcareous solonetz soils (expressed as wheat "units", q/ha)

Treatments	1.	2.	3.	4.	Average of 20 years		
	average of 5 years				Yield q/ha	Surplus q/ha	Yield %
	1948–52	1953–57	1958–62	1963–68			
1. ∅	7.0	6.2	15.1	16.5	11.2	—	100.0
2. T_I	15.1	21.8	21.1	25.2	21.1	9.9	188.4
3. T_{II}	15.4	22.6	20.8	26.1	21.6	10.4	192.3
4. T_{III}	16.0	23.6	20.5	27.6	21.7	10.5	193.8
5. M_I	16.1	25.9	20.6	23.7	21.9	10.7	195.5
6. M_{II}	16.6	24.8	21.0	26.2	23.1	11.9	206.3
7. M_{III}	17.0	25.6	19.9	26.8	22.7	11.5	202.7
$LSD_{5\%}$	3.5	4.3	3.8	5.6	—	5.0	44.6

1. ∅ = untreated control
2. T_I = spreading with calcareous subsoil 260 m³/ha
3. T_{II} = spreading with calcareous subsoil 520 m³/ha
4. T_{III} = spreading with calcareous subsoil 780 m³/ha
5. M_I = liming (lime sludge from sugar factory) 260 q/ha
6. M_{II} = liming (lime sludge from sugar factory) 520 q/ha
7. M_{III} = liming (lime sludge from sugar factory) 780 q/ha

effective. Subsoil-loosening (without turning and mixing the soil layers) seems to be a very good method for the cultivation of solonetzes. Due to the effect of mechanized subsoil loosening, the crop yield increases, on the average, by 15% on non-calcareous (near neutral) varieties of solonetzes, and by 25% on the slightly alkaline varieties. Subsoiling (50–60 cm deep) can, therefore, be regarded as a good supplementary method of solonetz amelioration.

In small plot field experiments the 30–60 cm deep manual subsoiling results in 21–77% yield increases. The difference in effectiveness clearly indicates the necessity of the further improvement of the subsoiler machines. The effect of the three blade deep subsoiler constructed on the proposal of the author was greater than that of the commonly used one.

The yield increasing effect of subsoiling was the greatest on hoed plants (44%), while in the case of fodder crops and cereals the increase was only 25.5% and 20.9%, respectively. Salt regime studies reveal that subsoiling results in a certain leaching of water soluble salts from the soil profile.

On the basis of our long-term experiments we elaborated and suggested a complex method for the amelioration of solonetz soils. The main elements of this are: water regulation, chemical improvement and deep subsoiling.

1/3. An important practical problem is the amelioration of sodic solonetzes occurring among the chernozem soils. They hinder proper tillage and large-scale agrotechnics. The amelioration of these soils can be carried out successfully with the application of gypsum, lignite dust or $CaCl_2$ containing materials, and shallow-ploughing. With deep-ploughing (30–35 cm) the highly alkaline, soda containing B horizon is turned to the surface and causes a considerable decrease in crop yields. The improvement of the whole 30–35 cm thick layer

would be very costly, large amounts of amendment would be needed. Therefore the author elaborated a special method for the amelioraton of these sodic-solonetz spots. First their 20 cm thick upper layer was improved by gypsum application, after that the subsoil was loosened to a depth of 60 cm on the salt affected spots and on their environment first in one direction, then across. As the next step, an about 15 cm thick layer of chernozem soil (scraped off the surface of the surrounding fertile land) was spread on the sodic solonetz spots. This accomplished, the field could be ploughed to a depth of 35 cm without any damage. According to long-term, large scale experiments, after this amelioration the sodic solonetz spots can be used even for corn production.

II. Effective irrigation on solonetz soils is possible only after their amelioration. Amelioration increases the efficiency of irrigation and their positive interaction results in high yield increases. According to our experimental data, under irrigated conditions liming increased the yields by 208%, the application of "digó-earth" by 164%.

On solonetz and meadow soils amelioration increases the rice yield only slightly or not at all, but it creates favourable possibilities for subsequent irrigated farming. If irrigation and rice growing is combined with amelioration, the salt content decreases considerably only in the light-textured varieties of non-calcareous solonetzes.

In our experiments the ameliorating effect of flooding and rice growing was insignificant.

III. Natural grassland vegetation reflects the alkalinity degree of the soil. This relationship can be used both in soil survey (indicator plants) and in selecting the best way to utilize salt affected areas.

Long-term experiments (1930—1961) on the improvement and utilization of natural grasslands on solonetz soils showed that liming alone resulted in an average annual hay-yield increase of 7.8 q/ha on non-calcareous, almost neutral solonetzes. On other non-calcareous solonetz varieties having worse properties, liming was not effective. In their case lignite dust brings some moderate results only if it is used together with $CaCO_3$. It gives nearly as good results as amelioration with lime and gypsum.

Both earlier (1932—1950) and more recent (1958—1961) fertilization experiments on these natural grasslands showed that where *Festuca pseudovina* is the dominant plant, first of all N fertilization is effective. The application of 0.34—1.06 q N/ha increased the hay-yield by 4.2—8.8 q/ha on non-reclaimed and by 6.9—13.0 q/ha on ameliorated solonetz grasslands. This data proves that due to soil amelioration, the water management of the grassland soil improved and the efficiency of N fertilization was much better. With an increase in alkalinity the effectiveness of N fertilization with or without amelioration is reduced; therefore the N fertilization of grasslands on strongly alkaline solonetz soils is not economic. The effect of P fertilization on these solonetz grasslands manifests itself first of all in the favourable changes in the species composition of the natural grass vegetation (absolute and relative increase of the occurrence of papilionaceae and other valuable species). N fertilization is most effective on low-lying and periodically waterlogged grasslands with *Alopecurus pratensis* association where, as a result of the application of 0.34—0.71 q N/ha and 0.71—1.06 q N/ha the surplus in hay-yield was 10.9—17.0 q/ha and 39.8—45.8 q/ha, respectively.

Table 4

The hay yields (q/ha) in a grassland experiment on non-calcareous solonetz soils

	Non-calcareous solonetz soil (neutral)		Non-calcareous solonetz soil (slightly alkaline)	
	without amelioration	with amelioration	without amelioration	with amelioration
Without irrigation average yields of 4 years	25	48	8	40
With irrigation average yields of 2 years	35	80	20	65

Due to the effect of amelioration, the vegetation of the grassland gradually becomes denser, grows more and more vigorously and the more valuable grass species and clover become dominant. The proportion of these can be increased by P fertilization.

The detailed soil investigations in the long-term field experiments on grassland amelioration showed favourable changes in the soil properties, as well.

Amelioration combined with irrigation is an even better method for the improvement and utilization of grasslands on non-calcareous solonetzes. According to the experimental results liming greatly increases the efficiency of irrigation and of the applied nitrogen fertilizers. Under irrigated conditions the hay-yield on these solonetz soils can be increased up to 51.9—77.9 q/ha with the application of higher doses of N fertilizers. In the case of irrigation, oversowing with papilionaceae is also successful.

A more effective method for the improvement of grasslands on non-calcareous solonetzes is the establishment of an artificial grassland on the previously ameliorated and upturned (ploughed) soils. In this case irrigation is rather important.

According to the results of our experiments under dry conditions hay-yields of 48 q/ha can be obtained on the better kinds of solonetzes, and of 40 q/ha on the worse ones by the proper selection of grass and clover species. With irrigation the hay-yield is as much as 80 and 65 q/ha, respectively (Table 4).

On calcareous, highly alkaline soda solonetzes, overgrown with a thin stand of *Puccinellia limosa*, the hay-yield varies between 6.9—8.7 q/h. With N fertilization (0.71—1.06 q N/ha) combined with irrigation it may be increased to 34.6—43.8 q/ha. The same result can be achieved also on areas with similar soils by applying low dosages of soil ameliorants and oversowing with *Puccinellia limosa*.

References

[1] PRETTENHOFFER, I.: Methoden und Ergebnisse der Melioration von kalkfreien Alkaliböden (ungarischen Solonetzböden). Kongr. Bodenkunde Ungarische Akad. Wiss. Budapest. 587—616. 1955.

[2] PRETTENHOFFER, I.: Le progrès en profondeur de l'amélioration dans les profils des sols alcalins décalcifiés. Rapp. VI^{ème} Congr. Internat. Sci. Sol. Paris. Vol. D. 621—630. 1956.

[3] PRETTENHOFFER, I.: Die Weiterentwicklung der Melioration der karbonatfreien Alkaliböden (Wiesen-Solonetzböden) durch Untergrundlockerung. Trans. 8th Internat. Congr. Soil. Sci. **2.** 881—889. 1964.
[4] PRETTENHOFFER, I.: Amelioration of sodic solonetz soils in the region east of the river Tisza. Agrokémia és Talajtan. **18.** Suppl. 227—236. 1965.
[5] PRETTENHOFFER, I.: Hazai szikesek javítása és hasznosítása. Tiszántúli szikesek. (Amelioration and utilization of salt affected soils in Hungary. Solonetz soils in the region east of the river Tisza). Akadémiai Kiadó. Budapest. 1969.
[6] PRETTENHOFFER, I. & GINÁL, I.: A szikjavítás tartamhatása szolonyec típusú szikes talajon. (The long term effect of amelioration on salt affected soils of solonetz type.) Délalföldi Mezőgazd. Kut. Intézet Évk. Szeged. 1969.
[7] 'SIGMOND, A. A. J. DE: Hungarian Alkali Soils and Methods of their Reclamation. Berkeley Univ. California. 1927.
[8] 'SIGMOND, A. A. J. DE: A magyar Alföld szikeseinek jellemzése és osztályozása. (Characterization and classification of salt affected soils of the Hungarian Lowland.) In Magyar Szikesek. Budapest. Pátria. 1934.