Chemical Reclamation of Sodic Solonetzes in the Southern Part of the Middle Dnieper Region by the Application of Gypsum and Calcium Chloride

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Sodic solonetz soils in the southern part of the region situated in the middle stretches of the Dnieper River are confined to the single-loess terraces of the Dnieper and its left-band affluents Psyël, Vorskla and Samara. These terraces are composed of sandy loessial mid-loamy, calcareous soil ranging from 50 to 200 cm in thickness and underlain by alluvial, fine-grained, quartz sands in which occur noticeably mineralized ground waters. The ground water table rarely falls below 3 m, but in spring it rises by 1 – 1.5 m in comparison with the summer level. Mineralization of the ground water ranges from 4.4 to 31.5 g/l, increasing with the terrace fall. Mono- and disubstituted soda accounts for 26.9 % of the total salt reserves, chlorides 61.2 % and sulphates 11.9 %. Since the ground water table is always above the critical level, a constant transit of ground water containing dissolved salts towards the dry surface is observed. The salt maximum, however, is concentrated in the solonetz horizon at a depth of 30 – 60 cm. The salt content in this horizon is 9 times that of the 0 – 20 cm horizon. Such salt localization is due to the negligible permeability of this horizon.

Alkalinization processes throughout the soil profile are enhanced by the high sodium content of the ground water (73.6 % to 96.5 % of the cations), and the presence of soda which precipitates calcium and insures the irreversibility of the exchangeable Na adsorption reaction. In the shallow and deep solonetz soils the exchangeable sodium content approximates 30 % and 75 % of the cationic sum respectively in the 0 – 20 cm soil layer and in the solonetz horizon. The effective fertility of these soils has been greatly decreased by: the high degree of alkalinity of both the plough layer and, especially, the subplough layer as well as the salinity of the soil profile deeper than 20 cm; the exceptionally bad physical properties of the soil; increased alkalinity (pH of the solonetz horizon reaching 9); negligible provision of solonetz with nitrogen and phosphorus; disturbance in the cation balance of the soil solution resulting in a predominant uptake of sodium cations by plants and a drastic decrease in the supply of calcium, magnesium and potassium. In accordance with long-term observations on the shallow sodic solonetz of the Middle Dnieper Region, the winter wheat yield on the average of 10 years has amounted to 3.66 c/ha or only 24.2 % of the yield obtained on the alkali chernozem. The average yield of winter rye over 11 years was 3.44 c/ha or 25.9 % of that obtained on the alkali chernozem. The yield of sugar beets on

the shallow solonetz soils in certain years was as low as 16.3 c/ha accounting for only 9.2% of that on the alkali chernozem.

The shallow solonetz spots are scattered among the more fertile alkali chernozems. As they occupy from 20% to 50% of the aggregate area, it is impossible to exclude them from tillage. Their tillage requires great effort although the solonetz spots contribute practically nothing to the total yield. Consequently, the reclamation of solonetz soils is aimed not only at increasing their fertility, but also at the more productive use of all the complex territory.

Since 1934, research work on the chemical reclamation of solonetz soils has been carried out on the Kremenchug Stationary Research Site with an object of developing methods for increasing the fertility of these soils by applying gypsum, adding calcium chloride, and treatment with gaseous chlorine.

Gypsum has been studied most carefully. We started this research in 1934 and completed it in 1962. We investigated the techniques of application, effectiveness, and influence on changes in the physico-chemical properties of soils, as well as the duration of the effect of a single gypsum application.

This investigation has resulted in establishing that the effect of using various techniques in applying gypsum is significant for only the two subsequent years. However, for rapid reclamation, gypsum should be applied to the surface of the plowed layer of the shallow solonetz and worked in with the cultivator and harrow. On the deep solonetz soils and alkali chernozems it is advantageous to apply gypsum before plowing. The average yields of cereal crops (winter wheat, winter rye, barley and millet) obtained on the three varieties of solonetz soils over 17 years are presented in Table 1.

Table 1

The 17 year average yield of cereal crops obtained on the solonetz soils of the Kremenchug Stationary Research Site

Variants of treatment	Alkali chernozems	Deep solonetz soils	Shallow solonetz soils
	centners/hectare		
Control	14.3	7.1	3.7
Farmyard manure	16.9	8.3	4.7
Gypsum	15.7	8.3	7.6
Gypsum+farmyard manure	16.6	9.2	9.3
Nitrogen and phosphorus	17.2	9.3	8.5
Gypsum+nitrogen+phosphorus	18.8	10.8	9.3
Gypsum+farmyard manure+NP	20.9	11.8	11.3

It has been established that:

a) Gypsum was most effective on shallow solonetz soils (increment 3.9 c/ha, the yield doubled); it was much less effective on the deep solonetz soils (yield increment of 1.2 c/ha or 16%), and on the alkali chernozems.

b) No essential difference in yield resulted from increasing the rate of gypsum application beyond the gypsum rate calculated for replacing the exchangeable sodium. This low rate of application caused amelioration approximately to the same extent as the application of one and a half times

as much. Gypsum applied at low rates was more effectively involved in the exchange reaction.

c) Gypsum application alone was not sufficiently effective on the solonetz soils of the Middle Dnieper Region. It had to be accompanied by the application of farmyard manure and mineral fertilizers. The increase in yield obtained on the fertilized and gypsumed shallow solonetz soils reached 7.6 c/ha or trebled; on the deep solonetz soils the yield increase amounted to 4.7 c/ha (a 65% increase); and on the alkali chernozems to 7.5 c/ha (a 56% increase).

d) A single gypsum application, without fertilization, significantly increased yields for approximately 20 years, and with added fertilizer, the effect lasted longer. The gypsum application must be repeated after this period. The effect of gypsum should last longer if the ground water table could be lowered.

e) The application of gypsum markedly decreased soil resistance to tillage. Specific shallow solonetz soil resistance to plowing amounted to 1.01 kg/cm^2; after gypsuming this value decreased to 0.62 kg/cm^2 or by 39%.

Alkali chernozem resistance to plowing, without gypsum application, was 0.37 kg/cm^2, and after gypsuming 0.31 kg/cm^2.

f) Complete desolonetzization of the plow layer of the shallow solonetz soil occurred in the 20th year after gypsuming and systematic fertilization; the exchangeable sodium content decreased from 30% to 2.7% of the sum of the exchangeable cations. There occurred a reduction in the exchangeable sodium content from 90.3% to 41.9% of the total cations in the 20–40 cm horizon. However this reduction did not normalize the soil and the solonetz horizon still presented, an obstacle to the development of root systems. The deep solonetz soils underwent desolonetzization nearly to the same extent. The alkali chernozem soil profile (0–60 cm thick) contained, after gypsum application, less than 6% exchangeable sodium.

g) The amelioration of solonetz soils provided for full desolonetzization of the plough layer, having decreased the content of the soluble salts to one third of the level in the untreated areas. In the 20–40 cm and 50–60 cm horizons the amount of soluble salts decreased also. The osmotic pressure of the soil solution at a soil moisture content equal to the minimum water capacity remained however, very high in the horizons below 20 cm (1.4 atm., 8.2 and 13.3 atm. in the 0–20 cm, 20–40 cm and 50–60 cm horizons respectively). The osmotic pressure exceeded the plant suction force in the 50–60 cm horizon. The salt situation is nearly the same in the deep solonetz soils. The alkali chernozems were desalinized to a depth of 60 cm.

h) Because of insufficient desolonetzization and desalinization of the lower horizons of the shallow and deep solonetz soils the yields obtained on them were not equal to those on the alkali chernozems. They still amounted to only 54.1% and 56.6% of those obtained on the improved alkali chernozem. Deep desolonetzization and desalinization of shallow and deep solonetz soils are necessary for achieving complete uniformity in fertility. This might be effected by applying leaching water with drainage. These methods have not yet been tested under the Middle Dnieper Region conditions.

The application of gypsum to sodic solonetz soils presents problems because of its low solubility in water. Solubility is decreased still further by the presence of soda owing to the formation of calcium carbonate and gel

films on the surface of gypsum particles. This delays the reclamation period over 2—3 years. Moreover, part of the gypsum applied can be reduced to sulphide, toxic to plants, due to the gleyzation processes going on under the meadow regime of soil formation. However, gypsum possesses a series of advantages: even very high doses of this substance are not toxic to plants and it is comparatively cheap.

Parallel with gypsum application we have studied the reclamative effect of calcium chloride — a by-product of soda production. Laboratory studies showed that exchangeable sodium is replaced by calcium chloride more effectively than by gypsum. Calcium chloride and gypsum equivalent solutions with the shallow solonetz during 72 hours replaced 45.4%—56.7% of the exchangeable sodium respectively. However, with leaching, the efficiency of $CaCl_2$ and gypsum was as shown in Table 2.

Table 2

The efficiency coefficients of the applied amendments (% of absorption)

Rates of $CaCl_2$ and gypsum application	Gypsum	$CaCl_2$
0.5 of the dose calculated for replacing the exchangeable Na	82.9	89.3
1.0 of the dose calculated for replacing the exchangeable Na	67.7	56.1
1.5 of the dose calculated for replacing the exchangeable Na	56.2	45.2

It is evident from the data that, an increase in the rate of applying calcium salts decreased their efficiency for replacing exchangeable sodium. This was especially true for calcium chloride which, therefore, should be applied in small doses. This would also reduce any possible toxic effect of this salt. Field experiments with $CaCl_2$ applied to shallow solonetz soils have been carried out for 6 years. The four-year average yields of winter rye are presented in Table 3.

Table 3

Average yields of winter rye obtained on reclaimed shallow solonetz soils

Variants	c/ha	%
Control	3.65	100.0
$CaCl_2$, 0.5 of the dose	5.29	144.9
Gypsum, 0.5 of the dose	6.38	174.8
$CaCl_2$, 1.0 (full dose)	6.33	173.4
Gypsum, 0.0 (full dose)	6.62	181.4
$CaCl_2$ and gypsum, 0.5 of the dose respect	8.22	225.2

The effectiveness of gypsum in field experiments was on the average somewhat greater than that of calcium chloride. The same results were observed with regard to desolonetzization of the soil. However, the efficiency of $CaCl_2$ application in the first year was somewhat higher than that of gypsum. An increased content of chlorine ions was observed only during the first year after the application of $CaCl_2$. The combined application of gypsum and

$CaCl_2$ (especially when $CaCl_2$ was applied on the furrow bottom during plowing and gypsum was applied in the plowed horizon) was rather promising as reclamation was more rapid.

VOROTNIK's experiments have shown high efficiency for calcium chloride applications to solonetz soils irrigated with sewage waters. Under those conditions gypsum was partly reduced to sulfides.

Gaseous chlorine was tested for reclaiming calcareous solonetz soils. It influenced the desolonetzization process rather well but its interaction with the soil solution resulted in the formation of hypochloride.

This was toxic to plants and reduced crop yields during the first year of reclamation. Proper methods have not been developed for the application of gaseous chlorine to the soil. This retards the utilization of this technique for ameliorating solonetz soils.