Soda-Saline Soils of the Ararat Plain and Methods for Their Reclamation

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Armenia is one of the most southern republics of the Soviet Union. It is situated in the latitudinal subtropical belt of the northern hemisphere but in vertical respect all the latitudinal bioclimatic belts are represented here.

Conditions of land-hunger are characteristic of the Republic whose territory is most unfavourable for an intensified agricultural production owing to the great steepness of slopes, rockiness, stoniness, erodability and limited area of arable land. The coefficient of land utilization ranges from 0.45 to 0.50. Only 18—19% of the Republic's territory is under ploughland, orchards and vineyards.

The Ararat Plain is notable among other bioclimatic vertical belts of the Republic not only for its grandeur and luxuriant vegetation, but also for its role in the people's economy as it is an area of ancient irrigation with highly developed field cropping, vegetable growing, viticulture, orcharding and processing industry. The irrigated agriculture in the Ararat Plain originated in the remote past at the period of Chaldian (Urartian) civilization in Asia Minor and is as ancient as the peoples inhabiting this country.

The Middle-Arax area is the largest geomorphological region of the type of an intermontane accumulative depression including the Ararat Plain (the bottom of depression) with the subregions: the piedmont inclined plain, inclined alluvial-prolluvial terrace plain and alluvial flood-plain-terrace flatland. A horst uplift of the Paleozoic base, dividing the Plain into two troughs filled with the modern alluvial, and proluvial deposits, has been discovered in the central part of the Ararat plain (Engidja — Tazagjukh). The alluvial-proluvial deposits are underlain by stratified pebble-sand water-bearing rocks and argellaceous impermeable lacustrine Upper Pliocene and Quaternary deposits, which resulted from the damning of the depression by the lavas of Minor Mont Ararat and formation of a runningwater lake.

Fissured, water-bearing doleritic basalts constitute the base of lacustrine deposits. In the central part of the plain they are at a considerable depth (400 metres near the village of Markara) becoming more shallower in the outlying areas (Fig. 1).

Non-continuous clay lenses create conditions for the hydraulic connection between the subsoil and ground waters. By penetrating between the lenses into the overlying aquifers, artesian waters form weakly pressing subartesian horizons of subsoil and ground waters.

The climate of the terrace and flood-plain-terrace parts of the Ararat

Plain is characterized by the following indexes: the sum of temperatures exceeding 10 °C ranges from 4,000° to 4,250°; annual sum of precipitation varies between 200 and 220 mm; annual evaporation is estimated at 600 mm, potential evaporation amounts to 1100—1200 mm; annual mean temperature is 11,3—14 °C.

Analysis of these data gives grounds to consider the climate of the flood-plain terrace part of the Ararat Plain to be arid. The afore-mentioned circumstances ensure intensive salt migrations on the background of the exudative water regime which are proved by the data on determining the salt regime index (< 1.0) of soil according to Polynov and coefficient of seasonal accumulation of salts (SAS > 1.0) according to Kovda [10].

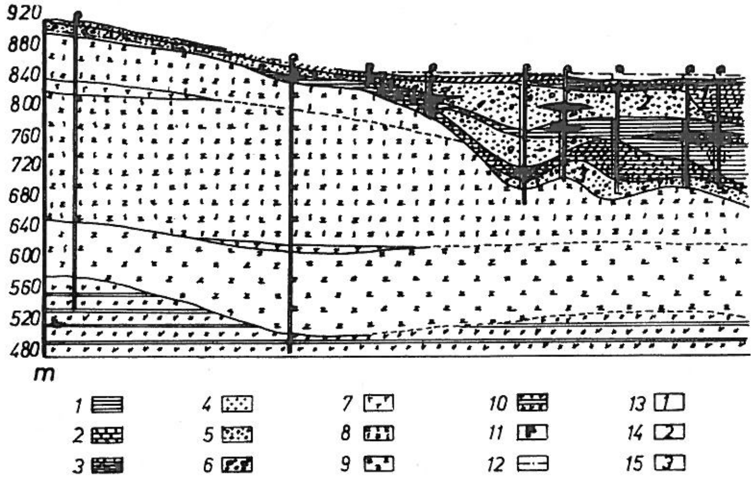


Fig. 1

Hydrogeological section of the Ararat Plain (along the line: village of Agavnatun — village of Markara). 1. Cinnamonic clays; 2. Blue-green clays with inclusions of fauna; 3. Loams with interbedded clays and sandy loams; 4. Sands; 5. Pebble and gravel with sand; 6. Boulders and Pebble with sand; 7. Tuffs; 8. Basalts, andesite-basalts, andesites and dacites; 9. Doleritic basalts (Upper Pliocene); 10. Rocks of gypsiferous and saliferous thickness (Middle Miocene); 11. Well; 12. Piezometric level; 13. Ground water aquifer; 14. First (low-head) aquifer; 15. Second (high-head) aquifer

Geohydrochemical differentiation of salts

The Middle-Arax depression, according to its geostructure and geomorphological characteristics, is a territory of discharge of the infiltrating waters from a very large water catchment basin of various vertical bioclimatic belts (lying on the absolute heights from 1,000 to 4,000 m) serving as areas of ground water recharge (Fig. 2).

The lava structures here play the main role in the formation of interstitial and subsoil waters. The porosity and fissuredness of ancient and Quaternary lavas promoted the stage accumulation of interlava and underlava waters and their movement above the regional aquifuges following the gradients of sedimentary and volcanogenic-sedimentary rocks of the underlava relief.

The movement of infiltrational waters through the fissures and pores of various geological formations and hydrolytic weathering have resulted in a partial dissolution of the innert rock-forming minerals which, according to the geochemical activity of the dissolved compounds, either precipitated or moved to the zones of discharge.

Fig. 2
Ground water recharge and discharge areas

By consulting the schematic profile constructed in the direction of the village of Markara along the line Mount Aragats (4095 m) — the Arax river (800 m) and taking into account the gipsometric position, rock composition of the geological formations, water regime data and other factors, one can form an idea on the peculiarities of the geohydrochemical regime in separate bioclimatic belts and on the general geochemical differentiation of salts.

Slow but continuous process of removal of soluble chlorides, sulphates, bicarbonates and molecular-soluble forms of SiO_2 and partly of Fe and Al is going on in the zone of percolative regime, conditioned by the elevated position of this zone, with excess of precipitation over evaporation, cold and moderate climate, mountain — meadow process of soil formation. The biosphere here is characterized by the biological fixation of elements participating in metabolism in the system: rock-soil (soil solution)-plant (Fig. 3).

A seasonal (both vertical and lateral) removal of soluble salts (chlorides, sulphates, bicarbonates) takes place in the zone of impermacidous regime where climate is moderately hot and precipitation balanced by evaporation. An increasing accumulation of soluble salts in the soil profile and precipitation of Ca and Mg carbonates and, less frequently, of gypsum under the horizon of maximum carbonate accumulation is observed in the moderately-humid and especially in the dry-steppe subzones.

In the foothill zone where ground waters occur at considerable depths and evaporation is compensated by precipitation and lateral inflow of moisture, a limited accumulation of halogens but considerable accumulation of gypsum are observed under the conditions of dry, hot continental climate due to the intrasoil (resulting from the interaction between plants and rocks) processes. This zone is characterized by the development of the carbonate forms of rock weathering and carbonate enrichment of soil. The bottom sides of rock fragments get covered with carbonate cutans, shirts, warts and stalagmite separates. Precipitation of silicosols from the liquid phase of soils results in the crust formation and intrasoil cementation.

In the zone of exudative water regime with high standing ground waters and their hampered outflow in the conditions of dry, hot, sharply continental climate where evaporation exceeds precipitation by more than 3 times, there takes place an intensified process of migration and accumulation of soluble salts and molecular-soluble SiO_2.

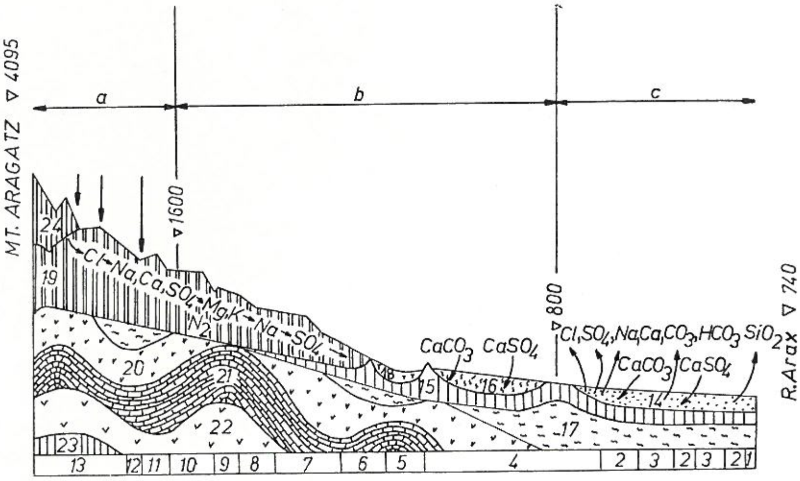


Fig. 3

Schematic profile (along the line: Mont Aragatz — Arax river) of geochemical differentiation of salts. a) Recharge area of ground waters (humid region). b) Non leaching regime. c) Discharge area of ground waters (arid region). Exudative (Evaporo-exudative) regime. Salt accumulating area

Soils and ground waters acquire soda-sulphate or soda-chloride type of chemism and the soil profile becomes enriched with precipitating carbonates.

Chemical composition of ground waters

Waters of rare springs, outpouring in the gullies and ravines on the territory with the occurrences of the saltbearing and gypsiferous rocks, are moderately saline and have sulphate-sodium-calcium and chloride-sodium hydrochemical composition.

The tertiary deposits in the spurs of the Urts mountain ridge composed of motley-coloured gypsiferous clays, conglomerates, breccias and limestones are subjected to deformation and decomposition which is responsible for enrichment of slopes and foothills in carbonate, clayey-gypsum and sand products of weathering. The spring waters of this arid territory are moderately saline and have chloride-sulphate-sodium-calcium and sulphate-calcium-sodium hydrochemical composition.

Table 1

Water sources containing normal and hydrocarbonate soda

	Site	Alkalinity g/l / meq/l CO_3^{2-}	Alkalinity g/l / meq/l HCO_3^-
Springs	Village: Tsaksar	0.012 / 0.40	0.122 / 2.00
Springs	V.: Zolakar	0.006 / 0.20	0.128 / 2.10
Springs	V.: Karavansarai	0.018 / 0.60	0.207 / 3.40
Springs	Lake Aigerlich	—	0.196 / 3.22
Springs	V.: Kulibeklu	—	0.268 / 4.40
Springs	V.: Gegard	0.050 / 0.63	0.320 / 5.24
Springs	at the bridge Hrazdan	0.024 / 0.80	0.270 / 4.50
Springs	at the bridge Kasakh	0.220 / 0.66	0.300 / 4.91
Springs	Gehyard	0.050 / 1.63	0.320 / 5.24

	Site	Alkalinity g/l / meq/l CO_3^{2-}	Alkalinity g/l / meq/l HCO_3^-
Rivers	Kasakh the bridge near V. Oshakan	0.012 / 0.40	0.128 / 2.10
Rivers	Hrazdan near Pobeda bridge	0.024 / 0.80	0.300 / 4.91
Rivers	Azat V. Janatly	0.035 / 1.17	0.280 / 4.60
Rivers	Vedi near V. Karabakhlyar	0.008 / 0.3	0.077 / 1.27
	Lake Sevan Mean chemical composition	0.026 / 1.2	0.299 / 6.8
	Artesian waters at the Yeraskhaun Experiment Station	0.012 / 0.40	0.207 / 3.40
	Vertical drainage Pumped water from well 3 Yeraskhaun Experiment Station	0.038 / 1.26	0.214 / 3.50

More ancient Paleozoic (Carboniferous — Devonian) limestone and marl particoloured rocks subjected to desertic weathering are encountered in the same south-eastern outlying part of the plain in the spurs of the Urts mountain ridge. Waters of piedmont springs (Asni, etc.) are distinguished by hardness and hydrocarbonate (predominantly sodium or calcium) hydrochemical composition.

The greater part of the territory on the left-bank middle-Arax basin is composed of the volcanogenic Pliocene rocks and younger Quaternary andesite-basalt lavas. Waters circulating in the pores and fissures of lavas as well as sublava waters are practically fresh with a sum of soluble salts ranging from 0.3 to 1.5 g/l. According to the type of chemism they belong to hydrocarbonate — sodium waters (Table 1).

Hydrocarbonate and normal soda (from 10 to 40 mg/l) have been found in the pressing waters of artesian and pumped water of vertical drainage wells within the confines of the Ararat Plain.

Hydrocarbonate and carbonate alkalinity of artesian waters allows to suggest possible abyssal geohydrobiochemical processes of soda formation which necessitate profound theoretical investigations.

Soda origin in soils and ground waters

A number of home and foreign scientists have dealt with the genesis of soda in various bioclimatic belts and elaborated different theories and working hypotheses relating to this subject. These theoretical postulates have been generalized by GEDROITS, POLYNOV, FERSMAN, VERNADSKY, VIGNER, KELLEY, HILGARD, 'SIGMOND, VYSOTSKY, KOVDA, ANTIPOV-KARATAEV, EGOROV, AIDINIAN, BAZILEVICH and others and in the papers of hydrochemists, microbiologists and biochemists. [3, 5, 6, 7, 9, 10, 11, 12, 28].

Various ways of soda formation are still being discussed due to the complexity of the object under investigation. The majority of researchers assume that a unified process of soda formation does not exist and in different natural conditions it can be influenced by various factors.

It has been stated above that the lava cover composed of dolerite andesite-basalt magma containing equal amounts of alkaline and alkaline-earth bases is the principal waterbearing rock in the Middle-Arax basin. The hydrolytic weathering of these rocks accounts for an expressed alkaline reaction of solutions. The crystalline-chemical structure of minerals and their ability to draw molecules-dipoles of water to the electrokinetically non-saturated ions of the external layer of the space lattice constitute a theoretical basis for the replacement of ions from the rock-forming minerals when weathering takes place in a water medium giving rise to the hydration of soil forming minerals, release of alkaline and alkaline-earth cations and their transition into a liquid phase in the system mineral solution.

The possible soda production from sodium silicates without undergoing the stage of solonetzization was experimentally proved by KIMTINS and KELLEY (1923), KOVDA and BYSTROV [13].

ANTIPOV-KARATAEV and TSYURUPA [5] showed that "soil silicate bacteria slowly but actively contribute to weathering of such soil silicate minerals as albite and muscovite". Cations from feldspars are removed through hydration and enleaching from the periphery of crystalline lattice which results in forming clay minerals, soda and silica in molecular and colloidal state:

$$Na_2Al_2Si_6O_{16} + 2CO_2 + n\,H_2O \rightarrow H_2Al_2Si_2O_8 \cdot H_2O + 4SiO_2 \cdot n\,H_2O + 2NaCO_3$$

$$2\,NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

Thus, the hydrolytic weathering of minerals from the feldspar group gives rise to formation of hydrocarbonates of alkaline bases which in the zone of aeration transfer into normal soda under the influence of dry and warm climate.

The investigations carried out at the Yeraskhahun Experiment Reclamation Station, Institute of Soil Science and Agrochemistry, Armenian SSR Ministry of Agriculture have revealed, among the soluble salts the presence of SiO_2 and Al_2O_3 (10—60 and 1—9 mg/100 g respectively) which are the products of alkaline hydrolysis of crystalline rocks. Alkaline reaction of the medium stabilizes $SiO_2 \cdot nH_2O$, stipulates formation of soluble forms of Na_2SiO_3, K_2SiO_3 and prevents their partial precipitation as amorphous gels. Under the effect of a two-stage hydrolysis, soluble forms of Na_2SiO_3 and K_2SiO_3

undergo transformation into hydrocarbonates and then (in the zone of aeration during a hot period) into carbonates, according to the following scheme:

$$Na_2SiO_3 + H_2O \rightarrow NaOH + NaHSiO_3$$

$$NaHSiO_3 + H_2O \rightarrow H_2SiO_3\ (SiO_2 + nH_2O) + NaOH$$

$$NaOH + CO_2 \rightarrow NaHCO_3$$

$$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

AGABABIAN [1] from the same Institute has carried out experimental work to establish soda formation under the effect of water and carbonic acid on magmatic rocks ground to various fineness (Table 2).

Data in Table 2 indicate that under the influence of water saturated with carbonic acid, basalt and sienite produce more HCO_3^- and SiO_2 than other rocks and the number of these ions in the hydrolysate increases parallel to an increase in specific surface. Fixation of HCO_3^- and SiO_2 ions by alkaline cations is responsible for the alkaline reaction of the medium.

Table 2

Chemical composition of hydrolysate, mg/100 g of rock*

Chemical compound	Particle diameter, mm	Granite	Andesite	Tuff		Sienite	Basalt
				Black	Red		
HCO_3^-	1.0 —0.10	25.0	30.0	38.0	54.0	40.0	43.0
	0.10—0.05	50.0	53.0	51.0	59.0	85.0	85.0
	<0.05	139.0	82.0	60.0	82.0	212.0	196.0
SiO_2	1.0 —0.10	1.20	10.03	5.38	13.58	7.10	2.59
	0.10—0.05	5.74	12.05	12.24	6.09	18.82	5.55
	<0.05	15.97	20.35	10.22	18.05	27.98	25.39

* 50 gm of rock placed on Buchner Funnel was thrice treated with distilled water (300 ml) preliminarily saturated with CO_2. The data in Table 2 are the sum of three independently made analyses. CO_3 and SO_4 ions have not been detected in the hydrolysate.

Research conducted at the Institute of Soil Science and Agrochemistry has shown that soda is formed not only by hydrolytic weathering of average and basic magmatic rocks but also under the influence of soil microbial population and extracellular enzymes if certain conditions for redox processes exist (Fig. 4).

An experiment on soil composting with the addition of potassium nitrate, sodium sulphate and salts of organic acids to study soda formation under the effect of microbiological process (carried out by MARKOSIAN [14]) has demonstrated that intensity of soda formation (according to the values of CO_3^{2-} and HCO_3^-) sharply increases parallel to an increase in the number of denitrifiers and sulfoficaters (Table 3).

Simultaneously with the research conducted by MARKOSIAN experimental work was carried on by GALSTYAN [8] to elucidate the enzymatic nature of soil

Table 3

Soda formation in composted non-uniformly aerated soils with addition of organic acid salts

Soil	Variants	Initial soil, %			On the 30th day of incubation		
		CO_3^{2-}	General alkalinity HCO_3^-	pH	CO_3^{2-}	General alkalinity HCO^-.	pH
Swampy-meadow	Control	0.017	0.124	8.5	0.012	0.129	8.4
	$+HCOONa$	0.011	0.672	8.3	0.282	1.369	9.8
	$C_3H_5O_3Na$	0.002	0.586	8.2	0.174	1.042	0.5
	$C_6H_5O_7Na_3$	0.002	0.574	8.4	0.106	0.810	0.5
Solonetz-solonchak	Control	0.017	0.095	8.5	0.015	0.112	8.4
	$-HCOONa$	0.007	0.610	8.3	0.346	1.574	9.9
	$+C_3H_5O_3Na$	not	0.590	8.0	0.264	1.179	9.8
	$+C_6H_5O_7Na_3$	0.012	0.728	8.4	0.190	0.884	9.6

alkaline reaction under the effect of sulphate-reductase and nitrate-reductase. Coenzyme I-diphosphopyridine was for the first time successfully applied as a hydrogen donor for sulphate-reductase (Table 4).

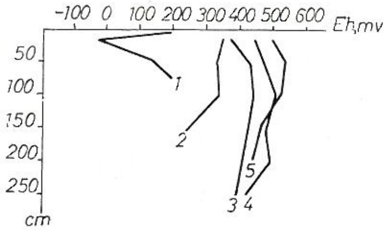


Fig. 4

Curves of redox processes in the following saline soils. 1. Swampy. 2. Solonetz. 3. Soda solonchak. 4. Sulphate solonchak. 5. Acidified soda solonchak

It is clear from the above data that soda formation in the soils of the Ararat Plain through biochemical reduction of sulphates and nitrates by microbial population as well as through enzymatic processes is possible only in the presence of organic matter, serving as a hydrogen donor, and sodium sulphates and nitrates whose oxygen accepts hydrogen during anaerobic respiration of the microflora. Thus, soda formation is possible in the soils of meadow genesis, viz. water-logged bog, bog-meadow ones as well as in that part of the soil profile which is affected by the seasonal fluctuations of ground water table. The considered processes may offer an explanation to the appearance of soda in abyssal waters of the artesian basins having fossil remains. So it is possible to conclude that the increasing alkalinity and soda accumulation in the Ararat Plain soils result from a complex combination of geological, geochemical, hydrochemical, physico-chemical and biological processes. The presented data give grounds for singling the Ararat Plain out into an independent region of the Transcaucasian soda-geochemical province.

Table 4

Effect of sulphate-reductase and nitrate-reductase in brown soil under aerobic and anaerobic conditions (Data of Galstyan [8])

Conditions	Donor	Added salt	Activity	pH (H_2O)	meq per 100 g of soil			Exchange Na^+, %
					CO_3^{2-}	HCO^-	Exchange Ca+Mg	
Aerobic	Glucose	—	0.0	7.6	—	5.4	0.7	1.9
		NaCl	0.0	7.5	—	5.7	0.0	3.8
		$NaNO_3$	0.1	7.2	—	10.8	4.5	2.8
		Na_2SO_4	0.0	7.3	—	9.1	2.4	3.5
		—	0.0	7.9	—	19.2	8.9	0.6
		NaCl	0.0	7.6	—	24.4	12.5	5.2
Anaerobic	Glucose	$NaNO_3$	8.5	8.6	4.8	28.0	4.1	15.5
		Na_2SO_4	24.0	9.4	9.6	32.9	3.7	17.0

Peculiarities of the Ararat plain soils

Soils of the Ararat Plain were formed on alluvia of the Arax river and its left tributaries as well as on the proluvial deposits of numerous mud flows. That is why lithologically they are represented by stratified sediments with rather a motley texture (Fig. 5).

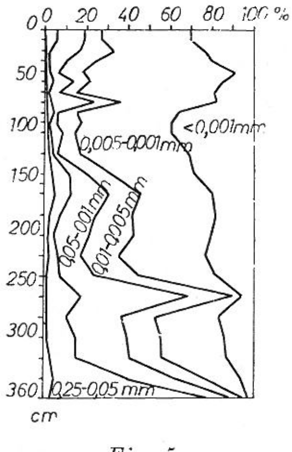


Fig. 5.

Particle size distribution in a soda-chloride-sulphate solonchak of the Arazdayan steppe

The thickness of loam and clay deposits in the western and central parts of the Ararat Plain ranges from 1.5 to 3.0 and in the Arazdayan Steppe from 2.0 to 7.0 metres. Rather unfavourable reclamative properties of the Arazdayan Steppe soils, conditioned by shallow ground waters; heavy-textured soilforming rocks and their hydrophilous character; high swelling capacity and low soil permeability; expanding salinization and solonetzization, should be underscored. Amelioration of such soils demands application of radical reclamative measures. Ground waters in the Arazdayan Steppe are stagnant. They are characterized by a considerable range of salinity. According to the data obtained by TCHITCHIAN and OGANESIAN [15, 24] soda accumulation. in those ground waters was observed at a salt content amounting to 40 gm/l. Ground waters of higher salinity (80—95 gm/l) in some areas of saline soil dis tribution have insignificant alkalinity.

The amount of soluble salts throughout the profile down tolthe ground-water table ranges, according to the averaged data, from 0.6 to .5 per cent (0.6—1.0 per cent in the western and central parts and up to 1.5 per cent in the south-eastern part of the Plain). In separate cases an average amount of salts in the soils of the sites with rather a hampered outflow of highly saline ground waters (50—80 gm/l) reaches 3.0 and general alkalinity 1.0—1.2 per cent. It has been calculated that salt reserves in the one-metre thick layer of soil range from 250 to 600 and more tons per hectare depending upon the degree of soil salinity. By consulting graphs a and b (Fig. 6) one can form an idea on the salt composition and distribution of exchangeable bases.

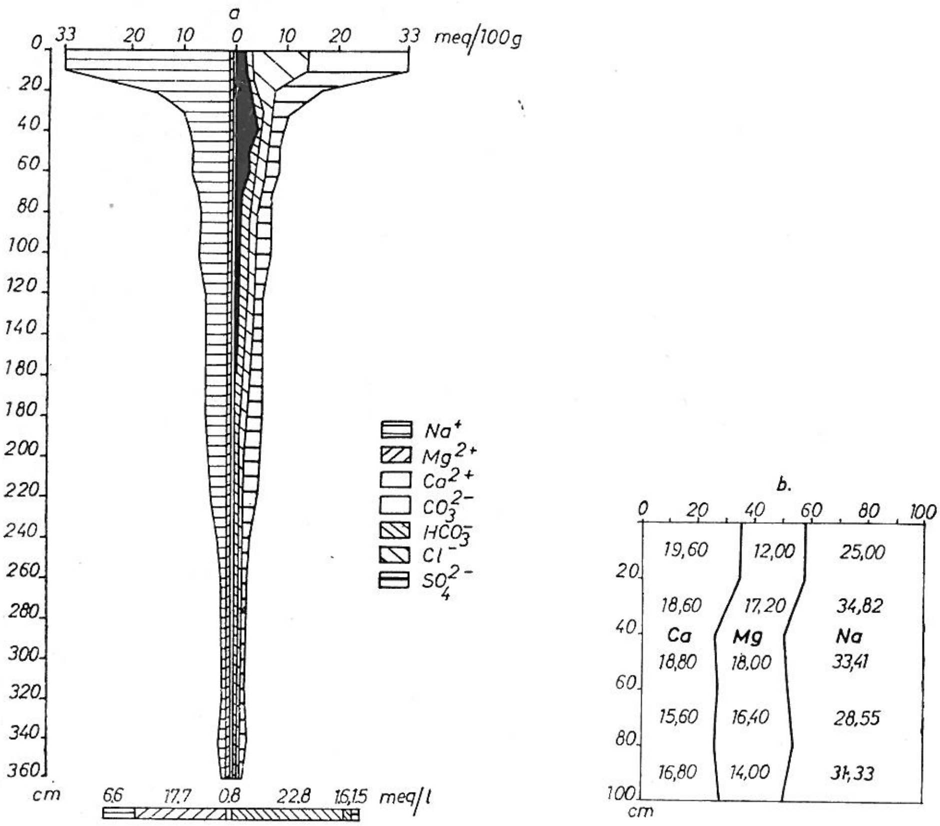


Fig. 6

Salt profile (a) and distribution of exchange bases (b) in a soda-sulphate-chloride solonchak of the Arazdayan steppe (per cent from the sum of bases is shown along the X axis and absolute amounts of exchangeable bases in meq/100 gm of soil are shown in the graph)

These graphs show that salt accumulation is going on in the upper one-metre thick layer which is indicative of expanding salinity of soil and toxic amounts of soda. Potential solonetzicity of alkali soda-saline soils is proved by the fact that exchangeable sodium accounts for about 50 per cent of the sum of exchangeable bases.

Mineralogical studies of a soda solonchak have revealed: in the group of heavy minerals (specific weight > 2.75) the biggest quantity of amphiboles (with the predominance of common hornblende) and pyroxene; in the group of light minerals (specific weight < 2.75) the predominance of plagioclases and volcanic glass. A negligible quantity of rock fragments has also been detected. The low soil horizons have been found to contain a small amount of quartz. Weathered grains of minerals defying determination have been stated to be dominant (50 per cent of the fraction).

Radiographic analysis of the clay fraction of the highly dispergated part of the soil has established the presence of montmorillonite (in predominating amounts), chlorite, hydromica and highly dispergated quartz.

Strong soil swelling when wet and sharp shrinkage when dry are stipulated by minerals of the montmorillonite group (present in sufficient amounts) owing to the peculiar structure of their crystalline lattice (three-layer, expanding). Minerals of this group possess great absorbing capacity with respect to electrolytes and moisture. In the conditions of soda salinity they decrease the water-yielding capacity and permeability of the soil and condition a number of negative water-physical properties responsible for the retention of salts (Table 5).

Table 5

Some physico-chemical characteristics of soda solonchak. Profile C-I.

Depth of sampling, cm	Maximum hygroscopicity, %		Exchange capacity, meq/ 100 gm of soil		Na		<0.001 fraction content	<0.01 fraction content
	<1.0 mm	<0.001 mm	<1.0 mm	<0.001 mm	water soluble	exchange able		
0— 20	9.40	29.40	12.50	97.50	32.20	5.21	10.70	18.90
20— 40	10.60	30.30	15.20	107.00	43.50	10.40	11.90	26.80
40— 60	9.80	30.70	16.50	102.00	13.10	20.70	10.60	26.30
60— 80	10.10	30.90	19.80	96.20	10.90	18.90	12.70	44.80
80—100	8.91	30.00	17.10	88.70	7.30	14.60	21.60	47.40
100—150	5.88	31.70	13.30	93.60	2.17	3.69	8.00	20.40
150	5.54	29.80	15.60	98.00	0.87	1.08	13.00	31.40

It is clear from Table 5 that the exchange capacity value of the clay fraction is high due to a large quantity of montmorillonite.

Small exchange capacity of the soil is determined by a low content of the clay fraction which is characteristic of alluvial deposits.

Montmorillonite in the photographs taken by means of electron microscope (Fig. 7) is represented by non-transparent or semitransparent aggregates and small scattered particles with strongly scoured confining lines.

High hydrophylity of the clay fraction throughout the soil profile has been proved by thermographic investigations (Fig. 8).

Reclamation of soda-saline soils

Alkali soils of soda salinity are known to be difficult to reclaim. Despite large acreages of such soils throughout the world they are almost nowhere reclaimed and are, at best, extensively used as pastures. These soils practically cannot be cultivated after leaching without chemical reclamation on the background of a collector-drainage system.

a)

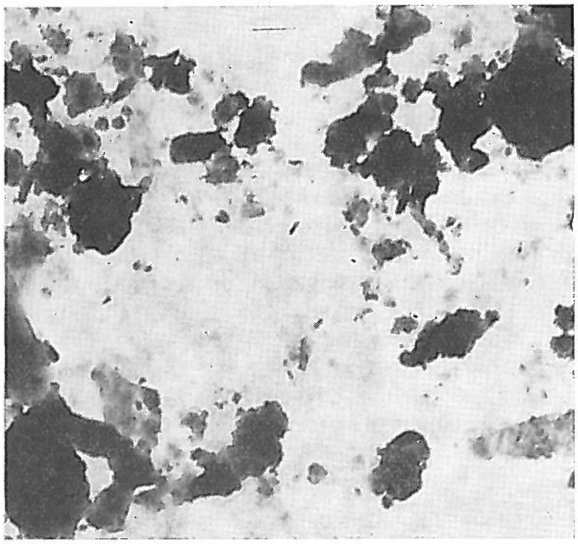


Fig.

Electron-microscope photographs of <0.001 mm fraction sampled from a soda

The experimental reclamation of the Ararat Plain soils was started in 1938 by staging laboratory and pot experiments and reclaiming small plots of land in the circumstances of hampered ground water outflow. Various leaching methods and agrotechnical measures have been employed and relatively salt-tolerant plants tested. A number of chemical amendments, viz. manure, river sand, natural gypsiferous soil containing from 30 to 80 per cent of gypsum, by-products of carbide production, gypsum-containing by-products of a tartaric acid producing plant, ground sulphur, gazha, alebaster, synthetic gypsum, metasilicate, calcium chloride, hydrolytically acid salts, ferric chloride, ferrous sulphate, aluminium, potash-ammonia alum as well as acetic, nitric, hydrochloric and sulphuric acids have been used.

Many of these amendments have turned out to be of low efficiency. Sulphuric and hydrochloric acids produced the strongest reclamative effect.

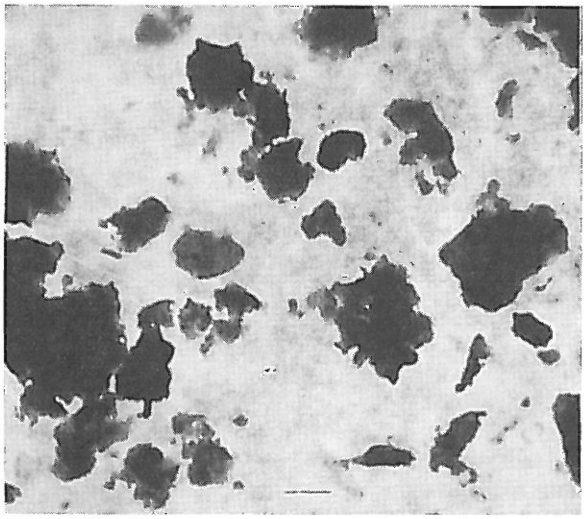
Small-plot experiments on alkali soil acidification with sulphuric acid gave good reclamative results.

The trench-hollow method for perennial crop planting was successfully devised to cultivate small patches of soda solonchaks up to 20—25 ha in size. This method implies substitution of a slightly saline soil from the lower horizons for the strongly saline one (of the upper layers) in the places of planting.

Experiments on reclamation of soda solonchaks were at different times carried out by POGOSOV, TCHITCHIAN, ANANIAN, AGABABIAN, RAFAELIAN, AGADJANIAN, PETROSIAN, OGANESIAN, K. A. PIRUZIAN, MELKONIAN, AKHNOYAN, SIRANOSIAN, MKHITARIAN, NURIDJANIAN and OGANESIAN A. S. [1, 2, 4, 15, 20, 22, 23, 25].

The investigations have shown that in the zone of penetration sulphuric acid decomposes calcium and magnesium carbonates thus giving rise to the formation of calcium sulphate (positively affecting the soil) as well as sodium and magnesium sulphates increasing soil salinity (Fig. 9).

b)



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solonchak at depths ranging from 0 to 20 cm (photo a) and 40 to 60 cm (photo b)

The newly-formed calcium and magnesium salts in the absence of soda participate in the soil collodial-chemical reactions replacing "active" (toxic) sodium from the exchange complex.

A sharp increase in the amount of soluble salts in the soil being reclaimed has necessitated the revision of a leaching requirement to adjust it to the total amount of watersoluble salts. This was achieved by inserting an additional coefficient into KOVDA's and VOLOBUEV's formulas.

The investigations carried out in 1960–1965 on the Yeraskhahun Experiment Reclamation Station showed that watersoluble salts, as geochemically active compounds, are leached down to the upper horizons of ground waters and partially carried away with drainage flow.

Accumulation of sodium and magnesium chlorides in the high standing (150 cm) ground waters (1965) could cause secondary salinization of soils. However, the possible restoration of salts was prevented by installing a drainage system (both horizontal and vertical) on the Station's territory.

New, more advantageous chemical amendments facilitating the reclamation of alkali soils are being disclosed. The positive effect of the by-products of the mining industry containing green vitriol has been experimentally proved. Apart from neutralizing the alkaline reaction, the application of green vitriol gives rise to a sharp increase in soil permeability and the removal of readily soluble salts. The experiments have shown that the application of half of the equivalent (with respect to sulphuric acid) dose of green vitriol ensures a positive reclamative effect (Fig. 10) which is, evidently, conditioned

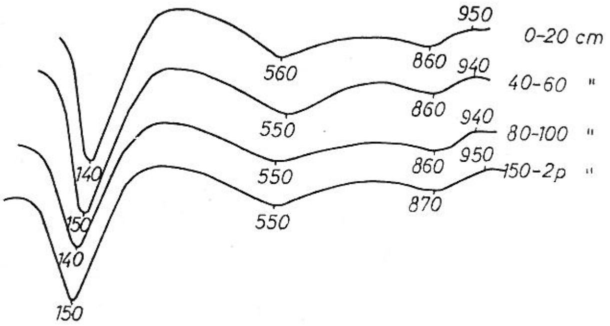


Fig. 8

Thermogram of <0.001 fraction sampled from soda solonchak

not only by the formation of sulphuric acid (in the course of acid hydrolysis of green vitriol), but also by the dehydrating ability of the high-valent Fe cation in the course of transition from Fe^{2+} to Fe^{3+} under the influence of chemical and biochemical catalysts.

Thus, the application of sulphuric acid and green vitriol has made it possible to reclaim soda solonchaks and grow a number of farm crops. However, the transition from reclamation of small plots to that of large acreages of land necessitated the elaboration of a complex of reclamative measures.

The most optimal, economically advantageous concentration of sulphuric acid (0.8—1.0 per cent) sufficient to neutralize the soil alkaline reaction has resulted from a number of laboratory and field experiments.

To accelerate the process of neutralizing the alkaline reaction in soils having high buffering capacity and to speed up the penetration of acid into the soil, a number of machines, ensuring the application of liquid and dry amendments to a greater depth, have been designed, viz. slitting machines for loosening the soil to a depth of 80 cm; modified three-furrow ploughs

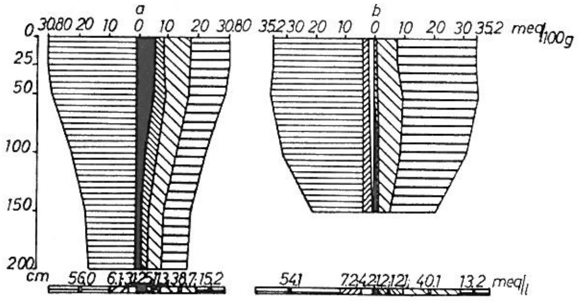


Fig.

Salt profile of saline soil on the Yeraskhahun Experiment Reclamation Station: a)
55,000

for a layer-by-layer application of amendments with an interval of 25 cm to a depth of 75 cm; ridging machines of an original design, etc.

The precalculated rates of acid and leaching water do not always ensure a uniform reclamative improvement of soils differing in texture and degree of salinity due to an insufficient acidification of separate, predominantely clayey patches hampering the removal of salts during leaching.

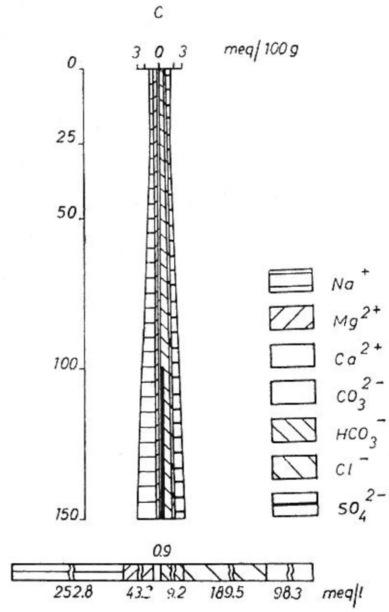
The above reason necessitated the sowing of indicator crops to reveal the insufficiently reclaimed patches of soil and carry out additional acidification and leaching. Winter wheat has been the best crop of this kind. Investigations have demonstrated that alfalfa is the best crop-ameliorant. It should substitute for winter wheat after a year of cultivation.

The Ararat Plain is a zone of fruit growing and viticulture. However, various varieties and species of crops do not uniformly respond to even insignificant amounts of soluble salts remaining in the soil during the first years upon reclamation. 90 varieties of 12 species of fruit crops and 60 varieties of grapes are being tested by PETROSIAN [17, 18 19] on the reclaimed solonchak with an object of recommending the introduction of the most resistant and perspective ones.

A complex of agrotechnical measures to cultivate perennial crops on the reclaimed solonchaks has been elaborated.

Close plantings of the trellis-trained fruit crops on dwarfish stocks and mulching of the inter-row spacings reduce evaporation and prevent soils from secondary salinization.

The technological schemes for reclaiming soda solonchaks have been



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before reclamation; b) upon acidification; c) upon leaching with a norm amounting to m³/ha

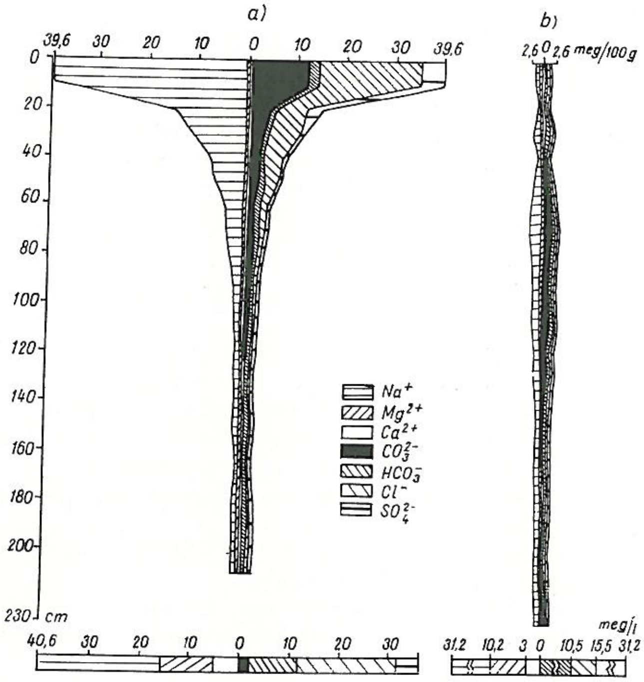

Fig. 10

Salt profile of soda-sulphate-chloride solonchak, Hoctemberian region of the Armenian SSR: a) before reclamation; b) upon reclamation with green vitriol

Table 6

Salt balance of the 0—150 cm thick soil profile (average data)

Year and period of investigation	pH	Σ of salts	Alkalinity CO_3^{2-}	Alkalinity HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+
			%/meq/100 g of soil						
1960 Before reclamation	9.5	1.551	0.080 / 2.68	0.368 / 6.04	0.238 / 6.81	0.510 / 6.18	0.004 / 0.18	0.003 / 0.23	0.428 / 18.62
1962 After acidification	8.6	2.002	0.014 / 0.47	0.066 / 1.08	0.226 / 6.46	1.022 / 21.28	0.021 / 1.06	0.029 / 2.42	0.638 / 27.76
1965 After leaching	7.8	0.175	0.002 / 0.08	0.065 / 1.06	0.015 / 0.43	0.044 / 0.92	0.006 / 0.30	0.003 / 0.28	0.042 / 1.83
Chemical composition of ground waters									
1960 Before reclamation	9.40	4.202	0.74 / 2.47	0.692 / 11.34	1.355 / 38.73	0.731 / 15.24	0.062 / 3.12	0.07 / 6.15	1.289 / 56.04
1962 After acidification	9.00	4.197	0.036 / 1.2	0.741 / 12.15	1.405 / 40.15	0.636 / 13.25	0.084 / 4.23	0.087 / 7.22	1.244 / 54.10
1965 After leaching	8.2	18.285	—	0.564 / 9.25	6.632 / 189.5	4.736 / 98.35	0.019 / 0.93	0.519 / 43.25	5.815 / 262.82

tested by scientific workers of the Institute in a number of farms situated in the Ararat Plain.

Based on the results of long-term investigations, the Armenian Ministry of Reclamation and Water Economy organized a special Reclamation Trust to conduct the reclamation of soda-saline soils of the Ararat Plain in conformity with instructions especially compiled by the Institute of Soil Science and Agrochemistry.

References

[1] Agababian, V. G.: & Aknimuan, M. S.: On the genesis of sod in the saline soils of the Ararat Plain. Pochvovedenie. (9) 69—79. 1966.

[2] Agadjanian, G. H. & Aslanian, E. E.: Reclamation of the Prearax Plain saline soils without constructing a drainage system. Izvestija Academy Sci. Armenian SSR (Biology), I—V. (5) Yerevan. 1952.

[3] Aidinian, R. H.: Nature of chemism of the Arazdayan Steppe solonetzes and solonchaks and methods for their chemical amelioration. Pochvovedenie. (3) 1935.

[4] Ananian, H. T.: Experimental results on leaching and cultivation of soda solonchaks and solonetzes-solonchaks of the Arazdayan steppe. Armgiz. Yerevan. 1963.

[5] Antipov-Karataev, I. N. & Tsjurupa, I. G.: Regularities of biochemical decomposition of Albite and Muscovite. In: Migration of chemical elements during weathering processes. 1966.

[6] Bazilevich, N. I.: Role of biological factors in the process of salt migration in the Barabinsk Steppe. Doklady USSR Academy Sci. **77.** (4) 1951.

[7] Egorov, V. V.: Soda salinization of soils in Southern Sintszyan. Pochvovedenie (5) 1—12. 1961.

[8] Galstyan, A. Sh.: The role of enzymes in the formation of soda in soils. Pochvovedenie. (5) 89—96. 1967.

[9] Gedroits, K. K.: Solonchaks, their evolution and reclamation. Selected works. **3.** Moscow. 1955.

[10] Kovda, V. A.: Movement and accumulation of silica in saline soils. Proc. V. V. Dokuchaev Soil Inst. I—XXII. 1940.

[11] Kovda, V. A.: Soil formation processes in deltas and flood plains of rivers in the USSR Continental Areas. Problems of Soviet Soil Science. Moscow. 1946.

[12] Kovda, V. A.: Alkaline soda-saline soils. Agrokémia és Talajtan. Suppl. **14.** 15—48. 1965.

[13] Kovda, V. A. & Bystrov, S. V.: On the nature of alkalinity. Proc. USSR Commission on Reclamation. **6.** 1936.

[14] Markosian, G. E.: Biological way of soda formation in saline (alkali) meadow soils of the Prearax valley. Izvestija USSR Academy Sci. (Biology). **2.** 1969.

[15] Oganesian, K. A.: Soda-saline soils of the Arazdayan Steppe. Trans. Inst. Soil Sci. and Agrochem. (2) Yerevan. 1963.

[16] Piruzian, S. S.: The influence of soil salinization on the growth and development of maize. Pochvovedenie. (2) 91—96. 1959.

[17] Petrosian, G. P.: Migration and accumulation of salts depending on irrigation regime. Collection of papers of young Scient. Workers, Armenian Agric. Inst. I. 1957.

[18] Petrosian, G. P.: Application of the trench method for reclaiming solonchaks (Hoctemberian region of the Armenian SSR) meant for vine and fruit crops growing. Autoreferat of the Candidate's Dissertation. Yerevan. 1958.

[19] Petrosian, G. P.: Some data on the lateral capillary salt migration in saline soils. Collection of Papers of the Armenian Agric. Inst. (10) 1958.

[20] Pogosov, P. S.: Experiment on structure creation in the saline soils of the Prearax Valley in the process of leaching. Collection of Papers. Armenian Academy Sci. (Sector of Soil Science). (2) Yerevan. 1950.

[21] Rafaelian, A. S.: Application of gypsum substitutes to reclaim saline soils in the Prearax Plain of the Armenian SSR. Trans. Inst. Soil Sci. and Agrochem. (1) Yerevan. 1959.

[22] Rafaelian, A. S.: Results of the comparative trials of some amendments used

for developing salt affected soils of the Prearax Valley of the Armenian SSR. Yerevan. 1961.

[23] TCHITCHIAN, A. I.: Development of alkali (soda) saline solonetzic soils of the Prearax Valley by acidification. Abstracts to 2d Congress of the All-Union Society of Soil Scientists. Kharkov. 1962.

[24] TCHITCHIAN, A. I.: Saline soils of Armenia and their rational utilization. Collection of papers presented to the Transcaucasian Scientific Session of Large-Scale Soil and Agrochemical Mapping. Yerevan. 1965.

[25] TCHITCHIAN, A. I.: Development of saline soils in Armenia. In the Collection of Papers: Salinization control on the irrigated soils. Moscow. 1967.

[26] VOLOBUEV, V. R.: Leaching of saline soils. Baku. 1948.

[27] VOLOBUEV, V. R.: Leaching and drainage of saline soils. In Problems relating to salinization of soils and water sources. Moscow. 1960.

[28] VYSOTSKY, G. N.: Solonetzes and soliferous rocks. Pochvovedenie. (2) 161—173. 1903.