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Evaluation of cycle technique aimed at leaching salts from saline soils

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Abstract: The article discusses the relevance of efficient management technology of mass transfer, water and salts on irrigated soils during reclamative and operating regimes. Solution of this problem is expedient through the development of a set of physical and mathematical tasks, which will describe the laws of movement and distribution in the root layer of soils and give quantitative assessment of the content of salts in the soil. The article aims at the development of resource-saving technologies and desalination with a view to leach salts along with the regulation of water-salt regime of soils and ground waters in the irrigated saline soils. The paper suggests the method of calculating the rate and degree of desalination of soils based on the analysis of motion of salt particles. Thus the basic element of calculation is the speed and running distance of salt particles in the solution. This method allows justifying and determining the cycle technique of leaching salts from saline soils. The main object of the study is the grey-brownish meadow soils: toxic salt content before leaching, at 1.650% and after leaching, at 0.514% given the surface salinity. The salt content resulting from the surface evaporation and depth of ground waters (0.35-2.0%) and salinity (0.5-10.0 kg /m^3). The results of the study indicated the following: The saving rate of flushing waters was 35-40% of the total consumption; Desalinization of soil in root layers was 1.5-2.0 times higher than during use of conventional technology; speeding up the flushing process within a short time frame in one season, higher rate of salt leaching and evaporation costs reduction.
Key words: Drainage water; Geoecosystem; Irrigation; Phosphogypsum; Phytomelioration; Sorbents

1. Introduction

Nowadays the geography of saline soils spreading has been determined, and the salt contents have been studied with regard to the soil-formation factors, geochemical and hydrological conditions, and the irrigation technology regimes. The resource-saving directions of saline soil melioration were developed: flushing, drainage, sub-soiling, the effect of sorbents, chemical and vegetative reclamation of soils. Presently more cost-effective technologies of mass-transfer, water and salts transfer on the irrigated soils during reclamative and operating regimes become topical. In order to solve this problem it is appropriate to develop the physic-mathematical task complex, which will give the description of the laws of their movement and distribution in the root layer of soils, and quantitative estimation of the salt content. With regard to environmental conditions of grey-brownish meadow saline soils and efficient use of water in the irrigated areas the methods aimed at the improvement of ecological-reclamation measures have been developed. The environmental factors characterizing the dangerous level of salt in the structure of soil layers have been identified (Seitkaziev et al., 2013).

Water melioration involves into the production process such important ecosystem components, as soil, water and plants, closely connected with water, energy and substance flows. Soil degradation, destruction of natural landscapes, productivity reduction of the meliorated land, exhaustion and pollution of water ecosystems put ecological aspects of water melioration development among top priorities.

The theory of salt accumulation and its role in the process of soil salinity was elaborated in the papers of such scientists as D.G. Vilenskiy, K.D. Glinka, V.A. Kovda, I. Antipov-Karataev, V.M. Borowskiy and others. Before sharing this particular viewpoint, we will take into account the evolutionary-genetic analysis of the transformation of the cationic composition of the complex salt areas of North Kazakhstan in the process of their steppe formation. V.A. Kovda believes that it is accompanied by updating exchange ground of the soil composition due to the accumulation of exchange layer having biogenic origin. The basic nature protection measure is the mode of irrigation and drainage were considered; that followed after putting the question about land reclamation, here salinization of irrigable

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soil was considered to be the basic problem (Seitkaziev et al., 2011).

Soil pollution in the form of salting takes place basically as a result of anthropogenic human activity during improper conduction of activities aimed at the land improvement, agro-technical and melioration measures. This happens as a result of ignoring the interrelated laws, which regulate the natural balance, soil evolution, and also hydrogeological, hydro-chemical and geochemical interactions during the conduct of ecologic-melioration activities.

Solution of a number of important geo-ecological and melioration problems is connected with the necessity to carry out reliable quantitative forecast of plant productivity under different climatic conditions and nutrition regimes. The basic problems here are the following: substantiation of the solutions on the rational use of biosphere resources, activities aiming at the environmental protection, elaboration of the water-saving technology for saline and irrigated lands and the improvement of the land melioration system substantiation etc. Land salinization is a serious problem for many countries of the world and it is one of the most important factors of desertification, posing a serious threat to the national economy. However, the degree of salinity in arid areas is different. According to FAO, the total area of saline land in the world reached 950 million hectares, and about 10 million hectares annually fall out of use due to salinization and alkalization. The current state of the desertification problem in Kazakhstan (Abbasov, 1990; Seitkaziev et al., 2012; Seitkaziev, 2002; Seitkaziev, 2000; Seitkaziev, 1999; Shirokova et al., 2007; Vadyunina, 1979;) is as follows:

- 20.5 million hectares of arable land and 25.0 million hectares of pasture are subject to wind erosion;
- Water erosion is already evident on the area of 19.2 million hectares;
- There is a widespread irrigation erosion on the irrigated lands (1.8 million hectares);
- Dehumidification resulting from soil erosion occurs on the area of 11.2 million hectares;
- 181.3 thousand hectares are subject to anthropogenic desertification;
- 376.7 thousand hectares of arable land are subject to salinity (salt marshes, sodic soils);
- Desertification of well-organized roads (96.5 thousand km);
- 0.5 million hectares from 1.4 million hectares of land suitable for irrigation, are not used due to secondary salinization;

This research aims at creating conditions for improving the soil-formation process, which provides the possibility of wider reproduction of soil fertility in the process of geo-ecological system development. To this end it is necessary to keep the automorphic regime of soil formation, and to keep subterranean waters deep enough in order to prevent possibility of the secondary soil salinization along with the minimal losses of irrigating waters.

The basic task of flushing saline soils is desalinization of root layer using minimal quantity of water. The soil flushing with extra water quantity could reduce their fertility and worsen the melioration-ecological state of the studied irrigation massif.

The principles of leaching efficiency are well-known from a number of previous studies. It is known that salt leaching of soil depends on many factors:

- It is easier to leach the soil having lighter texture than the heavy one;
- Intervals between leach cycles should be longer on heavy soils for the diffusion of salts from the solid phase;
- It is easier to quickly leach heavily saline soils to a light saline degree than to fully desalt the slightly saline soils; it is easier to leach soils salted with chlorides, than those salted with sulfates, and after leaching the main part of the chlorides the type of salinity becomes the chloride-sulphate or sulphate.

Quality leaching demands the drainage and sewerage provision. During the first leaching cycle free capacity of soils, filled with water is determined by the depth of ground water and serves as a capacity to dissolve the salts and then it should be followed by replacement of saline solution if the water is supplied in cycles and its outflow is provided. If the flush water outflow is not provided or it is very insignificant – the flushing loses its sense, as the supplied water evaporates or moves very slowly towards the dry area (dry drainage). Besides, studies of many authors indicate that the flushing efficiency depends on (given other similar conditions) the distance between the check and the drainage device (during horizontal drainage, for example, the worst conditions are in the middle sections of drain spacing).

The main criterion for evaluating the physical condition of the soil implies relevance of the soil properties to the functions performed by the soil in a particular landscape. In this context issues of the quantitative and qualitative evaluation of saline soils appear to be the most urgent. This means that, first of all, there is a need to determine how and to what extent the amount of salts affects ecological functions of the soil due to the change in their water-physical properties. Salinity has significant impact on the physical properties of the soil and water (Bresler et al., 1987; Sokolenko et al., 1981; Shamsutdinov et al., 2002; Volobuev et al., 1981; Seitkaziev et al., 2002). That is why the distribution of water-physical properties pursuant to the profile and space in the areas having different soil and climatic, hydrological and hydro-chemical conditions, has individual character.

Development of the complex melioration activities on the highly saline irrigating lands and salt marshes (irrigation, flushing, tillage and fertilizer application), including leaching of saline lands according to the type and degree of salinization as well as toxic salt properties, demand deep tillage at maximum possible depth of 1.0 m and more. The application of the deep tillage during flushing of strongly saline lands leads not only to the improvement of the soil structure, but also provides essential increase of their moisture content before the sowing. Our researches determined that the moisture content during deep tillage (overall and stripped) is increased up to 800-1200 m^3/ha, the distance between separate strips is determined in the following way: for heavy argillaceous soils - 0.5-1.0 m; for average argillaceous soils 1.0-3.0 m. The irrigating values, depending on the mechanical content of soils, decreased by 20-25%. The absorbing ability of the studied soils increased in 2.0-2.5 times, which, in turn, increased water-absorbing ability of the soil (Seitkaziev, 1999, 2002).

2. Material and methods

The main methods of hydrochemical regime regulation imply the impact on the groundwater level through the use of various measures (irrigation, flushing, soil tillage on the background of drainage). The formation of the water-salt, heat and food regimes in the rated soil layer is directly affected by the water-physical and physical-chemical processes. This is explained by the fact that irrigation and flush along with drainage result in the dramatic change of conditions related to the formation of incoming and outgoing items of water - salt balance, salt reserves, infiltration rate, changes in the moisture movement, evaporation, groundwater outflow and others. The use of ecological-reclamation complex measures allowed leaching toxic salts from the rated layer.

In order to substantiate the water-salt regime of saline soils the complex studies with the use of the following technologies were conducted in the irrigated lands: (Seitkaziev, 2002).

The first method. Field tillage, planning, making rolls, setting temporary irrigator and drainage along with permanently deep and open drainage. Water flushing in checks. The area of checks should be between 25000 and 10000 m^2.

The second method: Field tillage is not conducted; in turn the deep and comprehensive tillage is conducted (through the intervals of 0.5 m). With regard to the water-physical properties, salinization depth of compacted layers, the distance is changed to 1.0-3.0 m. Moreover, the temporary irrigators and temporary drainage are set at the distance of 40-100 m with the depth of 0.8-1.0 m. Thus, the deep tillage is conducted towards the irrigator and perpendicularly to the temporary drainage, leaving the distance 10-15 m, sometimes in parallel, depending on the surface slope.

The third method: The tillage and planning are conducted and organic fertilizers (manure, 0,2-0,3 kg/m^2) are put, and then the deep open-side tillage is conducted. In this case, the tractor should move in parallel to the loosened band. The soil moisture should not exceed its smallest moisture capacity; otherwise the consolidation of the already loosened layers will occur (Seitkaziev, 2000; Achmatov et al., 2005).

The intensity of desalination largely depends on the flushing technologies and salt leaching conditions of soils. Consequently, it is difficult to desalinize soils having heavy texture with low coefficients of filtration. The reclamation practice shows that during arid landscape formation the soils are saturated with water-soluble salts up to the depth of 10-20 m and more.

The new technological means of improving the soil and environmental conditions implies horizontal drainage along with deep loosening. It provides significant acceleration of the desalinization process. Plowing and planning are conducted, followed by the single-cycle loosening. The tractor should move in parallel to the loosened strip. The wheel of the tractor passes through the loosened strip at a distance which provides overlap of the loosened area. Reclamation practice shows that plowing along with loosening accelerates flush season in 2.5 - 3 times as compared with conventional practice and maintains soil fertility keeping mineral and organic substances intact, as well as contributes to the rapid movement of soluble concentrations of harmful salts in the rated layer.

One of the tasks during calculation of the groundwater balance of the irrigated geosystems implies definition of power and the parameters of the aquifer. These values are the most important benchmarks necessary for forecasting and calculating the level and the groundwater balance.

The effectiveness of leaching the saline soils directly depends on soil preparation and especially on the depth and method of plowing. Leaching rates of saline soils are one of the main ecological and agricultural activities that enhance crop growth. Therefore, the established norms of leaching cycles and ways to prepare the soil for the implementation of these measures on saline soils is of great practical importance in improving crop yields and the ecological condition of the irrigated geosystems.

The basic parameters of systemic horizontal drainage are the distance between drain lines, the position of subterranean water level (SWL) after drainage, the pressure between drain lines, the inflow of subterranean water and sewer. The inflow and outflow of water to the drain line from both sides is determined according to the formula (Seitkaziev et al., 2012; Sokolenko et al., 1981; Volobuev et al., 1981):

$$Q_0 = 4kh^2 l / R \qquad (1)$$

where Q – water outflow to the drain line, m^3; k – filtration coefficient, m/day; h – pressure of subterranean waters between drain lines, m; l – drain line length, m; R – distance between drain lines, m.

The inflow of water to the drain line per hectare per time unit is determined according to the following formula:

$$q_0 = \frac{Q_0}{t} \quad (2)$$

where q – module of the drainage outflow at the given pressure of subterranean waters, m³/m²; t – flush duration, day.

Therefore, given the known value of the actual speed of soil water movement V_f it is possible to determine net weight of leaching norm for saline soils according to the following formula (Seitkaziev, 2002; Vadyunina, 1979):

$$N_{nm} = \frac{Q_0 V_f}{q_0} \quad (3)$$

where N_{nm} – leaching norm (net weight), m³/ha; V_f – filtration speed in the saturated layers, m/day.

3. Results

Water-physical properties of massif soils were studied in 16 experimental areas. 11 areas are characterized as the non-saline types of soils and 5 areas - as the highly saline soils and alkaline soils which require leaching before being used and are combined with experimental areas to carry out the salt leaching study of soils.

The upper humus horizon, twisted by the plant roots has the smallest density.

While studying the mechanisms of salt transfer, right regulation of water-salt and food regime it is necessary to determine the following values – salt dilution, rock leaching, evaporation of soils and subterranean waters, convective diffusion, salt transfer with filtration flow, ionic-salt balance in the solution – hard phase system, exclusion of porous solutions and etc.

The results of studies as regards salt transfer mechanism given the conditions of left-bank Tenteksk massif and approbation of technological leaching schemes with regard to the speed of infiltration flow along with permanent drainage against the background of the temporary one, are given in Table 1 (Kazakov, 1988; Seitkaziev et al., 2005; Seitkaziev et al., 2010; Kuhlman et al., 1999; Skogerboe et al., 1984; Seitkaziev et al., 2011).

Table 1: The impact of flush norms on leaching the salts from the soil on the experimental plot “Zhanaminskiy”, % from the weight

Flush norms, (×10⁻⁴) m³/m²	Soil layer, m	HCO_3^-	CO_3^-	Cl^-	SO_4^{-2}	Ca^{+2}	Mg^{+2}	Na^++K^+	Salt content, %	Toxic salts, %
Before leaching	0.4	0.0744	0.2255	0.2721	0.8183	0.0399	0.0223	0.5249	1.7740	1.6502
	1.0	0.0581	0.0185	0.2361	0.7085	0.0327	0.0136	0.4655	1.5302	1.4321
	1.0...2.0	0.0361	0.0056	0.2201	0.3230	0.0331	0.0170	0.2441	0.8801	0.8102
6000	0.4	0.0765	0.0231	0.1551	0.3522	0.0146	0.0079	0.2841	0.9134	0.8660
	1.0	0.0685	0.0258	0.0671	0.3002	0.0128	0.0068	0.2060	0.6903	0.5580
	1.0...2.0	0.0370	0.0061	0.1310	0.2450	0.0130	0.0045	0.1970	0.6402	0.6001
8000	0.4	0.0777	0.0251	0.0752	0.2095	0.0204	0.0076	0.1622	0.5781	0.5202
	1.0	0.0694	0.0290	0.0497	0.2001	0.0084	0.0036	0.1601	0.5202	0.3901
	1.0...2.0	0.0387	0.0088	0.1025	0.2090	0.0079	0.0032	0.1715	0.5570	0.5142

Implementation of the saline soils leaching experience (soda-sulfate and sulfate-soda salinization) was conducted on the territory of LLC “Zhanaminskyi” located in Alakulsk district of Almaty region. The total experimental area was 350000 m².

Before field tillage the phosphogypsum was brought into the soil in combination with organic fertilizers. The field tillage on the depth 30-35 cm was done using the trenching plough (model PPN-40). For treatment of the soil compacted layer, the tillage was conducted on the depth 0, 6-0, 7 m using the ripper RN-80B. The planning of the field was conducted with long-span leveler P -2.8. The Creation of the irrigated checks rolls with height 0,35-0,4 m was conducted with the use of roll machine KZU-0.3D and making of the temporary irrigators-trenching plough – with the use of KZU-0.3 device with DT-75 trailer; making of the temporary drainage with the depth 1-1.2 m – by using the trenching plough (MK-16) with tractor K-701.

In order to provide the effective leaching and keeping in mind the soil filtration coefficient, the irrigating plots were divided into checks. The size of checks depends on the slope of the planned field and soil properties. The area of checks ranges from 1250 to 10000 m². The temporary drain lines were made within the distance ranging from 25 to 50 m. The temporary drain line groups were built with the distances ranging from 200 to 300 m. The checks were filled with water with a view to create the layer of 0, 1- 0, 12 m.

The practice shows that ploughing with tillage makes the leaching season 2.5-3 times faster than using the ordinary procedure and, accordingly, saves soil fertility by keeping useful mineral and organic substances. This also promotes quick movement of soluble concentrations of harmful salts in the rated layer. The tractor, passing through the loosened strip, simultaneously covers upper layers of soil, which promotes introduction of salts in soluble concentrations (Qadir, 2000; Mustafayev et al., 2012).

Such procedure keeps the soil fertility and promotes water-physical properties of soils. According to the results of studies the relevant leaching norms were obtained, which correspond to the above-mentioned formulas (1-3). The obtained data provided in the Table 2 show that leaching norms depend on the water-physical properties of soils and distances between the drain lines.

Table 2: Determination of flush norm

Filtration coefficient, C_f .m/day.	Pressure in the middle between drain lines h, m	Length of drain line, L,m	Leaching duration, t,day.	Distance between drain lines, R,m	Water outflow, Q_0 ,m^3/day	Water inflow, q_0,m^3	The smallest moisture capacity, β,%	Saturation norm .W_H, $m^3/10^4m^2$	Filtration speed in saturated layers V_H, m/day.	Leaching norms .$N_{nt,\ m}$
0.5	0.55	500	70	80	3.78	0.054	18	2556	0.008	0.56
0.8	0.35	500	84	100	1.96	0.023	20	2880	0.0073	0.62
1.0	0.25	500	116	120	1.04	0.009	23	3335	0.0060	0.69
2.0	0.10	500	139	300	0.13	0.0009	26	3822	0.0055	0.76

Consequently, in order to carry out regulation of water-salt and food regimes along with preservation and restoration of soil fertility, the deep soil tillage in the unfavorable lands is considered to be the most effective and efficient activity. In order to restore the leached fields or unfavorable lands their enrichment with organic substances is required, the manure and green fertilizers are especially important. The green fertilizer is a constantly renewable source of organic substance, as it helps to fight weeds and plant diseases, promotes reduction of soil salinization, and protects soil from erosion.

Bringing the manure or compost into the soil in the quantity of 15-20 ($\times 10^{-1}$) kg/m^2 a before or after leaching sharply increases the biological activity of plough horizon. Carbonic acid, emitted during the decaying of manure organic substances promotes transfer of soil phosphates into soluble forms, and the enrichment of bottom layer with carbonic acid noticeably improves the air nutrition of plants.

During the irrigation and leaching of saline soils the salts are washed out of the rated layer. The leached salts reach the subterranean waters together with filtration waters and then they go into the riverbeds. The surface evaporation of the subterranean waters was determined according to the method of water balance and the treatment of materials, during the conducted study showed that the interconnection between evaporation of subterranean waters and the depth of their deposition has the exponential character and is subdued to the following equation (Kuhlman et al., 1999; Skogerboe et al., 1984; Seitkaziev et al., 2013):

$$E_г = E_0\left(1-\frac{H}{H_{WLC}}\right)e^{-nH}, \qquad (4)$$

where $E_г$ - evaporation of subterranean waters, m; E_0 – evaporability of soil surface, m; H – deposition depth of subterranean waters; H_{WLC} – water-lifting capability of soils, m; n – parameter, which takes into account the water-physical properties of soils (n=0.7-1.5) .

Evaporation of subterranean waters ($E_г$) is determined according to the formula (4), and evaporability of soil surface (E_0) is determined pursuant to the formula of N.N. Ivanov, with regard to the Central Asian environment (Volobuev et al., 1981; Kazakov, 1988):

$$E_0=0.0018(25+t)^2(100-a), \qquad (5)$$

where t – air temperature, ^{0}C; a – relative air humidity, %.

Evaporation from the surface of the subterranean waters is the most important factor of soil salinization and bogging. Therefore, the quantitative determination of its values for soils, having different water-physical properties, has big scientific value.

The study of evaporation from the surface of subterranean waters required selection of 5 grounds deprived of vegetation on each experimental area. These selected grounds differed from each other as regards the salt content in soils and subterranean water mineralization. The results of irrigations, conducted in Tentekst massif during 1989-2007, show that the certain salt content of soils corresponds to the certain mineralization of subterranean waters. The studies of evaporation from the surface of subterranean waters were conducted on the experimental-production ground in July-august after third-fourth washing of the sugar beet. The level of subterranean waters in the period of study fluctuated within the limits from 0.9 to 2.8 m from the terrain. The data obtained are shown in the Table 2. Figure 1 show that evaporation from the surface of subterranean waters have the highest values when the level of subterranean waters is on the depth of more than one meter from the land surface, and the lowest values – on the depth nearly 2 m for soils of Group I and nearly 3 m for the rest of soil groups.

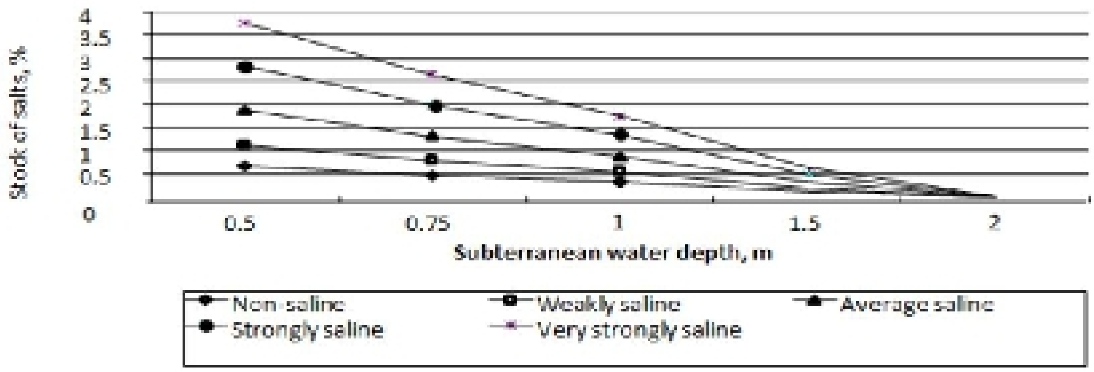

Fig.1: Dependence of the salt content from evaporation from the surface of subterranean water depth.

4. Discussion

The main data of the study concerns the grey-brownish meadow soils: with regard to surface salinity toxic salt content before leaching was 1.650%, reduced to 0.514% after leaching. The salt content resulting from the evaporation from the surface and depth of groundwater was 0.35-2.0% and salinity was estimated at 0.5-10.0 g / l.

The study resulted in the following:

- Flushing water saving was estimated at 35-40% of the total consumption;
- Desalinization of soil in the root thickness was 1.5-2.0 times higher than during use of conventional technology;

Faster leaching within short time frame in a single season, more favorable salt leaching along with reduction of costs on evaporation.

In this article we considered the application results of the world-known theoretical and laboratory, field and lysimetric studies of effective technologies used to improve the saline soils. However, it is not easy to leach the saline soils, as well as to use environmentally friendly and economically beneficial production technologies. The fact is that foreign experience requires large financial investments. Especially if the process of improvement of saline lands requires the use of tubular and vertical wells in the sewage-drainage system and leaching saline and sodic soils requires the use of electric equipment for reclamation. Our country doesn't have such opportunities. However, the suggested technologies of soil leaching, such as deep loosening of soil, the use of organic fertilizers, are much more effective on the one hand, and on the other they are quite advantageous from both the environmental and economic viewpoint. Considering the environmental-reclamation perspective of the data obtained as a result of long-standing field and production experience, statistical and chemical-physical analysis, mathematically simulated calculations is seems expedient that scientifically-founded crop rotations, planting crops, which could grow in saline soils be considered effective for improving saline soil. However, during the use of saline and sodic soils, more specifically, hydromorphic soils with close proximity of subterranean waters we suggest to provide biological drainage.

5. Conclusions

Having regard to the experimental studies, conducted in the Tenteksk massif of Taldykurgan region and in the Tasotkulsk massif of Zhambylsk region the water-effective technology of leaching was developed against the background of complex reclamation with the use of chemical substances (phosphogypsum) combined with organic fertilizers and deep tillage of dense soil layers. The results of the water-effective technology introduction show that it is economically appropriate to conduct leaching 5-6 times with the one-time norm of 800-1000 m^3/ha along with permanent drainage with the use of the temporary one, with inter-drain distance within 40-100 m and depth 1.2 m. Keeping this in mind, the general leaching norms were estimated at 5000-6000 m^3/ha.

Compared with the existing leaching technology this technology gave the following effects:

- Flushing water saving was estimated at 35-40% of the total consumption;
- Desalinization of soil in the root thickness was 1.5-2.0 times higher than during use of conventional technology;
- Faster leaching within short time frame in a single season, more favorable salt leaching along with reduction of costs on evaporation.

It is recommended to carry out such leaching technology during no less than three years and grow relevant salt-steady crops on the leached fields, taking into account the irrigation regime.

The recommended development of technology implies restoration of saline and salted compacted soils based upon deep tillage along with drainage with depth 0.8-1.0 m.

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