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The influence of fertilisation on the water-salt regime in the conditions of the Mugan-Salyan massif, Azerbaijan

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Abstract: The article presents research data on the amount of salts in the irrigated soils of the Mughan-Salyan massif, their composition, water-salt regime, and their forecast. It was found that the soils on the territory of the massif were saline to varying degrees. In general, the area of non-saline soils in the massif is 125,650 ha, mildly – 272,070 ha, moderately – 210,560 ha, highly – 125,850 ha, very highly – 109,450 ha and saline soils – 27,520 ha. The absorbed bases in the soils of the massif were studied, and it was determined that they change depending on the amount of salts as follows: in mildly saline soils, Ca – 57.82–68.31%, Mg – 25.26–36.28%, Na – 5.49–6.43%; in moderately saline soils – 56.77–65.76%, 27.03–35.58%, 7.12–7.94%, respectively; in highly saline areas – 54.05–64.75%, 24.94–43.67% and 9.19–14.42%. As you can see, the soils are mildly and moderately saline.

The soils in the surveyed areas are saline to varying degrees (i.e., the average value of salts in the 0–100 cm layer of the soil varies between 0.25 and 1.00%). The biological product used in these soils contains a wide range of macro and microelements, humic acids, fulvic acids, amino acids, vitamins and enzymes that do not contain BioEcoGum mineral fertilisers. This biological product was used for the first time and one of the main goals was to study the improvement of water-physical properties of soils after its use. Therefore, the water-salt regime of the soils of the study area was studied on three experimental sites selected for the area, the number of irrigations for different plants, and their norms were determined taking into account the depth of groundwater in the soils and shown in tabular form. They are widely used in farms and these regions, taking into account the proposed irrigation norms and their quantity.

Keywords: convective diffusion, forecast, ground water, irrigation norm, reclamation, salinity soils

INTRODUCTION

Recent reforms in all areas of agriculture led to a change in existing production relations in the agrarian sector because increasing soil fertility created conditions for increasing productivity and abundance of products. Currently, despite the prevalence of fertile soil farming, saline soils are also widespread – solonetsous, waterlogged, technogenically contaminated and eroded soil. The main factor limiting development in Azerbaijan irrigated agriculture, is the salinisation and solonetsousness of soils. This negative phenomenon is widespread in all areas of the republic, including in the Mugan-Salyan massif.

The main unfavourable phenomenon, delaying the development of agricultural crops is a widespread distribution of saline soils and a close occurrence of highly mineralised groundwater to the surface of the earth. From the beginning of the use of the lands of the Mugan-Salyan massif, there was a need to carry out large-scale irrigation-reclamation works here. According to the data of many years of research, it was revealed that for the normal and productive cultivation of crops, it is necessary to establish strict norms and terms of irrigation, to eliminate salinity and drainage in some areas, to maintain the level and mineralisation of groundwater, and also to operate the irrigation equipment correctly. In this regard, a comprehensive study of such indicators as the general volatility of the water-salt balance, humidity and salt composition of soils, level and mineralisation of groundwater in necessary. To achieve this goal, it is necessary to study the balance of precipitation, irrigation, salinity of surface, drainage and groundwater, and the chemical composition of the studied soils [VOLOBUYEV 1963].

The Mughan-Salyan massif is one of the most irrigated areas in the Republic of Azerbaijan, has high evaporation levels, and is very close to groundwater. Most of these soils are saline to varying degrees, highly saline areas are observed mainly in the lowlands of the relief. The environment is characterised by a hot and dry subtropical climate, low humidity, mild winters, hot and dry summers [MAMEDOV *et al.* 2010].

According to the average annual data, the total amount of evaporation is 5–6 times the amount of atmospheric deposition [FIGUROVSKIY 1936]. Therefore, during the growing season of plants, there is an acute shortage of moisture and watering is required. In the Mughan-Salyan massif, the parent rocks have different origins (deluvial-proluvial, alluvial and ancient Caspian deposits), and their particle size distribution is predominantly clay–clayey depending on the nature of the salt formation process. Therefore, it is more expedient to study the salts in the soil, especially their water-soluble compounds, the reasons influencing the accumulation of these salts, the regularities of the distribution of salts in the soil and the methods of their removal from the soil.

MATERIALS AND METHODS

The studies were carried out in 2000–2020 on the experimental sites of the plains of the Salyan, Sabirabad, Saatli, Imishli, Neftchala and Hajigabul districts of the Mughan-Salyan massif. Experimental plots are typical for all irrigated lands of the massif. Study of the water-physical properties of soils in the Salyan, Imishli and Saatli regions in separate areas for sowing grain and cotton, as well as the water-salt regime in the Salyan region with an area of 15 ha. In the Saatli and Imishli regions, 10 ha of irrigated meadow-grey and grey-meadow soils were studied on sown areas for cotton. During research in the field of three practices, the depth of the soils, the amount of water in the soil, the depth of water and its minerality and other parameters have been widely studied and used in a separate watermore.

The study of the water-salt regime and its regulation was carried out in accordance with the methods widely used in practice for a long time. The amount of salts in the soil, the mineralisation of groundwater, water in the collector-drainage systems and irrigation canals [ARINUSHKINA 1970], the volume of soil and water permeability [KACHINISKIY 1970], the amount of evaporation was determined folllowing the water balance method and the reporting method proposed by AVERYANOV [1965]. The pH was determined with a potentiometer, and soil moisture in the aeration zone was determined by gravity.

Changes in groundwater levels were detected by the size of hydrogeological observation wells, and water consumption of irrigation and drainage systems was studied using chipoletti-shaped aquifers.

Reclamation of soils in the studied territories by the method of VOLOBUYEV [1965] was widely used in the study of the state of salinity.

RESULTS AND DISCUSSION

One of the main directions of soil reclamation is the management of the water-salt regime in order to increase soil fertility and ensure the normal development of agricultural crops. From this point of view, it is important to study the water-salt regime under irrigation conditions and give its forecast [AZIZOV 2006; MUSTAFAYEV 2014; 2016; TUKENOVA *et al.* 2020]. Long-term studies show that one of the key issues for the normal development of agricultural crops is to determine the norms and terms of irrigation, regulate the salinity of a certain area, remove drainage water from the field, and maintain the level of groundwater and minerals at the optimal level and correct operation of the irrigation equipment. From this point of view, the water-salt regime of the studied territories depends on the general evaporation, moisture and salinity of the soil, the minerality of underground waters, the level of their location, etc., directly depends on the study of indicators. Changes in the water balance in the aeration zone under the influence of irrigation cause a radical change in the salt balance in a given area. Therefore, the joint study of the movement of water and salt in the soil is one of the main issues. In all three experimental plots, irrigation was carried out along surface furrows.

The amount of water supplied to the test sites was measured using sprinklers.

During the growing season, the irrigation rate ranges from 1250 to 1650 $m^3 \cdot ha^{-1}$, and the total irrigation rate ranges from 5000 to 6350 $m^3 \cdot ha^{-1}$. Determined by Equation (1), [AVERYANOV 1965] of leaks from irrigation canals, depending on the irrigation rate, their indicators on the experimental plots in Salyan, Saatli and Imishli regions are: 1259.25–1303.05 $m^3 \cdot ha^{-1}$; 1116.90–1281.15 $m^3 \cdot ha^{-1}$; 1314.00–1390.65 $m^3 \cdot ha^{-1}$.

$$F_k = (1/\eta - 1)Q_{\text{Watering}} \tag{1}$$

where: η = 0.82, Q = water flow in the canal.

The average price of mineral water for irrigation in Salyan region is 0.63–0.78 $g \cdot dm^{-3}$, respectively. Taking into account that in Saatli region the price is 0.58–0.67 $g \cdot dm^{-3}$, and in Imishli region it is 0.64–0.67 $g \cdot dm^{-3}$, the amount of salts entering the experimental areas were determined: 3.75–4.48 $Mg \cdot ha^{-1}$ and 3.10–3.92 $Mg \cdot ha^{-1}$; 3.91–4.13 and 0.82–0.98 $Mg \cdot ha^{-1}$; 0.68–0.86 $Mg \cdot ha^{-1}$, 0.88–0.90 $Mg \cdot ha^{-1}$.

One of the main issues in the study of the water-salt regime is the level of water pressure on irrigated lands and changes in their minerality. Because of long-term land reclamation and engineering-hydrogeological studies, the depths of confined waters in the Mughan-Salyan massif, the nature of their distribution, and their effect on groundwater have been determined. The study of this indicator makes it possible to determine their application and irrigation regime by conducting feasibility studies for land reclamation (drainage design). One of the main issues during the research is to study the amount of salts entering the area with irrigation water. These issues were studied for different plants and the results are given in Table 1 below.

In general, studies show that the piezometric level of water under pressure exceeds the depth of groundwater by 1.5–3.0 m. The mineral content of pressure waters in the Mughan-Salyan

Table 1. Irrigation regime and the amount of salts entering the experimental areas with irrigation water

Years	Irrigation ordinal numeral	Watering time	Irrigation norm ($m^3 \cdot ha^{-1}$)	General irrigation norm ($m^3 \cdot ha^{-1}$)	The amount of salts entering the irrigation water ($Mg \cdot ha^{-1}$)
Salyan district (experimental area)					
2000	sowing	11.I–16.I	1650	5950	3.75
	1*	15.VI–21.VI	1450		
	2*	18.VI–22.VII	1550		
	3*	15.VIII–20.VIII	1300		
2001	sowing	08.I–14.I	1750	5850	4.03
	1*	12.VI–17.VI	1350		
	2*	15.VII–20.VII	1400		
	3*	18.VII–22.VIII	1350		
2002	sowing	11.II–16.II	1800	5750	4.48
	1*	18.VI–23.VI	1300		
	2*	24.VII–28.VII	1400		
	3*	17.VIII–21.VIII	1250		
2003	sowing	19.II–24.II	1750	5950	4.28
	1*	13.VI–17.VI	1350		
	2*	23.VII–28.VII	1500		
	3*	21.VII–25.VIII	1350		
Saatlı district (experimental area)					
2000	sowing	15.I–21.I	1750	5850	3.92
	1*	10.VI–15.VI	1300		
	2*	14.VII–19.VII	1500		
	3*	16.VIII–20.VIII	1300		
2001	sowing	17.I–22.I	1950	5100	3.11
	1*	20.VI–25.VI	1600		
	2*	13.VIII–17.VIII	1550		
2002	sowing	11.I–15.I	1700	5600	3.25
	1*	17.VI–23.VI	1350		
	2*	21.VII–26.VII	1250		
	3*	15.VIII–1.VIII	1300		
2003	sowing	20.II–25.II	1850	5000	3.10
	1*	25.VI–30.VI	1650		
	2*	17.VIII–23.VIII	1500		
İmishli district (experimental area)					
2008	sowing	14.I–22.I	1750	6350	4.13
	1*	12.VI–17.VI	1550		
	2*	14.VII–19.VII	1650		
	3*	15.VIII–19.VIII	1400		
2009	sowing	18.II–23.II	1750	6000	4.02
	1*	16.VI–21.VI	1500		
	2*	21.VII–26.VII	1400		
	3*	19.VIII–23.VIII	1350		

Explanations: * = vegetable watering.
Source: own study.

massif was different. In the eastern part of the massif, it is 5–80 g·dm^{-3}, whereas in the western part it fluctuates between 1–60 g·dm^{-3}.

The composition of the pressurised water in the massif is mainly sodium sulfate, sodium chloride, and in some places, bicarbonate-sodium chloride [Babayev *et al.* 2011; Mustafayev 2012a; 2012b; Mustafayev *et al.* 2011; 2016; Pankova 2016].

The average amount of water under pressure entering the balance layer in the study areas was 1260 m^3·ha^{-1} in the Salyan district, 1300 m^3·ha^{-1} in the Saatli district and 1380 m^3·ha^{-1} in the Imishli district. According to the average annual mineral content of water under pressure, it has been determined for each area: 8.6 g·dm^{-3} in Salyan, 5.6 g·dm^{-3} in Saatli, and 6.5 g·dm^{-3} in Imishli. Taking into account the average values of the content of mineral substances, it was determined that the amount of salts entering the experimental plots with water under pressure is 10.84 Mg·ha^{-1} in the Salyan region, 7.28 Mg·ha^{-1} in Saatli, and 8.97 Mg·ha^{-1} in Imishli, respectively [Kireicheva, Yashin 2020; Mustafayev 2015; 2017; 2020; Mustafayev *et al.* 2018; Yashin 2020].

Particular attention was paid to the study of drainage flow in the study areas and the change in the cost of the drainage module by months and years, their average annual values were used to calculate the water-salt balance. Long-term studies have shown that drainage flow increases after irrigation and vegetation reaches its maximum value. After irrigation, the stabilisation process is practically in progress. In all three experimental plots, the minimum rate of drainage runoff is observed between September and December. In recent years, the rate of drainage runoff was 2345–2545 m^3·ha^{-1} in the Salyan region, 1942–2167 m^3·ha^{-1} in the Saatli region, and 2470–2526 m^3·ha^{-1} in the Imishli region.

Mineralisation of drainage water during the growing season is minimal, and in the non-growing season – maximal. Thus, the salinity of the drainage waters of the experimental plots is 5.11–5.97 g·dm^{-3} in the growing season. In the non-growing periods the salinity is 6.72–7.42 g·dm^{-3} and 5.32–5.99 g·dm^{-3}; 5.54–6.76 g·dm^{-3}; 7.43–7.98 g·dm^{-3} and ranges from 5.75 to 7.35 g·dm^{-3}. Average annual levels of mineral substances range from 5.89 to 6.00 g·dm^{-3}, 7.43–7.76 g·dm^{-3} and 6.10–6.38 g·dm^{-3}, respectively.

Based on the results obtained, it was established that the amount of salts removed from the experimental areas by drainage waters during the study period amounted to 13.42–15.21 t·ha^{-1} in the Salyan region, 14.51–16.82 t·ha^{-1} in the Saatli region, and 13.67–15.74 t·ha^{-1} in the Imishli region.

The modern development of agriculture requires high-quality processing of issues such as planning, forecasting, and operational management of production processes. The study and forecast of the water-salt regime is an integral part of these issues and is important for obtaining high and stable crop yields. Studies show that in the Mughan-Salyan massif, as in other regions, the distribution of salts in soils along the profile has a different character. Therefore, when studying the process of salt leaching in saline soils, the degree and type of salinity, the thickness of the washed soil layer, the time of leaching, soil salinisation, etc. as well as the salt reserve in the soil after leaching, and the total porosity along the profile of the soil, according to these parameters, the following equations were solved.

The forecast of the water-salt regime is of scientific and practical importance for the correct direction of reclamation measures taken to prevent salinisation of the soils of the Mughan-Salyan massif. The mathematical model is used to predict the water-salt regime. For this, one of the main issues is the determination of the physicochemical parameters included in the mathematical model, including the determination of the coefficient of hydrodynamic dispersion (λ) of the soil. Depending on the granulometric composition of soils, the value of λ differs if the amount of physical clay ≤10% – 0.01–0.05, at 10–20%, 20–40%, 40–60% and 60–80%: 0.05–0.10, 0.10–0.20, 0.20–0.50, and more than 0.5, respectively. One of the main parameters in solving these problems is the calculation of the convective diffusion coefficient. The correct determination of the convective diffusion coefficient is one of the main factors in determining the washing speed. Its value depends on the granulometric composition of soils, the rate of filtration, salinity and its type, and characterises the movement of salts dissolved in the leaching medium:

$$D^2 = \frac{V_0{}^2 t}{4m^2 a^2} \tag{2}$$

where: D^2 = convective diffusion coefficient (m^2·d^{-1}), V_0 = filtration rate (m·d^{-1}), a = coefficient depending on the ratio of the permissible (n_0) and initial (n) salinity (n_0:n), m = coefficient of porosity, t = duration of flushing per day.

As can be seen from the formulas, the convective diffusion coefficient is directly proportional to the filtration rate (V_0 = n:t) at constant values of porosity (m) and flushing time (t) and is inversely proportional to the salinity index soils (a). Value a, depending on the ratio $n = n_0/n$, is selected from the following list: at $\bar{n}$ = 0.00 – $a \to \infty$, at $\bar{n}$ = 0.001 – a = 2.19, at $\bar{n}$ = 0.005 – a = 182, at $\bar{n}$ = 0.01 – a = 1.65, at $\bar{n}$ = 0.02 – a = 1.45, at $\bar{n}$ = 0.04 – a = 1.24, at $\bar{n}$ = 0.06 – a = 1.10, at $\bar{n}$ = 0.08 – a = 0.99, at $\bar{n}$ = 0.10 – a = 0.91, at $\bar{n}$ = 0.12 – a = 0.83, at $\bar{n}$ = 0.14 – a = 0.76, at $\bar{n}$ = 0.16 – a = 0.70, at $\bar{n}$ = 0.18 – a = 0.65, at $\bar{n}$ = 0.20 – a = 0.60, at $\bar{n}$ = 0.25 – a = 0.48, at $\bar{n}$ = 0.30 – a = 0.37, at $\bar{n}$ = 0.35 – a = 0.27, at $\bar{n}$ = 0.40 – a = 0.18, at $\bar{n}$ = 0.45 – a = 0.09, and at $\bar{n}$ = 0.50 – a = 0.00.

The values of the convective diffusion coefficient can also be determined experimentally in the field. According to the results of studies carried out by employees of the Azerbaijan National Academy of Science and the Institute of Soil Science and AgroChemistry in the Kur-Araz lowland, the directions of leaching saline soils against the background of drainage values are 0.027–0.045 m^2·d^{-1} on the Shirvan plain, 0.035–0.055 m^2·d^{-1} on the Karabakh plain, 0.070–0.150 m^2·d^{-1} in Northern Mughan, 0.020–0.035 m^2·d^{-1} in South Mughan, 0.040–0.070 m^2·d^{-1} in the Salyan plain, 0.030–0.060 m^2·d^{-1} in the Mil plain. Currently, these indicators are widely used in the study of convective diffusion.

As can be seen, high values of the convective diffusion coefficient were obtained in the areas of Northern Mughan with a high dehydration capacity, and small values – in Salyan and Southern Mughan with a low dehydration capacity. In the study of the proposed processes, the following convective diffusion equation was used:

$$\theta(x,t) = 1 - 0.5\left[e\tau fc\phi_2 - (1 + Pe^* + Pe^*\tau^*)l^{Pe^*} erfc\phi_1 + 2\sqrt{\frac{Pe^*\tau^*}{\pi}l^{-\phi_2^2}}\right] \tag{3}$$

where: $\phi_{1,2} = \frac{\sqrt{Pe^*(1\pm\tau^*)}}{2\sqrt{\tau^*}} = \frac{x\pm\vartheta t|m_o}{2\sqrt{\bar{D}t}}$; $\bar{D} = \frac{D}{m_o}$; $Pe^* = \frac{\vartheta_x}{D}$; $\tau^* = \frac{\vartheta t}{m_o x}$; $\theta = \frac{c-c_{\Pi}}{c_o-c_{\Pi}}$

and

$$\theta(\xi,\eta)=0.5\left\{(\xi+1)\exp((4\eta)e\tau fc\left[(\xi+1)\sqrt{\frac{\eta}{\xi}}\right]-(\xi-1)e\tau fc\left[\xi-1\sqrt{\frac{\eta}{\xi}}\right]\right\} \tag{4}$$

where: $\theta=\frac{S_{CP}-C_{\Pi}}{C_0-C_{\Pi}}$; $\xi=\frac{l}{R}$; $l=\frac{\tau}{m}$; $\eta=\frac{R}{4\lambda}$, $\tau=\int_O^T\vartheta(t)dt$

where: θ = salt content in the considered layer, Pe = by satellite (number), λ = coefficient of hydrodynamic dispersion, d = the diameter of the drain, t = duration of flushing per day, R = wash layer, τ = wash norm obtained from the functions θ (x, t) and θ (ξ, η), η = 0.82, l = length of drain, C (c) = coefficient of variation, φ $(\varphi_1; \varphi_2)$ = probability integral, ϑ; ϑ_x = speed of water movement in the soil; the speed of movement on the interdrain, m = coefficient of porosity, x = the depth of the washed soil layer, m_o = porosity coefficient, D = convective diffusion coefficient, S_{CP} = average price of salts in 200 cm layer, C_{Π} (c_{Π}) = water minerality at the beginning of the study, C_0 (c_o) = initial salt content in the soil layer, c = water minerality, * = vegetable watering.

Also during the calculation of $\theta=\frac{C-C_{\Pi}}{C_0-C_{\Pi}}$, θ = (x, t) and θ = (τ, Pe), washing norm $\theta=\frac{S_{CP}-C_{\Pi}}{C_0-C_{\Pi}}$, using the values obtained from the functions θ (x, t) and θ (ξ, η), the λ – hydrodynamic dispersion parameter was determined. In this case, the indicators of the results given in Tables 2 and 3 were used in accordance with the above functions.

The λ (hydrodynamic dispersion parameter) was determined using the values of T – wash time, R – wash layer, and τ – wash norm obtained from the functions θ (ξ, t) and θ (ξ, η). In this case, the indicators of some generalised characteristic salt sections were used. According to one formula (Eq. 3), λ = 2.681, and according to the other formula (Eq. 4), λ = 3.220, and from the table above, the parameter λ was found with a smaller error according to the solution (3.2). Thus, P (1) = 5.37% > P (2) = 5.25%. Therefore, the value found by Equation (4) is more reliable, and therefore the value λ = 3.220 is expected (Tab. 4).

In general, the forecast of the water-salt regime of arable lands provides the basis for the proper use of agricultural crops in these areas in the future. The observation of balance in these areas, the study of water and salt balance, as well as the forecast of their regimes has practical value in reclamation studies.

Table 2. $\theta=\frac{c-c_{\Pi}}{c_o-c_{\Pi}}$ indicators

θ = (x, t)	**Pe**	**Wash norm (τ)**								
		3.36	**3.37**	**3.38**	**3.39**	**3.40**	**3.41**	**3.42**	**3.43**	**3.44**
1	0.26	0.389	0.388	0.387	0.387	0.386	0.385	0.384	0.384	0.383
2	0.21	0.383	0.382	0.381	0.380	0.380	0.379	0.378	0.377	0.377
3	0.28	0.376	0.376	0.375	0.374	0.375	0.373	0.372	0.371	0.370
4	0.29	0.371	0.370	0.369	0.368	0.367	0.367	0.366	0.365	0.364
5	0.30	0.365	0.364	0.363	0.363	0.362	0.361	0.360	0.360	0.359
6	0.31	0.359	0.359	0.358	0.357	0.356	0.355	0.355	0.354	0.353
7	0.32	0.354	0.353	0.352	0.352	0.351	0.350	0.349	0.349	0.348
8	0.33	0.349	0.348	0.347	0.346	0.346	0.345	0.344	0.343	0.343
9	0.34	0.344	0.343	0.342	0.341	0.341	0.340	0.339	0.338	0.338
10	0.35	0.339	0.338	0.337	0.337	0.336	0.335	0.334	0.333	0.333
11	0.36	0.334	0.333	0.333	0.332	0.331	0.330	0.330	0.329	0.328
12	0.37	0.330	0.329	0.328	0.327	0.326	0.326	0.325	0.324	0.323
13	0.38	0.325	0.324	0.324	0.323	0.322	0.321	0.320	0.320	0.319
14	0.39	0.321	0.320	0.319	0.318	0.318	0.317	0.316	0.315	0.315
15	0.40	0.317	0.316	0.315	0.314	0.313	0.313	0.312	0.311	0.310
16	0.41	0.312	0.312	0.311	0.310	0.309	0.309	0.308	0.307	0.306
17	0.42	0.308	0.308	0.307	0.306	0.305	0.305	0.304	0.303	0.302
18	0.43	0.305	0.304	0.303	0.302	0.301	0.301	0.300	0.299	0.298
19	0.44	0.301	0.300	0.299	0.298	0.298	0.297	0.296	0.295	0.294
20	0.45	0.297	0.296	0.295	0.295	0.294	0.293	0.292	0.292	0.291

Explanations: θ = (x, t), Pe as in Equations (3) and (4).
Source: own study.

Table 3. $\theta = \frac{S_{CP} - C_{\Pi}}{C_0 - C_{\Pi}}$ indicators

θ = (ξ, η)	λ	Washing time (T)								
		3.38	3.39	3.40	3.41	3.42	3.43	3.44	3.45	3.46
1	0.054	0.381	0.380	0.379	0.379	0.378	0.377	0.377	0.376	0.376
2	0.056	0.374	0.373	0.373	0.372	0.371	0.371	0.370	0.369	0.369
3	0.058	0.367	0.367	0.366	0.366	0.365	0.364	0.364	0.363	0.362
4	0.060	0.361	0.361	0.360	0.359	0.359	0.353	0.357	0.357	0.356
5	0.062	0.355	0.354	0.354	0.353	0.352	0.352	0.351	0.350	0.350
6	0.064	0.349	0.349	0.348	0.347	0.347	0.346	0.345	0.345	0.344
7	0.066	0.343	0.343	0.342	0.341	0.341	0.340	0.339	0.339	0.338
8	0.068	0.338	0.337	0.337	0.336	0.335	0.335	0.334	0.333	0.333
9	0.070	0.333	0.332	0.331	0.330	0.330	0.329	0.329	0.328	0.327
10	0.072	0.327	0.327	0.326	0.325	0.325	0.324	0.323	0.323	0.322
11	0.074	0.322	0.322	0.321	0.320	0.320	0.319	0.318	0.318	0.317
12	0.076	0.317	0.317	0.316	0.315	0.315	0.314	0.313	0.313	0.312
13	0.078	0.312	0.312	0.311	0.310	0.310	0.309	0.308	0.308	0.307
14	0.080	0.308	0.307	0.306	0.306	0.305	0.304	0.304	0.303	0.302
15	0.082	0.303	0.303	0.302	0.301	0.301	0.300	0.299	0.299	0.298
16	0.084	0.299	0.298	0.297	0.297	0.296	0.295	0.295	0.294	0.293
17	0.086	0.294	0.294	0.293	0.292	0.292	0.291	0.290	0.290	0.289
18	0.088	0.290	0.290	0.289	0.288	0.288	0.287	0.286	0.286	0.285
19	0.090	0.286	0.285	0.285	0.284	0.283	0.283	0.282	0.281	0.281
20	0.092	0.282	0.281	0.281	0.280	0.279	0.279	0.278	0.277	0.277

Explanations: θ (ξ, η), λ as in Equations (3) and (4).
Source: own study.

Table 4. Value of hydrodynamic dispersion parameter (λ) in Mughan-Salyan massif

Sections	Salinity in the layer of 0–100 cm (%)						θ		λ according to the Equation	
	S_o	S_d				S_m				
	0–100	0–25	25–50	50–75	75–100	0–100	75–100	0–100	(3)	(4)
1	2.50	0.805	0.826	0.832	0.849	0.828	0.324	0.315	2.703	3.289
2	2.00	0.768	0.784	0.797	0.805	0.789	0.333	0.326	2.778	3.472
3	1.50	0.661	0.672	0.689	0.691	0.678	0.335	0.319	2.857	3.165
4	1.00	0.621	0.630	0.648	0.654	0.638	0.342	0.333	2.941	3.571
5	0.50	0.425	0.440	0.453	0.463	0.445	0.281	0.268	2.128	2.604
$\bar{C} = \sum_{i=1}^{n} C_i \vert n$		0.656	0.670	0.684	0.692	0.676	0.323	0.312	2.681	3.220
$\sigma = \sqrt{\sum (C - C_i)^2 \vert n - 1}$		0.149	0.151	0.150	0.151	0.150	0.049	0.051	0.322	0.378
$V = 100\sigma \vert \bar{C}, \%$		22.71	22.54	21.93	21.82	22.19	15.17	16.35	12.01	11.74
$P = V \vert \sqrt{n}, \%$		10.16	10.08	9.81	9.76	9.92	6.78	7.31	5.37	5.25

Explanations: S_o = initial amount of salt, S_d = final amount of salts, S_m = average grade for 0–100 cm layer, θ = salt content in the considered layer, C = salt concentration in solution, C_i = amount of salt per layer, n = amount of samples, i = indicators for each layer, σ = mean square deviation, P = accuracy indicator, V = speed of water movement.
Source: own study.

Therefore, during the investigation of these issues, special attention was paid to the results of the previously conducted research in this direction. Based on the balance observations, the speed of water movement in the soil at the survey sites was determined. In this case, the following formula was used:

$$V = \frac{O_P + O_C - E}{t \cdot m \cdot 10000} \tag{5}$$

where: V = speed of water movement in the soil, m = porosity (%), O_p = irrigation water ($m^3 \cdot ha^{-1}$), O_C = precipitation ($m^3 \cdot ha^{-1}$), E = total evaporation ($m^3 \cdot ha^{-1}$), t = time (d). An example of calculating the water-salt regime of the study area was carried out using the values of the specified parameters (m, E, V, t). Using the above Equation (5), the movement of water in the experimental areas was studied and the results are given in Table 5.

Calculations show that there is a weak desalination process in the experimental plots. The water velocity in the selected experimental site in the Salyan region is 0.0812–0.1067 $m \cdot d^{-1}$ and 0.0015–0.0018 $m \cdot d^{-1}$. In the Saatli practice region, these indicators are 0.0738–0.1117 $m \cdot d^{-1}$, and 0.0016–0.0018 $m \cdot d^{-1}$ respectively.

In the conditions of the field selected in the Imishli region, the water velocity is 0.0771–0.1013 $m \cdot d^{-1}$ and 0.0016–0.0017 $m \cdot d^{-1}$. These indicators make it possible to determine the upper and lower limits of the speed of movement of water in the soil of experimental plots (Tab. 5).

Calculations based on the solution of the convective diffusion Equation (3) showed that in order to reduce the salt regime to the optimal level (0.25–0.30% by dry residue) in these investigated areas, it is necessary to adjust the irrigation regime. Thus, to regulate the salt regime on the irrigated areas of the Mughan-Salyan massif, it is proposed to irrigate arat at the rate of 1000–1300 $m^3 \cdot ha^{-1}$, and during the growing season – at the rate of 5000–6000 $m^3 \cdot ha^{-1}$ [Mustafayev *et al.* 2020].

Recent studies show that the correct implementation of agrotechnical measures when using land in the Mughan-Salyan massif, taking into account the soil and climatic conditions of the area, the continuous planting in the area for several years, its water, requires the determination of irrigation regimes.

Table 5. Calculation of water-salt regime in experimental fields in Mughan-Salyan massif

Term	S_0 (%) 200	t (d)	Irrigation norm ($m^3 \cdot ha^{-1}$)	General evaporation ($m^3 \cdot ha^{-1}$)	Water velocity ($m \cdot d^{-1}$)
Salyan district					
2020	0.810	11	5950	650	0.1067
Break	0.835	232	–	4750	–0.0018
2020	0.795	12	5850	600	0.0961
Break	0.806	236	–	4710	–0.0016
2020	0.780	14	5750	550	0.0812
Break	0.798	265	–	4635	–0.0015
2020	0.752	–	–	–	–
Saatli district					
2020	0.798	10	5850	625	0.1117
Break	0.812	245	–	4740	–0.0016
2020	0.780	13	5100	670	0.0738
Break	0.792	250	–	4890	–0.0018
2020	0.765	15	5750	560	0.0746
Break	0.779	260	–	4850	–0.0017
2020	0.747	–	–	–	–
Imishli district					
2008	0.800	12	6350	630	0.0991
Break	0.835	235	–	4800	–0.0016
2009	0.783	11	6000	690	0.1013
Break	0.815	240	–	4880	–0.0017
2010	0.771	15	6100	595	0.0771

Explanations: S_0 = initial amount of salt.
Source: own study.

Therefore, based on the results of many years of comprehensive research the need for water irrigation for plants on the irrigated lands of the Mughan-Salyan massif, the granulometric composition of soils, the change in the amount and type of salts in the soil profile, the level of groundwater and mineralisation, its composition, and water – the irrigation regimes of the main crops intensively used in these territories taking into account changes in their physical properties were studied.

One of the main conditions for soil salinisation in the Mughan-Salyan massif is low mineral content and the depth of groundwater occurrence below the permissible level (1.75–2.00 m).

In addition, for the effective use of water resources in the Mughan-Salyan massif, based on the data from meteorological stations, research changes were made to the existing irrigation regimes in the irrigated territories. The groundwater depth is taken into account and given in the form of recommendations in the following tables (Tabs. 6, 7).

Table 6. Groundwater depths greater than 3.0 m above the Earth's surface

The name of the plant	Type of irrigation	Number of irrigation	Duration of irrigation	Arat, moisturising and vegetation irrigation norm ($m^3 \cdot ha^{-1}$)
Cotton	sowing	1	10 II–5 IV	1550
	vegetation	4	15 VI–27 VIII	3300
Autumn cereals	sowing	1	20 IX–15 XI	1000
	vegetation	2	20 IV–30 V	2100
Covered clover	vegetation	4	30 VI–28 IX	4850
Biennial clover	vegetation	6	5 IV–25 IX	6800
Vegetables	sowing	1	5 IV–25 IV	750
	vegetation	4	10 V–10 VIII	4250
Cotton	sowing	1	10 II–5 IV	1500
	vegetation	4	14 VI–28 VIII	3400
Autumn cereals	sowing	1	25 IX–20 XI	1000
	vegetation	2	22 IV–31 V	2050
Covered clover	vegetation	4	29 VI–28 IX	4900
Biennial clover	vegetation	6	1 IV–20 IX	6950
Vegetables	sowing	1	10 IV–30 IV	700
	vegetation	4	15 V–16 VIII	4200
İmishli region				
Cotton	sowing	1	10 II–5 IV	1500
	vegetation	4	14 VI–28 VIII	3350
Autumn cereals	sowing	1	25 IX–20 XI	1000
	vegetation	2	22 IV–31 V	2000
Covered clover	vegetation	4	29 VI–28 IX	4800
Biennial clover	vegetation	6	1 IV–20 IX	6750
Vegetables	sowing	1	10 IV–30 IV	700
	vegetation	4	16 V–15 VIII	4100
Cotton	sowing	1	10 II–5 IV	1550
	vegetation	4	15 VI–27 VIII	3400
Autumn cereals	sowing	1	20 IX–15 XI	1050
	vegetation	2	20 IV–31 V	2100
Covered clover	vegetation	4	30 VI–27 IX	4850
Biennial clover	vegetation	6	5 IV–25 IX	6850
Vegetables	sowing	1	5 IV–25 IV	750
	vegetation	4	10 V–10 VIII	4200

Source: own study.

Table 7. For groundwater depths less than 3.0 m above the Earth's surface

The name of the plant	Type of irrigation	Number of irrigation	Duration of irrigation	Arat, moisturizing and vegetation irrigation norm ($m^3 \cdot ha^{-1}$)
Cotton	sowing	1	15 II–10 IV	1550
	vegetation	4	10 VI–20 VIII	4250
Autumn cereals	sowing	1	25 IX–20 XI	1000
	vegetation	2	20 IV–6 VI	2100
Covered clover	vegetation	5	5 VII–20 IX	5550
Biennial clover	vegetation	8	1 IV–25 IX	8800
Vegetables	sowing	1	5 IV–25 IV	700
	vegetation	5	15 V–20 VIII	5250
Cotton	sowing	1	10 II–5 IV	1500
	vegetation	4	15 VI–26 VIII	4300
Autumn cereals	sowing	1	25 IX–20 XI	1000
	vegetation	2	20 IV–6 VI	2150
Covered clover	vegetation	5	1 VII–15 IX	5500
Biennial clover	vegetation	8	1 IV–28 IX	8850
Vegetables	sowing	1	10 IV–30 IV	700
	vegetation	5	15 V–20 VIII	5200
Cotton	sowing	1	10 II–5 IV	1500
	vegetation	4	15 VI–26 VIII	4200
Autumn cereals	sowing	1	25 IX–20 XI	1000
	vegetation	2	20 IV–6 VI	2100
Covered clover	vegetation	5	1 VII–15 IX	5400
Biennial clover	vegetation	8	1 IV–28 IX	8700
Vegetables	sowing	1	10 IV–30 IV	700
	vegetation	5	16 V–15 VIII	4100
Cotton	sowing	1	10 IV–30 IV	700
	vegetation	4	15 V–20 VIII	5100
Autumn cereals	sowing	1	22 IX–25 XI	1100
	vegetation	2	20 IV–5 VI	2200
Covered clover	vegetation	5	5 VII–20 IX	5500
Biennial clover	vegetation	8	1 IV–30 IX	8750

Source: own study.

CONCLUSIONS

1. The research results show that the humus content (0–100 cm layer) in the sown areas of agricultural crops on slightly degraded soils is 1.35–0.21%, nitrogen – 0.18–0.02%, carbonate – 6.53–4.08%, and the pH ranges from 8.60 to 8.51. In areas with severe degradation – 0.42–0.27%, 0.05–0.02%, 8.46–9.89%, 9.02–9.20%, respectively. It was determined that the depth of groundwater accumulation and mineralisation in non-saline soils areas was 2.55–3.00 m and 2.8–1.2 $g \cdot dm^{-3}$. In the areas with the strongest mineralisation – it was 1.64–1.72 m and 9.2–9.9 $g \cdot dm^{-3}$. However, in saline areas, these values varied between 1.20 and 1.50 m, and 20.86 and 29.91 $g \cdot dm^{-3}$.
2. Based on experimental calculations and solving the conjunctive diffusion equation, the hydrodynamic dispersion coefficient, λ = 3.22, which is of particular importance in the mathematical modelling of the water-salt regime, and the water velocities "up" and "down" (V) were determined. It was determined that the irrigation regime should be adjusted to maintain the optimal salt level (S = 0.25–0.30%) in the research areas, so that the irrigation norm for sowing must be between 1000 and 1300 $m^3 \cdot ha^{-1}$, but during the growing season, it is appropriate to carry out 5–6 irrigations with a total irrigation rate of 5000–6000 $m^3 \cdot ha^{-1}$.
3. The use of the natural preparation of biological origin will enable the population of the country to consume ecologically fresh agricultural products. The conducted research will make it possible to recommend the creation of methods of using a biological product in the cultivation of agricultural crops, ensuring maximum economic efficiency, and considering environmental requirements.

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