**ESTADO DE MELHORAMENTO DOS CHERNOSSOLOS CLAROS IRRIGADOS DA
REGIÃO DO TURQUESTÃO****THE AMELIORATIVE CONDITION OF THE IRRIGATED LIGHT SEROZEM OF THE
TURKESTAN REGION****МЕЛИОРАТИВНОЕ СОСТОЯНИЕ ОРОШАЕМЫХ СВЕТЛЫХ ЧЕРНОЗЕМОВ
ТУРКЕСТАНСКОЙ ОБЛАСТИ**

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RESUMO

A relevância do estudo se deve ao fato de que a irrigação em grande escala de campos de algodão em regiões áridas e desérticas da região do Turquestão leva inevitavelmente a processos de salinização do solo. A salinização é um problema global para a humanidade. A salinização do solo está associada a problemas de drenagem, uso inadequado dos recursos hídricos; crescente demanda por produtos agrícolas, o que leva a um aumento da pressão sobre as terras agrícolas. A este respeito, o presente trabalho tem como objetivo estudar a salinidade do solo cinza claro (serozem) irrigado na indústria de algodão do Cazaquistão do Sul (agora região do Turquestão) sob condições de drenagem vertical, o que fornecerá o pano de fundo necessário para a reconstrução do sistema de drenagem coletor em toda a região, o que contribui para um aumento no rendimento líquido e na qualidade de algodão em linha e também evita a deterioração do solo. O método principal para estudar as questões do artigo é o método de dispersão, segundo o qual a salinidade do solo foi determinada de acordo com estações do ano. As principais tarefas eram estudar a dinâmica das mudanças sazonais e oportunas nos sais sob drenagem vertical e estudar a distribuição espacial dos sais nas fazendas de algodão. Os resultados mostraram que em 2014 houve uma dinâmica positiva de mudanças em comparação com 2012. Na primavera de 2014, a área sob solos moderadamente salinos na camada de 0-20 cm diminuiu de 79,5 para 57,7%; a área de solos levemente salinos aumentou de 20,5 para 34,6%. No período de outono-inverno, a área de solos altamente salinos diminuiu de 25,6 para 14,1%. A área de solos não salinos foi de 7,7%. Os resultados mostraram que a mudança no número de íons, tanto verticalmente quanto de acordo com a estação do ano, ocorre com a transferência de sais ao longo do perfil do solo sob a influência dos gradientes de temperatura e níveis de água subterrânea, ou seja, na primavera de baixo para cima, no outono e no inverno – vice-versa. O valor teórico e prático do estudo reside no facto de que o material para a melhoria, prevenção da salinização do solo levará a um aumento no nível geral de segurança ecológica da região e do país como um todo.

Palavras-chave: *irrigação, solo cinza claro (serozem), salinidade do solo, distribuição espacial, distribuição sazonal, drenagem vertical.*

ABSTRACT

The relevance of the study is conditioned by the fact that the large-scale irrigation of cotton fields in arid and desert areas of the Turkestan region inevitably leads to the processes of soil salinization. Salinity is a global problem for humanity. Soil salinization is associated with drainage problems, improper use of water resources, growing demand for agricultural products, which leads to increased pressure on agricultural land. In this regard, this paper is directed at investigating the soil salinity of the irrigated light serozem in a cotton farm of Southern Kazakhstan (now Turkestan region) under the vertical drainage, which would provide the necessary background for the reconstruction of the collection-drainage system of the whole region, thus contributing to the increasing the net yield and the quality of the row cotton, as well as preventing soil deterioration. The leading method for studying the issues of the article was the dispersion method, according to which the salinity of soils was determined by seasons. The main objectives were studying the dynamics of salts changes seasonally and timely under the vertical drainage and studying the spatial distribution of salts in the cotton-based farm. The results showed that in 2014 there was recorded a positive dynamic of changes compared to 2012. In spring 2014, the area under medium saline soil in the 0-20 cm layer decreased from 79.5 to 57.7 %; the weakly saline soil area increased from 20.5 to 34.6 %. In the autumn and winter periods, the area of strongly saline soils decreased from 25.6 to 14.1 %. The area of non-saline soils was recorded at 7.7 %. The results showed that changes in the amount of the ions, both vertically and seasonally, occur with the transport of salts along with soil profile under the influence of temperature gradients and the level of groundwater, i.e., in spring from up to down, and in autumn and winter, contrary from down to up. The theoretical and practical value of the study lies in the fact that the material for improving, preventing the salinization of soils will lead to an increase in the general level of ecological safety of the region and country in general.

Keywords: *irrigation, light serozem, soil salinity, spatial distribution, seasonal distribution, vertical drainage*

АННОТАЦИЯ

Актуальность исследования обусловлена тем, что масштабное орошение хлопковых полей в засушливых и пустынных районах Туркестанской области неизбежно приводит к процессам засоления почв. Засоление является глобальной проблемой человечества. Засоление почв связано с проблемами дренажа, неправильным использованием водных ресурсов; ростом спроса на сельскохозяйственную продукцию, что приводит к повышенной нагрузке на сельскохозяйственные земли. В связи с этим данная работа направлена на исследование засоленности почвы орошаемого светлого серозема в хлопковом хозяйстве Южного Казахстана (ныне Туркестанская область) в условиях вертикального дренажа, что обеспечит необходимый фон для реконструкции коллекторно-дренажной системы по всему региону, что способствует повышению чистой урожайности и качества пропашного хлопка, а также предотвращает ухудшение состояния почвы. Ведущим методом изучения вопросов статьи явился метод дисперсии, согласно которому засоленность почв определялась по сезонам года. Основными задачами были изучение динамики сезонных и своевременных изменений солей под вертикальным дренажем и изучение пространственного распределения солей в хлопководческих хозяйствах. Результаты показали, что в 2014 году зафиксирована положительная динамика изменений по сравнению с 2012 годом. Весной 2014 года площадь под средnezасоленными почвами в слое 0-20 см уменьшилась с 79.5 до 57.7 %; площадь слабозасоленных почв увеличилась с 20.5 до 34.6 %. В осенне-зимний период площадь сильнозасоленных почв уменьшилась с 25.6 до 14.1 %. Площадь незасоленных почв составила 7.7 %. Результаты показали, что изменение количества ионов, как по вертикали, так и по сезонам, происходит с переносом солей по профилю почвы под влиянием градиентов температуры и уровня грунтовых вод, то есть весной снизу вверх, осенью и зимой наоборот. Теоретическая и практическая ценность исследования заключается в том, что материал для улучшения, предотвращения засоления почв приведет к поднятию общего уровня экологической безопасности области и страны в целом.

Ключевые слова: *орошение, светлый серозем, засоление почвы, пространственное распределение, сезонное распределение, вертикальный дренаж.*

1. INTRODUCTION:

The large-scale irrigation of cotton fields in arid and desert areas of the Turkestan region inevitably leads to soil salinization processes. According to A. Singh and R. S. Sengar (2014),

the problems of salt-affected paddy soils might be due to inadequate water management in irrigated areas of Kazakhstan. Scientists Y. Sugimori *et al.* (2008), in his study of irrigated and low-salt soils, determined that due to improper irrigation practices, moderately or highly saline soils on

irrigated lands reached 42.1 %, and the yield decreased by 8.6 %. W.A.M. Abdel Kawy and Kh. M. Darwish (2019) reported that the salinization process is referred to as the most frequently occurring land degradation type in aridic regions. Soil salinization lasting for a longer period causes lower production potential of soil (Metternicht and Zinck, 2003; Farifteh et al., 2006; Adibah et al., 2020; Ahmed et al., 2017; Iqbal, 2018).

Turkestan region is the only region growing cotton on an area of 204.1 thousand hectares in 2005 (11.4 % of the territory), that was reduced to 99.3 thousand hectares in 2015 due to inappropriate agricultural management that resulted in a decrease of soil fertility and cotton yield (Umbetaev et al., 2015; Petrick et al., 2017; Murzabaev et al., 2019; Pachykyn et al., 2019; Pereira et al., 2019). Due to the deterioration in operating both irrigation and drainage systems, disorders in intensive cotton cultivation technology, reducing water supply both in the growing season and for soil washing, a sharp increase of the areas subject to secondary salinization was recorded (Bekbayev, 2016; Tanirbergenov et al., 2016; Hamidov et al., 2016; Issanova et al., 2017; Murzabaev et al., 2019; Suska-Malawska et al., 2019). The parent rocks of Golodnaya Steppe are ancient alluvial modified in the upper strata by the secondary processes of lessivage (Rukhovich et al., 2010). The mineralogical composition of these rocks is presented by weakly weathered and re-deposited calcite-quartz-feldspar, which is considered favorable in terms of mineral nutrition of plants (Schoups and Hopmans, 2002; Suleimenov, 2008; Rath et al., 2016).

In this respect, observation of salt movement and advanced geophysical survey, for detection and prediction of salt-affected areas, considered as promising tools for the evaluation and control of ameliorative soil state of irrigated agricultural lands (Kitamura et al., 2006; Weng and Gong, 2006; Mandal et al., 2009; Chernousenko et al., 2012; Bhat et al., 2015; Shrivastava and Kumar, 2015; Vyrahmanova et al., 2020). The repeated salt survey allows obtaining a quantitative characteristic of changes in the salt regime of the soil for a given period (Arunachalam et al., 2011; Allbed and Kumar, 2013). The spatial modeling of salt accumulation regime provides vital information on understanding the dynamic of salt movement regime laterally and vertically (Laiskhanov et al., 2016; Nuruzzaman Manik et al., 2019; Zhumadilova et al., 2019; Hu et al., 2020).

The research was conducted in the Golodnaya Steppe geological formation that is a

vast intermountain drainage basin, bounded on the south by Turkestan range and on the northeast by Kuramin and Chat Kal ranges (Mueller et al., 2014; Bekbayev et al., 2015; Micklin et al., 2016; Kaushal et al., 2018; Soltanaeva et al., 2018). The main goal of the research was establishing the soil salinity state of the irrigated light serozem soils in a cotton farm of Turkestan region (Maktaaral district) under the vertical drainage, which would provide the necessary background for the reconstruction of the collection-drainage system of the whole region, thus contributing to the increasing the net yield and the quality of the row cotton (Sugimori et al., 2008; Stoilova et al., 2014; Wang et al., 2019; Wichern et al., 2020), as well as preventing soil deterioration. The main objectives were studying the dynamics of salts changes seasonally and timely under the vertical drainage and studying the spatial distribution of salts under the vertical drainage in a cotton-based farm in the Turkestan region.

2. MATERIALS AND METHODS:

Soil and solution samples were collected in 2012 and 2014 from the cotton monoculture experimental station in Maktaaral district in Turkestan region (Dzhalankuzov et al., 2011) (40°49'58.03"N and 68° 30'3.07"E) on light serozem soil (Nabyeva, 2016). Soil samples were taken with a dedicated sampler tool. The mean annual precipitation is 262 mm; the average air temperature is 12.4°C. To study the effect of vertical drainage on soil amelioration state, the 78 ha of the experimental plot was divided into 15 basic sub-plots, with each subplot around 5 ha (Figure 1). Each subplot was sampled in three replications three times per year: in winter – before washing; in spring – after washing and before sowing; and in autumn – during cotton ripening from three soil depth: 0-20, 20-50, and 50-100 cm. The soil was washed with 5000 m³/ha in winter; the irrigation rate was 2000-3000 m³/ha in summer (2nd and 3rd parts of July). Water samples were taken from the irrigation canal, the vertical drainage, and the discharge canal. The level of groundwater was measured seasonally. Salt regime survey was conducted according to methodology to the E. Pankova, M. Gerasimova, and T. Korolyuk (Pankova et al., 2018). Soil salinity was determined based on the assessment of the “cumulative effect” impact of toxic ions according to the Equation 1: $1 \text{ Cl}^- = 0,1 \text{ CO}_3^{2-} = (2.75) \text{ HCO}_3^- = (5.5) \text{ SO}_4^{2-}$, where 1 mEq. of Cl⁻ for 10 times less toxic for plants than 1 mEq of CO₃²⁻; for 2.5-3 times, more toxic than HCO₃⁻, and for 5-6 times more toxic than SO₄²⁻. This experimental data was

obtained for 2012-2014 and mapped to build a soil salinity map (1: 10.000) by seasons (spring, autumn, winter) and vertically (0-20, 20-50, and 50-100 cm). Using MapInfo Professional software. Soil samples were air-dried and passed through a 1-mm mesh sieve for chemical analyses. Soil samples were analyzed for water-soluble salts by extractions at a ratio 1:5. Concentrations of HCO_3^- , CO_3^{2-} were calculated using their ratio determined by solution pH. The K^+ and Na^+ contents were determined by flame photometer FLAPHO 4 (Carl Zeiss Jena); Mg^{2+} , Ca^{2+} content by complexometric titration; Cl^- – by Mohr method with titration (AgNO_3 – 0.02N); SO_4^{2-} was calculated as ions (anions and cations) and content of carbonate CO_2 by gas calorimetry method.

It is also called the Scheibler method based on determining the carbonate content in the soil by the volumetric method. The carbonates in the sample are converted to CO_2 by adding hydrochloric acid to it. The Analysis of Variance (ANOVA) was done using IBM SPSS statistical analysis package. The Least Significant Difference (LSD) among different treatments was tested individually on triplicate data and collectively by considering the mean values of data for each year as a single replication (Equation 1), where, a – the sum of numbers, N – the amount of numbers. The overall significance/effectiveness of treatments (by considering the years and locations as fixed variables) was also evaluated by applying the LSD test on grand mean data at the 5 % level of probability ($p \leq 0.05$) based on the F-test of the analysis of variance. Correlations between some of the study parameters were also considered by using SPSS 12 for Windows (Equation 2), where t = t-distribution value; MSw = ANOVA root mean square; n = number of points used to calculate the average.

3. RESULTS AND DISCUSSION:

In 1964, the Resolution of the All-Union Scientific and Technical Conference was adopted on combating salination and improving the ameliorative condition of irrigated lands in Central Asia, based on the construction of drainage and irrigation leaching regime, recognized as the main measure to combat salination on irrigated lands. It was envisaged to create a leaching irrigation regime on the irrigated lands with an intensity of 20-30% of the net irrigation norm. This allowed to create downdraft flows of moisture in the aeration zone, which was supposed to ensure the desalination of the soil, and drainage was supposed to ensure the removal of the leaching

part of the irrigation norm and maintain the groundwater level at a depth of 2.5-3 m. However, this approach had a serious side effect: water intake from rivers for irrigation, considering filtration losses from canals (with efficiency <0.7), increased by 1.7-1.9 times. Discharge of drainage water into rivers by the end of the 20th century increased the salinity of river water, which also aggravated the situation. As a result of a decree adopted in 1964, by the second half of the 20th century, the area of irrigated land in the region considerably increased (Glazovsky, 1987). In addition to that, hydromorphic and semi-hydromorphic regimes were established and maintained on the irrigated lands, which contributed to the activation of secondary salination on the irrigated lands of the studied region. Thus, the foreseen leaching irrigation regime against the background of 2.5-3 m drainage did not lead to the expected positive effect: the area of saline soils on irrigated lands increased and reached 50% of the irrigated land area. In general, the area of saline irrigated soils in the Turkestan region territory is currently high and even increasing. There is no doubt that the cause of salt accumulation on irrigated lands is the hydromorphic regime, which is artificially maintained on the irrigated lands of the Central Asian region. The high salt content in the soil-forming and underlying rocks of the region, due to both the modern geochemical runoff and the high relict reserves of salts in the underlying rocks, including those associated with sea transgressions, allows to state that the drainage runoff carries not only salts from the soils of irrigated fields but also salts contained in rocks and groundwater, which significantly increases the total amount of salts carried out with drainage runoff. This conclusion is in good agreement with the calculations performed by I.P. Aydarov (Aydarov, 2006; Aydarov and Pankova, 2007) for individual irrigation tracts (Golodnaya Steppe), which indicated that despite the large removal of salts with drainage runoff on the irrigated tracts, a positive salt balance is maintained due to the input of salts from groundwater and underlying rocks. Thus, the reason for the widespread development of secondary salination on the irrigated lands of the Turkestan region is the hydromorphic irrigation regime, against the background of the high salinity of the parent rocks, as well as the arid climate, which contributes to the evaporative concentration of salts in hydromorphic conditions.

The solution to this issue requires new approaches to the development of irrigation in the region. First of all, it is necessary to make an inventory of irrigated lands based on modern

methods of remote sensing and modeling of salination-desalination processes for individual irrigation areas in order to establish the direction and intensity of the salt accumulation process. These data alone can help identify the most promising lands for irrigation. On these tracts, the new irrigation methods, which are currently widely used in the world, should be introduced.

Generally, the soil pH ranged from 8.38 to 8.58 (medium alkali), carbonate CO_2 is 7.02-8.11 % (Bhargavarami Reddy *et al.*, 2013). In spring, the medium saline groundwaters are located at 0.8-1.0 m depth, while in the autumn and winter, they went down to 2.0-3.0 m. Such groundwater depths ensure the constant moisture flow from the lower layers of soil and into the root zone. The up moving moisture transports water-soluble salts, which accumulated in upper horizons resulting in salt accumulation in all the experimental plots by the end of vegetation season (Bekbayev *et al.*, 2015; Yang *et al.*, 2019). The obtained results classified sampled soils according to Table 1.

Spring soil washing allowed a significant decrease in the salinity of soil profile simultaneously, increasing the salinity of groundwater up to 11.1 g/l (Table 2). The total salinity of groundwater by autumn was decreased to 3.6 g/l due to the capillary moving of salts up to the soil surface. The salinity of irrigation and drainage waters was not exceeding 1.1 and 1.4 g/l, respectively. During irrigation, the salts brought by irrigation water and the salts from groundwater and soil solution are all involved in re-distribution laterally and vertically. The vertical re-distribution of salts under irrigation started at the time when groundwaters were still deep. The essence of this process lies in the periodic desalination of flat and low areas. Simultaneously, less wet and more dry micro reliefs are subject to secondary salinization due to the salts migrating from the flat and low relief with film-capillary currents in the soil profile. As a result of such migration, the small spots of saline soils are formed on the irrigated fields.

Unlike other salt-affected soils, in which chloride or sulfate anions prevail, in this study, the Cl^- , HCO_3^- and SO_4^{2-} (the latter estimated by difference) ions along the soil depth (0-20, 20-50 and 50-100 cm) were balanced (Table 2). However, seasonally (spring, autumn, and winter), chlorides and sulfates tended to dominate. Na^+ dominated among the ions, and its amount increased from 0-20 cm to 1 m depth and from spring to winter, while K^+ decreases with depth during the whole season. Content of Mg^{++} and Ca^{++} generally increased downward the soil profile,

except in spring and winter at 20-50 cm where more Mg and Ca cations in upper and deeper layers were recorded. The prevalence of Mg^{++} explains this and Ca^{++} as cations and SO_4^{2-} as an anion in the composition of water-soluble salts in the soils.

The favorable physical characteristics of studied loess loam soils were good permeability, porosity, and relatively low conjunction. Negative properties of the parent rocks shown to be high water-lifting capacity (2.5-3.5 m), relatively low infiltration coefficient (an average of 0.003 mm/sec), which explains the rapid rise in groundwater under irrigation and the slow decline after the termination of irrigation. The secondary re-distribution of salts occurred slower in natural non-drained, and weakly drained areas. However, as time passed, the secondary re-distribution resulted in serious salinization. Also, in non-drained and weakly drained irrigated soils during the re-distribution of salts, some areas showed a relatively satisfactory reclamation state. In contrast, others had many hotspots of salt accumulation (Bekbayev *et al.*, 2015).

The secondary salinization in 2012 was strongly developed covering all the area. However, after the soil washing was undertaken, the salinization process has been reduced, and the gradual desalinization has been recorded. In spring 2012, in the upper layer, there were prevailing the medium and weakly saline soils, occupying respectively 79.5 and 20.5 % of the studied area after winter washing. In the autumn-winter period of 2012, there were recorded spots with salinization levels from weakly saline to strongly saline (weakly saline – 33.3 and 20.5 %; medium saline – 9.0 and 39.7 % and strongly saline – 57.7 and 39.7%, respectively). Our studies showed that the salinity of most of the studied soils significantly differs from spring to winter. In 2014 there was recorded a positive dynamic of changes comparing to 2012. In spring 2014, the area under medium saline soil in the 0-20 cm layer decreased from 79.5 to 57.7 %; the area of weakly saline soils increased from 20.5 to 34.6 %, and 7.7 % of non-saline soil area was recorded (Figures 2 and 3). The spatial distribution of the salt accumulation seasonally and annually is shown in Figures 3-5.

In the autumn-winter period of 2014, the area under strongly saline soils decreased from 25.6 to 14.1 %, respectively, in 0-20 cm comparing to 2012 (Figures 2, 4 and 5). The areas of medium saline soils increased to 24.3 % in autumn and to 6.5 % in winter, while areas of weakly saline soils decreased in autumn to 6.4 % and didn't change

in winter. The area of non-saline soils was 7.7 %. This studies showed that using the vertical drainage for three years transforms strongly saline soil recorded in 2012 into medium, weakly, and non-saline soils. So, the washing of soil in spring significantly reduces soil salinity due to the moving of salts downward, and on the contrary, in the autumn-winter period increases soil salinity.

Analysis of the vertical distribution of salts allows assuming that the reasons for soil salinity in light serozem soil of the Turkestan region could be one or a combination of the following circumstances: 1. Capillary rise of the saline groundwater table from shallow water tables to the soil surface. 2. Salt accumulations in the plow layer, where subsoil leaching is insufficient to remove the salt. 3. Poor water management and inadequate drainage system subjected to periodic flooding and high evaporation. The dynamic of ion content seasonally and vertically is presented in Table 3. In the period from 2012 to 2014, the amount of HCO_3^- decreased from 0.36 to 0.25 mEq (at significance 0.00), while the amount of SO_4^{2-} increased from 7.06 to 7.75 in 2012 and from 5.85 to 7.7 mEq in 2014 (sig. 0.032); the amount of Mg^{2+} increased from 3.1 to 3.31 mEq in 2012 and from 1.97 to 2.57 mEq in 2014 (sig. 0.001) in 1 meter soil layer from spring to winter.

In spring 2012, there was recorded increase of HCO_3^- (sig 0.001), Cl^- (sig 0.013), SO_4^{2-} (sig 0.016) and Na^+ (sig 0.002) and K^+ (sig 0.000) from upper to lower layers. In spring 2014 amount of Cl^- (sig 0.013) and Na^+ (sig 0.002) also increased, while amount of K^+ (sig 0.000) didn't change. In autumn and winter 2012 there was recorded decrease of HCO_3^- (sig. 0.013) and K^+ (sig 0.000) in 0-20, 20-50, 50-100 cm. In autumn 2014, the amount of HCO_3^- (sig 0.012) and K^+ (sig 0.000) also decreased with depth. In winter, the decrease was observed only for K^+ (sig 0.000). These results show that changes in the amounts of ions vertically and seasonally occur with the transport of salts along with soil profile under the influence of temperature gradients and the level of groundwater, i.e., in spring from up to down, and in autumn and winter, contrary from down to up. Obtained results assume that after winter washing (5000 m³/ha) in spring, the amount of salts in soil decreases, but the level of groundwater approaches the soil surface (to 0.8 m), and the salinity of groundwater increases (11.1 g/l). While in the autumn-winter period, due to evaporation and transpiration sharp decrease in groundwater level (to 2-3 m), a salinity of 3.6 g/l is recorded. These processes result in the enrichment of salt exchange between groundwater and soil.

4. CONCLUSIONS:

The reclamation state of studied soils primarily depends on soil physical properties and saline groundwater depth. Washing the soil in spring significantly reduces soil salinization due to migration of salts into deeper layers, while contrarily, in autumn and winter, an increase of salinization in upper soil layers occurs due to the high water-lifting capacity of studied light serozem soil. The research results indicated that reducing soil salinity using vertical drainage allows adjustment of groundwater level maintaining more optimal use of water (1.4 g/l) for washing in winter and spring periods and for watering crops. For the improvement of soil quality and management of irrigated light serozem soil in the Turkestan region and for maintaining higher cotton yield, it is necessary to not only ameliorative and agro-technical measures but also additional investments for the restoration of vertical drainage wells with systematic cleaning.

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$$\bar{x} = \frac{a_1 + a_2 + a_N}{N} \quad (\text{Eq. 1})$$

$$LSD_{A,B} = t_{0.05/2DFW} \sqrt{MSW(1/n_A + 1/n_B)} \quad (\text{Eq. 2})$$

Figure 1. Location of the sampling site

Figure 2. Dynamic of salt regime seasonally and vertically, %

Figure 3. Map of soil salinity in spring (A – 0-20 cm; B – 20-50 cm; C – 50-100 cm)

Figure 4. Map of soil salinity in autumn (A – 0-20 cm; B – 20-50 cm; C – 50-100 cm)

Figure 5. Map of soil salinity in winter (A – 0-20 cm; B – 20-50 cm; C – 50-100 cm).

Table 1. Soil classification on salinity level as “cumulative effect” of toxic ions (Pankova et al., 2018)

Salinity level	“Cumulative effect” of toxic ions (CO_3^{2-} , HCO_3^- , Cl^- , SO_4^{2-}), mEq Cl^-
Non-saline	<0.3
Weakly saline	0.31-1.0
Medium saline	1.1-3.0
Strongly saline	3.1-7.0
Extremely saline	>7.0

Table 2. Content of water-soluble salts seasonally and by depth, 2012-2014

Horizon, cm		Sum of salts, %	mEq								CO ₂ %	pH
			HCO ₃ ⁻	CO ₃ ²⁻	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺ ₊	Na ⁺	K ⁺		
Spring												
0-20		0.374 a	0.36 a	-	0.35 a	4.91	2.31	1.95	1.24 a	0.11 a	7.02 a	8.4 6
20-50		0.538 ab	0.33 ab	-	0.53 ab	7.28	3.75	2.55	1.74 ab	0.09 ab	7.21 ab	8.4 0
50-100		0.513 c	0.29c	-	1.05c	6.67	3.00	2.54	2.45c	0.02c	8.11c	8.4 9
ground water	g/l	11.1	0.51	-	1.73	5.76	0.96	0.9	1.26	0.00 2	-	
	mEq q		8.39	-	48.8	120. 0	48.1 5	74.2 5	54.8	0.07	-	
Autumn												
0-20		0.588	0.34 a	-	1.46	7.15	3.61	2.35	2.76	0.16 a	7.03 a	8.5 2
20-50		0.620	0.30 ab	-	1.32	7.81	3.72	2.65	3.00	0.08 ab	7.57 ab	8.4 8
50-100		0.641	0.25c	-	1.54	8.03	3.78	2.72	3.27	0.04c	7.83c	8.5 8
ground water	g/l	3.56	0.24	0.02	0.18	2.12	0.37	0.19	0.43	0.00 6	-	7.6 6
	mEq q		3.96	0.63	5.21	44.3	18.6 7	15.7 9	18.8	0.16	-	
Winter												
0-20		0.570	0.35 a	-	1.10	7.31	2.83	3.32	2.49	0.12 a	7.55	8.3 8
20-50		0.711	0.31 ab	-	1.52	9.15	3.97	3.96	2.92	0.10 ab	7.42	8.3 8
50-100		0.654	0.27c	-	1.35	8.46	3.64	3.56	2.84	0.04c	-	8.4 6
irrigation water	g/l	1.05	0.15	0.00 6	0.08	0.52	0.13	0.05	0.09	0.00 6	-	8.4 4
	mEq q		2.47	0.2	2.44	10.8	6.87	4.72	4.02	0.15	-	
drainage water	g/l	1.35	0.17	0.00 5	0.09	0.72	0.14	0.09	0.12	0.00 6	-	8.4 8
	mEq q		2.79	0.17	2.66	15.0 1	7.25	7.94	5.13	0.15	-	

Table 3. Dynamic of ion content in soil seasonally and vertically, mEq

Ions	Season	2012	2014	depth, cm	Spring		Autumn		Winter	
					2012	2014	2012	2014	2012	2014
HCO ₃ ⁻	Spring	0.37	0.33	0-20	0.33	0.36	0.33	0.34	0.28	0.30
	Autumn	0.33	0.30	20-50	0.38	0.30	0.32	0.28	0.27	0.24
	Winter	0.29	0.25	50-100	0.39	0.32	0.33	0.30	0.32	0.22
Cl ⁻	Spring	1.04	0.90	0-20	0.29	0.40	0.45	0.61	1.04	1.06
	Autumn	1.14	1.11	20-50	1.67	1.24	1.53	1.12	1.48	1.61
	Winter	1.30	1.33	50-100	1.15	1.04	1.44	1.60	1.37	1.33
SO ₄ ²⁻	Spring	7.06	5.85	0-20	4.53	5.28	7.05	7.52	5.81	7.53
	Autumn	9.27	6.89	20-50	7.65	6.66	8.94	6.69	8.15	7.92
	Winter	7.75	7.70	50-100	9.01	5.61	11.82	6.47	9.28	7.64
Ca ²⁺	Spring	3.03	2.80	0-20	1.83	2.80	3.60	3.89	2.27	3.72
	Autumn	4.25	3.38	20-50	3.99	3.22	4.37	3.08	4.12	3.45
	Winter	3.24	3.70	50-100	3.28	2.38	4.78	3.16	3.35	3.93
Mg ²⁺	Spring	3.11	1.98	0-20	2.13	1.77	2.68	2.42	2.62	2.46
	Autumn	3.75	2.36	20-50	2.51	2.19	2.99	2.31	2.63	2.82
	Winter	3.31	2.57	50-100	4.68	1.97	5.57	2.35	4.68	2.44
Na ⁺	Spring	2.22	2.11	0-20	1.12	1.36	1.45	2.03	2.22	2.68
	Autumn	2.67	2.44	20-50	3.06	2.47	3.38	2.61	3.11	3.44
	Winter	2.75	2.97	50-100	2.47	2.52	3.16	2.68	2.91	2.77
K ⁺	Spring	0.14	0.12	0-20	0.10	0.12	0.10	0.09	0.02	0.03
	Autumn	0.09	0.10	20-50	0.19	0.14	0.09	0.08	0.04	0.03
	Winter	0.03	0.04	50-100	0.12	0.12	0.08	0.13	0.03	0.05