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EFFECT OF IRRIGATION ON THE EXCHANGEABLE CATIONS COMPOSITION IN CHERNOZEMS

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Abstract

The results of studies of the exchangeable cations composition in chernozems of the Forest-steppe and Steppe of Ukraine in irrigation are presented. The degree of change in the qualitative composition of the soil absorbing complex cations is determined by the irrigation water quality and irrigation norms. With irrigation by suitable water a slight decreasing of the content of absorbed calcium and increasing of the sodium content are noted. Changes in the cations composition of the absorbing complex are most significant on systematic irrigation by limited suitable and unsuitable waters. In the soil alkalinization in a weak and medium degree is developing. The part of absorbed sodium and potassium cations ranges from 3.0 to 6.6% of the total cations. Changes in the soil absorbing complex are due by increasing of the activity of sodium ions and decreasing of the activity of calcium ions in the soil solution. The regression model of the dependence between the absorbed sodium and potassium cations content in chernozem ordinary and the salinity of irrigation water and the Ca/Na ratio in the water extract was developed.

***Key words**: alkalinisation, irrigation water, soil, soil absorbing complex.*

INTRODUCTION

Irrigated agriculture has a paramount importance for the food supply of the country, feeding the burgeoning global population, sustainable functioning of the agroindustrial complex, increasing crop yields and adapting to weather and climatic conditions (Singh, 2021; Climate, 2007; Vorotyntseva, 2020). Irrigation has contributed greatly to the improvements in global agricultural productivity and output in recent decades (The state.., 2011).

The importance of irrigation in the world's agriculture is rapidly increasing. The food need will increase by 70-100% to 2050. So the problem arises of how to simultaneously guarantee food security and preserve natural resources and soil fertility (Gomiero et al., 2011). Sustainable land use and soil protection play perhaps the most important role in food security and human security in general (Nkonya et al., 2016; Conception…, 2021). The value of this agricultural measure grows in terms of climatic transformations that are marked the last years worldwide (Climate..., 2007), especially in areas with insufficient moisture: insufficiently moist Forest-steppe and arid Steppe (40%) of Ukraine (Baliuk et al., 2018; Vorotyntseva, 2020). In addition, in modern conditions one of the factors affecting the properties and soils state in particular the composition of the soil absorbing complex is climate aridization. This can lead to the intensification of salinization soil processes, especially in hydromorphic conditions (Pankova, 2017). In such climatic conditions the likelihood of aridization processes increases.

Irrigated lands are anthropogenically transformed natural systems. Under the influence of irrigation, a complex transformation of the soil composition and properties, changes in the direction and intensity of the soil processes evolution were occurred (Baliuk et al., 2009; 2017; Vorotyntseva, 2016). Irrigation increases agricultural productivity and inevitably affects soil properties.

The sustainability of irrigated agriculture depends on the quality of irrigation water used (Rengasamy, 2018; Vorotyntseva, 2016; 2017). Climatic and hydrogeological conditions of the region, relief, initial soil properties, irrigation technology and agriculture also effect on the soil properties transformation. Irrigation enhances soil formation processes. On irrigated

areas, both fast-flowing and long-term processes of the formation of soil signs and properties are activated.
The evolution of soils can develop in the direction of both the preservation of properties and the development of degradation processes. This determines the ability of the soil to fulfill its biospheric, ecological, ecosystem and social functions (Kramer, 2020).
A recent FAO estimate reported that a large portion of total global soil resources are degraded and this problem is persistently expanding (The state.., 2011; Kramer, 2020; Baliuk et al., 2017).
The Sustainable Development Goals identify the need to restore degraded soils and improve soil health. Therefore, sustainable soil management is essential. It ensures balanced development, reduction of degradation and adaptation to arid conditions for the food security of the country (Vorotyntseva, 2020; Shah et al., 2019).
The analysis of international experience shows that improving the efficiency of irrigation, rational use of water resources, sustainable management of irrigated soils is an urgent and significant issue at the global level (Kachi, 2016; Lamaddalena, 2013, Voluntary.., 2017). The shortage of fresh water makes it necessary to use saline waters in areas of unstable and insufficient humidification (Baliuk et al., 2020; Li et al., 2020; Wei et al., 2019; Yuan et al., 2018).
The controlled management of the soil salinization is imperative for achieving most of the Sustainable Development Goals (SDGs) of the United Nations. It is necessary for achieving the "Zero Hunger" (SDG2) and "Life on Land" (SDG15) among other SDGs (Singh, 2021).
Soil salinity and alkalinization are the most prevalent and widespread problem limiting crop productivity in irrigated agriculture (Tomaz et al., 2020; Kramer et al., 2020; Baliuk et al., 2009; Handbook…, 2018).
The use of salt water for irrigation requires complex researches of the "irrigation water-soil-plant" system to study the dynamics and interconnection of soil processes and regimes during irrigation, monitoring and management of the fertility of irrigated lands. Studies of salt regimes and exchangeable cations composition in these soils are especially relevant to evaluate possibility and preventing the development of degradation processes, developing predictive models of soil fertility, and also well as measures to protect and improve their fertility (Baliuk, 2017, 2020; Vorotyntseva, 2016).
The aim of our researches was to study long-term effect of irrigation with sweet ("suitable") and saline waters ("unsuitable") on the salt regime, the composition of the soil absorbing complex of chernozems in the Forest-steppe and Steppe of Ukraine.

MATERIALS AND METHODS

The research was conducted in the agroclimatic zones with different humidification - Forest-steppe (Kharkiv region) and Steppe zones of Ukraine (Donetsk region). Hydrothermal coefficient of Selyaninov (HTC) characterizes the level of moisture in the zone. In the Forest-steppe it is 0.9-1.4, in the Northern steppe - 0.7-0.9. But due to the dryness of the climate, stable yields can only be obtained with irrigation.
The interconnected system "irrigation water - soil - crop" was studied. The researches were conducted on the key experimental stationars with sprinkler irrigation. They differ in natural and climatic conditions, soils, irrigation water quality.
The main subtypes of chernozems dominated in the composition of the irrigation were selected as a study objects. Irrigation waters of natural sources are essentially different on the chemical composition and quality. Therefore, they have a different effect on the intensity of soil processes and the transformation of the physicochemical properties of the soil.
As an object of comparison, we used non-irrigated soils similar in properties before irrigation on non-irrigated experimental stationars stationary plots (key-analog method).
Experimental stationar 1 - ***Merefa stationar*** - in Kharkiv District of Kharkiv Region (49.77 N, 36.03 E), is located in the southern part of the Left-Bank Forest-Steppe of Ukraine. This is stationar of Institute of Vegetable and Melon Growing. The soil is chernozem typical (Chernozems Chernic, WRB).
Monitoring site is with a longterm vegetable-fodder crop rotation (Figure 1). On the experimental site grown tomato, cucumber,

cabbage, onion, beet. Irrigation was carried out by DDA-100 M during 24 years. Groundwater was located at a depth more 8-10 m.

Figure 1. Growing vegetables in rotation (Merefa stationar)

Irrigation was carried out with water from the Mzha river. Duration of irrigation is 24 years. Irrigation norms in the experiment were 350-1350 m^3/ha, depending on the crops grown and the weather. The mineralization of the irrigation water is 0.6-0.7 g/dm^3; pH - 8.1; type of salt - principally calcium and magnesium bicarbonates and chlorides (Table 1). On national classification (State standard of Ukraine 2730:2015) the irrigation water is classified as "suitable" for irrigation.
The content of physical clay (<0.01 mm) in layer 0-25 cm of chernozem typical was 55%. The soil was characterized by a heavy loamy granulometric composition. Humus content was 3.3% (layer 0-25 cm).

Table 1. Chemical composition of irrigation waters

Values of indicators	Mineralization of water, g/dm^3	pH	Ion content, meq/dm^3						
			HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
Mzha river (Experimental stationar 1)									
mean	0.68	8.1	6.9	1.1	0.9	4.1	2.7	2.0	0.10
min	0.60	7.5	6.2	0.6	0.3	3.6	2.2	1.2	0.09
max	0.70	8.3	8.8	1.5	2.7	4.6	3.0	2.5	0.16
Water of the pond (Experimental stationar 2)									
mean	2.50	8,0	6.0	9.0	22.9	7.5	12.2	17.4	0.80
min	2.36	7.8	5.5	8.1	21.2	6.8	11.7	16.5	0.65
max	2.60	8.0	6.7	9.8	23.0	8.2	12.8	17.4	0.82

Experimental stationar 1 - ***Pervomaysk stationar*** - in Yasinovatsky District of Donetsk Region (48.06 N 37.36 E) is located in the Northern Steppe of Ukraine. Soil is chernozem ordinary (Chernozems Chernic, WRB). The stationar was laid on the fields of vegetable-fodder crop rotation. The crop rotation included the alternation of crops: winter wheat, beetroot, cabbage, pepper, bow; barley; tomatoes, cucumbers; corn.
Irrigation was carried out by DDA-100 M with water from the local pond. Duration of irrigation was 50 years. Irrigation norms in the experiment were 1000-1500 m^3/ha depending on the crops grown and the weather.
Groundwater was located at a depth more 10 m. The content of physical clay (<0.01 mm) in layer 0-30 cm of chernozem ordinary was 69%. The soil was characterized by a light clay granulometric composition. Humus content was 3.9% (layer 0-25 cm).
The mineralization of the irrigation water is 2.4-2.6 g/dm^3; pH - 8.0; type of salt - magnesium and sodium chlorides and sulphates. On national classification the irrigation water was classified as "unsuitable" for irrigation on the dangers of soil alkalinization and partially suitable on the dangers of soil salinization and alkalization. The chemical composition of irrigation water is presented in Table 1. The water is contaminated with toxic metals such as lead, cadmium and cobalt. Thus the irrigation water is mineralized and contains toxic compounds. Such irrigation will affect the properties of the soil and the quality of vegetable products. It is used for irrigation due to the limited amount of fresh water.
On the experimental stationars the influence of irrigation on soil processes, properties and morphology of chernozems was studied. On each stationar profile pits were laid to a depth of 1.5-1.7 m and probing from genetic horizons. In addition, auger probes on experimental sites from boreholes were taken. The soluble salt content in water extracts and pH of water suspensions (with the soil-to-solution ratio of 1:5) were determined. The

composition of exchangeable bases was determined after extraction from the soil with 1 mol/dm^3 ammonium acetate solution (pH 7.0)

RESULTS AND DISCUSSIONS

Our long-term studies have established that irrigation leads to significant changes in the direction of natural soil processes and regimes, as well as indicators of the morphological structure of the profile, composition and properties of chernozem ordinary. The chemical composition of irrigation water is one of the main factors determined the degree of these changes.

With long-term irrigation by limited suitable and unsuitable waters the irrigation alkalinization in the morphological profile of the soil in the humus-eluvial (He) and humus-iluvial (Hi) horizons is visualized. There is glossiness on the edges of structural aggregates. Compaction of the surface horizon has occurred. The lumpy-granular soil structure has changed to lumpy-silty structure (in the plow horizon) and lumpy-prismatic (in subsurface horizon).

The irrigated soil profile in comparison with the non-irrigated analogue has a greater thickness of the humus-accumulative horizon. This is due to the improvement of the water regime and the creation of favorable conditions for the plants growth. The depth of the carbonate horizon (carbonates in the form of a white soft spot) increases with irrigation. This indicates the leaching of calcium by irrigation water.

Our research has established that gallochemical processes are increased during irrigation. This leads to the transformation of the cation-anionic composition of salts, a change of their chemical composition, type of salinity. The degree of these changes are mainly determined by the chemical composition of the irrigation waters and the initial properties of the soil.

Soil salinization is one of the most common processes on irrigated soils, especially when using saline waters. It restricts the sustainability of agriculture. Soil salinization impacts on the agricultural productivity by causing disruptions to the processes of nitrogen uptake and plant growth development. An increase in soil salinity further deteriorates soil ecosystem services and decreases revenues for farmers and smallholders (Handbook…, 2018).

The diffusion process in response to the concentration gradient determines the distribution of salts in the soil profile, especially the distribution between large and small pores. Additional simultaneous interaction of dissolved salts with other ions in the solution or with the soil surface changes the composition of the solution (Soil Salinity…, 1984).

Our researches on Merefa stationar were established in automorphic conditions on irrigation during 24 years by sweet water with a mineralization of less than 1 g/dm^3, the salts storage in the aeration zone practically did not change (Table 2). The content of water-soluble salts in the soil (up to a depth of 1 m) was 0.04%. The content of toxic salts in the upper 0-30 cm layer was 0.03%, and deeper - 0.02%. Therefore, chernozem typical of stationary is characterized as non-saline.

In the long-term cycle a stable salt regime is formed in the seasonal cycle it is seasonally reversible with insignificant (0.01-0.05%) dynamics. Irrigation causes a noticeable transformation of the qualitative composition of salts. The total toxic alkalinity (HCO_3-Ca) increases slightly (on 0.01-0.14 meq/100 g). As a result the pH of the soil increased from 6.6-6.7 (0-25, 25-50 cm) to 7.3-7.4. The content of water-soluble sodium increases throughout the soil profile. The calcium content decreases or tends to decrease.

Table 2. Salt regime in chernozem typical of Merefa stationar

Irrigation/ non-irrigation	Depth, cm	Total soluble salt, %	Toxic salts, %	pH	Ca^{2+}, mmol (equiv.) /100 g of soil	Na^{+}, mmol (equiv.) /100 g of soil	Ca/Na
Non-irrigation	0-25	0.04	0.02	6.6	**0.37**	0.06	**6.2**
	25-50	0.04	0.02	6.7	0.35	0.07	5.0
	50-75	0.04	0.02	6.7	0.32	0.06	5.3
	75-100	0.04	0.02	6.8	0.33	0.07	4.7
Irrigation	0-25	0.04	0.03	7.4	**0.28**	0.17	**1.6**
	25-50	0.04	0.02	7.3	0.23	0.11	2.1
	50-75	0.04	0.02	7.3	0.25	0.10	2.5
	75-100	0.04	0.02	7.3	0.25	0.10	2.5

The ratio of calcium to sodium (Ca/Na) in the soil profile progressively narrows from 4-6:1 to 1-3:1 in the soil of Merefa stasionar. Sodium content usually increases in the first 3-5 years of irrigation and then it relatively stabilizes. The decrease of the calcium content has a stable progressive character, especially in layer 0-50 and 0-100 cm.

On Pervomaysk stationar in long irrigation with saline water changes in the salt composition of the soil were significant. The total content of water-soluble salts increased from 0.04-0.08 % (non-irrigated soil, layers 0-25, 25-50 cm) to 0.16% in the irrigated soil (Figure 2).

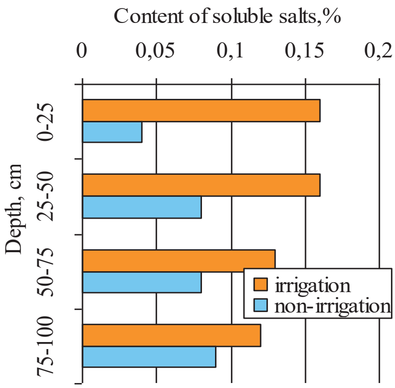

Figure 2. Content of soluble salts in chernozem ordinary (Pervomaysk stationar)

The concentration of toxic salts in the 0-50 cm layer rises to 0.10-0.11%. In this case the degree of soil salinity increases to slightly saline (Figure 3).

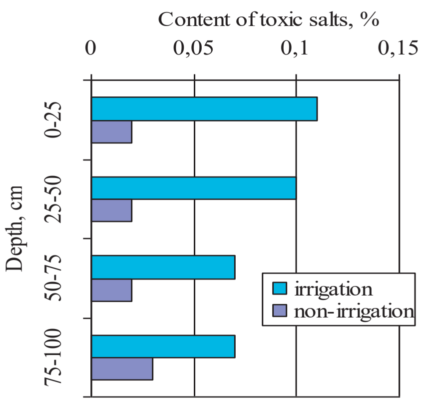

Figure 3. Content of toxic salts in chernozem ordinary (Pervomaysk stationar)

The pH of the soil increased from 7.4-7.6 (layer 0-25, 25-50 cm) to 7.9-8.0. The reaction of water extract of chernozem ordinary is alkaline. On irrigation with saline waters the content of water-soluble sodium in the soil increased from 0.10-0.13 mmol/100 g to 1.35-1.37 mmol/100 g in 0-50 cm layer. The ratio of water-soluble cations Ca/Na in the soil profile decreases from 4.4-10.3:1 (non-irrigation) to 0.4-0.6:1 (irrigation) (Table 3). This indicates the development of the process of irrigation alkalinization and its gradual advance deeper along the profile with systematic irrigation by saline waters.

Table 3. Salt regime in chernozem ordinary of Pervomaysk stationar

Option	Depth, cm	pH	Ca^{2+}, mmol (equiv.) / 100 g	Na^{+}, mmol (equiv.) / 100 g	Ca/Na
Non-irrigation	0-25	7.4	**0.86**	**0.13**	**6.6**
	25-50	7.6	0.82	0.10	8.2
	50-75	7.7	0.74	0.09	8.2
	75-100	7.7	0.79	0.17	4.6
Irrigation	0-25	7.9	**0.58**	**1.37**	**0.4**
	25-50	8.0	0.67	1.35	0.5
	50-75	8.1	0.62	0.94	0.7
	75-100	8.0	0.53	0.98	0.5

According to the results of statistical analysis a high inverse correlation between the mineralization of the irrigation water and the Ca/Na ratio in the water extract from the soil was established - r = (–0.92). Regression models of the dependence of the toxic salts content in the soil from the irrigation water mineralization and their total content were constructed.

In the long-term dynamics for the irrigated chernozem ordinary of Pervomaysk stationar the type of salt accumulation is seasonally reverse with a tendency to an increase in their concentration in certain years. This is due to the intensity of irrigation and the irrigation rates of vegetable crops.

Under the influence of irrigation changes in the composition of the soil absorbing complex occur. The degree of change in the qualitative composition of the soil absorbing complex cations is determined by the irrigation water quality irrigation norms, initial soil properties, ecology-agroameliorative condition of irrigated lands. Alkalinization is the most widespread degradation process on irrigated soils.

The content and composition of soil absorbing complex cations allows us to evaluate changes in soil quality. Changes in the composition of the soil-absorption complex are caused by irrigation water of any composition, however, the severity of these changes is different.

On irrigated with sweet waters (Merefa stationar), the content of exchangeable calcium in the chernozem typical tends to gradually decrease in absolute and relative content.

The content of exchangeable magnesium tends to increase somewhat. In this case, the content of exchangeable sodium increases in absolute and relative content - from 0.6% to 1.5-1.6% from the sum of all cations (Figure 4, Table 4). The potassium content remains practically unchanged. The total content of exchangeable sodium and potassium cations increases from 1.5 % to 2.5-2.6 % from the sum of all cations.

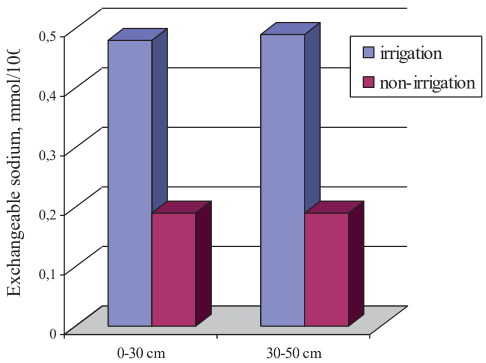

Figure 4. Content of exchangeable sodium in chernozem typical (Merefa stationar)

Table 4. Percentage content of exchangeable cations in chernozem typical (Merefa stationar)

Option	Depth, cm	% from the sum of cations			
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Non-irrigation	0-30	83.5	14.8	0.6	0.9
	30-50	83.5	15.0	0.6	0.8
Irrigation	0-30	77.6	19.9	1.5	1.0
	30-50	77.8	19.7	1.6	1.0

On long irrigation by saline waters the transformation of the soil exchangeable complex is more intense, and the degree of manifestation of degradation processes increases. On the Pervomaysk stationar with prolonged irrigation with unsuitable water and the use of chernozem ordinary in an intensive vegetable-fodder crop rotation the intensity of alkalinization increases.

The composition of the absorbed complex changed significantly. The concentration of exchangeable sodium in chernozem ordinary increased from 0.30-0.37 to 1.28-1.70 mmol/100 g (Figure 5). The content of exchangeable calcium was decreased (Table 5).

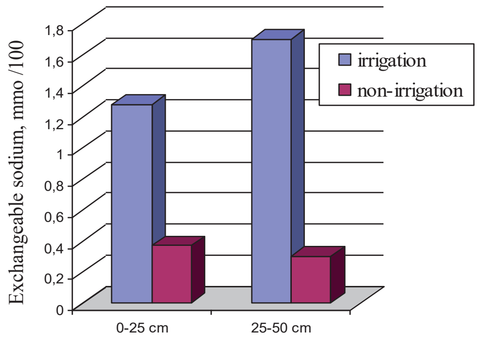

Figure 5. Content of exchangeable sodium in chernozem ordinary (Pervomaysk stationar)

Table 5. Percentage content of exchangeable cations in chernozem ordinary (Pervomaysk stationar)

Option	Depth, cm	% from the sum of cations			
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Non-irrigation	0-25	71.2	26.4	0.9	1.4
	25-50	70.7	27.1	0.8	1.4
Irrigation	0-25	68.2	26.4	3.6	1.9
	25-50	62.7	30.6	4.5	2.1

The content of exchangeable sodium and potassium increased to 5.3-6.6% of the total contents of cations in the 0-25 and 25-50 cm layers (Figure 6). The soil was characterized by a weak and medium degree of alkalinization. A tendency towards more intensive progression of alkalization down the profile was established.

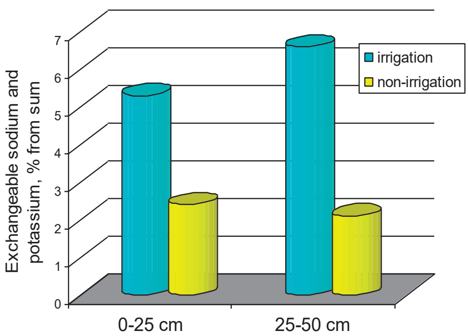

Figure 6. Content of exchangeable sodium and potassium in chernozem ordinary, % sum exchangeable cations (Pervomaysk stationar)

Changes in the soil absorbing complex are due by increasing of the activity of sodium ions and decreasing of the activity of calcium ions in the soil solution especially in the plowing layer on irrigation with unsuitable waters. Non-irrigated soil on to the activity of calcium ions was characterized as medium-buffered to alkalization (7.5-7.9 meq/dm^3). On long-term irrigation with unsuitable waters the buffering capacity of chernozem ordinary decreased to a low level due to an increase in the activity of sodium ions (from 0.85 to 4.36 meq/dm^3) and a decrease in the activity of calcium ions to 4.73 meq/dm^3 (Naydyonova, 2015).
The regression model of the dependence between the exchangeable sodium and potassium cations content in chernozem ordinary and the salinity of irrigation water and the Ca/Na ratio in the water extract was developed (Figure 7).
It is described by the equation:
B_{Na+K} = 14.07 – 7.85·x – 6.69·b + 1.26·x^2 + + 2.05·xy + 1.32·y^2;
B_{Na+K} - the content of exchangeable sodium and potassium cations, meq/100 g of soil;
x - mineralization of irrigation water, g/dm^3;
c - Ca/Na ratio in water extract.
The multiple correlation coefficient (r) is 0.90, the determination coefficient is R^2 = 0.81.

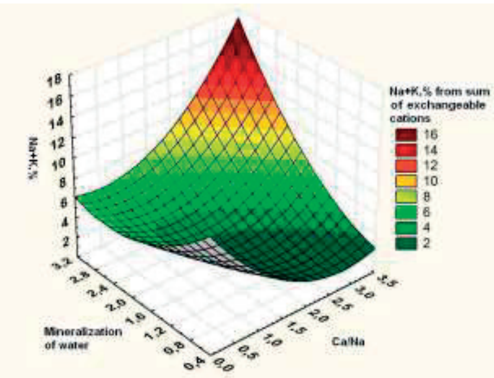

Figure 7. Dependence of the soil alkalinisation from the mineralization of irrigation water and Ca/Na ratio in the water extract

Changes in the cationic composition of the soil absorbing complex affect the agrophysical, physicochemical properties of irrigated soils and determine the level of their fertility, soil buffering to anthropogenic loads, the fulfillment of ecosystem services by the soil (provisioning, regulating and others).

CONCLUSIONS

Long-term irrigation in vegetable-fodder crop rotation by sweet water did not lead to an increase in the total content of water-soluble salts in chernozem typical. The soil in layers 0-25 and 25-50 cm is classified as unsalted. The transformation of the cation-anionic composition of the salts was established. In typical chernozem total toxic alkalinity, pH of the soil increased. The content of water-soluble sodium increases throughout the soil profile. The calcium content decreases or tends to decrease. The ratio of calcium to sodium (Ca/Na) in the soil profile progressively narrows from 4-6:1 to 1-3:1. The content of exchangeable calcium in the chernozem typical tends to gradually decrease. The total content of exchangeable sodium and potassium cations increases from 1.5% to 2.5-2.6% from the sum of all cations.
Long-term irrigation with saline waters ("unsuitable") led to significant changes in the salt composition of the water extract and the composition of the soil absorbing complex. The total content of salts and toxic salts in chernozem ordinary has increased in comparison with non-irrigated soil. The 0-50 cm layer was classified as slightly saline. The content of water-soluble sodium in the soil has increased significantly. pH is increased.
On long irrigation by saline waters the transformation of the soil exchangeable complex is more intense, and the degree of manifestation of degradation processes increases. The content of absorbed sodium and potassium in the soil-absorbing complex increased to 5.6-6.6%. Alkalinization in the soil was developed in a weak and medium degree.
Changes in the soil absorbing complex are due by increasing of the activity of sodium ions and decreasing of the activity of calcium ions in the soil solution especially in the plowing layer on irrigation with unsuitable waters.
The regression model of the dependence between the exchangeable sodium and potassium cations content in chernozem ordinary and the salinity of irrigation water and the Ca/Na ratio in the water extract was

developed. She showed a close relationship between these indicators.

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