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CHANGE OF CHERNOZEMS SALT REGIME IN IRRIGATED AND POST-IRRIGATED PERIODS

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Abstract

The results of studies of chernozems salt regimes in the forest-steppe and steppe of Ukraine during irrigation, in post-irrigated period and their non-irrigated analogues are presented. In irrigated soils accumulation of salts up to the level of classification-significant changes when using "suitable" and "limited suitable" waters (national classification of the irrigation water quality) not observed. With long-term use of "unsuitable" water for irrigation, the degree of soil salinization is low. Salt regimes of post-irrigated chernozems are characterized by a tendency to restore their parameters to values characteristic of non-irrigated analogues. The intensity of transformations depends of the degree of soil changes during irrigation, the climatic features, soil properties and duration of post-irrigated period. In post-irrigated period after long-term irrigation by "suitable" and "limited suitable" waters, forest-steppe and steppe chernozems restore the salt regime to the level of non-irrigated analogues in 4-12 years. The ending of irrigation with "unsuitable" waters of the steppe chernozems also make for their desalinization, however, it is needed a longer period of time. The predictive model of the soil processes direction in post-irrigated period is developed.

***Key words**: desalinization, irrigated soils, irrigation water, salinization, salt regime.*

INTRODUCTION

An analysis of natural conditions of Ukraine (Baliuk et al., 2018) and current trends of climate transformation on different spatial scales (e.g. global, continental, regional, watershed-scale) (Fischer et al., 2007; Gondim et al., 2012; Save et al., 2012) gives reason to believe that high-productivity agriculture in the steppe and forest-steppe zones of Ukraine is possible only with irrigation. There are three climatic zones: excessively moistened Forest (25% of the territory), insufficiently moist Forest-steppe (35%) and arid Steppe (40%) in Ukraine. Crops are grown in conditions of insufficient natural moisture on 75% territory of the country. Moisture deficiency is a major factor limiting productivity in these regions.

The country's food and resource supply depends to a large extent on the availability, condition and efficiency of the use of the irrigated land (Bezugliy et al., 2012; Stashuk et al., 2009; Gadzalo, 2018; EU Water Framework Directive, 2000; United Nations Convention, 1994)). The irrigated lands occupied the greatest area (2.6 mln. ha) at the beginning of the 90's of past century, which is 8% of area of plowed land. In recent years in the Ukraine the areas of the irrigated lands has decreased (predominantly spontaneously, without control). Currently, irrigation sector is facing a period of unprecedented challenge. Today, only 500-600 thousand hectares are irrigated in Ukraine. Large areas of previously irrigated lands are being used for rainfed farming. After years of reduced irrigation the need for rehabilitation and modernization is becoming ever more pressing.

At present, it has to be admitted that under the influence of the existing system of agriculture in Ukraine, there is often a deterioration of the soil-reclamation state of the land, loss of soil fertility and the imbalance of natural systems in general (Baliuk et al., 2018). The Sustainable Development Goals identify the need to restore degraded soils and improve soil health. At the 39th session of the FAO Conference, members unanimously approved a new edition of the World Soil Charter as an instrument for promoting and institutionalizing the sustainable use of soil resources at all levels (FAO, 2015). According Revised World Soil Charter (2015): "Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity". Voluntary Guidelines for Sustainable Soil Management (FAO, 2017) were developed on account of concerns about the state of soils resulted. In a broader context, the 2030 Agenda for Sustainable Development adopted a number of related targets in 2015, i.a. those aimed at restoring degraded soil, striving to achieve a land degradation-neutral world and implementing resilient agricultural practices that progressively improve soil quality and minimize soil contamination. Sustainable soil management strongly contributes to collective efforts towards climate change adaptation and mitigation, combating desertification and promoting biodiversity, and therefore has specific relevance to the United Nations Framework Convention on Climate Change (UNFCCC) (1992) and United Nations Convention to Combat Desertification (UNCCD) (1994).

Irrigation restoration is a key tool development of the agrarian sector of economy and increase of export potential of Ukraine. It will minimize the impact of climate change on the processes of socio-economic development. The Cabinet of Ministers of Ukraine approved Irrigation and drainage strategy of Ukraine until 2030 (Strategy) in 2019. It is a nationwide cross-sectoral policy document. The scope of the Strategy is to ensuring sustainable eco-balanced agriculture development in Ukraine. The authors participated in the development of the Strategy. Our research focused on the necessary to clarify the soil aspects of the implementation of the Strategy in Ukraine given the current state of irrigated lands, the need to restore and increase the area of irrigated lands, the significant prevalence of degradation phenomena.

The adoption of the Strategy makes possible to use post-irrigated soil in irrigated agricultural again.

In this context, special studies of the modern status of irrigated and post-irrigated soils are necessary.

Studies of salt regimes in these soils are especially relevant to evaluate possibility and preventing the development of degradation processes (Aidarov, 1978; 2012; Aidarov & Zavalin, 2015; Baliuk, 2016; 2017; EU Association, 2017; Vargas, 2018).

The aim of our study was to reveal the character of salt regime changes in the irrigated and post-irrigated soils in the forest-steppe and steppe of Ukraine (Kharkiv and Donetsk regions). The influence of irrigated and non-irrigated periods on the soil properties was studied.

MATERIALS AND METHODS

About the direction of the salinization-desalinization processes we judged from the analysis of long-term data on the contents of soluble salts, the composition of exchangeable bases and pH in the soil profile. In order to reveal the character of changes in the soils, we compared the properties of the post-irrigation soils with the soil properties during the irrigation period and non-irrigated areas.

Each studied stationar was characterized by a pit, soil samples were taken from the genetic horizons. In addition, auger samples were taken on experimental sections from boreholes.

The soluble salt content in water extracts, the composition of exchangeable bases and pH of water suspensions (with the soil-to-solution ratio of 1: 5) were determined in the laboratory. The average values of total soluble salt, exchangeable bases and pH were calculated from 10-15 point values.

The data on the contents of soluble salts, the composition of exchangeable bases, pH of water suspensions in the irrigated soils were taken from authors archived materials.

Grakovo stationar (Chuguevsky district of Kharkiv region) is located in the southern part of the Left-Bank Forest-Steppe of Ukraine with chernozem typical (Chernozems Chernic, WRB). The studies were conducted in long-term stationary field experience. Experience was founded in 1967-1968. Irrigation continued from 1970 to 1990. Since 1991, no irrigation was carried out.

Mineralization of irrigation water during irrigation was 0.4-0.6 g/l. Options: non-irrigated areas without fertilizers (control), excluded from irrigation without fertilizers and with aftereffect of mineral fertilizers.

Irrigation was carried out by DDA-100 M sprinkling machines with using "suitable" waters (national classification of the irrigation water quality). Irrigation norms in experiment were: 380-2380 m^3/ha. Groundwater depth was 9.4-9.9 m.

Pervomaysk stationar (Pervomaysky district of Kharkov region) is located within the northern part of the Left-Bank Steppe with ordinary chernozem (Chernozems Chernic, WRB). The experimental sections are located on non-irrigated and irrigated arable land under automorphic conditions. Irrigation continued from 1977 to 1995. Irrigation has not been carried out since 1996.

Mineralization of irrigation water during irrigation was 1.1-1.2 g/l. Water is limitedly suitable for irrigation because of the danger of soil alkalization and, at certain times, water sampling - because of the risk of soils salinization. Irrigation during irrigation was carried out by DDA-100 M sprinkling machines. The irrigation rate ranged from 300-500 to 1000-1500 m^3/ha. Groundwater depth was from 1.5 to 7.0 m.

Maryinka stationar (Maryinsky district of Donetsk region) is located within the northern part of the Left-Bank Steppe of Ukraine with ordinary chernozem (Chernozems Chernic, WRB). The experimental sections are located on non-irrigated and irrigated arable land under automorphic conditions. Irrigation continued from 1965 to 1995. Irrigation has not been carried out since 1996.

Mineralization of irrigation water during irrigation was 2.9-3.1 g/l. Water is unsuitable or limited suitable for irrigation due to the risk of alkalinization and salinization of the soil. Irrigation during irrigation was carried out by DDA-100 M sprinkling machines. The irrigation rate ranged 1500-3000 m^3/ha. Groundwater depth was more than 10 m.

In present irrigated lands of studied stationars are being used for rainfed farming.

RESULTS AND DISCUSSIONS

The content of soluble salts in irrigated soils depends on the quality of irrigation water, groundwater depth and lithological composition of parent materials (Lyubimova & Novikova, 2016). Researches by S.A. Balyuk on Grakovo stationar (Stashuk et al., 2009) during the irrigation period established that, using fresh water, salt reserves form a stable salt regime in a long-term cycle, seasonal invertible seasonality with insignificant (0.01-0.05%) dynamics. At the same time, irrigation causes a noticeable transformation of the qualitative composition of salts. The total toxic alkalinity (HCO_3-Ca) increases slightly (by 0.01-0.14 meq/100 g). The content of water-soluble sodium increases, and the calcium content tends to decrease. As a result of this, the ratio of calcium to sodium (Ca:Na) narrows (Table 1).

Table 1. Change of salt regime in chernozems of Grakovo stationar

Option	Depth, cm	Total soluble salt, %	Na^+, mmol (equiv.) /100 g of soil	Ca:Na
Non-irrigation	0-30	0.06	0.11	6.2
	30-50	0.08	0.10	11.6
	50-100	0.09	0.07	17.6
Irrigation, 20 years	0-30	0.07	0.24	2.4
	30-50	0.09	0.21	4.4
	50-100	0.09	0.20	4.5
Post-irrigation, 10 years	0-30	0.04	0.12	3.8
	30-50	0.08	0.15	6.2
	50-100	0.09	0.16	6.1

In the post-irrigation period, the total amount of water soluble salts decreased. The decrease was due to sodium bicarbonates and sulfates. In 10 year after irrigation, the studied soils of Grakovo stationar according to salt characteristics corresponded to non-irrigated analogues. In this time the Ca:Na ratio in the soil of the studied variants reached the level of rainfed control.

In post-irrigation soils, a gradual decrease in sodium content is observed, which is a natural consequence of the influence of fresh atmospheric precipitation, and after 10 years, the studied options reached the level of rainfed.

Research by S.A. Balyuk on Pervomaysk stationar (Stashuk et al., 2009) during the irrigation period established that using by irrigation with weakly mineralized water (1.1-1.2 g/l) caused a slight increase in salt content due to sodium chlorides and sulfates, but to a depth of 2 m the salt content did not exceed the toxicity threshold. The concentration of chlorine ion in the soil profile reaches the toxicity threshold of 0.3 mmol (equiv.)/100 g of soil. The author noted an increase in the salt content from spring to autumn, which were washed out by precipitation during the cold period. Moreover, along with an increase in the content of water-soluble sodium, there is a noticeable decrease in the calcium content and, as a consequence, a narrowing of the ratio of Ca to Na (Table 2).

In the period after irrigation, the total amount of water-soluble salts decreased. In 10 years after irrigation, the studied soils of Pervomaysk stationar of total soluble salts content corresponded to non-irrigated analogues. The Ca:Na ratio in the studied soil reached the level of rainfed control. In the soils after irrigation, the content of water-soluble sodium was a gradual decrease. After 10 years, its content in the soil layer of 0-50 cm reached the rainfed level. In deeper layers, the sodium content remains somewhat elevated.

Table 2. Change of salt regime in chernozems of Pervomaysk stationar

Option	Depth, cm	Total soluble salt, %	Na^+, mmol (equiv.)/ 100 g of soil	Ca:Na
Non-irrigation	0-30	0.09	0.06	8.2
	30-50	0.10	0.09	8.0
	50-100	0.11	0.08	12.6
Irrigation, 18 years	0-30	0.08	0.29	1.0
	30-50	0.11	0.36	2.7
	50-100	0.14	0.32	4.7
Post-irrigation, 10 years	0-30	0.08	0.06	8.6
	30-50	0.10	0.08	8.7
	50-100	0.12	0.16	8.6

Researches by L.I. Vorotyntseva on Maryinka stationar during the irrigation period established that using by irrigation with mineralized water (2.9-3.1 g/l) caused an increase in salt content due to magnesium and sodium chlorides and sulfates in the 2 m soil layer (Vorotyntseva, 2016; 2017). Significant qualitative and quantitative changes in the composition of water-soluble salts are noted: the content of water-soluble sodium increases significantly, the calcium content decreases markedly, the ratio of Ca to Na sharply narrows to values characteristic of highly and medium-degraded soils (0.2-0.5) (Table 3).The horizon of salt accumulations is noted at a depth of 100-150 cm.

In the post-irrigation period, halochemical processes gradually fade and desalination processes developing the soil layer of 0-25 cm. In 16 years after irrigation, the studied soils of Maryinka stationar of total soluble salts content corresponded to non-irrigated analogues in the soil layer 0-25 cm only. The Ca:Na ratio in the upper half-meter layer of studied soil increased, but it didn't reach the level of rainfed control. The content of water-soluble sodium in the lower horizons remained high due to prolonged irrigation with mineralized water and aridity. The Ca:Na ratio in deeper layers of the studied soil did not increase significantly.

Table 3. Change of salt regime in chernozems of Maryinka stationar

Option	Depth, cm	Total soluble salt, %	Na^+, mmol (equiv.)/100 g of soil	Ca:Na
Non-irrigation	0-30	0.09	0.12	6.8
	30-50	0.09	0.22	4.0
	50-100	0.07	0.08	7.0
Irrigation, 30 years	0-30	0.13	1.20	0.2
	30-50	0.13	0.96	0.4
	50-100	0.16	1.20	0.5
Post-irrigation, 16 years	0-30	0.10	0.19	4.2
	30-50	0.12	0.38	2.1
	50-100	0.11	0.56	1.1

The content and composition of exchange bases 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 may vary depending on the quality of irrigation water, the initial soil properties and ecology-ameliorative condition of irrigated land.

In the soil of the Grakovo stationar, the content of exchangeable calcium tends to a gradual decrease during irrigation with fresh water. At the same time, the content of exchangeable sodium and potassium increases from 0.6-1.0% to 1.4-1.9% (Figure 1). An increase in the content of absorbed sodium takes place to a depth of 2 to 3 m.

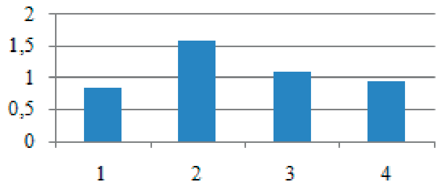

Figure 1. Exchangeable sodium and potassium in soil surface layer (0-30 cm) of the Grakovo stationar, % (1 - non-irrigation; 2- irrigation, 20 years; 3 - post-irrigation, 10 years; 4 - post-irrigation, 12 years)

In the post-irrigation period, the composition of the soil absorbing complex undergoes a reverse

transformation and approaches its initial state under the influence of fresh atmospheric precipitation. This is expressed in a noticeable decrease in the content of exchangeable sodium, the content of exchangeable calcium almost does not change.
The contents of all exchangeable cations in post-irrigation soils return to non-irrigated control for about 12 years.
In the soil of the Pervomaysk stationar, the content of exchangeable calcium also tends to a gradual decrease during irrigation with weakly mineralized water. At the same time, the content of exchangeable sodium and potassium increases from 1.2-1.8% to 2.4-4.6% (Figure 2), and the content of exchangeable potassium increases too. Soil chemical properties have been altered by long-term irrigation with weakly mineralized water - irrigation caused a slight degree of soils secondary salinization.

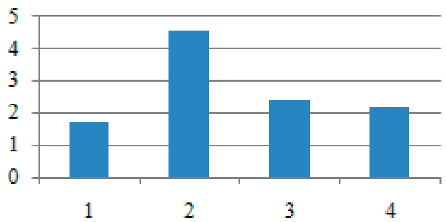

Figure 2. Exchangeable sodium and potassium in soil surface layer (0-30 cm) of the Pervomaysk stationar, % (1 - non-irrigation; 2- irrigation, 18 years; 3 - post-irrigation, 5 years; 4 - post-irrigation, 10 years)

In the post-irrigation period, we observe the process of soil desalinization: the content of exchangeable sodium is significantly reduced. The content of exchangeable calcium is practically unchanged.
The total content of exchangeable cations in post-irrigation soils does not return to non-irrigated control over 10 years of observation.
Long-term irrigation with mineralized waters induces he development of degradation processes (secondary salinization and alkalinization) in soil of Maryinka stationar. The process of soil alkalinization reached an average degree, and the amount of exchangeable sodium and potassium was 6.1-7.1% of the amount of exchangeable cations (Figure 3). The content of exchangeable calcium decreases during irrigation with mineralized water.
In the post-irrigation period, the process of soil dealkalinization begins: the content of exchangeable sodium is significantly reduced and corresponds to slight degree of soils secondary alkalinization. The content of exchangeable calcium is practically unchanged.

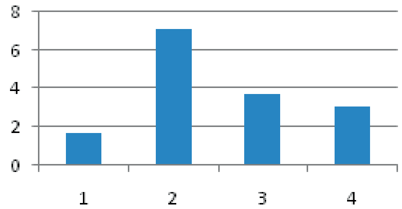

Figure 3. Exchangeable sodium and potassium in soil surface layer (0-25 cm) of the Maryinka stationar, % (1 - non-irrigation; 2- irrigation, 30 years; 3 - post-irrigation, 6 years; 4 - post-irrigation, 16 years)

The total content of exchangeable cations in post-irrigation soils does not return to non-irrigated control over 16 years of observation.
To predict the development of soil processes in Maryinka stationar, the method of exponential smoothing was used.
$S_t = S_0 + at$; S_0 - the value of the indicator at the time of the last observation from which the calculation is made; a - coefficient calculated from experimental data; t - the period for which the forecast is developed, year.
Soil evolution in post-irrigated period is directed toward approaching the parameters of the non-irrigated analog. According to forecast model, processes desalinization and dealkalinization will continue depending on time and weather conditions. The composition of the soil absorption complex, which underwent changes during irrigation by mineralized water, is restored more slowly than the salt composition. Ordinary chernozem will reach the level of non-irrigated analogue on the content of exchangeable sodium and potassium for 37 years, on the content of toxic salts - 28 years (0-25 cm).
Changes in pH are one of the main indicators of salinity. The variation of pH in the surface layer was from 0.1-0.2 (Grakovo stationar) to 0.3-0.5 (Pervomaysk and Maryinka stationars).
The rise in pH was also observed in the lower part of the profile of studied soils. In the post-irrigation soils pH in the surface layer is reduced. It does not return to non-irrigated

control in soils of Maryinka stationar. The variation of pH was not significant in the lower part of the profile of post-irrigation soils.

CONCLUSIONS

Long-term irrigation with «suitable» and «limited suitable» waters did not induces accumulation of salts in soil. However, it caused an increase in the content of water-soluble sodium, a decrease in the calcium content, and the pH changed. Long-term irrigation with «unsuitable» waters also induces salt accumulation in soil.

Irrigation induced increase of exchangeable sodium and potassium in soil and decrease of exchangeable calcium.

Salt regimes of post-irrigated chernozems are characterized by a tendency to restore their parameters to values characteristic of non-irrigated analogues. The intensity of transformations depend of the degree of soil changes during irrigation, the climatic features, soil properties and duration of post-irrigated period. In post-irrigated period after long-term irrigation by «suitable» and «limited suitable» waters, forest-steppe and steppe chernozems restore the salt regime to the level of non-irrigated analogues in 4-12 years. The ending of irrigation with "unsuitable" waters of the steppe chernozems also make for their desalinization, however, it is needed a longer period of time. The predictive model of the soil processes direction in post-irrigated period is developed - ordinary chernozem will reach the non-irrigated analogue on the content of exchangeable sodium and potassium for 37 years.

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