https://doi.org/10.26898/0370-8799-2024-9-1
УДК: 58.01/.07
Тип статьи: оригинальная
Type of article: original

Влияние модельного засоления на свойства степных черноземов Высокого Заволжья

Галактионова Л.В., (✉)Юлдашева И.З.
Федеральный научный центр биологических систем и агротехнологий Российской академии наук
Оренбург, Россия
(✉)e-mail: gubaidullinae@mail.ru

Развитие процессов засоления почв степной зоны является серьезной угрозой для обеспечения продовольственной безопасности страны. Это одна из основных экологических и социально-экономических проблем во всем мире, которая будет усугубляться в связи с прогнозируемыми климатическими изменениями. Территория Оренбургской области практически полностью расположена в зоне плодородных черноземов. В работе изучено воздействие модельного засоления почв на агрономические свойства и биологическую активность черноземов южных Оренбургской области. Полевой опыт (2019–2022 гг.) проведен на яровой твердой пшенице сорта «Оренбургская 10» в периоды активной вегетации растений. Растворы солей готовили путем смешивания соли с деионизированной водой в концентрации NaCl (хлорид натрия) – 1,1 и 11,7 г/л. Показатели ферментативной активности черноземов продемонстрировали разную чувствительность к моделируемому солевому стрессу и по устойчивости к внесению токсичной соли сформировали следующий ряд: уреаза > каталаза > протеаза > полифенолоксидаза > пероксидаза. В ходе исследования наблюдалось снижение содержания органического вещества и аммонийной формы азота в почве. Увеличение концентрации раствора хлорида натрия до 1,1 и 11,7 г/л способствовало развитию процессов пептизации и снижению показателей агрегатного состава степных черноземов. Представленные результаты влияния засоления на агрономические и биологические свойства почв позволили провести оценку устойчивости степных черноземов к данному виду деградации.

Ключевые слова: засоление почв, чернозем южный, структурное состояние, гумус, ферментативная активность

Effect of simulated salinization on the properties of steppe chernozems of the Upper Volga Region

Galaktionova L.V., (✉)Yuldasheva I.Z.
Federal Research Centre of Biological Systems and Agrotechnologies of the Russian Academy of Sciences
Orenburg, Russia
(✉)e-mail: gubaidullinae@mail.ru

The development of soil salinization processes in the steppe zone is a serious threat to food security in the country. This phenomenon has become one of the main environmental and socio-economic problems worldwide, and it is expected to worsen due to predicted climate changes. The territory of the Orenburg region is almost entirely located in the zone of fertile chernozems. The paper studies the effect of simulated soil salinization on the agronomic properties and biological activity of southern chernozems in the Orenburg region. The field experiment (2019–2022) was conducted on spring durum wheat variety "Orenburgskaya 10" during the periods of active vegetation of plants. Salt solutions were prepared by mixing salt with deionized water at NaCl (sodium chloride) concentrations of 1.1

and 11.7 g/l. The enzymatic activity indices of the chernozems demonstrated different sensitivity to the modeled salt stress and form the following series in terms of resistance to the introduction of toxic salt: urease> catalase> protease> polyphenol oxidase> peroxidase. During the course of the study, a decrease in organic matter and ammonium form of nitrogen in the soil was observed. Increasing the concentration of sodium chloride solution to 1,1 and 11,7 g/l promoted the development of peptization processes and a decrease in the aggregate composition of steppe chernozems. The presented results of the effect of salinization on the agronomic and biological properties of soils made it possible to assess the resistance of steppe chernozems to this type of degradation.

Keywords: soil salinization, southern chernozem, structural condition, humus, enzymatic activity

Для цитирования: *Галактионова Л.В., Юлдашева И.З.* Влияние модельного засоления на свойства степных черноземов Высокого Заволжья // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 9. С. 5–14. https://doi.org/10.26898/0370-8799-2024-9-1

For citation: Galaktionova L.V., Yuldasheva I.Z. Effect of simulated salinization on the properties of steppe chernozems of the Upper Volga Region. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science,* 2024, vol. 54, no. 9, pp. 5–14. https://doi.org/10.26898/0370-8799-2024-9-1

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Работа выполнена при поддержке НИР № FNWZ 2022-0014.
Acknowledgments
The work was carried out with the support of the Research and Development No. FNWZ 2022-0014.

INTRODUCTION

Saline soils occur mainly in arid and semi-arid climatic conditions, where the amount of precipitation is insufficient for salt leaching [1]. They accumulate under irrational agricultural practices or as a result of residual salt accumulation during weathering of rocks, deposition of dust and precipitation, capillary rise of groundwater table and excessive irrigation [2].

Generally, saline soils are unfavorable environments for plant growth because high salt content increases osmotic pressure and subsequently limits water uptake by plants [3]. The uptake of nutrient elements is hampered due to ion competition and pH changes, the deterioration of structural condition caused by high sodium content affects soil water balance and plant development [4].

At the initial stages of lightly soluble salts entering the profile, the mobility of humus acids increases, active mineralization of organic compounds is observed and microorganisms' living conditions change [5].

Input of easily soluble salts into the profile is accompanied by changes in physical, chemical and biological properties and regimes of soils, the degree of manifestation of which is determined by sodium saturation of the SAC (soil absorbing complex) [6].

Genesis peculiarities of steppe chernozems determine the development of carbonization, humification and salinization, with the latter acting as an antagonist of the processes of synthesis and accumulation of humic acids and carbonates in the upper part of the profile [7].

The steppe zone of the Orenburg region is characterized by rather heterogeneous soil-climatic conditions. Thus, complex relief, significant carbonateness, chemistry of soil-forming and underlying rocks become the main prerequisites for the development of salinization on vast territories[1].

The purpose of the research is to study the influence of model soil salinization on the structural state, nutrient regime and enzymatic activity of steppe chernozems of the Upper Volga region.

[1]*Blokhin E.V.* Ecology of the Orenburg region soils: Soil resources, monitoring, agroecological zoning. Ekaterinburg: Ural Branch of the Russian Academy of Sciences, 1997, p. 228.

MATERIAL AND METHODS

The object of the study were the soils of southern chernozems of the experimental site of the Federal Research Centre of Biological Systems and Agrotechnologies of the Russian Academy of Sciences located 15 km east of Orenburg. The soils were characterized by thickness of plow horizon (A_p) 45–55 cm, humus content in the arable layer of 3.9–4.7%, total nitrogen 1.1–1.3%, available phosphorus 17.3–41.2 mg in 100 g of soil, exchangeable potassium 147–246 mg in 100 g of soil with pH of soil solution equal to 6,8–7,0.

Field experiments (2019-2022) were laid each year and were carried out during the active vegetation of plants. The small-division experiment was laid with standard placement of the variants on plots (size 0.50 m^2) and fivefold repetition. The effect of salt influence on spring durum wheat of "Orenburgskaya 10" variety was studied by watering the plots in the phase of the 3rd leaf. Salt solutions were prepared by mixing salt with deionized water in the concentration of NaCl (sodium chloride) – 1.1 and 11.7 g/l. The choice of salt concentrations was determined by the creation of minimum and maximum osmotic stress for spring wheat crop, which were obtained as a result of experimental studies outlined in the work of T.S. Aniskina et al. [8].

The control was sprayed with water at the same time with irrigation of the experimental variants and after the plots were mulched with dry soil. The norm of water consumption was 40 liters per 1 m^2, which corresponds to the monthly norm of precipitation in the region.

After the application of the solutions at the beginning and at the end of the vegetation period, the samples were taken according to generally accepted recommendations in layers: 0–10 cm, 10–20, 20–30, 30–40, 40–50 and 50–60 cm. Agrochemical data and indicators of biological activity were determined for the samples using standard methods[2].

Catalase was determined by the method of A.Sh. Galstyan[3]. The principle of this method is based on measuring the rate of decomposition of hydrogen peroxide, formed in the process of respiration of living organisms and as a result of various biochemical reactions of oxidation of organic substances, into water and molecular oxygen.

Protease activity was estimated by the method of F.Kh. Khaziev and Ya.M. Agafarova[4]. The method is based on the cleavage of peptide CO-NH bonds in proteins or peptides to form peptides with lower molecular weight or free amino acids.

Urease was determined by the method of T.A. Scherbakova[5]. The principle of this method is based on measuring the amount of unhydrolyzed urea by the difference between the amount of urea added to the soil sample and detected after the reaction.

The activity of polyphenol oxidase and peroxidase was estimated by the method of L.A. Karyagina and N.A. Mikhailova[6]. The method is based on the estimation of oxidation of soil organic substances at the expense of oxygen of hydrogen peroxide formed in the soil as a result of life activity of microorganisms and the action of some oxidases. These enzymes play an important role in the process of formation and mineralization of humus.

The method of N.I. Savinov[7] was used to study the structural state of the soil.

All studies were carried out in threefold analytical repetition with an average soil sample. The experimental data were analyzed using the software package "Statistica" V8 ("StatSoft Inc.", USA).

[2] *Khaziev F. Kh.* Methods of soil enzymology. Moscow: Nauka, 2005, p. 251.

[3] *Galstyan A.Sh.* Unification of the methods of soil enzyme activity research // Eurasian Soil Science, 1978, N 2, p. 34.

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[5] *Shcherbakova T.A.* Enzymatic activity of soils and transformation of organic matter // Science and Technology, 1983, p. 222.

[6] *Karyagina L.A., Mikhailova N.A.* Determination of the activity of polyphenol oxidase and peroxidase // Bulletin of the Academy of Sciences of the BSSR. Agricultural sciences series, 1986, N 2, pp. 40–41.

[7] *Gorbyleva A.I.* Soil science: laboratory practice. Design PRO, Minsk, 2000, p. 192.

RESULTS AND DISCUSSION

The development of salinization processes is one of the factors of yield reduction, so the study of the influence of easily soluble salts on agronomic properties of steppe chernozems will allow assessing their stability and predicting further dynamics of soil fertility indicators.

Determination of the structural state has shown that under the conditions of sodium salts input into chernozems there is a qualitative change in the aggregate composition of the soils (see Fig. 1).

Comparison of the experimental variants on this indicator demonstrates an increase in the share of lumpy structure of soil in the rooting layer from 28.61% in the soils of the control plot to 35.6% in the variant of maximum concentration of sodium chloride. Similar dynamics is characteristic of the subsoil horizon, which indicates the migration of sodium ions down the profile. Soils of agrocenosis of the control plot are characterized by good structural condition according to the Shein's scale[8] [9] by the value of the content of agronomically valuable fractions, but the introduction of sodium chloride solution at a concentration of 1.1 g/l and more leads to the deterioration of this indicator to satisfactory. Analogous dynamics was noted for the index of the coefficient of structure in the soil layer 0-20 cm, in the subsoil its value characterizes the quality of the aggregate composition as satisfactory (see the Table).

Under conditions of easily soluble salts supply, the chernozems were characterized by the content of water-stable fractions more than 60%, which characterizes their structural state as good. As a result of the experiment, the value of this index gradually decreases and redistribution of the aggregates from larger fractions (5–3, 3–2, 2–1 mm) to smaller ones is noted, which is associated with active peptization of colloidal particles under conditions of SAC saturation with sodium ions.

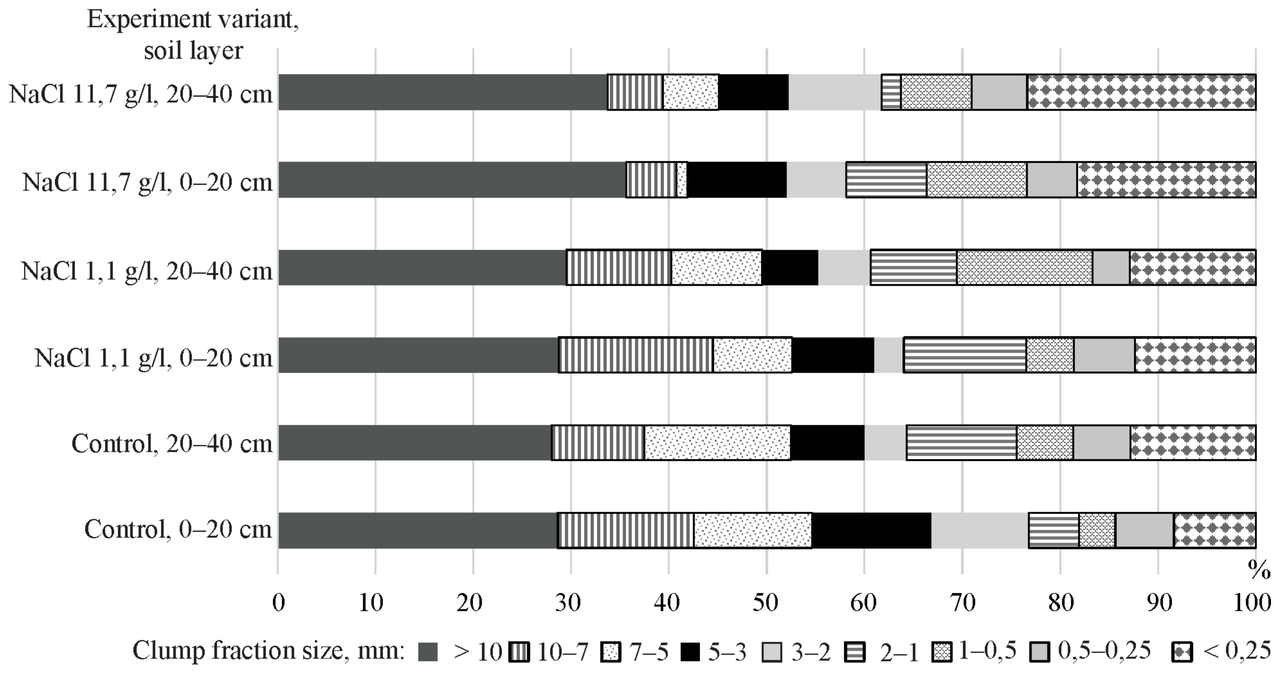

Рис. 1. Структурное состояние почв участков исследования

Fig. 1. The structural condition of the soils of the study sites

[8] *Shein E.V., Arkhangelskaya T.A., Goncharov V.M., Guber A.K., Pochatkova T.A., Sidorova M.A., Smagin A.V., Umarova A.B.* Field and laboratory methods of research of physical properties and soil regimes. Moscow: MSU, 2001, p. 200.

Показатели качества структурно-агрегатного состава почв
Quality indicators of the structural and aggregate composition of soils

Experiment option	Sampling depth, cm	Content of agronomically valuable aggregates, %	Structure coefficient	By total number of the aggregates larger than 0.25 mm obtained by wet sieving, %	Agronomically valuable structure, %	API, %
Control	0–20	63,01	1,70	75,40	83,56	364,17
	20–40	59,18	1,45	77,80	76,07	243,63
NaCl solution 1.1 g/l	0–20	58,94	1,44	62,30	94,61	210,04
	20–40	57,60	1,36	67,00	85,97	126,12
NaCl solution 11,7 g/l	0–20	46,11	0,86	57,30	80,48	128,63
	20–40	42,92	0,75	59,10	72,62	118,94

Indicators of agronomically valuable structure (according to Dolgov and Bakhtin)[9] [10] and API (criterion of water resistance of the aggregates) correspond to excellent and good structural condition. At the same time, the proportion of microaggregates increases and reaches higher values with the application of sodium chloride solution with a concentration of 11.7 g/l. It should be noted that the obtained data on the preservation of water resistance of microaggregates against the background of salt intake are consistent with the results of S. Tang et al. [11], which explain this phenomenon by high content of physical clay fraction, including montmorillonite and silty nature, which under the influence of soil salinization are able to retain moisture well and under saline conditions maintain aggregative stability [12].

Thus, increasing the concentration of sodium chloride solution up to 11.7 g/l under conditions of microplot field experiment contributes to the reduction of soil structure quality.

Soil organisms and their activity contribute to the realization of a wide range of ecological functions by soil, which determines the stability of the whole ecosystem. Application of sodium chloride solution promoted changes in the intensity of biochemical processes and transformation of the indicators of nutrient regime and biological activity of chernozems.

In terms of content of mineral nutrition elements, the soils of the plots were characterized by low and medium content of mobile form of potassium (147–246 mg/100 g of soil), phosphorus – medium and increased (from 17.3 to 41.2 mg/100 g of soil). The absence of statistically reliable difference in the results of phosphorus and potassium content is probably due to the fact that their main source are crystal lattices of soil minerals, as well as to the short duration of the field experiment and leveling of sodium influence by atmospheric precipitation during the growing season. It should be noted that under salinization conditions the dynamics of nitrate nitrogen content increased significantly ($U = 0.01$ at $p = 0.0007$), and ammonium nitrogen content decreased ($U = 9.5$ at $p = 0.01$). Sensitivity to salinization of the indicators of the content of different forms of nitrogen is explained by the leading participation of microorganisms in the processes of transformation of its compounds, which show a high dependence on the input of

[9] *Bakhtin P.U.* Physico-granulometric and technological properties of soils. Moscow: Znanie, 1971, p. 46.

toxic compounds into the soil solution. Studies have shown that there is a close relationship between the nutrients, activity of soil enzymes and soil humus, which are important factors in maintaining the conditions of microorganisms' vital activity [13].

Soil enzymes carry out the processes of decomposition of organic residues, humus formation and participate in the cycle of plant nutrition elements [14]. The main source of enzymes in the soil are microorganisms, but their pool is constantly replenished by the activity of plants and animals. Enzyme reserves are constantly changing, they can be accumulated, inactivated or decomposed in the soil, which is important for the utilization of complex organic compounds [15]. In addition, the sensitivity of enzymes to the changes in external conditions determines the possibility of using them as indicators of the state of the soil environment.

Evaluation of the dynamics of activity dynamics of enzymes of oxidoreductase class showed that catalase, peroxidase and polyphenol oxidase exhibited high sensitivity to the processes of light soluble salt solution supply. The main regularity in the distribution of enzyme stock is the decrease in their activity down the profile (see Fig. 2), which is associated with the change in the amount of plant biomass and decreasing distribution of humus.

Being an exoenzyme, catalase reflects the general response of soil biota to the impact of salinization. Thus, the enzyme activity varied from 12.52 in the variant of sodium chloride application at a concentration of 1.1 g/l to 6.36 ml O_2 at the maximum salt dose at the end of the growing season.

Peroxidase and polyphenol oxidase are the enzymes involved in the transformation of carbon compounds. Their activity is traditionally studied together, as they give an idea of opposite sides of the same process – oxidation and new formation of humus compounds. Salt application in field conditions led to differences in the dynamics of these enzymes. Thus, the activity of polyphenol oxidase was described by a dose-dependent effect and decreased by more than 10% when sodium chloride was applied. Peroxidase activity increased on average by 22.7%, up to 0.5 mg 1.4 p-benzoquinone 1 g of soil, indicating the activation of organic matter mineralization processes under conditions of maximum concentration of easily soluble salt solution input by the end of vegetation.

Urease and protease play an important role in soil nitrogen transformations (see Fig. 3). Thus, the indicators of urease and protease activity were significantly correlated with the content of ammonium (r = 0.61 and r = 0.58 at p > 0.01) and nitrate forms of nitrogen (r = -0.45 and r = -0.38 at p > 0.01).

Urease activity decreases at maximum salinity dose by more than 30% to 26.0 mg $N\text{-}NH_4$ per 1 g of soil for 4 h, as well as by the end of the growing season and when moving down the profile. Similar dynamics was noted for protease, its activity significantly decreases at maximum salinization by 19.3% at the beginning of the growing season and by 39.8% by its end. Indicators of enzymatic activity of chernozems showed different sensitivity to the simulated salt stress.

The activity of enzymes of two classes was significantly correlated with humus content (all r > ±0.82 at p < 0.01). The content of organic matter in the study soils was characterized as low (less than 4%), and under the influence of salinization there was a significant decrease in the indicator in both variants of concentration (U = 30,4 at p = 0,005).

CONCLUSION

The study has shown that the application of sodium chloride to steppe chernozems causes deterioration of qualitative and quantitative indicators of their structural state, expressed in the reduction of the content of agronomically valuable and water-resistant fractions of the aggregates to satisfactory values.

When the concentration of sodium chloride increases, the content of nitrate nitrogen increases reliably, while the share of ammonium nitrogen decreases. Indicators of plant availability of mobile forms of potassium and phosphorus in

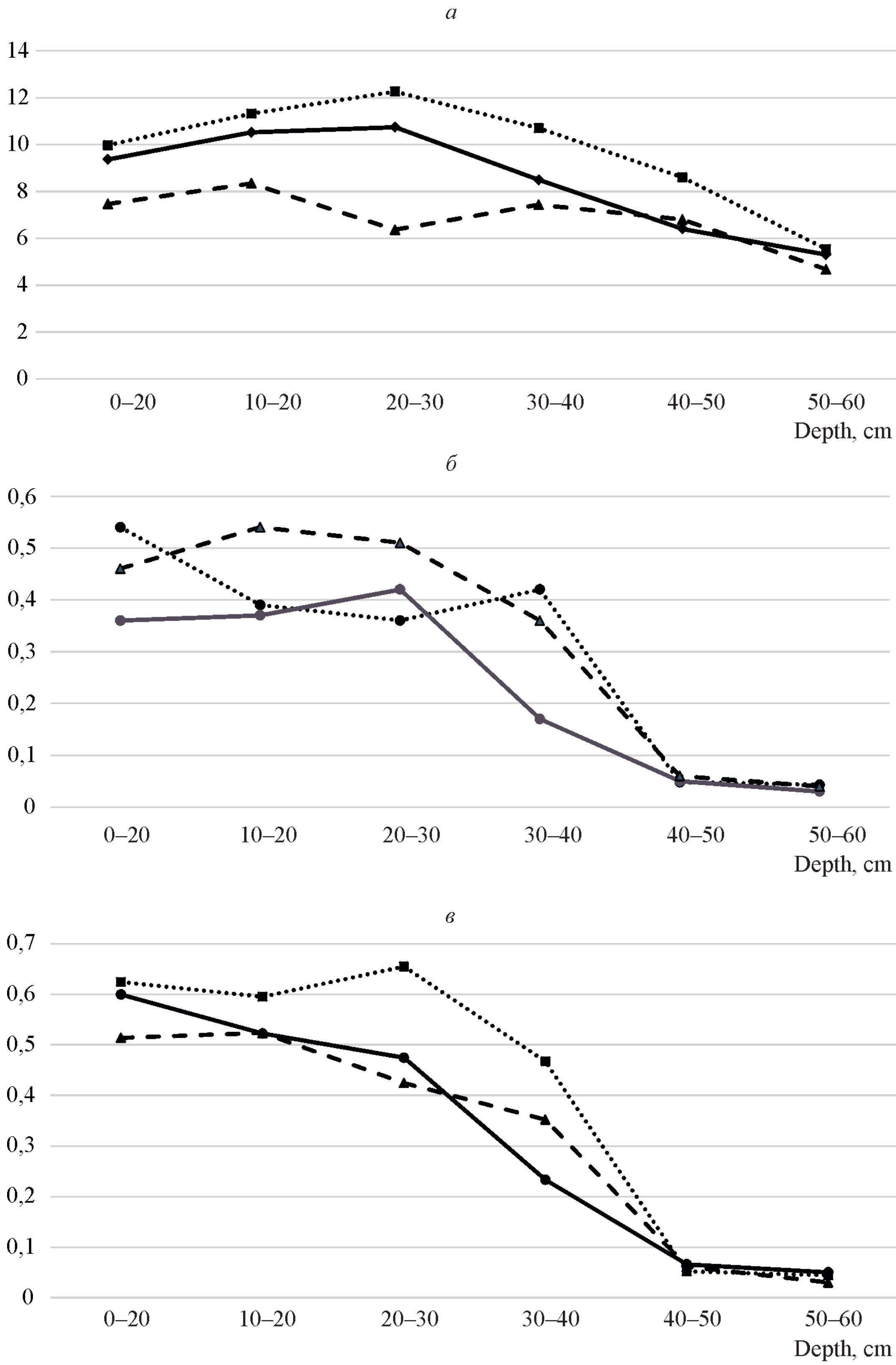

Рис. 2. Активность оксидаз в почвах в условиях моделируемого засоления:
а – каталаза, O_2 за 1 мин в 1 г почвы, мл; *б* – пероксидаза, 1,4 п-бензохинона в 1 г почвы, мг; *в* – полифенолоксидаза, 1,4 п-бензохинона в 1 г почвы, мг

Fig. 2. Oxidase activity in the soils under simulated salinization conditions:
а – catalase, O_2 for 1 min in 1 g of soil, ml; *б* – peroxidase, 1,4 p-benzoquinone in 1 g of soil, mg; *в* – polyphenol oxidase, 1,4 p-benzoquinone in 1 g of soil, mg

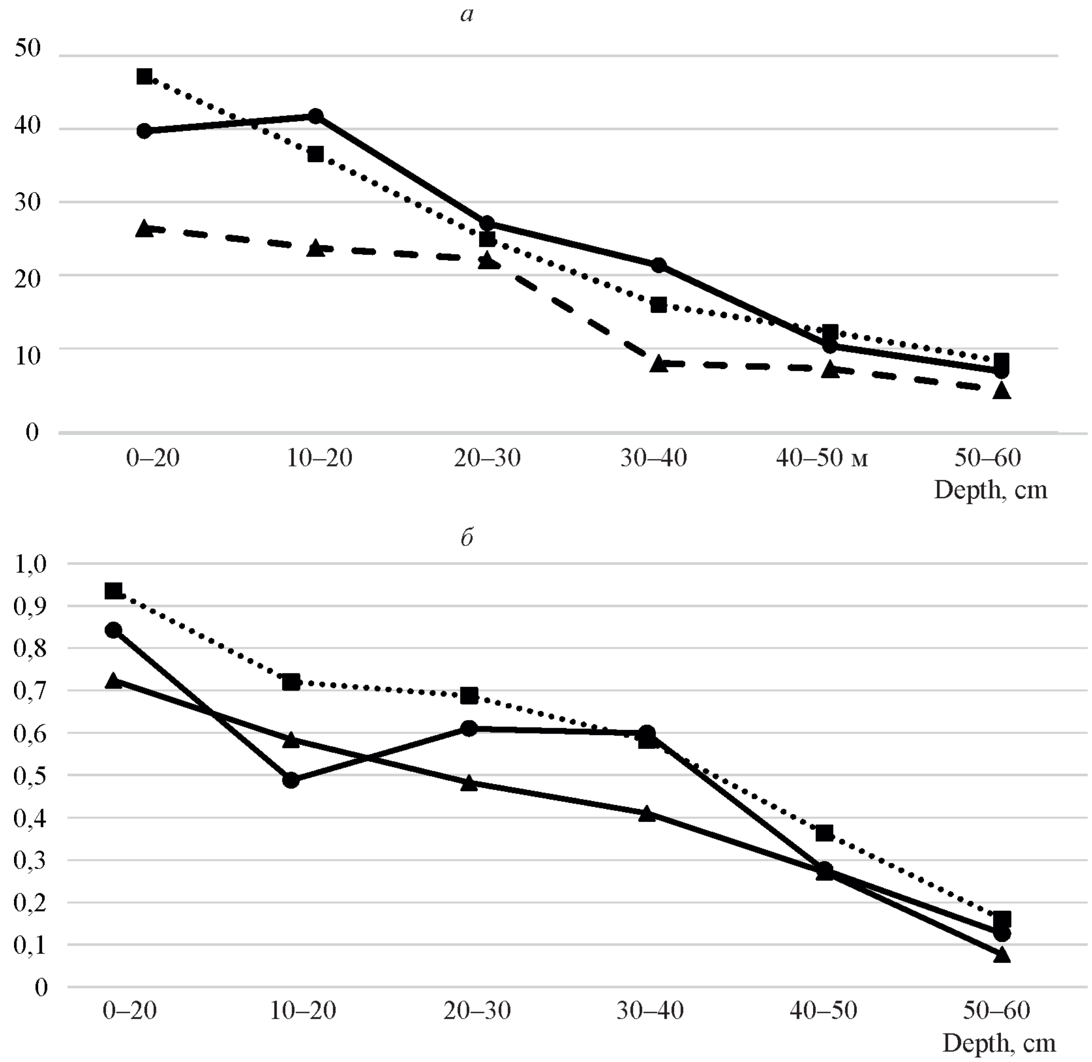

Рис. 3. Активность гидролаз в почвах в условиях моделируемого засоления:
а – уреаза, N-NH_4 в 1 г почвы за 4 ч, мг; *б* – протеаза, тирозин за 24 ч на 2 г почвы, мг
Fig. 3. Hydrolase activity in the soils under simulated salinization conditions:
a – urease, N-NH_4 in 1 g of soil for 4 h, mg; *б* – protease, tyrosine for 24 h in 2 g of soil, mg

chernozem are not characterized by statistically reliable dependence on salt intake, but only tend to decrease in the samples of the experimental plots.

The humus content in soil is of great importance for maintaining fertility, and this indicator significantly decreased against the background of sodium chloride input at the concentrations of 1.1 and 11.7 g/l.

Indicators of soil enzyme activity showed reliable dependence on the application of toxic salt and formed the following series of resistance to salinization: urease > catalase > protease > polyphenol oxidase > peroxidase.

Thus, the input of sodium chloride into steppe chernozems has a significant impact on the complex of biological, agrochemical and agrophysical properties of soils.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

Галактионова Л.В., кандидат биологических наук, научный сотрудник отдела технологии зерновых и кормовых культур

(✉)**Юлдашева И.З.,** кандидат биологических наук, научный сотрудник отдела технологии зерновых и кормовых культур; **адрес для переписки:** Россия, 460000, Оренбургская область, Оренбург, ул. 9 Января, 29; e-mail: gubaidullinae@mail.ru

AUTHOR INFORMATION

Lyudmila V. Galaktionova, Candidate of Science in Biology, Researcher at the Department of Grain and Forage Crops Technology

(✉)**Ilmira Z. Yuldasheva,** Candidate of Science in Biology, Researcher at the Department of Grain and Forage Crops Technology; **address:** 29, January 9th St., Orenburg, Orenburg Region, 460000, Russia; e-mail: gubaidullinae@mail.ru

Дата поступления статьи / Received by the editors 09.07.2024
Дата принятия к публикации / Accepted for publication 01.09.2024
Дата публикации / Published 21.10.2024