Evaluation of Functioning of Calcic Chernozems Under Irrigation Conditions in the Pre-Ural Steppe Zone of the Republic of Bashkortostan (Russia)

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Abstract: In the conditions of climate change, the issue of sustainable harvesting of various agricultural crops is acute. One of the issues of solving this problem is the development of irrigation reclamation, but at the same time it is necessary to maintain a balance between increasing yields and not allowing soil degradation. The paper gives an assessment of the condition of the irrigated Calcic Chernozems of the Engalyshevsky inter-farm irrigation reclamation system located in the valley of the Kaigalysh stream within the Chermasan-Ashkadar plain agro-soil district of the Pre-Ural steppe zone of the Republic of Bashkortostan. The climate of the territory is characterized as slightly arid. The water used for irrigation is of the bicarbonate-magnesium-calcium type and is suitable for irrigation. During the application of irrigation reclamation (9 years), no significant degradation processes have been observed. The content of soil organic matter is characterized as average, the reaction of the medium is neutral, the soil profile is not saline. However, the removal of mobile phosphorus and exchangeable potassium with the crop and irrigation waters is noted, which indicates the need for periodic application of mineral fertilizers.

1 INTRODUCTION

Climate warming due to an increase in the share of greenhouse gases in the atmosphere contributes to changes in moisture regimes and an increase in the number of droughts around the world, which ultimately poses a threat to sustainable agricultural food production. This is especially important in the context of the constant growth of the world's population (Leisner, 2020). In such changing socio-climatic conditions, an important role falls on the ecosystem functions of soils due to their ability to provide numerous services, including carbon sequestration and conservation and food supply (Maha, 2020; Mangi, 2022; Yicheng, 2022).

In terms of sustainable and stable performance of ecosystem functions, the soils of floodplains and river valleys have a special advantage, since it is possible, first of all, to regulate their water regime. In case of waterlogging, it is possible to carry out drainage reclamation, in case of lack of moisture – irrigation reclamation (Schomburg, 2018; Jun, 2022; Everard, 2022).

At the same time, various types of irrigation in arid ecosystems can limit greenhouse gas emissions into the atmosphere, for example, with subsurface drip irrigation, gas emissions are limited due to targeted access of the rhizosphere to water and nitrogen fertilizers (Andrews, 2022), with pre-sowing and docking irrigation, an increase in the accumulation of soil organic carbon was noted as

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against the background of organic fertilizers, and without them (Zhenxing, 2022). However, with long-term use of irrigation reclamation, it is also possible to reduce the carbon and nitrogen content in the soil profile (Gabbasova, 2006; Mudge, 2021).

With regard to the use of various reclamation systems, taking into account natural and climatic conditions, the Republic of Bashkortostan can be divided into two parts, in the northern part drainage reclamation is used mainly in the floodplain of rivers, and in the southern part irrigation reclamation using water resources of rivers, lakes and reservoirs (Suleymanov, 2021).

The purpose of our research was to assess the state of the soil cover and bioproductivity in the functioning of the Engalyshevsky inter-farm irrigation reclamation system (Fig. 1).

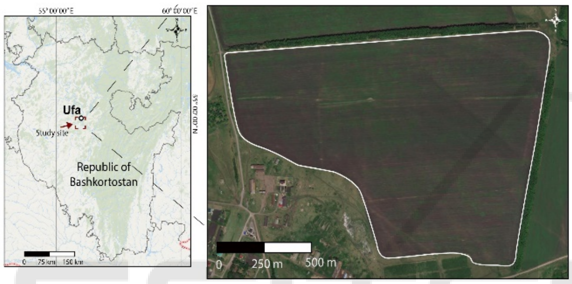

Figure 1: The location of the research area (Engalyshevsky inter-farm irrigation reclamation system).

2 MATERIALS AND METHODS

The Engalyshevsky inter-farm irrigation reclamation system is located in the Chishminsky district of the Republic of Bashkortostan north of the village of Engalyshevo. The irrigation method is sprinkling; grain, vegetable and fodder crops are present in the structure of the sown areas. The water source is a pond on the Kaigalysh stream, the water is of the bicarbonate-magnesium-calcium type, suitable for irrigation. The duration of irrigation is 9 years (Fig. 1). According to the agro-soil zoning, the irrigation system is located in the Pre-Ural steppe zone in the Chermasan-Ashkadar plain agro-soil district. The climate of the territory is slightly arid. The average annual air temperature is 2.5 °C, the average annual precipitation is 416 mm (Khaziev, 1995). The site directly surveyed is located on a gentle slope of the southern exposure. The soil-forming rocks are eluvial-deluvial and deluvial carbonate clays.

The research was carried out by the route-field method with the laying of full-profile soil sections and the selection of soil samples. The soil cover is represented by Calcic Chernozems (IUSS Working Group WRB, 2015). The following indicators were determined in the selected soil samples: the content of soil organic carbon by Tyurin, mobile phosphorus and exchangeable potassium by Machigin, alkaline hydrolyzable nitrogen by Cornfield, absorbed Ca^{2+} and Mg^{2+} cations – trilonometrically, pH H_2O – potentiometrically, dry residue – by evaporation (Arinushkina, 1970; Sokolov, 1975), volume density – by drilling method, water permeability – by filling cylinders with water (Shein, 2007).

Determination of the normalized difference vegetation index (NDVI) and removal of mobile phosphorus and exchangeable potassium from the field was carried out using the online platform for precision farming OneSoil (https://onesoil.ai/ru/) (fig. 2).

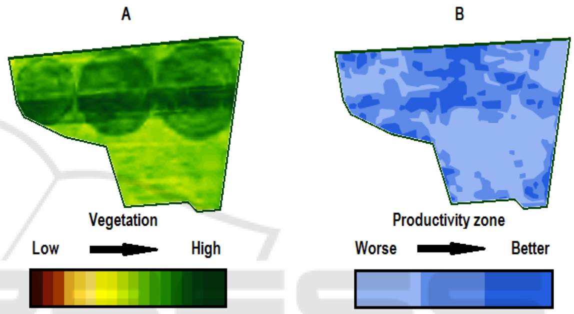

Figure 2: The value of the NDVI index (A) and the productivity zone (B) on the irrigated plot of Calcic Chernozems (performed using the online platform for precision farming OneSoil (https://onesoil.ai/ru/).

3 RESULTS AND DISCUSSION

Analysis of morphological properties of Calcic Chernozems shows that the arable horizon (Aai) has a finely lumpy structure, heavy loamy, crumbly, volume density is 1.15 g cm^{-3}, the transition to the underlying ABca horizon can be determined only by the color and structure, which becomes granular. Below is the illuvial horizon In gray-brown color with patches of organic matter from the overlying horizons, the structure is already becoming nutty, the volume density increases to 1.30 g cm^{-3} (table 1). The profile of the chernozem was formed by eluvial-deluvial and deluvial carbonate structureless clay of yellow-brown color (the horizon of the Cca). The entire soil profile is impregnated with carbonates in the form of mycelium and veins.

Among the physical properties of soils used for irrigation, such an indicator as water permeability is important. Determination of water balance is the main

Table 1: Water-physical and chemical properties of Calcic Chernozems.

Determination	Unit	Horizon, depth, cm			
		Aai	ABca	Bca	Cca
		0-32	32-58	58-83	83-120
pH H_2O	-	6.9±0.2	7.1±0.3	7.8±0.2	8.2±0.1
C org	g kg^{-1}	41.8±2.3	16.2±4.4	6.9±1.7	2.8±1.1
Nitrogen, alkaline hydrolysable	mg kg^{-1}	172.7±20.2	80.9±13.8	35.6±7.4	25.2±6.6
Phosphorus, available (P_2O_5)	mg kg^{-1}	34.6±9.8	29.7±9.8	15.0±2.6	8.3±3.5
Potassium, exchangeable (K_2O)	mg kg^{-1}	123.7±30.5	132.8±27.4	95.8±14.8	72.8±10.2
Ca^{2+}, exchangeable	$cmol_{(+)}$ kg^{-1}	48.6±2.1	39.6±1.2	39.3±1.2	57.3±2.5
Mg^{2+}, exchangeable	$cmol_{(+)}$ kg^{-1}	14.9±0.9	14.3±0.6	13.3±0.6	12.7±2.1
Dry residue	%	0.16±0.03	0.13±0.02	0.09±0.01	0.11±0.01
Bulk density	g cm^{-3}	1.15±0.07	1.21±0.02	1.30±0.04	1.39±0.12
Water permeability	mm for 1 hr	152±8	not determ.	not determ.	not determ.

criterion for sustainable cultivation of agricultural crops, since it allows optimizing soil irrigation schedules (Jun, 2022). Determination of the water permeability of the arable horizon of Calcic Chernozems showed that the average value is 152 mm per hour, which meets the requirements for irrigated soils (Shein, 2007).

The average content of soil organic matter in the arable horizon is 41.8 g kg^{-1} and further decreases with depth in the soil profile to 8.2 g kg^{-1} to the soil-forming rock. The reaction of the medium in the upper humus-accumulative horizons is neutral (pH H_2O 6.9-7.1) and gradually turns into alkaline with depth (pH H_2O 8.2). Calcium predominates among the absorbed cations throughout the profile, it exceeds magnesium by 3-5 times (Table 1).

One of the negative aspects of soil irrigation is the threat of secondary salinization (Ruiqi, 2022; Xiaomin, 2022). Analysis of the content of water-soluble salts in the Calcic Chernozems profile will change from 1.15 to 1.39 %, which indicates the absence of salinization (Table 1).

Another factor determining the growth and development of agricultural crops is the availability of nutrients – nitrogen, phosphorus and potassium in an accessible form for plants. At the same time, irrigation reclamation and cultivation of various crops have a significant impact on the nutritional regime of soils (Fengmei, 2022; Amir, 2022; Mohammed, 2022). The average content of alkaline hydrolyzable nitrogen in the arable horizon of irrigated soil was 172.7, mobile phosphorus – 34.6 and exchangeable potassium – 123.7 mg kg^{-1} (Table 1).

Recently, methods of remote sensing of the Earth and machine learning have become widely used to assess the state of agricultural lands (Long, 2021; Diaz-Gonzalez, 2022.; Mahjenabadi, 2022). These data make it possible not only to determine and predict crop yields using the vegetation index (NDVI) (Roznik, 2022), but it is also possible to assess the content and migration routes of mobile phosphorus (Hezhen, 2016; Jinlong, 2019) and exchangeable potassium (Yiming, 2017; Jing, 2020).

Analysis of the irrigated field using data from the online platform for precision farming OneSoil (https://onesoil.ai/ru/), showed that the maximum NDVI values (0.7-0.8 as of July 19, 2021) were in areas with the maximum amount of irrigation water intake (in Figure 2A, these areas are highlighted in the form of dark green circles), in the areas located to the north, the NDVI values were slightly lower (0.4-0.5). If we compare these NDVI values with productivity zones calculated taking into account the values of mobile phosphorus and exchangeable potassium in the arable horizon (Figure 2B), it turns out that their maximum removal falls on areas with higher NDVI values and productivity. It should be noted that when statistically calculating the average values of the content of mobile phosphorus and exchangeable potassium in the arable layer, their maximum and minimum values differed twice. For phosphorus, they were 24.3 and 48.4 mg kg^{-1}, for potassium – 80.7 and 164.2 mg kg^{-1}, respectively. At the same time, the minimum values fell on the most irrigated areas with high productivity, in the same areas there was an accumulation of nutrients in the underlying ABca horizon, which indicates their leaching from the arable horizon. Also, part of the nutrients is spent on the growth and development of crops.

4 CONCLUSIONS

Thus, the conducted studies have shown that the site of the irrigation system located in the Pre-Ural steppe zone of the Republic of Bashkortostan is represented by Calcic Chernozems. The use of this soil in irrigation reclamation has not led to degradation of its basic properties. This soil is characterized by favorable morphological and water-physical properties. The humus-accumulative horizon contains about 42 g kg^{-1} (average content) (Kiryushin, 1996) of soil organic matter, the reaction of the medium is neutral, calcium predominates among the absorbed cations, the soil profile is not saline.

Analysis of the content of mobile phosphorus and exchangeable potassium shows that part of them is washed into the underlying horizons, and the other part goes to feed crops, which indicates the need for their regular application in the form of fertilizers. The maximum removal of nutrients is observed in areas with maximum irrigation water intake and biological productivity.

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