Ameliorative potential and rating of the agrochernozem in the Trans-Ural steppe zone of the Republic of Bashkortostan (Russia)

R R Suleymanov ORCID 0000-0002-7754-0406, I M Gabbasova ORCID 0000-0002-9238-9011, A R Suleymanov ORCID 0000-0001-7974-4931, I F Adelmurzina ORCID 0000-0003-4119-1467, G M Gizatshina ORCID 0000-0003-4874-989X

1 Ufa Institute of Biology UFRC RAS, Ufa Russia
2 Bashkir State University, Ufa, Russia
3 Bashkir State Agrarian University, Ufa, Russia

Email: *soils@mail.ru

Abstract. Under the conditions of an intensive growth of the Earth’s population, a decrease in the area and quality of productive arable land, the question of reproduction of a sufficient amount and quality of plant agricultural products arises. The arid areas, where amid climate is marked by an increase in soil production moisture shortages and declining crop yields are particularly problematic in this regard. One of the possible ways to solve this problem is to use irrigation reclamation. However, change in the water regime can lead to degradation of the soil cover, in connection with which there is a need for a preliminary assessment of the soil resistance to irrigation. The research was carried out on an agricultural site, which is planned for use in irrigated agriculture. It is shown that the soil cover of the site is represented by agrochernozem (ChernozemsLuvic (CHlv), which is characterized by an average level of organic matter and nutrients, a slightly acidic reaction, favorable water-physical properties and, accordingly, it is resistant to irrigation. Assessment of the soil cover based on the soil-agro-climatic index showed that the limiting factor in this area is insufficient moisture. In this connection, carrying out irrigation reclamation will increase the productivity of agricultural crops.

1. Introduction

Recently, the acceleration of climate change processes has a significant impact on various aspects of economic activity. One of the most dependent industries is crop production [1, 2]. Under the conditions of climate aridization, an increase of the lack of productive moisture in the soils is noted, which is necessary for sustainable obtaining of high yields of agricultural crops [3, 4]. One of the ways to solve the lack of moisture is the usage of irrigation reclamation. At the same time, a change in the water balance of agricultural lands is a powerful environmental factor capable of changing the direction of soil-forming processes that can lead to degradation of the soil cover (development of water erosion, secondary salinization, destruction of the soil structure, decrease in the content of organic matter, removal of nutrients) [5, 6].

Agriculture is one of the leading sectors of the economy in the Republic of Bashkortostan (Russia). More than a half of the territory of the republic has been developed for agriculture, in the structure of which the share of crop production is about 35%, and which accounts for about 4.8 million hectares of...
arable land. The territory of the republic is divided into several agricultural zones, which differ from each other in natural and climatic conditions and soil cover. According to the natural-agricultural zoning of the republic, the following zones are distinguished: Northern forest-steppe zone, North-eastern forest-steppe zone, Southern forest-steppe zone, Pre-Ural steppe zone, Trans-Ural and Mountainous forest zones. The soil cover is represented mainly by sod, gray and mountain soils, as well as all subtypes of chernozems. The climate of the republic is continental with cold winters and dry hot summers; the most arid one is the Trans-Ural zone with a predominance of flat dry steppe landscapes. The main limiting factors for the cultivation of various agricultural crops here are soil moisture and the content of nutrients in the soil. Today there are about 15 thousand hectares of irrigated land in the Trans-Urals, the areas of which should grow in the future in relation to the construction of a number of reservoirs [7]. In this connection, there is a need for a more detailed study and assessment of the reclamation potential of the soil cover of each individual territory in order to prevent the development of degradation processes and sustainably obtain high yields of agricultural crops under irrigation conditions.

2. Objects and Methods

The research was carried out on the territory of the Uchalinsky administrative district of the Republic of Bashkortostan, located within the Trans-Ural zone, where the construction of an irrigation system in the Talyshman River valley is planned. According to agroclimatic zoning, this territory is characterized by a moderately warm, slightly arid climate. The sum of temperatures during the active growing season is 1800–2000° C. The duration of the period is 119-127 days; the duration of the frost-free period is 90–110 days. The impact of the barrier effect of the Ural Mountains is noted, which is expressed in the lack of hydration. Annual precipitation is 350–400 mm, during the period of active vegetation the precipitation is 200–250 mm. The moisture supply of the leading grain crop (spring wheat) is 50–60%, potatoes - 50% [8].

The field survey was carried out according to the methods for assessing soil cover heterogeneity and soil mapping. Soil pits were laid along the perimeter and on the experimental field itself at the rate of 1–2 pits per 1 hectare [8].

Soil classification, diagnostics of the soil profile and genetic horizons were carried out taking into account the substantive genetic classification [10]. The resulting soil name is duplicated in accordance with the World Reference Base for Soil Resources [11]. Soil samples were collected from each soil pit from every genetic horizon over a width of the soil profile. Agrochemical analyses were determined by the next methods: the total carbon content, using the Tyurin method with termination according to Orlov and Grindel [12]; total and alkaline hydrolysable nitrogen, according to Cornfield [13]; total and available phosphorus, according to Machigin, exchangeable potassium, according to Chirikov [13]; exchange cations Ca²⁺ and Mg²⁺ by the trilonometric method; soil reaction by potentiometry and content of water-soluble salts by the weighting method [12].

The physical properties of soils were determined by the next methods: the granulometric composition by the pipette method, the bulk density by a drilling, the categories of humidity by the water saturation and further weighing, the water permeability by the constant flow tubing method, structural-aggregate composition by the gravimetric-sieve method and water resistance of soil aggregates by the wet sieving, water permeability by the cylinder method [14].

The content of trace elements and heavy metals was determined by atomic-absorption spectrophotometry. The provision of soils with organic matter, nutrients and microelements was determined according to Kiryushin [15]. Soil rating was carried out according to Karmanov et al. [16]. Statistical analysis was performed using MS Excel 2007.
3. Results

The conducted field research showed that the explored site is located on a relatively leveled area with gentle slopes of southern and southwestern expositions. The soil cover is homogeneous and represented by the only type of soil – agrochernozem (ChernozemsLuvic (CHlv). Soil-forming rocks are eluvial-deluvial calcareous yellow-brown clays.

The analysis of morphological properties shows that the competence of the humus-accumulative horizon of agrochernozem varies within 70–87 cm. The ploughing part of the humus-accumulative horizon (PU, 0–30 cm) is dark gray in color and it possesses a powdery-lumpy structure, the AU (30–49 cm) part is fine- and medium-lumpy-nuciform structure. The illuvial horizon is yellowish-brown and it possesses a pronounced lumpy-nuciform structure with thin glossy films along the edges of structural units and humic streaks in the form of tongues.

The acidity varies from slightly acidic in the upper horizons to medium acidic in the illuvial ones. The reaction of the environment becomes slightly alkaline in the carbonate horizon transitional to the parent rock. The sum of exchangeable bases is 44.1–49.5 cmol c−1 kg−1 soil, calcium prevails in their composition. The soils are saturated with bases. The degree of saturation with bases averages is about 95%. The analysis of the content of water-soluble salts shows the absence of salinity throughout the soil profile (table 1).

### Table 1. Physical and chemical characteristics of agrochernozem.

| Horizon, depth, cm | Corg g kg−1soil | pH H2O | Ca2+ cmol,c−1kg−1 soil | Mg2+ cmol,c−1kg−1 soil | Ca2++Mg2+ cmol,c−1kg−1 soil | Water-soluble salts% |
|-------------------|-----------------|--------|-------------------------|------------------------|-----------------------------|----------------------|
| PU, 0–30          | 43.3±3.4        | 6.1±0.2| 37.3±3.0                | 10.3±1.6               | 47.6±2.5                    | 0.09±0.02            |
| AU, 30–49         | 37.1±4.4        | 6.1±0.4| 34.5±3.9                | 9.6±0.9                | 44.1±4.5                    | 0.08±0.02            |
| AUBI, 49–62       | 25.3±5.7        | 6.3±0.5| 34.0±3.6                | 10.9±1.8               | 44.9±3.1                    | 0.07±0.02            |
| BI, 62–120        | 10.9±1.5        | 6.7±0.8| 36.0±5.3                | 10.8±1.3               | 46.8±5.4                    | 0.06±0.01            |
| BICc3, 120–150    | 5.8±0.2         | 7.9±0.1| 38.5±0.7                | 11.0±1.4               | 49.5±2.1                    | 0.05±0.01            |

mean±standarddeviation, n = 12

According to the criterion of the humus content of soils [15], the content of organic matter in the humus-accumulative horizon is characterized as an average. In the ploughing (PU,0–30 cm) horizon, the content of organic carbon is 43.3 g kg−1, in the AU (30–49 cm), 37.1 g kg−1. Down the profile, the content gradually decreases to 5.8 g kg−1 in the BICc3(120–150 cm) horizon (table 2).

### Table 2. Agrochemical characteristics of agrochernozem.

| Horizon, depth, cm | Nitrogen total mg kg−1 soil | Nitrogen mobile mg kg−1 soil | Phosphorus total mg kg−1 soil | Phosphorus mobile mg kg−1 soil | Potassium exchangeable mg kg−1 soil |
|-------------------|-----------------------------|-------------------------------|-------------------------------|--------------------------------|----------------------------------|
| PU, 0–30          | 4018±420                    | 209±35                        | 1367±266                      | 22.2±1.9                       | 108±35                          |
| AU, 30–49         | 2542±452                    | 140±58                        | 1024±322                      | 16.1±2.3                       | 73±30                           |
| AUBI, 49–62       | 1326±277                    | 54±3.5                        | 661±79                        | 4.6±0.8                        | 63±5.8                          |
| BI, 62–120        | 720±85                      | 21±9.9                        | 563±14                        | 5.8±0.2                        | 75±14                           |
| BICc3, 120–150    | 493±25                      | 13±1.4                        | 569±36                        | 9.1±0.5                        | 68±11                           |

mean±standarddeviation, n = 12

The amount of total and alkaline hydrolyzable nitrogen in the horizon is 4018 and 209 mg kg−1 soil, respectively, which is a fairly good indicator due to the cultivation of lucerne in this area. The nitrogen content gradually decreases with depth. At the same time, the content of these nutrients is estimated as an average according to the criteria of soil availability with mobile phosphorus and exchangeable potassium [15] (table 2).
The granulometric composition determines many aspects of the economic use of soils. The water permeability, water-holding and water-lifting capacity of soils depends on it [14]. Analysis of the granulometric composition of the humus-accumulative horizon showed that, on average, the content of sand (1–0.05 mm) is 41.6%, silt content (0.05–0.001 mm) is 39.4%, and the content of clay (less 0.001 mm) is 19.0%. According to the Kachinsky scale [14], the granulometric composition is classified as medium loam. Signs of illuviation are noticeable in the illuvial horizon, but its differentiation by granulometric composition is not expressed. The parent rock contains fragments of gravel and small stones. The bulk density of the ploughing horizon is 1.09 g/cm³ and it is estimated to be optimal for most crops.

Analysis of the structural and aggregate state (table 3) showed that agronomic valuable fractions prevail in the structure of the in the humus-accumulative horizon of agrochernozem (on average about 85%), which are represented mainly by structured lumps ranging in size from small to large. The most important condition for the agronomic value of a structure is its water resistance. The content of water-resistant aggregates >0.25 mm in size in the PU (0–30 cm) and AU (30–49 cm) is 84 and 87%, respectively, which makes it possible to assess the water resistance as excellent and excessively high [14], which is favorable for irrigated soils.

Table 3. Structural and aggregate composition of agrochernozem.

| Horizon, depth, cm | Fraction sizes | Fraction content % | Rate | water permeability |
|-------------------|----------------|--------------------|------|-------------------|
|                   | 10–7 | 7–5 | 5–3 | 3–1 | 1–0.5 | 0.5–0.25 | <0.25 | structure | 10–7 | 7–5 | 5–3 | 3–1 | 1–0.5 | 0.5–0.25 | <0.25 | evaluation |
| PU, 0–30          | 4.6  | 9.5 | 14.0 | 21.5 | 15.5 | 14.4 | 9.5 | 11.0 | 5.4 | 94.8 |
| AU, 30–49         | 3.2  | 7.0 | 10.9 | 19.8 | 15.8 | 20.6 | 12.6 | 11.0 | 6.0 | 97.3 |

Note: in the numerator - the content of fractions during dry sieving, in the denominator - at wet sieving

Agrochernozem is also characterized by a fairly high moisture capacity and water retention capacity, in the ploughing PU (0–30 cm) the lowest moisture capacity is 42.9%, capillary and total moisture capacity consistently increase to 44.6 and 46.1%, respectively, these indicators gradually decrease with depth (table 4).

Table 4. Water and physical characteristics of agrochernozem.

| Horizon, depth, cm | Bulk density g/cm³ | Field moisture % | minimum moisture-holding capacity | capillary moisture capacity | maximum water holding capacity | mmh⁻¹ | evaluation |
|--------------------|-------------------|------------------|-----------------------------------|-----------------------------|--------------------------------|--------|------------|
| PU, 0–30           | 1.09              | 13.7             | 42.9                              | 44.6                        | 46.1                           | 81.5   | good       |
| AU, 30–49          | 1.31              | 19.8             | 32.8                              | 34.0                        | 37.5                           | 74.9   | good       |
| AUBI, 49–62        | 1.48              | 14.7             | 20.9                              | 22.5                        | 26.1                           | 46.5   | satisfactory |
| BI, 62–120         | 1.54              | 11.6             | 17.9                              | 19.9                        | 22.9                           | 51.8   | satisfactory |
| BICa, 120–150      | 1.55              | 12.6             | 22.9                              | 23.6                        | 25.6                           | 37.0   | satisfactory |

mean, n = 6
Water permeability is extremely important for the irrigated soils of the arid zone. The researchers showed that agrochernozem is generally characterized by good water permeability. The water permeability of the upper soil horizons was 81.54 and 74.94 mm per hour and this is a good indicator [15]. The water permeability of the middle and lower horizons is satisfactory. Thus, the water-physical properties of clay-illuvial agrochernozems are generally favorable for growing crops under irrigation (table 4).

Along with the basic nutrients, plants need a certain amount of trace elements; however, excessively high concentrations of these elements can be toxic. The problem of plant nutrition with microelements is increasingly acquiring general biological significance, since their excess or deficiency causes unfavorable consequences not only for the growth and development of plants, but also affects the quality of agricultural products [17].

The analysis of the content of trace elements showed that the availability of agrochernozems with cobalt and zinc is low, and the availability with copper, manganese and molybdenum is average [15]. Consequently, agricultural crops grown in this area under irrigation conditions will need micronutrient fertilization, especially cobalt and zinc, to a lesser extent - copper, manganese and molybdenum. Analysis of the content of elements of class I toxicity showed that the amount of lead, cadmium, mercury and arsenic in all soils is significantly lower than the maximum permissible concentrations (table 5).

Table 5. Content of trace elements and heavy metals.

| Horizon, depth, cm | Co (mg kg⁻¹ soil) | Zn (mg kg⁻¹ soil) | Cu (mg kg⁻¹ soil) | Mn (mg kg⁻¹ soil) | Mo (mg kg⁻¹ soil) | Pb (mg kg⁻¹ soil) | Cd (mg kg⁻¹ soil) | Hg (mg kg⁻¹ soil) | As (mg kg⁻¹ soil) |
|--------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| PU, 0–30           | 0.21             | 0.78             | 0.40             | 16.2             | 0.20             | 1.60             | 0.31             | 0.03             | 0.2              |
| AU, 30–49          | 0.05             | 0.03             | 0.27             | 4.93             | 0.16             | 0.97             | 0.18             | 0.02             | 0.1              |
| AUBI, 49–62        | 0.06             | 0.02             | 0.29             | 2.71             | 0.13             | 2.05             | 0.05             | 0.01             | 0.1              |
| BI, 62–120         | 0.08             | 0.08             | 0.46             | 1.75             | 0.14             | 2.95             | 0.07             | 0.01             | 0.2              |
| BIC, 120–150       | 0.16             | 0.08             | 0.56             | 1.45             | 0.13             | 1.44             | 0.91             | 0.02             | 0.3              |

MPC – maximum permissible concentration; mean, n = 6

An integral indicator of the agroecological potential of soils is their comprehensive assessment (soil rating) [18]. This assessment is carried out taking into account the natural and anthropogenic conditions of the functioning of the soil cover and the main properties of the soils themselves [19, 20]. This methodology allows evaluating in points the efficiency of land management, to make a forecast of transformation and changes in the properties of the soil cover and its productivity within the framework of the applied cropping pattern [16].

The assessment of the soil cover of the studied area, taking into account the key properties of the soil (the thickness of the humus-accumulative horizon, the content of organic matter and mobile phosphorus, acidity, granulometric composition) showed that the estimated score for agrochernozem was 54.9 (with the maximum assessment of the reference soil of 100 points).

When calculating the soil-agroclimatic index based on the natural and climatic characteristics of the territory (the sum of active temperatures, the moisture coefficient, and the coefficient of continental climate, the exposure and steepness of slopes) and the biological potential of cultivated crops, the estimated score was 48.9 for spring wheat and up to 46.9 for perennial grasses. But according to the calculation methodology [16], these scores should be at least 55.6 for spring wheat and 57.6 for perennial grasses in order to obtain a long-term sustainable high yield. The main factor that reduces the estimated score of the agrochernozem in the studied area is insufficient moisture and for which, the implementation of irrigation reclamation in this case will increase the productivity of agricultural crops.
Conclusions

The research showed that on the site, which is planned to be used in irrigated agriculture, the soil cover is represented by agrochernozem (ChernozemsLuvic (CHlv) formed on carbonate eluvial-deluvial clay. Analysis of the morphological properties of agrochernozem showed that the thickness of the humus-accumulative horizon varies within 70–87 cm. This horizon is characterized by a lumpy-nuciform structure, a slightly acidic reaction of the medium; calcium predominates among the exchange bases, the degree of saturation with bases is about 95%, the granulometric composition corresponds to the category of medium loam, the bulk density is estimated as optimal for the growth and development of crops.

The content of organic matter in the humus-accumulative horizon varies with depth from 43.3 to 37.1 mgkg$^{-1}$ soil and it is characterized as average. The amount of nutrients (alkaline hydrolysable nitrogen, mobile phosphorus and exchangeable potassium) is also characterized as average.

The analysis of the water-physical properties showed that water-resistant agrochemical valuable aggregates prevail in the aggregate-structural composition of agrochernozem. Agrochernozem is also characterized by a fairly high moisture capacity and water-holding capacity, the water permeability of the upper soil horizons is good, the water permeability of the middle and lower horizons is satisfactory.

The degree of provision with microelements of agrochernozem is low in terms of the content of cobalt and zinc, and medium in terms of the content of copper, manganese and molybdenum. The content of lead, cadmium, mercury and arsenic is below the maximum permissible concentrations.

The scores obtained when assessing the fertility of agrochernozem by key soil properties and soil-agro-climatic index are slightly lower than those recommended for this type of soil in this climatic zone. The main reason for the decrease in scores is insufficient moisture.

Thus, the studied agrochernozem is characterized by good reclamation potential, good agrochemical and water-physical properties, resistance to anthropogenic influences, and needs irrigation.

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