Evaluation of soils of agrocenoses in the forest-steppe zone of the Omsk Irtysh region by the level of cultivation and fertility

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Abstract. We assessed soil fertility of agricultural lands based on the relative index and the complex agrochemical index (CAI), which was calculated from the data on the content of humus, mobile forms of phosphorus and potassium, and the reaction of the environment. The reaction of the soil medium was neutral, with the exception of calcareous soils and solonetzes. The structural condition in the arable layer (0–20 cm) of the soils was assessed as good. Fractions, the most valuable from the agronomic point of view (10.0–0.25 mm), prevailed in the aggregate composition. In the soils of the Kormilovka and Lyubinsky districts, their quantity was below the optimal level and amounted to 60.9–61.9%. The content of the blocky fraction (> 10 mm) exceeded the critical level by 5.0–6.0%. The deviation from the optimal parameters indicated a low degree of physical degradation in the soils. The structural aggregates were not resistant to the destructive effects of water. The calculation of the CAI showed that the soils of the Kormilovka and Lyubinsky districts had the highest fertility, the estimated score was 66–95. The soil fertility of the Azov district was estimated at 53 points. Soils under fallow and forage lands had high CAI (71–100 points). The degree of cultivation of arable land was medium and high.

1. Introduction

Intensive use of soils in agricultural production, a sharp reduction in the volume of their improvement led to soil depletion [1], progressive development of dehumification [2], alkalinization, salinization, erosion, destructuring and compaction of their arable layer [3]. These processes contributed to a change in agrochemical parameters [4, 5] and a decrease in soil fertility in general. At present, in Russia, significant areas of arable land have been withdrawn into the fallow due to the impossibility of their profitable use and high capital costs to restore the lost fertility.

Incomplete and simple reproduction of fertility led to a decrease in the content of humus, phosphorus, potassium and other nutrients and an annual increase in the area of soils with the insufficient provision with them not only in the Omsk region [5] but also in many other regions, territories and regions of Russia [6-10].

In 2013, the Dokuchaev Soil Science Institute assessed the soil quality of the Siberian region, as a result, the territory was classified as “the most unfavourable” in agricultural terms or “with poor soil quality”. The soils of the Omsk region are characterized by a relatively low potential fertility and are mainly represented by thin and low-humic species since they are formed in a sharply continental climate, severe winter, prolonged and deep freezing, and a shortened vegetation period [11, 12].

Rational and efficient use of the soil cover is impossible without regular monitoring of the state and qualitative assessment of its constituent soils [12, 13]. Soil cover assessment is necessary when planning agricultural production, increasing its efficiency, choosing a specialization, developing an effective system of fertilizers and land reclamation. It allows you to judge the profitability of land use,
to justify the calculations of purchase prices for agricultural products, land prices, payroll calculations. In accordance with the materials and results of land appraisal work, the optimal size of land plots for land use and the need to alienate land from agricultural production are determined.

2. Problem Statement

Under modern conditions, when the problem of increasing the productivity of agrocenoses is solved mainly through the intensification of agricultural production, soil assessment using modern technologies is of paramount importance [14]. The severity of this problem is associated with the need for quantitative and qualitative accounting of land resources. Materials of large-scale soil survey and data on soil properties obtained in the 70s – 80s of the last century have lost their relevance and require adjustment since the state of most of the lands in the regions has changed significantly under the influence of agricultural use and the development of degradation processes [15]. There is also a lack of reliable information about the degree of conformity of land use with their intended purpose.

Allocation of land for the construction of cities, industrial facilities, roads, the active development of degradation processes are accompanied by a gradual reduction in the area of arable land and a decrease in soil fertility. The introduction of new lands into agricultural production is limited, since about 70% of Russian land resources are located in cold and arid regions, and territories located under favourable natural and climatic conditions have been developed by 70–90%.

A significant decrease in the productive capacity of soils can cause significant damage to the production potential of agricultural land and the agro-industrial complex of regions or the country. Therefore, the determination of the soil quality should be the basis of state supervision over the state of their fertility, the development and implementation of a set of measures to restore disturbed lands, reproduction and increase the fertility of the soil cover of farms or region as a whole.

The main factors limiting the use of soils in agriculture and reducing the farming efficiency include the low thickness of the humus layer, low humus content, deficiency of productive moisture, rapid destruction of soil structure and agronomically valuable structure, high compliance to erosion processes. Taken together, natural and anthropogenic factors change the degree of cultivation and the level of soil fertility in the direction of their increase or decrease. The aim of this work was to carry out a comparative assessment of the soils of agricultural lands in the forest-steppe zone of the Omsk region based on the index of cultivation and a complex agrochemical indicator.

3. Materials and Methods

The objects of the research are located in the southern forest-steppe natural and agricultural zone of the Omsk region on the territory of the Azov, Kormilovka and Lyubinsky districts. The soil and climatic conditions of the zone are favourable for the cultivation of all zonal crops.

According to the Center of Agrochemical Service “Omsky” [16], the area of agricultural land in the Azov district is 116,002 hectares, of which 104,052 hectares are arable land and 10,257 hectares are fodder lands. The soil cover of arable land is represented by ordinary chernozems (77.8%), meadow-chernozem (21.8%) and chernozem-meadow soils (0.4%). The weighted average humus content in the soils of the region is low (4.63%), the provision with mobile phosphorus is increased (111 mg/kg), the supply of potassium is very high (307 mg/kg). The research was carried out in ordinary chernozem and chernozem-meadow solonetz.

The area of agricultural land in the Kormilovka district reaches 148,146 hectares, arable land occupies 108,365 hectares, fodder lands – 37,705 hectares. The basis of the arable fund is represented by ordinary chernozems (31.9%) and meadow chernozem soils (33.7%), 20.8% of the arable land are occupied by solonetzes. In general, in the district, the content of humus is average and reached 5.3%, phosphorus – increased (123 mg/kg), potassium – very high (306 mg/kg). The studies were carried out in ordinary chernozem and chernozem-meadow solonetz.

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In the Lyubinsky district, agricultural land accounts for 224,243 hectares, 143,021 hectares are allotted to arable land and 80,079 hectares – for hayfields and pastures. The soil cover of arable land is represented by meadow chernozem soils (43.0%), ordinary chernozems (22.0%) and solonetzes (23.0%). The soils of the district are more supplied with humus than the soils of the Azov and Kormilovsky districts, its weighted average value reached 5.9%, although it is at an average level. The
phosphorus content is increased (104 mg/kg), the amount of potassium is very high (236 mg/kg), but noticeably lower than that in the soils of other districts. The studies were carried out in meadow-
chernozem, chernozem-meadow and meadow soil.

The content of organic matter was determined by Tyurin’s method in the modification of the Central Research Institute of Agrochemical Service (GOST 2613-91); nitrate nitrogen – by the
phenoldsulfonic acid method; mobile forms of phosphorus and potassium in soils with pH value less
than 7.0 – according to Chirikov’s method in the modification of the Central Research Institute of
Agrochemical Service (GOST 26204-91), with pH values more than 7.0 – according to Machigin’s
method (GOST 26205-91); soil pH – by potentiometric method; particle size distribution – by pipette
method (GOST 12536-2014); the degree of soil cultivation and the complex agrochemical indicator
were calculated by the method of T.N. Kulakovskaya.

4. Results and discussion
In the southern forest-steppe, soil formation takes place in a warm and moderately humid climate. The
amount of precipitation on the territory of the studied land varies from 300 to 370 mm/year, the sum of
active temperatures (> 10 °C) is 1850–2050 °C. Previously investigated soils were formed under
perennial herbaceous meadow vegetation, which supplied a significant amount of biomass rich in
alkaline earth metals. The decomposition of fresh organic matter proceeded under relatively
favourable hydrothermal conditions, as a result of which a developed humus layer with a thickness of
33 to 54 cm was formed in the studied soils.

The humus content in agrocenoses varies over a wide range and is determined by the volume and
frequency of application of organic fertilizers, cultivated crops and the amount of plant biomass
supplied to the soil, soil processing methods. In arable soils, most of the biomass is alienated with the
harvest, and with a lack of plant material, the mineralization process prevails, which is accompanied
by a decrease in the amount of humus. According to research data, humus content in arable land was at
the average and high levels (Table 1).

Table 1. Agrochemical characteristics of soils in agrocenoses

| Soil Characteristics | Humus Content, % | Nutrient Concentration, mg/kg of Soil | pH |
|---------------------|------------------|--------------------------------------|----|
| **Soils of arable lands** |                 |                                      |    |
| Azov district       |                  |                                      |    |
| Ordinary chernozem  | 4.8              | 5.84                                 | 75.4| 325| 8.1   |
| calcareous medium thick low-humic heavy loamy | | | | | |
| Kormilovka district | 7.2              | 12.2                                 | 160.0| 200| 6.6   |
| Ordinary chernozem  | 6.2              | 3.43                                 | 83.3 | 212| 6.8   |
| medium thick medium-humic clayey | | | | | |
| Ordinary chernozem  | 7.0              | 1.39                                 | 87.5 | 123| 7.0   |
| medium-thick medium-humic middle loamy | | | | | |
| Lyubinsky district  | 4.8              | 1.95                                 | 150.0| 251| 8.1   |
| Meadow chernozem medium-thick medium-humic middle loamy | | | | | |
| Meadow solodic medium thick low-humic middle loamy | | | | | |
| **Soils of fallow and fodder lands** |                  |                                      |    |
| Kormilovka district |                  |                                      |    |
| Meadow low thick medium-humic middle loamy | 8.0 | 5.38 | 175.0 | 247| 6.9   |
| Lyubinsky district  |                  |                                      |    |
| Chernozem-meadow low thick medium-humic middle loamy | 6.9 | 3.25 | 144.0 | 187| 7.9   |
| Azov district       |                  |                                      |    |
| Chernozem-meadow solonetz calcareous deep columnar heavy clayey | 7.2 | 2.69 | 130.0 | 150| 8.1   |
| Kormilovka district |                  |                                      |    |
| Meadow low thick medium-humic middle loamy | 8.0 | 5.38 | 175.0 | 247| 6.9   |
| Lyubinsky district  |                  |                                      |    |
| Chernozem-meadow low thick medium-humic middle loamy | 6.9 | 3.25 | 144.0 | 187| 7.9   |
The soils of fallow areas and fodder lands had a high provision with humus since the processes of humification and mineralization proceed at the same rate and its amount stabilizes.

Omsk chernozem soils are rich in mobile forms of potassium, as evidenced by its high and very high content in the humus layer of arable, fodder and fallow lands. Soils are provided with mobile forms of phosphorus to a lesser extent. Its content varied in a wide range, from medium and increased to high levels, and depended on the amount of phosphorus fertilizers applied on arable land. Soils under perennial herbaceous vegetation are more abundant in phosphorus, its content was higher on average by 50 mg/kg. All the studied soils were in acute need of nitrogen since they had a very low and low supply of the element. The exception was ordinary chernozem in the Kormilovka district, in which its amount reached an average level due to the use of nitrogen fertilizers.

The reaction of the soil medium in the upper part of the humus layer (horizons A, A1) of the studied soils is close to neutral, with the exception of the calcareous soils, in which the pH value was in the alkaline range. Due to some moisture deficit, carbonates in the soils of the southern forest-steppe are less leached and lie higher to the surface: from the AB or B1 horizon.

The structural state of arable soils in the 0–20 cm layer largely depended on their readiness for cultivation (state of “physical ripeness”) during the period of agrotechnical work and the quality of cultivation. The aggregate composition was dominated by the fractions most valuable from the agronomic point of view (10.0–0.25 mm). In the ordinary chernozem of the Kormilovka district and the meadow-chernozem soil of the Lyubinsky district, their number was below the optimal (70–80%) level and amounted to 60.9 and 61.9%, respectively (Figure 1).

![Figure 1. Aggregate composition of arable soils in the layer of 0–20 cm (1 – ordinary chernozem calcareous medium thick low-humic heavy loamy of the Azov district; 2, 3 – ordinary chernozems medium thick medium-humic clayey of the Kormilovka district; 4 – meadow-chernozem medium-thick medium-humic middle loamy soil of the Lyubinsky district; 5 – meadow solodic medium thick low-humic middle loamy of the Lyubinsky district.)](image)

The content of the blocky fraction (> 10 mm) in these soils was higher than the optimal level (20–30%) by 5.0–6.0%. The deviation from the optimal parameters indicated a low degree of development of physical degradation. In other soils, the value of the blocky (9.5–24.5%) and agronomically valuable fraction (71.8–80.7%) was at the optimal level.

The structural condition of the soils was assessed as good. However, with a good structure, the soil aggregates were not resistant to the destructive effect of water. The amount of water-resistant aggregates did not exceed 26%, which may be due to the weak bond strength of the soil mineral part with calcium humates.

To characterize and assess soil fertility, we used the relative index of a complex of agrochemical properties (soil medium reaction, the content of humus, mobile forms of phosphorus and potassium). According to this methodology, the soils have a high degree of cultivation (Table 2), but the complex agrochemical index is higher in soils under fallow and fodder lands due to the higher supply of humus and phosphorus.
Table 2. Assessment of soil fertility in agroecososes

| Soil | Cultivation index | Complex agrochemical index |
|------|-------------------|----------------------------|
| **Soils of arable lands** | | |
| Azov district | | |
| Ordinary chernozem calcareous medium thick low-humic heavy loamy | 0.77 | 53.9 |
| Kormilovka district | | |
| Ordinary chernozem medium thick medium-humic clayey | 0.98 | 95.1 |
| Ordinary chernozem medium thick medium-humic clayey | 0.84 | 66.4 |
| Lyubinsky district | | |
| Meadow-chernozem medium-thick medium-humic middle loamy | 0.87 | 68.7 |
| Meadow solodic medium thick low-humic middle loamy | 0.91 | 78.3 |
| **Soils of fallow and fodder lands** | | |
| Azov district | | |
| Chernozem-meadow solonetz calcareous deep columnar heavy clayey | 0.85 | 71.2 |
| Kormilovka district | | |
| Meadow low thick medium-humic middle loamy | 1.00 | 100.0 |
| Lyubinsky district | | |
| Chernozem-meadow low thick medium-humic middle loamy | 0.99 | 96.7 |

The methodology does not take into account other indicators of soil properties and regimes, which may limit their use as arable land or for any set of crops. Such limiting factors include waterlogging, the presence of solonetzicity, carbonate content, erosion and other unfavourable soil properties. For example, the meadow solodic soil of the Lyubinsky district has higher estimated indicators than the chernozems and meadow-chernozemic soil of the Azov and Kormilovka districts. However, the constant waterlogging associated with the shallow groundwater level (1–3 m) creates an unfavourable water-air and thermal regime and reduces the agronomic value of the soil. Despite its high potential fertility, it is rational to use the soil for forage lands. In chernozems, the limiting factor in use is the carbonate content, which increases the density of the humus layer and its susceptibility to erosion processes, creates an alkaline reaction of the environment, etc.

5. Conclusion
The soils of the surveyed administrative districts of the forest-steppe zone have a high degree of cultivation, but differed in their fertility. The potassium regime is characterized by stability, and soils have very high provision with this element. The limiting element of plant nutrition is nitrogen; most of the soils of arable land have a lack of phosphorus. To improve the nutritional regime, increase soil fertility and the productivity of cultivated crops, an increase in the volume of application of mineral and organic fertilizers is required. The use of organic fertilizers in the form of manure, straw, sowing of perennial leguminous grasses will contribute to an increase in organic matter in soils, improve its quality, and increase the resistance of soil aggregates to the destructive effects of technology, water and wind

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5
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