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SOIL AND ECOLOGICAL EVALUATION OF AGRO-CHERNOZEMS OF SIBERIA

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ABSTRACT

The comparative assessment of natural potential of agro-chernozems of Siberia in order to plan rational land use, protection of soils and soil cover is carried out. The score was determined by soil-ecological index (SEI). SEI calculation was carried out on climatic, agrochemical and soil parameters. At calculating the climate index, the sum of temperatures above 100°C and precipitation was taken into account; the agrochemical index was calculated by the content of humus, mobile forms of phosphorus and potassium, the reaction of the medium and the soil index – by alkalinity, salinity, erosion, granulometric composition of soils. According to the data of the Landsat satellite and the QGIS software, a map of the distribution of chernozems in the Siberian region was created. Interactive map is comparable to the relief map of the study area, cadastral, geological and other maps. The most valuable soils for agricultural use are formed in the Krasnoyarsk and Altai Krai, where up to 50% of the total chernozem area of the Siberian Federal district (SFD) is concentrated. SEI of agro-chernozems of Siberia decreases in a number: Krasnoyarsk Krai – Altai Krai – Irkutsk region – Omsk region – the Republic of Tuva. The development of erosion and deflation to an average degree reduces the SEI value by 14-36%. The calculated SEI values of agro-chernozems can be used to determine their resource potential, cadastral and market assessment, development of recommendations for land transformation. In modern conditions, the unused chernozems are considered as unrecorded reserve for expansion of arable land, most balanced, anthropogenic, environmental resource.

1. INTRODUCTION

The first fundamental work on the chernozems of Siberia is the report of V.V. Dokuchaev "On

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the Siberian chernozem" (Dokuchaev, 1950). In the report, it was noted that "Siberian chernozem does not represent such continuous areas as European chernozem ...", as well as that "under chernozem in Siberia they often understand soils that have nothing to do with the present chernozem; it is clear, thus, the area of Siberian chernozems can grow to infinity". The Dokuchaev's position of the properties of chernozems looks like as follows: "The composition and structure of the Siberian chernozems as diverse as the chernozems of European Russia; and both lie indifferently on clay, sand, limestone and massive rocks (what are granites). Obviously, the quality of Siberian chernozems should not be the same".

A number of generalizing works are devoted to chernozems of different regions of Siberia (Khmelev and Tanasienko, 1983; Burlakova, 1984; Mishchenko and Prudnikova, 1984; Krupkin, 2002), but they were studied more in the regional aspect, often with the use of "local" soil classifications and groupings, with different approaches to their assessment.

In accordance with the integrated assessment of soil quality for agricultural use, all subjects of the SFD, with the exception of the Altai Krai, are classified as "the most unfavorable regions" or "regions with poor soil quality" (Ivanov et al., 2013). Long-term agricultural use of chernozems led to the progressive development of a number of degradation processes (alkalinization, salinization, dehumidification, increased hydromorphism, erosion), contributing to a decrease in their fertility and a change in agrochemical indicators in the unfavorable direction (Wen and Liang, 2001; Vlček et. al., 2011; Chendev et. al., 2015; Hristov et. al., 2017; Stepanova and Korenkova, 2018). The percentage of soils unsuitable for agricultural production is 82 in the Republic of Tuva, 81 in the Krasnoyarsk Krai, 63 and 62 in the Omsk and Irkutsk regions, respectively, and 42 in the Altai Krai.

This work is based on the calculation of soil-ecological indices (SEI), which are used in the comprehensive monitoring of soil fertility of agricultural land. The purpose of the study is by means of SEI to assess agro-chernozems of a number of subjects of the Siberian region for the planning of their rational land use and protection.

2. OBJECTS AND METHODS

The main sources of data on the distribution of chernozems in the SFD are the soil map of the RSFSR of 1988 and the monograph "Soil cover and land resources of the Russian Federation" (Shishov et al., 2001). For each subject of the SFD types of agro-chernozems were allocated (Shishov, 2004) and their area was calculated using standard GIS tools. According to the Landsat series of satellites, the interactive map of the spread of chernozems on the territory of subjects of the Siberian Federal district was created. The map is compared with the relief map of the territory and, if necessary, can be combined with cadastral, geological and other maps.

Various methods are used to assess soil fertility and suitability for use in agriculture (Shishov et al., 1991; Molchanov et al., 2015; Rousseva et al., 2016; Amara and al., 2017; Sirotkin and al., 2017; Musakwa, 2018; Mehra and Singh, 2018). In this work, the assessment of chernozems is carried out by the technique developed by I. I. Karmanov (Shishov et al., 1991), which is based on the calculation of SEI. This is a quantitative value that reflects the natural potential of arable land in points (from 1 to 100) of productivity of leading crops.

The source data for the calculation of the SEI of agro-chernozems in Omsk region was taken from the materials of agrochemical examinations conducted in the service areas of CAS "Omsk" and AAS "Tarskaya". Agro-chernozems clay-illuvial typical (Luvic Chernozems) provided with humus have an increased amount of mobile phosphorus and potassium. Agro-chernozems texture-calcareous (Calcic Chernozems) and dispersed-carbonate (Veronica Chernozems Pachic), and their alkaline counterparts have less humus. Soils are characterized by average phosphorus and very high – potassium, neutral and close to neutral reaction of the soil medium.

Agro-chernozems of Altai Krai are characterized according to the CAS "Altai" (The fertility monitoring, 2016). Agro-chernozems clay-illuvial typical and dispersed-carbonate provided with humus have a neutral reaction of the soil solution, medium-loamy granulometric composition. Agro-chernozems textural and carbonate have less humus and differ by slightly alkaline reaction and lighter granulometric composition, very high and high movable potassium provision. Soils are less provided with mobile phosphorus.

For the Krasnoyarsk Krai data for chernozems was generalized by I.P. Krupkin (Krupkin, 2002) for largest agricultural Kansk natural district. The high content of humus is typical of agro-chernozems clay-illuvial podzol. Agro-chernozems clay-illuvial typical and dispersed-carbonate differ from it by a lower content of humus, by 1 and 2%, respectively.

All soils have a neutral medium reaction and a very high provision of mobile phosphorus and potassium.

Data for the chernozems of Tuva are taken from the materials of agrochemical inspection of SAAS "Tuvan" (Savich et al., 2012). The amount of humus in agro-chernozems dispersed-carbonate and texture-carbonate is low. Tuva agro-chernozems are characterized by light granulometric composition, slightly alkaline and neutral reaction of soil solution, average provision of mobile phosphorus and potassium.

Data on agro-chernozems of the Irkutsk region are obtained from the materials of agrochemical survey carried out by CAS "Irkutsk" (Soils of the Irkutsk region, 1983; Annual production report..., 2015). Agro-chernozems clay-illuvial typical and dispersed-carbonate are sufficiently provided with humus, have a neutral medium reaction and an average provision of mobile phosphorus and potassium.

3. RESULTS AND DISCUSSION

Siberian chernozems are widespread in the south Asian part of Russia and are formed in all subjects of SFD. The area of chernozems distributed across the regions is extremely uneven, from 20 thousand hectares in the Tomsk region to 10 million hectares in the Altai Krai (table 1). The total area of chernozems of SFD is more than 27 million hectares, among them, the types of dispersed carbonate (42.4%) and clay-illuvial typical (33.1%) are dominated. The areas of chernozems clay-illuvial podzolic (7.9%) and texture-carbonate typical (14.7%) are significant. This is the most valuable soil, "gold" fund of arable land, allowing conducting profitable agricultural production. Chernozems

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alkaline are boundedly distributed, in the structure of the soil cover they occupy about 1%.

In the Altai Krai, there are more than one-third of all chernozems of the SFD, which are dominated by clayey-illuvial typical (35.6%) and dispersion-carbonate (32.0%) types.

Table 1: Chernozems distribution on the territory of the Siberian Federal district, thousand hectares

Subject	Chernozem						Area
	Clay-illuvial		Migration micellar	Dispersed-carbonate	Texture-carbonate typical	Alkaline	
	podzol	typical					
Altai Krai	690,10	3355,92	203,84	3014,68	1953,00	202,40	9419,94
Krasnoyarsk Krai	191,36	2301,06	-	1563,49	56,50	-	4112,41
Omsk region	27,30	288,86	-	2352,53	429,44	51,30	3149,43
Novosibirsk region	522,53	1350,62	-	405,97	540,21	22,09	2841,42
Zabaikalsky Krai	-	-	-	1968,45	-	32,43	2000,88
Kemerovo region	649,31	1262,13	-	-	-	-	1911,44
The Republic of Khakassia	32,81	116,55	-	876,45	750,37	-	1776,18
The Republic of Buryatia	-	-	-	672,11	-	-	672,11
Irkutsk region	-	212,40	-	292,16	-	28,28	532,84
The Republic of Tuva	-	-	-	100,53	241,17	-	341,69
Altai republic	38,33	47,14	-	85,64	144,40	-	315,52
Tomsk region	-	22,30	-	-	-	-	22,30
Total	2151,74	8956,98	203,84	11472,65	3974,45	336,50	27096,16

Here migration micellar chernozems (Chernozems Voronic) are formed, which other subjects of the Siberian Federal district do not have. The zonal feature of the chernozems of the plain part of the Altai Krai is their meridional location associated with hydrothermal conditions. Chernozems clay-illuvial, formed in the east of the Altai Krai, in conditions of sufficient moisture supply, in the west are replaced by chernozems dispersed-carbonate, which causes greater complexity of the soil cover in the transition zones. Over 60% of the chernozems area is plowed and is eroded and deformed.

In the Krasnoyarsk Krai, more than 4.1 million hectares of chernozems are formed, which are mainly clay-illuvial typical (55.5%) and dispersed-carbonate (38.0%) types. The region occupies the second place in the SFD for the spread of chernozems. Sharply contrasting, harsh temperature regime defines a number of provincial peculiarities of Krasnoyarsk chernozems: short humus horizon and its high humus content; low biological activity; lower boundary stoniness of the humus layer; the signs of permafrost gley; layered texture. Chernozems are characterized by the complexity of the soil cover and lithological heterogeneity of soil-forming rocks. In connection with the active development of erosion processes in the open areas eroded and deflated chernozems are widespread. Tens of thousands of hectares of fertile clay-illuvial and dispersed-carbonate chernozems are subject to chemical degradation (Tandelov, 2012) and more than 129 thousand hectares of agricultural lands are polluted to varying degrees.

The territory of chernozems distribution in Omsk region is characterized by high complexity, weak drainage and lack of water, salinity of soil-forming and underlying rocks, high occurrence and mineralization of groundwater (Mishchenko and Prudnikova, 1984). The region is on the third place among subjects of the Siberian Federal district according to the chernozems distribution. Chernozems are dispersed-carbonate, often alkaline, occupy here up to 75% of the total area of chernozems.

Formed in the conditions of sharply continental climate, severe winter, and deep freezing, chernozems of the region are characterized by relatively low potential fertility (Krasnitsky and Schmidt, 2016; Fedorova et al., 2016) and are represented mainly by low-power and low-humus species.

Significant areas of chernozems, from 1.8 to 2.8 million hectares, are concentrated in the Novosibirsk and Kemerovo regions, the Zabaikalsky Krai and the Republic of Khakassia. The unfavorable situation is with the clay-illuvial chernozems of the Kemerovo region, where the territory is uncontrollably withdrawn for open (quarry) coal mining, the main reserves of which are concentrated within the Kuznetsk basin, in the structure of the soil cover of which chernozems are dominated.

In the Irkutsk region, chernozems occupy about 0.53 million hectares and are distributed on the terraces of the Angara, Kuda rivers, their tributaries and do not form large massifs. These soils have a shallow humus layer, high content of humus, intense freezing and long persistence of seasonal permafrost(Kuzmin, 1988).

On the territory of Tuva, the area of chernozems is 0.34 million hectares and is formed locally on the sloping ridges and foothills in the Turano-Uyuk basin, in the northern foothills of the Eastern and Western Tannu-Ola. For soils lithological heterogeneity of soil-forming rocks, stoniness, light (often sand) granulometric composition is typical.

The chernozems clay-illuvial typical, common in the north of the Omsk region, have the highest SEI (Table 2). For chernozems dispersed carbonate and texture-carbonate typical that are formed in conditions of low moisture, the input of organic substances, accelerated process of mineralization and development of deflation, SEI is reduced by 14-19 points. Alkaline subtypes of these soils are estimated in 24.5 points.

The development of erosion and deflation reduces the SEI value to an average degree. On average eroded soils, against the degraded standards, are assessed higher by 6 points. The weighted average value of SEI of agro-chernozems of the region is lower by 8-10 points than for soils of the Altai and Krasnoyarsk Krai.

The highest SEI are calculated for agro-chernozems clay-illuvialin Altai Krai, which are the most fertile and productive soils of the SFD. They are characterized by a high climate index, which makes them the most valuable. Agro-chernozems dispersed-carbonate and texture-carbonate are estimated lower by 14-22 points. Erosion processes decrease their SEI on average by 10and a manifestation of average degree alkalinity by 9 points.

SEI of different types of agro-chernozems of Krasnoyarsk Krai is quite high and is within 47-48 points. Erosion and deflation reduce their value by 12 points. In general, agro-chernozems of the region are characterized by high soil and agrochemical indices but are inferior to Altai agro-chernozems in the climatic index, for this reason, the value of the final SEI of agro-chernozems of these regions differs slightly.

On the territory of Tuva SEI of agro-chernozems dispersed and texture-carbonate is the lowest one, the development of deflation and stoniness of soils reduces it on average by three points.

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Table 2: Soil-ecological index of agro-chernozems of the Siberian Federal district, point

Name of soil	Index			
	Soil	Agro-chemical	Climate	Soil-ecological
Omsk region				
Agro-chernozem clay-illuvial typical	9.41	1.05	4.93	48.7
also moderately eroded	6.49	1.05	4.93	33.6
Agro-chernozem dispersed-carbonate	8.11	1.05	4.05	34.5
also moderately deflated	7.14	1.05	4.05	30.4
Agro-chernozem texture-carbonate typical	7.77	1.05	3.61	29.5
also moderately deflated	6.84	1.05	3.61	25.9
Average for non-eroded soils	*8.43*	*1.05*	*4.20*	*37.2*
Weighted average for non-eroded soils	-	-	-	*34.5*
Average for eroded and deflated soils	*6.39*	*1.05*	*4.20*	*28.2*
Agro-chernozem dispersed-carbonate moderately alkaline	5.77	1.05	4.05	24.5
also moderately deflated	5.08	1.05	4.05	21.6
Altai Krai				
Agro-chernozem clay-illuvialpodzol	9.26	1.11	5.25	54.0
also moderately eroded	6.39	1.11	5.25	37.2
Agro-chernozem clay-illuvial typical	9.31	1.16	5.18	55.9
also moderately eroded	6.43	1.16	5.18	38.6
Agro-chernozem dispersed-carbonate	8.82	1.05	4.31	39.9
also moderately deflated	7.76	1.05	4.31	35.1
Agro-chernozem texture-carbonate typical	7.94	1.04	4.11	33.9
also moderately deflated	6.98	1.04	4.11	29.8
Average for non-eroded soils	*8.83*	*1.09*	*4.71*	*45.3*
Weighted average for non-eroded soils	-	-	-	*45.0*
Average for eroded and deflated soils	*6.89*	*1.09*	*4.71*	*35.4*
Agro-chernozem texture-carbonate moderately alkaline	5.95	1.04	4.11	25.4
also moderately deflated	5.24	1.04	4.11	22.4
Krasnoyarsk Krai				
Agro-chernozem clay-illuvial podzol	10.08	1.23	3.85	47.7
also moderately eroded	6.96	1.23	3.85	33.0
Agro-chernozem clay-illuvial typical	9.98	1.23	3.88	47.6
also moderately eroded	6.88	1.23	3.88	32.8
Agro-chernozem dispersed-carbonate	10.26	1.23	3.77	47.6
also moderately deflated	9.02	1.23	3.77	41.8
Average for non-eroded soils	10.11	1.23	3.83	47.6
Weighted average for non-eroded soils	-	-	-	47.6
Average for eroded and deflated soils	7.62	1.23	3.83	35.9
The Republic of Tuva				
Agro-chernozem dispersed-carbonate	8.28	1.00	2.55	21.1
also moderately deflated	7.29	1.00	2.55	18.6
Agro-chernozem texture-carbonate typical	7.94	1.00	2.55	20.3
also moderately deflated	6.98	1.00	2.55	17.8
also moderately stony	6.74	1.00	2.55	17.2
Average for non-eroded soils	8.11	1.00	2.55	20.7
Weighted average for non-eroded soils	-	-	-	20.6
Average for deflated soils	7.14	1.00	2.55	18.2
Irkutsk region				
Agro-chernozem clay-illuvial typical	9.12	1.03	3.68	34.6
also moderately eroded	6.29	1.03	3.68	23.8
Agro-chernozem dispersed-carbonate	10.35	1.03	3.48	37.1
also moderately deflated	9.11	1.03	3.48	32.7
Average for non-eroded soils	9.74	1.03	3.58	35.9
Weighted average for non-eroded soils	-	-	-	35.8
Average for eroded and deflated soils	7.70	1.03	3.58	28.4

In Irkutsk region, the greatest value has agro-chernozems dispersed-carbonate, clay-illuvial slightly inferior to it. As a result of the development of erosion and deflation SEI of these soils is reduced by more than 7 points.

Analysis of all available data suggests that the most fertile agro-chernozems are formed in the Altai and Krasnoyarsk Krai. For comparison, all the soil in Krasnodar region has SEI equal to 100 points. According to the study, Siberian agro-chernozems are inferior in fertility to Krasnodar ones more than by 2-5, and taking into account the development of erosion and deflation – by 3-6 times.

The soil index makes a great contribution to the resulting SEI. Depending on the type of soil, the presence or absence of erosion and deflation, stoniness the soil index varies in 1.2-1.9 times. The values of the agrochemical index are comparable, as the soils of the same genesis were estimated, similar in properties and characteristics of fertility. In most cases, the soil had a favorable medium response, the average and above the average provision of mobile forms of phosphorus and potassium.

Agro-chernozems of Krasnoyarsk Krai have maximum agrochemical index, characterized by a very high supply of nutrients. Climate index naturally decreases in the direction from west to east – from Omsk agro-chernozems to Irkutsk ones. This series does not include agro-chernozems of Tuva because of their orographic isolation and formation in the most severe, even for Siberia, climatic conditions.

Comparing the agro-chernozems of Omsk and Irkutsk regions, we can note their close final values of SEI. The final SEI of Omsk agro-chernozems is influenced by higher values of climate index, and SEI of the Irkutsk agro-chernozems is formed to a greater extent by soil index.

Thus, the SFD has a huge soil potential in the form of different types of chernozems. The most valuable agro-chernozems are formed in the Altai and Krasnoyarsk Krai. In these subjects, up to 50% of the area of all chernozems of the macro region is also concentrated. Siberian chernozems are inferior to European analogs infertility, have a number of provincial, often negative features. For the most rational use of these soils, it is necessary to study fully their properties and regimes, to develop for them at the species level the agrotechnical, agrochemical and soil protection measures aimed at obtaining economically optimal yields, at ensuring the implementation of the soil cover its global environmental functions.

4. CONCLUSION

The total area of SFD chernozems is more than 27 million hectares, among them, the types of dispersed-carbonate (42.4%) and clay-illuvial typical (33.1%) prevail. Chernozems clay-illuvialpodzol (7.9%) and texture-carbonate typical (14.7 %) are less spread.

A favorable hydrothermal regime is formed on the territory of the Altai Krai, where the sum of t > 10ºC is higher in relation to other subjects of the SFD (except for Omsk region) by an average of 230-467ºC, and moisture supply – by 30-50 mm. Chernozems of Irkutsk region, Krasnoyarsk Krai and the Republic of Tuva are formed in areas of insufficient moisture and lower average annual temperatures, so the value of the climate index decreases at moving from the Altai Krai and Omsk

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region to the Krasnoyarsk Krai, then Irkutsk region and the Republic of Tuva.

The mobile forms of phosphorus and potassium are only in the chernozems of the Krasnoyarsk Krai. The potassium content is sufficient in the chernozems of the Altai Krai and Omsk region. By the amount of phosphorus the chernozems of other subjects of the Siberian Federal district have average provision, which is below the optimum level recommended for grain and vegetable crops. The chernozems of the Krasnoyarsk Krai and Irkutsk region contain more humus. The reaction of the environment is favorable for most crops cultivated in the Siberian region, a small alkalinization is characteristic of the chernozems of the Republic of Tuva. In general, chernozems need to be improvedin the nutritional regime by applying phosphorus-potassium fertilizers. The value of the agrochemical index decreases in a number of Krasnoyarsk Krai–Altai Krai – Omsk region –Irkutsk region – the Republic of Tuva.

The value of the soil index decreases from the chernozems of the Krasnoyarsk Krai to the soils of Irkutsk region, Altai Krai, Omsk region and the Republic of Tuva. The score of the soil index is lower in the presence of salts, alkalinization in the soils, which is typical for the chernozems of Omsk region. Chernozems of the Republic of Tuva are more prone to erosion processes due to the predominant light particle size distribution, which significantly reduces their soil index score. The development of degradation processes in the form of salinization of soils, their alkalinization and carbonation is not typical for the Krasnoyarsk and Altai Krai, Irkutsk region, so they have a higher soil index score.

The weighted average of the SEI of agro-chernozems of the SFD change from 47.6 to 20.6 points and decreases in the row: Krasnoyarsk Krai – Altai Krai – Irkutsk region – Omsk region – the Republic of Tuva. Development of erosion and deflation in agro-chernozems lower the value of their SEI from 3 to 17 points in the average degree, and the presence of alkalinity – by 9-10 points.

The value of the final soil-ecological index is largely determined by the values of soil and climate indices. The values of the agrochemical index change insignificantly, due to the fact that the soils of the same genesis, similar in properties and characteristics of fertility were estimated.

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