Ecological functions of soils and criteria for their assessment

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Abstract. In modern soil ecology, there is a need to develop a unified approach to assessing the ecological functions of the soil cover. Analysis of publications on this topic shows that this question is open. There are many criteria for evaluation individual soil properties. However, there is no general approach to assessing the eco-functions of the soil. The purpose of the work is the development of universal criteria for evaluation the ecological functions of soils. In this paper, it is proposed to use 2 criteria for assessing the ecological functions of the soil cover. These criteria are based on the fixation of changes in properties and their favorableness to the ecosystem. The proposed criteria were used to evaluate 5 biogeocenotic soil functions. This assessment approach is acceptable for agricultural soils.

1. Introduction
The soil is a mirror of the landscape and the soil is the core of the ecosystem [1]. However, there are not practically natural landscapes untouched by human activity in the modern world. Even specially protected territories are experienced of anthropogenic impact to one degree or another. Territories with fertile soil cover have been developed by man on 80% of their areas, mainly for agriculture and including the areas with the difficult relief. Voronezh region of the Russian Federation is a typical representative of such areas. In settlements, there are not biocenoses that do not experience anthropogenic impact. Large-scale and many-sided human influence affects all components in biogeocenoses, including soils. In agrocenoses, such changes are the purposeful. Studies of soil properties in anthropogenically altered landscapes are contained in many domestic and foreign works. In these works, the dynamics of different soil fertility indicators are examined in conditions of intensive agricultural use [2-8]. Much attention is paid to research in various experimental sites with different doses of fertilizer application and soil treatment technology [9-13]. Unfortunately, not many authors used the data to assess changes in the ecological functions of soils in the created anthropocenoses [14-17].

The purpose of our work is the development of universal criteria for assessing the ecological functions of soils. The following biogeocenotic soil functions were selected for evaluation: 1) support function (mechanical support); 2) a source of nutrients and compounds; 3) a depot of moisture, batteries and energy; 4) a stimulant and inhibitor of a number of biochemical processes, 5) sanitary function [18].

2. Materials and methods
The soil profile has the following set of genetic horizons: Ap-A1-A1B-Bca-BCca-Cca. The thickness of the humus profile was about 80 cm. The morphological structure is characteristic of this chernozem subtype.
To study the ecological functions of soils we carry out two stationary field experiments. The first one was provided to for estimate the influence of different doses of fertilizers on sugar beet (year of establishment - 1936). Location: Russia, Voronezh region, Ramon district, Ramon, Russian research Institute of sugar beet and sugar named by A. L. Mazlumov. Soil is leached chernozem. The soil profile has the following set of genetic horizons: Ap-A1-A1B-Bca-BCca-Cca. The thickness of the humus profile was about 80 cm. The morphological structure is characteristic of this chernozem subtype. The variants of the experiment are: 1) control (without fertilizers); 2) N45P60K45+25 t/ha manure; 3) N90P120K90+25 t/ha manure; 4) N45P50K45+50 t/ha manure; 5) N190P190K190; 6) N135P180 K135+25 t/ha manure. The second experiment was aimed to understand the influence of land-use types (created in 1911-1925, and located in Russia, Voronezh region, Talovsky district, Research Institute named by V. V. Dokuchaev, Kamenno-Stepnoye rural settlement). Soil was ordinary chernozem. The soil profile had the following set of genetic horizons: Ap-A1ca-A1Bca-Bca-BCca-Cca. The thickness of the humus profile was about 70 cm. The morphological structure was characteristic of this chernozem subtype. The variants of experience were: 1) fallow (area not affected by anthropogenic activities); 2) hayfield; 3) arable land 10-25 years; 4) arable land 45-60 years; 5) arable land 75-90 years; and 6) forest belt. The studies were conducted in the period from 1999 to 2018. The work presents the average figures for this period of time.

Soil sampling was carried out in different periods of vegetation – spring (May), summer (July) and autumn (September-October). Soil drill was used for sampling. In each variant of experiment, the soil sampling was carried out from 5 different points to obtain a mixed sample. Sampling depth was 0-20 and 20-40 cm. In the field, samples were taken to determine the bulk density of the soil by the N.A. Kachynski method [19]. Preparation of samples for laboratory research included drying the soil samples naturally in a well-ventilated dark room to an air-dry state. Then, organic and mineral inclusions (roots, leaves, stones, etc.) were carefully selected from the samples manually using tweezers and a magnifier. Then, the samples were ground in chalcedony mortars and sieved through sieves with diameter of holes - 1 and 0.25 mm.

Laboratory studies of soil properties were carried out by the following methods. Gravimetric method was used for determination of hygroscopic moisture content. The method is based on the calculation of the differences in the weight in the sample of air-dry soil and in the weight in this sample after drying a constant weight at +105°C in a desiccator SM50/350–60SHS (Russia). Titrimetric method we used for determination the content of easily hydrolysable nitrogen by Cornfield. The method is based on hydrolysis of organic compounds in the soil with 1 M NaOH solution. The released ammonia is bound by a micro-diffusion method. We used titrimetric method for determination of carbon content by wet combustion. The method is based on the oxidation of soil organic matter with chromic acid to form carbon dioxide. The amount of oxygen consumed for the oxidation of organic carbon is determined by the difference between the amount of chromic acid taken for oxidation and the amount of it remaining unspent after oxidation. The 0.4 M K2Cr2O7 in sulfuric acid was used as an oxidant solution. Colorimetric helped us to determine the phosphorus content according by photoelectrocolorimeter KFK-2 (Russia). This method is based the extracting the available phosphate from the soil by 0.5 M acetic acid at a ratio of "soil-solution" = 1:25. Photometric determination was used for the measurement of exchangeable potassium in the soils by L. Maslova at flame photometer PFA 378 (Russia), where exchangeable potassium was extracted from soils by 1 M ammonium acetate [20].

The following indicators were determined to characterize the biological activity of the studied soils:

- ureasa activity determination estimated by colorimetric method by photocolorimetry,
- invertase activity determined by titrimetric method with the reduction of copper Felling liquid [21],
- phosphatase activity determined by colorimetric method by taking into account the amount of phenolphthalein,
- catalase activity determined by the gasometric method for accounting the amount of released molecular oxygen formed during the interaction of hydrogen peroxide with the soil [21].
We selected environmental soil functions according to their variability compared with fallow and control options (unchanged and changed) and the degree of satisfaction of the biocenosis components with this function (satisfactory and unsatisfactory). The degree of variability on base of many criteria was determined for individual properties. The degree of satisfaction was analyzed on the state of other components of the ecosystems under consideration. Statistical processing of the results was carried out with using the program STATISTICA.

3. Results and discussion

Different plants have different requirements for soil density. These demands are due to the biological characteristics of the culture. In natural ecosystems, bulk density, as consequence, soil support function is optimal. In agrocenoses, the equilibrium density rarely corresponds to the optimum. This affects on the environmental function.

Changes in the bulk density of leached chernozem with long-term use of fertilizers are shown in table 1. The optimal soil bulk density is 1.0-1.2 g/cm³ for sugar beet growth. Increasing or decreasing in this parameter may to cause a decline in the productivity of sugar beet.

| Variant            | Depth, cm | Bulk density, g/cm³ | Deviation from optimum |
|--------------------|-----------|---------------------|------------------------|
| Control            | 0-20      | 1.06                | -                      |
|                     | 20-40     | 1.11                | -                      |
| N₄₅P₆₀ K₄₅+25 t/ha| 0-20      | 1.13                | -                      |
| manure             | 20-40     | 1.14                | -                      |
| N₉₀ P₁₂₀ K₉₀+25 t/ha| 0-20   | 1.10                | -                      |
| manure             | 20-40     | 1.17                | -                      |
| N₄₅P₆₀K₄₅+50 t/ha | 0-20      | 0.95                | -0.05                  |
| manure             | 20-40     | 0.98                | -0.02                  |
| N₁₉₀ P₁₉₀ K₁₉₀    | 0-20      | 1.14                | -                      |
|                    | 20-40     | 1.20                | -                      |

The studied soil initially has an optimal addition density for growing sugar beets. Insignificant deviations are observed in the variant with the fertilizing dose N₄₅P₆₀K₄₅+50 t/ha manure to the direction of the density reduction. Thus, the basic function of leached chernozem is practically not disturbed. There is satisfactory for sugar beet.

The presence of nutrients, especially nitrogen, potassium, and phosphorus in an accessible form for plants, especially nitrogen, potassium, and phosphorus, is important characteristic of soil fertility. In biogeocenoses, a balance between nutrients and vegetation is evolutionarily created. In agrolandscapes, this balance is disturbed. Therefore, mineral and organic fertilizers are introduced to improve the function of soils as a source of nutrients and compounds. There are criteria for assessing the availability of plant nutrients. The presented data are taken from agrochemical reference materials. For each crop, this criteria varies in the different regions. In our work, we uses the classification scheme for sugar beets in the chernozem zone (table 2).

| Level of provision | Easily hydrolysable N | K₂O | P₂O₅ |
|--------------------|-----------------------|-----|------|
| Very low           | < 30                  | < 5.5 | < 2   |
| Low                | 30-60                 | 5.5-10 | 2.1-5 |
| Medium             | 60-90                 | 10-15 | 5.1-10 |
| Increased          | 60-90                 | 15-20 | 10.1-15 |
| High               | > 90                  | 20-30 | 15.1-20 |
| Very high          | >30                   | >30  | >20   |
Tables 3 and 4 present data on the content of nutrients in ordinary and leached chernozems. Fertilization improves the function of the "soil as a source of nutrients and compounds" in the experiment, but not enough. Potassium content is low and medium (table 3). The maximum content of exchange potassium in the arable layer is observed in the variants with increased introduction of potash fertilizers (not less than 90 kg/ha). Moreover, this indicator varies quite a lot in the range of 10.6 - 14.0 mg/100 g of soil. A low potassium content (less than 10 mg/100 g of soil) is characteristic of the control variant and the subsurface layer. The need for potassium in sugar beets is much stronger than in other cultivated plants, for example, cereals. Therefore, the potassium content is the main limiting factor in beet yield on chernozems. This should be noted when this crop is grown. The studied chernozems are characterized by a high level of nitrogen content. On leached chernozem, there is a clear tendency to rise of this indicator with increasing doses of nitrogen fertilizers and manure (from 148 mg/kg to 220 mg/kg of soil). Similar trends are observed for mobile phosphorus. However, for sugar beet, the content of nitrogen and phosphorus with constant fertilizing is not a priority limiting factor. It has little effect on the ecological function in this case. The function of leached chernozem as a source of nutrients and compounds is impaired and is not satisfactory for sugar beet.

**Table 3. The content of nutrients in the leached chernozem.**

| Variant                  | Depth, cm | N mg/kg of soil | Level of provision | P2O5 mg/100 g of soil | Level of provision | K2O, mg/100 g of soil | Level of provision |
|--------------------------|-----------|-----------------|--------------------|-----------------------|--------------------|----------------------|--------------------|
| Control                  | 0-20      | 148             | High               | 7.5                   | Medium             | 8.3                  | Low                |
|                          | 20-40     | 141             | High               | 6.9                   | Medium             | 6.9                  | Low                |
| N45P60 K45+25 t/ha manure| 0-20      | 167             | High               | 9.9                   | Medium             | 9.8                  | Low                |
|                          | 20-40     | 153             | High               | 9.5                   | Medium             | 8.3                  | Low                |
| N90 P120 K90+25 t/ha manure | 0-20  | 196             | High               | 13.2                  | Increased           | 10.6                | Medium             |
|                          | 20-40     | 162             | High               | 12.1                  | Increased           | 9.8                  | Low                |
| N135P180 K135+25 t/ha manure | 0-20  | 220             | High               | 14.4                  | Increased           | 14.0                | Medium             |
|                          | 20-40     | -               | High               | 11.6                  | Increased           | 11.0                | Medium             |
| N45P60 K45+50 t/ha manure | 0-20        | -               | High               | 11.5                  | Increased           | 10.6                | Medium             |
|                          | 20-40     | 188             | High               | 10.5                  | Increased           | 9.1                  | Low                |
| N190 P190 K190           | 0-20      | 200             | High               | 15.8                  | High                | 10.8                | Medium             |
|                          | 20-40     | 175             | High               | 12.4                  | Increased           | 9.4                  | Low                |

Long-term use of ordinary chernozem (more than 45 years) as arable land for growing crops has a positive effect on the content of available potassium and phosphorus. The content of easily hydrolysable nitrogen in agricultural use is reduced, as well as in the soil under the forest belt. However, the level of nitrogen content remains high. The nutritional function of ordinary chernozem, used as hayfields and arable land, is slightly changed. It can be characterized as satisfactory (table 4).

We will evaluate the soil function of the "depot of moisture, nutrients and energy" by the content of humus. The studied leached chernozem classified as low-humus. Higher humus content is noted compared with the control (by 9.1%) in variants with the combined introduction of increased doses of mineral and organic fertilizers. A slight decrease in the humus content of soils is noted on the variants without the use of organic fertilizers and with the minimum introduction of minerals fertilizers. Common chernozems are characterized by the average humus content for this type of soil. At the same time, there is a negative dynamics in the humus content depending on land use. The maximum drop in this indicator is typical for arable land with an age of 75-90 years and is 25.3% compared with the control. At a younger arable land, the magnitude of the fall is markedly reduced (table 5-6).
Table 4. The content of nutrients in the ordinary chernozem.

| Variant           | Depth, cm | N mg/kg of soil | Level of provision | P2O5 mg/100 g of soil | Level of provision | K2O mg/100 g of soil | Level of provision |
|-------------------|-----------|-----------------|--------------------|-----------------------|--------------------|----------------------|--------------------|
| Fallow land       | 0-20      | 217             | High               | 4.9                   | Low                | 19.7                 | Increased          |
|                   | 20-40     | 179             | High               | 6.2                   | Medium             | 12.3                 | Medium             |
| Hayfield          | 0-20      | 210             | High               | 5.2                   | Medium             | 12.7                 | Medium             |
|                   | 20-40     | 182             | High               | 5.8                   | Medium             | 10.1                 | Medium             |
| Arable land 10-25 years | 20-40    | 162             | High               | 8.0                   | Medium             | 21.6                 | High               |
| Arable land 45-60 years | 20-40    | 154             | High               | 20.5                  | Very high          | 21.2                 | High               |
|                   | 20-40     | 141             | High               | 19.1                  | High               | 23.5                 | High               |
| Arable land 75-90 years | 20-40    | 136             | High               | 21.1                  | Very high          | 14.8                 | Medium             |
| Forest belt       | 0-20      | 199             | High               | -                     | -                  | -                    | -                  |
|                   | 20-40     | 188             | High               | -                     | -                  | -                    | -                  |

Table 5. The humus content in leached chernozem (in the layer 0-40 cm).

| Variant | Humus content, % | The change of humus content compared to control, % | Classification name for humus content |
|---------|------------------|---------------------------------------------------|--------------------------------------|
| Control | 5.0              | -                                                 | Low humus                            |
| N45P60K45+25 t/ha manure | 4.9 | -1                                               | Low humus                            |
| N80P120K80+25 t/ha manure | 5.4 | +9.1                                             | Low humus                            |
| N135P180K135+25 t/ha manure | 5.4 | +9.1                                             | Low humus                            |
| N45P60K45+50 t/ha manure | 5.2 | +5.1                                             | Low humus                            |
| N190P190K190            | 5.0 | 0                                                | Low humus                            |

Table 6. The humus content in ordinary chernozem (in the layer 0-40 cm).

| Variant | Humus content, % | The change of humus content compared to control, % | Classification name for humus content |
|---------|------------------|---------------------------------------------------|--------------------------------------|
| Fallow land | 7.9              | -                                                  | Medium humus                         |
| Hayfield | 7.7              | -2.4                                              | Medium humus                         |
| Arable land 10-25 yr | 6.5 | -17.7                                             | Medium humus                         |
| Arable land 45-60 yr | 6.5 | -17.7                                             | Medium humus                         |
| Arable land 75-90 yr | 5.9 | -25.3                                             | Low humus                            |
| Forest belt | 6.4              | -19                                               | Medium humus                         |

The function of the leached chernozem as “depot of moisture, nutrients and energy” can be estimated as slightly changed and satisfactory, but for ordinary chernozem as strongly changed and unsatisfactory. Despite a different assessment, special attention should be paid to this environmental function, since the
humus content in leached chernozem is low, and in ordinary during agricultural use it is reduced. This can to cause interruptions in the supply of plants and microorganisms with nutrients when depleted available forms of nitrogen, phosphorus and potassium.

Studying the enzymatic activity of soils will allow us to evaluate the function of “stimulant and inhibitor of a number of biochemical processes”. Tables 7 and 8 show the enzymatic activity of the soils of the experimental plots. The application different doses of fertilizers stimulated the urease activity of leached chernozem, while invertase, phosphatase and catalase activities are inhibited. The use of ordinary chernozem as arable land inhibited its enzymatic activity.

Thus, the ecological function of the stimulant and inhibitor of biochemical processes in leached chernozem and ordinary chernozem in the experiments under consideration has been changed and follows the path of inhibition.

**Table 7.** Enzymatic activity in leached chernozem.

| Variant                | Depth, cm | Urease, mg NH₃ for 24 h on 1 g of soil | Invertase, mg glucose for 24 h on 1 g of soil | Phosphatase, mg phenolptaleine for 1 h on 1 g of soil | Catalase, ml O₂ for 1 min on 1 g of soil |
|------------------------|-----------|----------------------------------------|-----------------------------------------------|--------------------------------------------------|----------------------------------------|
| Fallow land            | 0-20      | 0.55                                   | 39.5                                          | 0.27                                             | 8.1                                    |
|                        | 20-40     | 0.41                                   | 28.0                                          | 0.15                                             | 5.8                                    |
| Control                | 0-20      | 0.73                                   | 20.7                                          | 0.15                                             | 7.2                                    |
|                        | 20-40     | 0.72                                   | 19.5                                          | 0.13                                             | 7.2                                    |
| N₄₅P₆₀ K₄₅+25 t/ha manure | 0-20   | 0.74                                   | 20.6                                          | 0.15                                             | 7.3                                    |
|                        | 20-40     | 0.70                                   | 18.5                                          | 0.15                                             | 6.5                                    |
| N₉₀P₁₂₀ K₉₀+25 t/ha manure | 0-20   | 0.77                                   | 23.5                                          | 0.18                                             | 6.3                                    |
|                        | 20-40     | 0.80                                   | 22.2                                          | 0.17                                             | 7.0                                    |
| N₃₅P₇₅ K₁₃₅ +25 t/ha manure | 0-20   | 0.62                                   | 21.3                                          | 0.17                                             | 6.3                                    |
|                        | 20-40     | 0.55                                   | 19.4                                          | 0.17                                             | 5.9                                    |
| N₄₅P₆₀ K₄₅+50 t/ha manure | 0-20   | 0.87                                   | 22.3                                          | 0.20                                             | 7.1                                    |
|                        | 20-40     | 0.83                                   | 20.7                                          | 0.18                                             | 6.6                                    |
| N₁₉₀ P₁₉₀ K₁₉₀           | 0-20      | 0.65                                   | 21.3                                          | 0.13                                             | 6.6                                    |
|                        | 20-40     | 0.58                                   | 18.6                                          | 0.13                                             | 7.3                                    |

**Table 8.** Enzymatic activity in ordinary chernozem in layer 0-40 cm.

| Variant                  | Urease, mg NH₃ for 24 h on 1 g of soil | Invertase, mg glucose for 24 h on 1 g of soil | Phosphatase, mg phenolptaleine for 1 h on 1 g of soil | Catalase, ml O₂ for 1 min on 1 g of soil |
|--------------------------|----------------------------------------|-----------------------------------------------|--------------------------------------------------|----------------------------------------|
| Fallow land              | 1.23                                   | 25.9                                          | 8.9                                              | 7.1                                    |
| Hayfield                 | 1.23                                   | 25.9                                          | 7.5                                              | 9.1                                    |
| Arable land 10-25 yr     | 0.62                                   | 23.5                                          | 6.2                                              | 4.4                                    |
| Arable land 45-60 yr     | 0.37                                   | 16.8                                          | 5.7                                              | 3.8                                    |
| Arable land 75-90 yr     | 0.32                                   | 16.6                                          | 5.0                                              | 1.9                                    |

One of the aspects of the sanitary function of soils is the destruction by soil microorganisms and enzymes of toxic metabolic products in the root layer, which is an important condition for the normal existence of soil organisms. The catalase activity of soils is important indicator of the functional activity of microflora in different environmental conditions. Catalase belongs to the class of redox enzymes.
Under the influence of this enzyme, hydrogen peroxide decomposes into water and molecular oxygen. The use of chernozems in agriculture leads to a decrease in catalase activity of soils.

Plowing of chernozem causes significant changes in this indicator. The longer the anthropogenic impact occurs, the more significant the decrease. The introduction of fertilizers eliminates this negative trend and in the experiment on leached chernozem, the differences in catalase activity by options are insignificant.

The dependence of catalase activity on land use types on ordinary chernozem, the maximum values of this indicator are observed on a fallow plot and hayfields. A sharp decrease in catalase activity to minimum values is typical for arable land (3-4 times in comparison with the fallow). Moreover, depending on the age of arable land, the decrease in the activity of this enzyme reaches 2 times the level. The negative effect of intensive farming on the enzymatic activity of soils was noted in the works of many authors. Long-term use of soils in agriculture reduces their biological activity. Our results also affect this trend [2,3,10].

4. Conclusion
In connection with the increasing anthropogenic pressure on the environment, the urgent question is the creation of the environmental assessment system for the functional quality of soils. In this work, we assessed the biogeocenotic ecological functions of soils according to two criteria: their variation in comparison with fallow and control variants (unmodified and modified) and degree of satisfaction for biocenosis components with this function (satisfactory and unsatisfactory).

For agrocenoses this approach to assessment is acceptable, but we are faced with the need to differentiate the degree of variability. This may not be enough for ecosystems experiencing other types of human impact, this may not be enough. There are required the development of new approaches and criteria for assessing the ecological functions of soils. The set of analyzed functions can also significantly change, when specific assessment problems are solving.

The supporting function (mechanical support) of leached chernozem is practically unchanged and is satisfactory for sugar beet. The function of the source of nutrients and compounds of leached chernozem is impaired and not satisfactory for sugar beets, and in ordinary chernozem used as haymaking and arable land is slightly change and satisfactory. The function of the depot of moisture, nutrients and energy can be estimated for leached chernozem as changed (slightly) and satisfactory, and for ordinary chernozem - strongly changed and unsatisfactory. The ecological function of the stimulant and inhibitor of a number of biochemical processes of leached and ordinary chernozem has been changed and follows the path of inhibition. This function can be considered as unsatisfactory. The sanitary function of leached chernozem is changed (slightly) and satisfactory and ordinary chernozem is strongly changed and unsatisfactory.

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