Agro-ecological basis of conservation and reproduction of fertility of agricultural soils in arid territories of Altai

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Abstract. It is established that the set of climatic conditions and low erosion resistance of arable soils caused by anthropogenic effects is considered as fundamental factors determining agro-ecological tension. In order to develop an agro-ecological strategy that allows to stabilize the fertility of agricultural soils and thereby increase productivity, it is necessary to adjust the anthropogenic factor taking into account the current agro-ecological situation, which was assessed with the levels of agro-ecological state, which are based on agro-ecological indicators. They are, in turn, a tool determining the agro-ecological tension of fertility parameters. Each level of agro-ecological state has developed modes of use that take into account not only anthropogenic load, but also the potential of the land user. The level of agro-ecological state “Norm” can be used in any crop rotation with the recommended conventional agricultural technique. The levels of agro-ecological state “Risk” and “Crisis” require a sparing farming system such as no-till.

1. Introduction
At the present stage of agricultural soil science development, ecology is considered as a tool that allows assessing the intensity of degradation and the soil formation process in general. The soils of arid territories are poor in their potential, and therefore require more prudent, scientifically valid decisions on its conservation and reproduction when used. Agro-ecological tools, on the basis of which soil fertility can be managed, are individual for each territory of the soil-climatic zone and a specific field in particular. In the general scheme, agro-ecological indicators determine fertility; they can be divided into abiotic, biotic, and anthropogenic. Abiotic factors are an evaluation criterion of agro-ecological deviation in the soil formation process, which are influenced by anthropogenic and biotic factors. The conservation and reproduction of the fertility of agricultural soils have always been and remain an urgent problem of the farmer.

The research objective was to create an agro-ecological basis for conservation and reproduction of the fertility of agricultural soils in the arid territories of Altai.

2. Method of research
Digital, GIS technologies such as Exact Farming, One Soil, Cropio, MapInfo were used to create an agro-ecological basis for conservation and reproduction of the fertility of agricultural soils in the arid territories of Altai, and cameral, field, and laboratory studies were conducted. The object of the study was chestnut agricultural soils located in the zone of dry steppe in Altai, the fertility of which is...
undergoing changes. This determines the search for new methodological approaches that make it possible to assess the development of the agro-ecological situation of degradation processes. Agro-ecological tension of arable soil fertility was assessed by edaphic factors, such as humus content, humus horizon power, environment response, structural and aggregate composition, sodium content, silt fraction, colloidal particles, etc., using archive materials of OAO “AltaiNIIGiprozem” and the results of own research [1]. To assess orographic factors, the QGIS was used [2], climatic factors were assessed from archival materials [1], weather conditions were fixed by a professional weather station Sokol-M, designed for automatic measurements of meteorological parameters. As a basis for the estimation of changes in biotic factors under anthropogenic load, the materials of FSBI GSAS “Kulundinskaya” of different rounds of the survey were used. Microbiological indicators, such as the number of phytopathogens, phytophagans, weed plants, suppression activity, phytotoxicity, the presence of ammonifying bacteria, etc., allow estimating the agro-ecological tension of agricultural soils [3]. As a result, these indicators change in agricultural soils with different intense load, which allows attributing the flow of these processes to different levels of agro-ecological state and develop different modes of use. It is generally recognized that anthropogenic factors often determine the agro-ecological tension of the fertility of agricultural soils to a greater extent, these include elements of the farming system, given that each specific field requires its own system of agriculture predetermining the end result: the productivity of cultivated crops. The no-till farming system is today’s reality, which is a powerful tool for conservation and reproduction of fertility in arid territories, although it is not without its shortcomings.

3. Results and discussion

Agro-ecology of conservation and reproduction of fertility provides for the identification of the negative anthropogenic influence that causes a deviation from the natural soil formation process, followed by the development of the degradation phenomenon and, as a result, the reduction of effective fertility. In the first stages, this is the unseen damage to agricultural production, which is due to the intensity of these environmental violations and becomes global over time. In the general scheme, the agro-ecological basis of conservation and reproduction of fertility in arid territories, although it is not without its shortcomings.

The set of abiotic factors determining the agro-ecological state can be presented as a function of the following indicators: $Ab = f(Sf, O, Cl, Ed)$, where $Sf$ – soil-forming rocks; $O$ – orographic factors; $Cl$ – climatic factors; $Ed$ – edaphic factors. In turn, soil-forming rocks have their own historical basis for arid territories, which does not have significant influence on the development of negative processes in the agro-ecological aspect. Orogenic factors characterized by relatively small changes in the arid territories of Altai are more important in the agro-ecological assessment. However, the set of irregularities at small intervals leads to significant changes in the microclimate, the nature of ground and surface waters, the level of their mineralization, the soil formation process and, as a consequence, requires its own approach. The set of orographic indicators was constructed in the following functional series: $O = f(Al, Sg, Se, Sl, Sp)$, where $Al$ – altitude; $Sg$ – the slope gradient; $Se$ – the slope exposure; $Sl$ – the slope length; $Sp$ – part of the slope. The climate of the dry steppe of Altai is extreme continental, and the sum of active temperatures up to $2400 \, ^{\circ}C$, with the annual precipitation of $240–300 \, mm$, with more than $70\%$ occurring in the growing season. The hydrothermal coefficient is in the interval of $0.6–0.9$, which indicates the predominance of moisture evaporation over its income. For the agro-ecological assessment of fertility, the characteristics of climatic conditions ($Cl$) were used, such as: $HTI$ – Selyaninov hydrothermal index, $RRR$ – precipitation, $t^*$ – temperature, $U$ – relative humidity, $VV$ – horizontal range of visibility, $FF$ – wind speed, $sss$ – snow cover depth. Functionally, this can be reflected in the following series: $Cl = f(HTI, RRR, t^*, U, VV, FF, sss)$.

Edaphic factors characterize soil conditions, which in the agro-ecological aspect should be considered as taxonomic, morphological, physical, chemical, water-physical, thermophysical, and microbiological. Taxonomic factors are fundamental and most significant, including soil types (T),

2
subtypes (St), generic (G), specific (S) features, and varieties (Vr). The structure of the soil cover of the arid territory of Altai is dominated by the type of chestnut soils, dark chestnut and chestnut subtypes, they account for 42% of the territory, 14% are occupied by the subtypes of light chestnut and light chestnut with a generic sign of alkalinity. Solonetz and solonchaks are found, which occupy 11% of the territory; they tend to be located on lower relief features adjacent to drainless lakes with high salt mineralization. In the dry steppe, such generic signs as the degree of deflation (\( \phi \)), flushing (\( \phi' \)), salinization (sch), solonization (sn) are relevant. Morphological signs are the humus horizon power (MA+AB), coloration of the humus horizon (Ch), neoformations and inclusions (Nin). Chemical properties of agricultural soils include: gross forms of nitrogen (NG), phosphorus (PG), potassium (KG), humus content (C), cation exchange capacity (CEC), absorbed calcium (Ca\(^{2+}\)), magnesium (Mg\(^{2+}\)), potassium (K\(^{+}\)), sodium (Na\(^{+}\)), soil base saturation level (V), pH, soil salt content (Sc). To characterize the physical properties of agricultural soils (PP), the values of the granulometric composition (Gr), soil density (d), solid phase density (SPd), porosity (Pr), structural-aggregate composition (SA) were used. Water-physical properties (WP) include humidity (H), productive moisture reserve (PM), water permeability (WPM), imbibition (IM), filtration (F), water-raising capacity (WRC). The group of thermophysical properties includes soil temperature (st), thermal capacity (TC), thermal conductivity (TC). It is generally known that the agro-ecological basis of fertility depends not only on the listed properties of soils, but also on the soil microflora, its microbiological indicators (Mb), the presence of pathogens. In our studies, the assessment of microbiological activity was carried out in fresh samples based on indicators of microbiological activity of soils. Microorganisms using organic forms of nitrogen were identified by colony counting on the dense nutritional environment of beef-extract agar (BEA); microorganisms (including actinomycetes) capable of using mineral forms of nitrogen were studied on starch-and-ammonia agar (SAA). The organic matter mineralization coefficient in the soil was determined by the ratio of the number of microorganisms that grew on SAA to the number of microorganisms that grew on BEA (SAA/BEA). An important microbiological indicator is considered to be azotobacter (Ab), it is a genus of bacteria living in the soil and able to transform gaseous nitrogen into a soluble form available for assimilation by plants as a result of the nitrogen fixation process. In addition to microbiological activity, the mushroom microflora on the Czapek's medium (MMF), suppressiveness (self-cleaning capacity) of the soil (Sup), the number of phytopathogens (Np) were determined.

The listed characteristics of agricultural soils can be contradictory in their importance in the agro-ecological assessment of fertility, some create favorable conditions for others and vice versa [4]. For example, heavy granulometric composition will predetermine the development of anaerobic processes, sabulous varieties lead to the development of aerobic ones. Classification schemes of these indicators are quite complex, so the development of an agro-ecological basis for the conservation and reproduction of fertility of agricultural soils requires a modeling tool that takes into account a set of factors in full, which allow to distinguish such levels of agro-ecological state as “Norm”, “Risk 1”, “Risk 2”, “Crisis”, “Disaster” [5]. The proposed scheme of agro-ecological assessment in other territories of Altai was tested. In the modern agro-ecological aspect, agricultural soils should be considered as a single natural system consisting of soil individuals, and these, in turn, characterize the soil cover of the dry steppe territory of Altai or a particular land user. It goes without saying that the land user uses the field entirely, regardless of how heterogeneous it is; in this case, the critical state of heterogeneity of the agro-ecological deviation should be taken from the natural soil formation process as a basis. Indicators of desertification in arid, sub-arid and sub-humid territories have been proposed in international practice by such organizations as FAO and UNEP [6]. As indicators characterizing the desertification process, the combination of changes in vegetation and soil cover, air pollution, water mineralization, etc. was considered. For agro-ecological assessment of agricultural soil fertility agro-ecological indicators of fertility parameters have been developed, that allow characterizing the degree and intensity of degradation of elementary soil areals or local territories of soil cover, whose values are shown in table 1. In agroecology, the term indicator is used to establish the boundaries of the phenomenon behavior under consideration [7]. In the agro-ecological assessment of fertility, the indicator was used as an
interval characterizing the changes in the considered fertility parameter, which causes the development of degradation processes to a certain level. The set of deviations of the considered properties of agricultural soils from the natural soil-formation process, which cause changes in elementary soil areas, can be combined and attributed to the level of agro-ecological state characterizing the soil formation process development under anthropogenic load.

Typical belonging of a soil individual is the basis. According to the Unified State Register of Soil Resources of Russia, under arid conditions, chestnut soils make up the basis [8]. Taking into account that at each level of agro-ecological state there may be a particular type or subtype with different intensity of development of degradation processes due to the anthropogenic factor load and concomitant natural conditions, agricultural soils can be referred to the “Norm” level if they are not subject to such degradation processes as deflation, salinization, solonization. The level of agro-ecological state “Risk” is characterized by agricultural soils with a weak degree of deflation processes, salinization, and solonization. Soils of medium and severe degradation degrees are assigned to the “Crisis” level. Typical and subtypical signs of agricultural soils characterize the general state of fertility. Properties such as humus horizon power, humus content, pH, etc. display a private case. Proceeding from this, agro-ecological indicators of fertility parameters allow to study the mechanism of the soil formation process management, the modes of effective use of a particular field. To establish the relative deviations of the indicators, the time segments of past survey years and the results of our own studies were used. This allowed to set the interval of changes in the properties of agricultural soils.

**Table 1. Agro-ecological indicators of fertility of agricultural soils.**

| Soil type                      | Agro-ecological indicators of fertility | C³, C², C¹, Cl | Agro-ecological indicators of fertility | C³, C², C¹, Cl | Agro-ecological indicators of fertility | C³, C², C¹, Cl | Agro-ecological indicators of fertility | C³, C², C¹, Cl | SN, SCH |
|-------------------------------|----------------------------------------|----------------|----------------------------------------|----------------|----------------------------------------|----------------|----------------------------------------|----------------|--------|
| humus horizon power, cm       | ≤3                                     | 3–10           | ≤25                                    | 26–50          | >50                                    |
|                              | >30                                    | 20–30          | 20–30                                  | <              |                                        |
| humus content, %              | ≤3                                     | 3–10           | 11–20                                  | 21–40          | >40                                    |
|                              | >4                                     | 3–4            | 2–3                                    | <2             |                                        |
| phys. clay, %                 | ≤6                                     | 6–15           | 16–22                                  | 22–28          | >28                                    |
|                              | 30–45                                  | 20–30          | 60–75                                  | 10–20          |                                        |
| silt fraction, %              | ≤4                                     | 4–10           | 11–20                                  | 21–40          | >40                                    |
|                              | 15–13                                  | 15–12          | 10–12                                  | <10            |                                        |
| pH                            | ≤3                                     | 3–10           | 11–15                                  | 16–20          | >20                                    |
|                              | >6                                     | 5.5–6          | 5.5–6                                  | ≤5.5           |                                        |
| total biogenesity, mln CFU    | ≤3                                     | 3–10           | 11–15                                  | 16–20          | >20                                    |
|                              | >18                                    | 12–18          | 12–18                                  | <12            |                                        |
| azotobacter, %                | ≤3                                     | 3–10           | 11–15                                  | 16–20          | >20                                    |
|                              | >20                                    | 10–20          | 10–20                                  | <10            |                                        |
| crop yield, t/ha              | ≤3                                     | 3–10           | 11–15                                  | 16–20          | >20                                    |
|                              | >20                                    | 10–20          | 10–20                                  | <10            |                                        |
| levels of agro-ecological state | Norm                                  | Risk 1         | Risk 2                                  | Crisis         | Disaster                               |

*In the numerator – % of deviation from the initial; in the denominator – intervals of fertility parameters.

If the fertility parameters deviate from the natural soil formation process, which should proceed upwards according to the general canons, then the deviation of 3–4% in one direction or another should not be considered as the degradation process and attributed to the agro-ecological state “Norm”. Deviations from 3–4% to 25% should be considered significant and attributed to the “Risk” level. Since the intensity of changes in different fertility parameters is due to a combination of anthropogenic load, some may change and others remain unchanged, it is advisable to highlight two sub-levels “Risk 1” and “Risk 2” inside the level of agro-ecological state “Risk”. The level of agro-ecological state “Crisis” includes the intervals of change from 16 to 50%, this means that the degradation process of this level of agro-ecological state is significantly large; in case of taking no action, effective fertility will not be restored. The presented scheme of agro-ecological indicators allows considering only a part of the parameters, some of them can no longer be affected, and the effective part of fertility can be maintained.
only through increasing material costs. The microbiological component of the agro-ecological assessment, which was considered as an indicator, draws attention. Microbiological activity is determined not only by a set of indicators under consideration, but also by weather conditions, fertilizers used, culture, variety, etc. It is encouraging that in modern conditions, the microbiological activity of agricultural soils can be regulated by biological products. Certainly, in chestnut soils, biogenesity is very low, which in most cases is due to climatic and anthropogenic factors, such as the farming system. Each level of agro-ecological state needs modes of use that take into account not only the anthropogenic load, but also the potential of the land user. Based on this postulate, a sparing farming system such as no-till is necessary for “Risk” and “Crisis”, as shown in figure 1.

![Figure 1. Anthropogenic factor as a tool for managing agro-ecological indicators of fertility.](image1)

The organization of the territory on an agro-ecological basis requires a modern approach based on geoinformational systems that allow to clearly perceive the agro-ecological situation, make decisions about their suspension and thereby restore effective fertility. The restoration of effective fertility requires the developed regimes for the use of each level of agro-ecological state, as shown in figure 2.

![Figure 2. Organization of the territory of the agricultural production cooperative “Grigoryevka” on an agro-ecological basis.](image2)
1. Levels of agro-ecological condition according to major soil types
2. Levels of agro-ecological condition according to the granulometric composition
3. Levels of agro-ecological condition of the pH
4. Levels of agro-ecological condition of the humus content.
The basis for the development of degradation processes is the anthropogenic load. Modern farming systems allow it to be leveled. The most effective system for this area is the no-till farming system. By implementing no-till, the boundaries of the level of the agro-ecological state “Norm” were expanded.

4. Conclusion
On the basis of abiotic, biotic, and anthropogenic factors, changes in the fertility of agricultural soils have been established, which allowed to develop the levels of agro-ecological state. Our methodology of agro-ecological assessment of the territory was tested, built with the presence of a large actual material reflecting the most important agro-ecological features of agricultural soils. This made it possible to assess the agro-ecological situation and develop measures to preserve and reproduce fertility. The level of agro-ecological state “Norm” can be used without restrictions; at the same time, it is believed that in crop rotation, the steam field should be as an exception, as it is the cause of the intensive development of deflationary processes. At the allocated level of agro-ecological state “Risk”, it is enough to apply the no-till farming system, which will make it possible to suspend the degradation processes due to the constant presence of “covering material” in the form of stubble. The “Crisis” requires the mandatory introduction of cover crops into the no-till farming system, which will be a vegetative “covering material”, which will prevent deflation processes, improve humification processes and create positive changes in the microbiological and phytosanitary background of agricultural soils. For all levels of agro-ecological state, it is recommended to use binary (poly-species) crops. This will increase the productivity of the farm ecosystem, create favourable conditions for the development of the microbiological component of the soil, improve its phytosanitary state, and increase its suppressiveness [9].

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References
[1] Kudrjavzev A E, Guggenberger G, Illiger P, Stetsov G Ya and Yurov V V 2020 Ecological aspects of soil fertility evolution during intensive use of soil resources in arid ecosystems Agrokhim. Vestn. 1 14–24 (in Russian)
[2] Projects QGIS Desktop
[3] Ivanova E A, Pershina E V, Andronov E E, Kutoyaya O V, Tkhakakhova A K, Chernov T I, Markina L G and Kogut B M 2015 The structure of microbial community in aggregates of a typical chernozem aggregates under contrasting variants of its agricultural use Eurasian Soil Sci. 11 1242–56
[4] Molchanov E N, Savin I Y, Bulgakov D S, Yakovlev A S and Makarov O A 2015 National approaches to evaluation of the degree of soil degradation Eurasian Soil Sci. 11 1268–77
[5] Kudryavtsev A, Stetsov G and Toropova E 2019 Agroecological substantiation of the sustainable development of arable soil fertility of the Altai dry steppe IOP Conf. Series: Earth Env. Sci. 012016
[6] Zonn I S, Kust G S and Andreeva O V 2017 Desertification paradigm: 40 years of development and global efforts Arid Ecosystems 3(72) 3–16 (in Russian)
[7] Laverov N P (ed. board) Ecological encyclopedia (Moscow: Encyclopedia)
[8] Gerasimova M I 2019 Russian soil classification system: towards the next approximation Eurasian Soil Sci. 52(1) 25–33
[9] Toropova E Yu, Sokolov M S and Glinushkin A P 2016 Induction of soil suppressiveness – the most important factor of limiting the severity of root infections Agrochem. 8 46–55 (in Russian)