Agroecological substantiation of the sustainable development of arable soil fertility of the Altai dry steppe

A Kudryavcev¹, G Stetsov² and E Toropova³

¹ Altai State Agrarian University, 98 Krasnoarmeysky avenue, Barnaul 656049 Russia
² Altai State University, 61 Lenin avenue, Barnaul 656099 Russia
³ Novosibirsk State Agrarian University, 160 Dobrolyubova str., Novosibirsk 630039 Russia

E-mail: kae5959@mail.ru

Abstract. The soil resources of the Altai dry steppe (and their fertility in particular) degrade in their evolutionary anthropogenic development. Transformation of fertility is occurring due to a combination of phenomena, such as natural conditions, intensive use, farming system practiced in the absence of science-based regimes. It is established that the humus content and humus horizon thickness are statistically significantly reduced due to the activation of deflation and dehumification processes. More than that, areas of alkaline soils are increasing. The authors also point out to the degrading granulometric composition. Also, the amount of physical clay, silt fractions, cation exchange capacity, exchangeable calcium, potassium, and mobile phosphorus decreases. Statistical processing of fertility parameters of allowed us to develop a scale of process dynamism and establish the degree of dynamism in the considered soil properties, as well as to assess the rate of increasing adverse changes or their absence. Intensity of degradation processes and indicators determining it contributed to the development of levels of agro-ecological state, such as “Norma”, “Risk”, “Krizis” and “Bedstviye” (based on GIS).

1. Introduction
Preservation and reproduction of arable soil fertility is the key to sustainable development of the agro-industrial complex, in general, and the Altai dry steppe in particular. It has been established by practice that the intensive use of arid territories leads to global catastrophes, such as the tragedy that occurred in the Stone Steppe in the late 19th century. Decades have been spent to eliminate its effects. A series of dust storms in the prairies of the United States and Canada of the 1930s (where the fertile layer was completely lost) are to be remembered for a long time [1]. Today, those soil resources being once subjected to the processes of deflation and practically turned into a desert, are restored in their original state. However, huge costs are required for this restoration.

Quite a few works on the causes of deflationary catastrophes and recovery mechanisms have been published. In these works, the authors analyzing events come to the conclusion that it is necessary to create conditions for preservation and (under favorable circumstances) restoration of fertility The fundamental factor in the suspension of this process is the organization of territories on an agro-ecological basis and the use of farming systems that would allow to hinder deflationary processes when introducing elements of innovation, such as binary crops and cover crops [2]. According to foreign scientists, about 28% of the land resources of the world are subject to the process of deflation, it progresses over time. Today, about 2 billion hectares of productive soil resources are irretrievably lost.
[3, 4]. Arid territories of Altai used in agriculture should not comprehend such negative phenomena. To prevent such a phenomenon and maintain a stable productivity of agrocenoses, modern science-based agro-ecological approaches are necessary. The results of implementing these approaches are presented in our study.

2. Materials and Methods
Experimental studies are carried out in the arid area of the Kulunda steppe, the soil cover of which develops on the parent rocks of the sandy-sandy sediments with lake-alluvial origin, on steppe landscapes of tipchak-wormwood-feather grass vegetation. Its development is accompanied by the continental climate, which is characterized by harsh winter and hot summer, with a sum of active temperatures up to 2400°C and with the annual amount of precipitation reaching 240-300 mm, more than 70% of them occur during the growing season [5]. A soil cover of this area consists in 42% of chestnut and dark chestnut soils. Light chestnut and light chestnut solonets soils occupy 14%. 8% fall to the share of chestnut and dark chestnut solonets, they are used in arable land [6]. Intensive use of soil resources indicates that significant changes in fertility have occurred over time [7].

Analyzing archival materials of 1899-1913, 1980-1990 and using results of our own research for 2016-2018, we established the rate of degradation of fertility processes of agrogenic soils [8; 9; 10]. Using MapInfo Professional 10.0, we linked to archival materials a number of digitizing field soil maps and set the coordinates of cuts, making it possible to open them according to the “cut in the cut” principle. In field conditions, 35 cuts opened and showed the structure of soil cover, allowing to estimate the load intensity on soil resources. Selected soil samples were analyzed in the laboratory “Agrogenesis and Soil Fertility” of the Altai State Agrarian University (Barnaul, Russia). The results obtained allowed us to use the comparative chronological method, providing us with estimates of changes in fertility parameters over time, such as a humus horizon thickness, a humus content, a medium response, an amount of absorbed bases, as well as compositions of absorbed sodium, calcium, magnesium. To confirm the reliability of evolutionary changes in fertility over time, we used a mathematical method for statistical processing (Statistica 6.0). As a research outcome, we established dynamics and indicators of fertility parameters, as well as a degree of degradation. Using geographic information systems (GIS), a number of levels in the agro-ecological state and modes of their use have been developed and analyzed.

3. Results
The contemporary scholarship clearly shows that the intensive use of soil resources provokes agro-ecological tensions. It is established that in the modern era, soil formation proceeds along the steppe type with a significantly significant participation of the anthropogenic factor. Together with natural factors (climate, topography, vegetation, hydrography, and hydrology), this factor causes the development of such degradation processes as deflation, salinization, and alkalinization, for which the suspension of tools that allows one to quickly bring the agricultural soil to a progressive level of evolutionary development is necessary.

Assessing the deflation process intensity, it was found that over a century-long period of time, the humus horizon thickness in arable soil had changed significantly. On average, soil resources of the Kulunda plain have lost about 9 cm of the fertile layer. In modern conditions, the humus content was statistically significantly reduced by over 2%; while at the beginning of the last century, its content was more than 3%. The growing anthropogenic impact on the soil resource significantly stimulates the process of alkalinization. It has been established that the areas of alkaline spots are multiplied in size due to the activation of evaporation processes when plowing. The general trend of degradation of such indicators of fertility as the granulometric composition, cation exchange capacity, absorbed calcium, exchangeable potassium, mobile phosphorus under the existing anthropogenic load can be clearly seen. At the same time, the statistical processing of empirical data made it possible to establish that these changes are unreliable. It should be noted that the dark chestnut subtypes of agrosoils are less susceptible to this phenomenon than chestnut and light chestnut. This is due to the lower anti-deflationary stability of the latter, acquired in the evolutionary development.
We believe that the considered soil properties can serve as indicators that determine the intensity in the development of degradation processes or their absence. The analysis of these indicators would allow developing a scale of dynamism, evaluating the evolution of elementary soil-forming processes, establishing the intensity of degradation processes, and determining the dynamism of the considered fertility indicators. Those cases when the soil properties under anthropogenic impact do not undergo significant transformation in time should be attributed to the natural process of soil formation and the first degree of dynamism. These are weakly dynamic deviations, which correspond to changes not higher than 0.2% per year. Moderately dynamic deviations correspond to the second degree of dynamism and range from 0.2 to 0.3% deviation per year. The degradation of fertility parameters of arable soil from 0.3 to 0.5% per year is attributed to the average dynamic, this is the third degree of dynamism, and above 0.5% per year is the fourth degree of dynamism, which is called “highly dynamic deviations.”

The proposed assessment of the dynamism of the negative evolution of agricultural soils fertility is acceptable for spatial indicators characterizing anthropogenic disturbance in general. For a more objective assessment of the evolution of fertility, we suggest using changes in the considered soil property within the boundaries of the lower and upper values of the confidence interval. The developed dynamism scale states that fertility parameters undergo negative changes over time. The obvious manifestation of degradation processes can be traced by the example of alkalinity, humus content, humus horizon thickness, partly physical clay, silt fraction, and mobile batteries.

The conducted research is a scientifically based foundation for organizing a territory on an agro-ecological basis, taking into account degradation processes and characterizing the current state of the Altai agralandschaft dry steppe as a whole. For agroecological assessment of agrosols fertility, indicators of fertility parameters have been developed. It allows one to characterize the degree and intensity of degradation processes in elementary soil ranges (ESR). In essence, this is an individual approach to ESR, in which not all soil properties and profile have degraded. Those properties that have significant deviations from the natural soil-forming process inside the ESR are called “indicators.” The boundaries of indicator values signal the maximum permissible development of the degradation process, which determines the state of fertility and indicates critical changes that are occurring, which makes it possible to draw a boundary that determines levels of the agro-ecological state. In turn, the levels of agroecological condition of arable land is a set of ESR, they characterize a structure of the soil cover within the limits of permissible temporary deviations of fertility indicators, causing the degree of degradation and taking into account peculiarities of the territory. In fact, this is an on-farm land management on an agro-ecological basis, which allows to increase the efficiency of arable soil use and halt the development of degradation processes caused by human activities [11].

For the sustainable development of the dry steppe of the Altai, such levels of agro-ecological state as “Norma”, “Risk”, “Krizis”, “Bedstviye” have been developed and tested [12]. The agroecological state level “Norma” corresponds to the natural soil-forming process, in which the deviation of soil properties in arable horizons does not exceed 10%. Changes in the parameters of fertility at the maximum deviation from the “Norma” by 20-40% characterize the agro-ecological state level “Risk”. Arable soils related to the agroecological state level “Krizis” are characterized by a change in the state of fertility up to 80% of the “Norma.” Those ESRs located on low relief elements and near water bodies are related to the agro-ecological state level “Bedstviye.” Because of intensive use, evaporation processes causing degradation processes of salinization and alkalization are intensified.

For preserving and reproducing fertility of crisis areas, progressive methods and approaches in the use of arable soil are necessary. At the agroecological state level “Norma,” the use of the Strip-Till farming system is desirable, while it is necessary to limit the use of the traditional farming system based on flat-cutter. We believe that in crop rotation, the steam field should be an exception, since it is the cause of intensive development of deflationary processes. At the selected agroecological state level “Risk,” the No-Till farming system is sufficient to apply. It will allow to stop the degradation processes due to the constant presence of “covering material” in the form of stubble. The “Krizis” provides for the mandatory introduction of cover crops into the No-Till farming system, which will be a vegetative “covering material” during the spring and autumn periods. This will ensure the prevention of deflation
processes, improve the processes of humification, and create positive changes in the microbiological and phytosanitary background of arable soil. For all levels of the agro-ecological state, we recommend using binary (poly-species) crops. Selecting binary crops should be based on the compatibility of plants, such as rapeseed and legumes, for example. This will increase the productivity of agrocenoses, create favorable conditions for developing a microbiological component of soils, improving their phytosanitary condition [13].

4. Discussion
We believe that the solution of the problem of preserving and reproducing the agrosoil fertility of the Altai dry steppe should be carried out on an agro-ecological basis, highlighting the levels of the agro-ecological state. And using modes should be developed for each level individually. In these modes, all elements of the farming system must be combined. Time is needed for introducing new farming systems. Of course, every farming system has its positive and negative sides, which cannot be strengthened without scientific support. Each proposed farming system requires practical implementation. An integrated plant protection system, a fertilizer system, breeding and seed production, etc. should be developed. Of course, Strip-Till and No-Till are the farming systems of the future involving biologization, preservation, and reproduction of fertility. At the present stage, the practice of testing innovative farming systems has shown that in the conditions of the Altai dry steppe, the grain yield of 3 t/ha and more can be obtained. Until recently, such a yield was considered an unattainable result, it can be considered random or implemented as a pattern.

5. Conclusion
Thus, the conducted studies allow us to conclude that, at the present stage, the arable soil of the Altai dry steppe undergo significant changes in fertility. It has been established that the agroecological stress of agrosoils is caused by anthropogenic load in combination with natural conditions, contributing to the development of the deflation process, salinization, and alkalinization. Of course, in order for the area under study not to suffer the fate of the “dust storm syndrome,” the proposed scientific developments with outlining the agro-ecological state levels and the modes of their use must be implemented on an agro-ecological basis. This will allow for a differentiated use of the soil fertility potential in the dry steppe of the Altai.

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