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FORECAST OF SOIL FERTILITY DYNAMICS IN UKRAINE UNDER CLIMATE CHANGE

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As a result of the long-term development of natural sciences (agriculture, plant physiology, microbiology, soil science, agrochemistry) and primarily when developing the problem of plant nutrition, the concept of the fertility of the pedosphere and its ecosystems was formed as an opportunity to provide organisms with life factors: energy, nutrients, water, physical and physiological conditions for plant growth. According to V.I. Vernadsky, fertility should be studied as a planetary phenomenon that underlies life processes for the capture of substances by organisms. He noted: “It should be borne in mind that the entire scientific formulation of the question of fertility, of the amount of substance formed by life processes on a given area of land, can be correctly posed only on the basis of geochemical phenomena” [1].

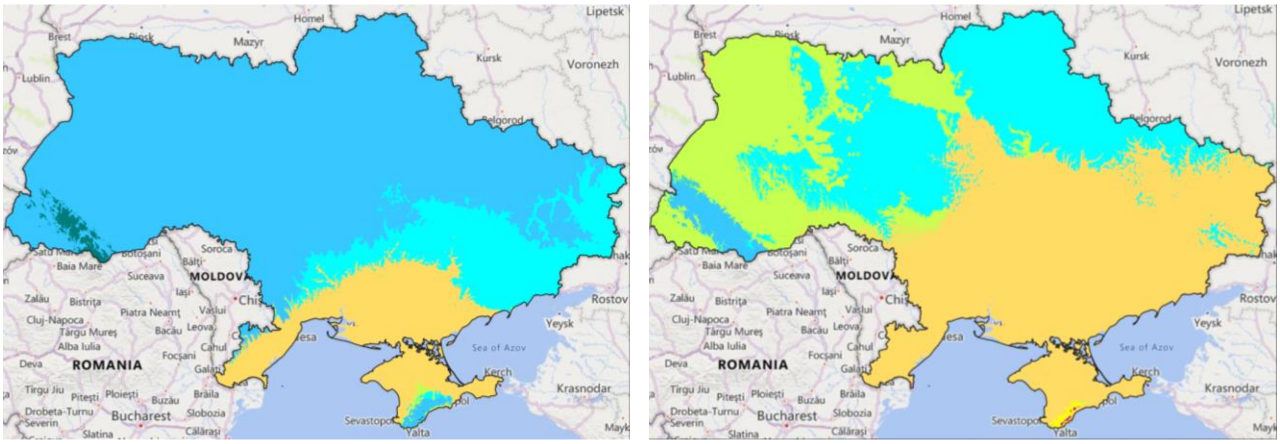
Attempts to assess the properties of soils and their fertility were inherent in the first agricultural civilizations in primitive society. The development of science led to a deeper understanding of the relationships between the quantity and quality of agricultural crops and the complex of soil-climatic and organizational-economic measures. This issue had and has great social importance; therefore, several generations of scientists have focused their efforts on soil fertility. The result of these efforts are past and modern methods for assessing the productive and qualitative characteristics of soils in various ways [2]. Most methods use mathematical operations based on the arithmetic mean and linear calculation of the values of indicators relative to standards. Other methods use the averaging of factor parameters using the geometric mean or harmonic mean [3-5]. A feature of the latter approach is a more accurate accounting of the characteristics of both soil and climatic factors. This is especially important if the coefficient of characteristics in the calculations has low numerical values. It is important to note that it is the presence of climatic and meteorological indicators, in particular the sum of active temperatures of the vegetation period, the hydrothermal coefficient, the temperature at the emergence of seedlings and the formation of generative organs, that quite fully cover the requirements of plants for life factors [3] and allow us to assess the dynamics of the overall fertility level when climatic indicators drift towards deterioration.

It is known that a significant part of the territory of Ukraine was in the zone of insufficient and unstable moisture, respectively, obtaining stable and high yields was possible only under irrigation conditions, especially in dry years. With the current dynamics of climatic conditions, i.e. global warming, this problem is becoming increasingly important. The territory of southern Ukraine, according to the classical zoning of the territory, belongs to the Steppe and Dry Steppe, and over the past decades, the issues of soil moisture and excessive temperatures have concerned primarily this part of Ukraine. In order to regulate the water regime of soils and reduce the dependence of agricultural production on adverse natural and climatic conditions in Ukraine in the 60-90s of the last century, a significant number of meliorative systems were created, including irrigation systems. Most of them are located in the arid steppe and dry-steppe zones.

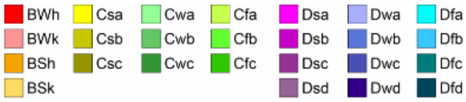
However, it is worth noting that the critical current situation caused by the war is being overshadowed by challenges related to global climate warming, as well shown in the study by Beck et al. [6]. The classification of climate into five main classes and 30 subtypes according to the Köppen-Geiger system, which is based on the threshold values and seasonality of monthly air temperature and precipitation, shows clear changes in the area of Ukraine. Fig. shows the climate dynamics from the current state (a) to the modeled situation in 2071–2099 (b) according to the SSP5-8.5 scenario.

Trends in decreasing precipitation and increasing temperatures indicate a potential future trend of decreasing precipitation, which is also confirmed by Beck et al [6]. Let us recall a recent report by Climate Central, according to which from November 2022 to October 2023, the average air temperature on the planet was 1.32°C above the industrial level, which is more than the previous record for the same period in 2015-2016 and makes this period the hottest in the entire history of observations [7]. This situation creates a rather threatening picture of the desertification of significant territories, especially southern Ukraine, in the next 30-40 years [8].

The increasing aridification of the climate requires a competent land use policy that is fully consistent with the system of measures mentioned in the UN Convention to Combat Desertification. Sustainable development and achieving a neutral level of land degradation can be achieved, first of all, by implementing measures to preserve and increase the content of organic Carbon in soils. According to the current dynamics of warming, from the 2030s in the southern regions of the Steppe, growing crops will be possible only if there is irrigation.



a) b)



Köppen climate classification scheme symbols description table

1st	2nd	3rd
B (Dry)	W (Arid Desert), S (Semi-Arid or steppe)	h (Hot), k (Cold)
C (Temperate)	w (Dry winter), f (No dry season), s (Dry summer)	a (Hot summer), b (Warm summer), c (Cold summer)
D (Continental)	w (Dry winter), f (No dry season), s (Dry summer)	a (Hot summer), b (Warm summer), c (Cold summer), d (Very cold winter)

Fig. Climate dynamics model according to the Köppen-Geiger classification for the territory of Ukraine from the present day (a) to 2071–2099 (b)

Source: Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data, 5(1), 1-12. https://doi.org/10.1038/sdata.2018.214

This difficult task is complicated by a complex of military actions, the consequences of hostilities, mining of the territory, and, importantly, the consequences of the destruction of the Kakhovka reservoir dam and its disappearance. And given the change in temperature regime and the corresponding shift of climatic zones from south to north by 160-200 km [8, 9] and even more in the future [6], the southern regions of Ukraine are threatened with desertification, the signs of which are already evident in the Kherson region and will progress in other regions. It is extremely important that the basis of Ukraine's pre-war successes in agricultural production was the ruthless exploitation of soil resources [9] with an extremely unsuccessful structure of sown areas throughout the territory of Ukraine, in particular, in the south, cereals accounted for about 56% and 37% of the area - oil crops. At the same time, up to half of the grain areas were sown with wheat, mainly soft varieties, up to a third with barley, and the rest with corn.

Accordingly, assessing the level of changes in soil fertility based on the above data on climatic trends based on the generalized soil fertility index (GSFI) [3-5] allows us to more fully and clearly characterize the negative dynamics of fertility in relation to individual types of agricultural plants and to search for ways out of the situation that has developed in both the short and long term. At the same time, the generalized soil fertility index, using the mean harmonic formula, averages the absolute values of the fertility factors previously converted into equivalents of the 0-100% scale. The normalization of the fertility factors is carried out by polynomials of the 3-4th degree in accordance with the scales of compliance of individual factors with the requirements of crops. The value of the GSFI is in the range from 0 to 100 points and includes eight soil factors (humus content, thickness of the humus layer, content of physical clay, nitrogen, phosphorus and potassium, pH (KCl) and equilibrium density) and agroclimatic factors (hydrothermal coefficient for the period with effective temperatures, sum of effective temperatures, average daily air temperature during the emergence of seedlings and the formation of productive organs).

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