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Theoretical and applied aspects of forecasting state of soil cover

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Goal. To substantiate on the basis of generalization of the available experience theoretical aspects of forecasting changes in the state of soil cover and to develop models of forecasting changes in the basic physical, agrochemical, physicochemical properties of arable soils of Ukraine. **Methods.** Information-analytical, mathematical-statistical (correlation-regression, pedotransfer modeling). **Results.** Based on the analysis of literature sources, the relevance is proved of issues related to forecasting changes in the basic properties of arable soils of Ukraine to prevent the development of degradation processes and timely use of soil protection measures that will stabilize their fertility in modern conditions. The main methods of forecasting (expert, extrapolation, interpolation, etc.) are analyzed and the theoretical aspects of forecasting in soil science are substantiated. Using samples from the database «Soil Properties of Ukraine» they developed models for predicting changes in humus, physical, physicochemical, and agrochemical properties of arable soils. The main state priorities for technological measures to protect and stabilize the level of fertility of arable soils are proposed. **Conclusions.** It is established that with the preservation of the current level of relationships in the agrosphere, which is characterized by the development of degradation processes in conditions of existing deficit of essential nutrients, acidification and contamination of soils with radionuclides and heavy metals, forecasting changes in soil properties and biodiversity will remain negative. The main state priorities for technological measures to protect and stabilize the level of fertility of arable soils are outlined.

Key words: *soil properties, estimation, pedo- transfer modeling, change forecast.*
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One of the most important socio-economic problems of modern development of Ukrainian society is the research of the environment, especially soil as the main and indispensable resource, forecasting changes in its state in natural conditions and assessing possible risks under the influence of anthropogenic factors.

In a wide sense, forecasting is a scientifically based judgment about the possible state of the object in the future and/or alternative ways and timing of their implementation [1], that is determining trends and prospects for certain processes based on data analysis of their past and present state. In the narrow sense, it is the distribution of all judgments about the future state of the object of research. The term "forecast" is equivalent to the term "extrapolation", that is the calculation of the studied indicators outside the obtained (experimental) values; it is clearly a search for the most justified model for identifying intermediate values in a number of observations.

The peculiarity of soil forecasting is that when making forecasts should take into account the trends of natural development (evolution) of soils and their possible transformation under the influence of human economic activity.

Analysis of recent research and publications. Many works have been published in the literature on various types of forecasting, including soil forecasting. Many researchers are interested in developing a methodology for this issue. The author [2] made an attempt to analyze and generalize the methods of forecasting scientific and technological progress used in various fields of science and technology by public authorities, private firms and research institutes in a number of capitalist countries. The author assessed the possibilities and prospects of using forecasting methods, considering organizational forms of forecasting in industrial companies and military departments, described the main forecasting research.

The author [3] argues that at this time the forecast of the future soil body or its individual horizons can only be anticipation, i.e. a logically constructed model of a possible future with an as yet uncertain level of probability.

In the monograph [4] it is noted that soil forecasts are in the process of formation. The use of mathematical apparatus is based on great simplifications and assumptions. According to the author, soil scientists are still insufficiently prepared for forecasting, considering it one of the most developed branches of forecasting soil halochemical processes in the conditions of land melioration.

A significant amount of scientific work is devoted to forecasting the state of soils and lands in connection with the manifestation of negative environmental consequences of human economic activity, in particular the pollution of soils with heavy metals [5 - 9]. The authors [10] summarized the work on forecasting in soil science. It should be noted that achievements in this area have foreign researchers, who can rightly be considered innovators [11 - 14].

The analysis of literature sources showed that in general forecasting is a rather unpopular state of research. Most often it is almost not included in the plans of scientific institutions; there are almost no prognostic publications. In our opinion, the main reason for this is the lack of long series of equidistant observations that can be mathematically processed and identify the dominant trends in the change of the object of study.

The factual absence of monitoring and full agrochemical certification in Ukraine (due to imperfect methods of sampling, change of fields during the observation period and reduced list of monitored indicators) also slows down the development of various forecasting models - migration of moisture, heat, most pollutants, risk erosion, acidification, salinization, compaction, etc.), gas emissions, leaching of nitrogen compounds, phosphorus, pesticides. And if interpolation forecasts (selection of linear, nonlinear and sinusoidal-trigonometric functions) sometimes occur [15], then extrapolation forecasts (outside the experimental data) are almost unknown. Due to this, the processes of soil formation in the conditions of climate change and, especially, the strengthening of climate aridization in the steppe and forest-steppe zones of Ukraine remain unclear.

In this regard, in modern conditions are actual issues related to forecasting changes in the basic properties of arable soils of Ukraine to prevent the development of degradation processes and the timely use of soil protection measures that will help stabilize their fertility.

The purpose of research – to substantiate on the basis of generalization of the available experience theoretical aspects of forecasting changes in the state of soil cover and to develop models of forecasting changes in the basic physical, agrochemical, physicochemical properties of arable soils of Ukraine.

Materials and methods of research. Information-analytical, mathematical-statistical (correlation-regression, pedotransfer modeling method), forecasting methods were used. To develop pedotransfer models, samples from the database "Ukrainian Soil Properties" were used, which was created in Geoecophysics of soil laboratory National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky".

Results of research. The simplest methods of forecasting (forecast) are the methods of Brown and moving average, based on the detection and analysis of trends in the series, which is carried out by aligning or smoothing. Exponential smoothing is one of the simplest and most common ways to align a series. The implementation of these methods is shown on the example of the analysis of a number of observations on the humus content in the arable layer of chernozem soils of loam and heavy loam granulometric composition, starting from the time of V.V. Dokuchaeva. More complex, but not effective enough is the regression, the most perfect - the Boxing-Jenkins method [16].

The use of linear regression for long-term forecasting, unfortunately, is inefficient, because outside the experimental values of the forecasted curve deviates sharply from the real one (Fig. 1).

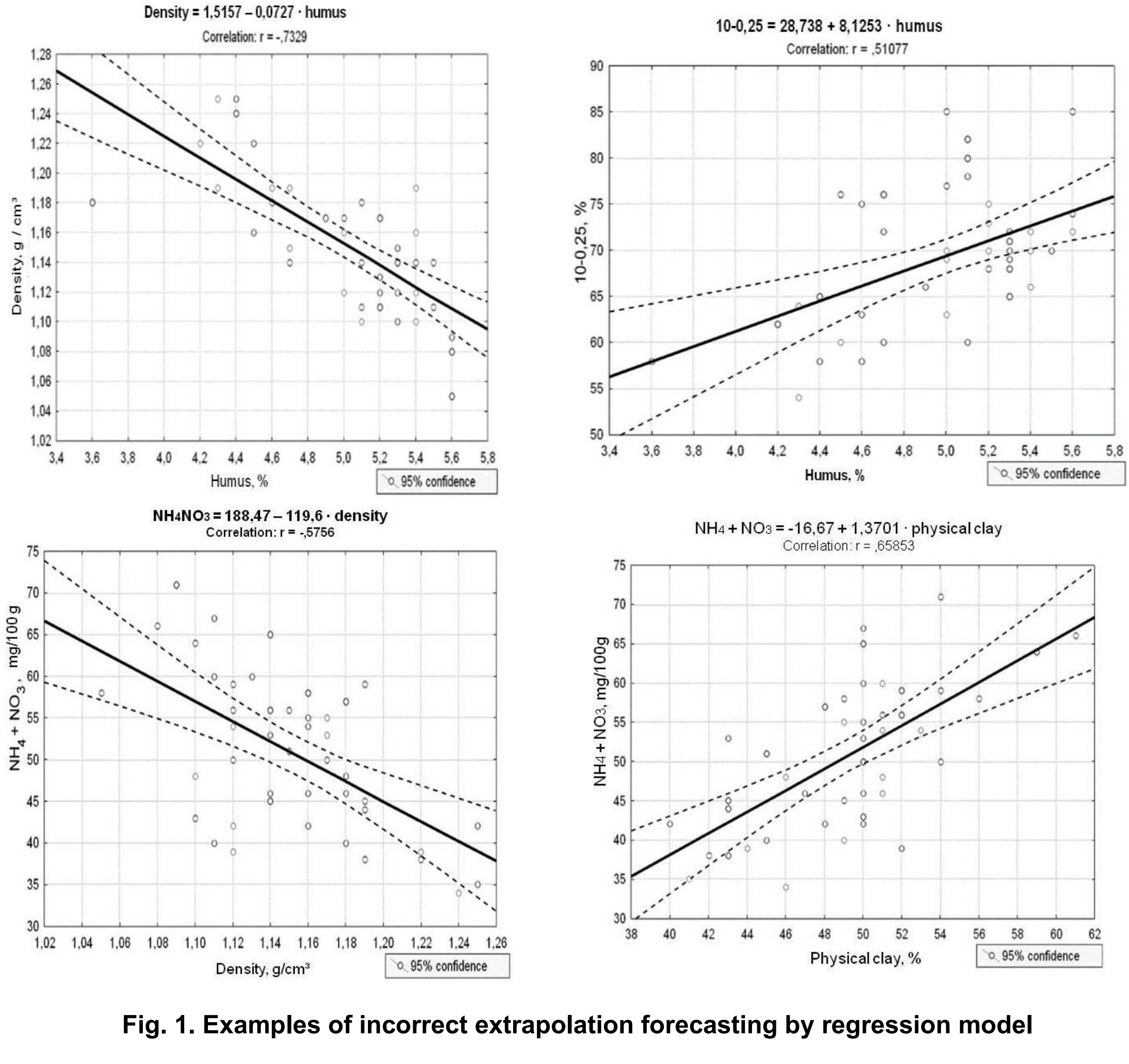


Fig. 1. Examples of incorrect extrapolation forecasting by regression model

The dominance of linear dependencies, which most often occurs in the search for connections in soil science research, is incorrect, because in biological objects the most characteristic are more complex nonlinear dependencies (Fig. 2).

There are expert forecast that are usually made by reputable scientists with extensive experience in soil research. These include V.V. Dokuchaev, who more than 100 years ago forecast the development of physical soil degradation due to the intensification agricultural activity, German scientist H. Lemerman, Russian scientist N.A. Kachynskyi, who also warned against uncontrolled seizure of heavy agricultural machinery for tillage more than 100 years ago.

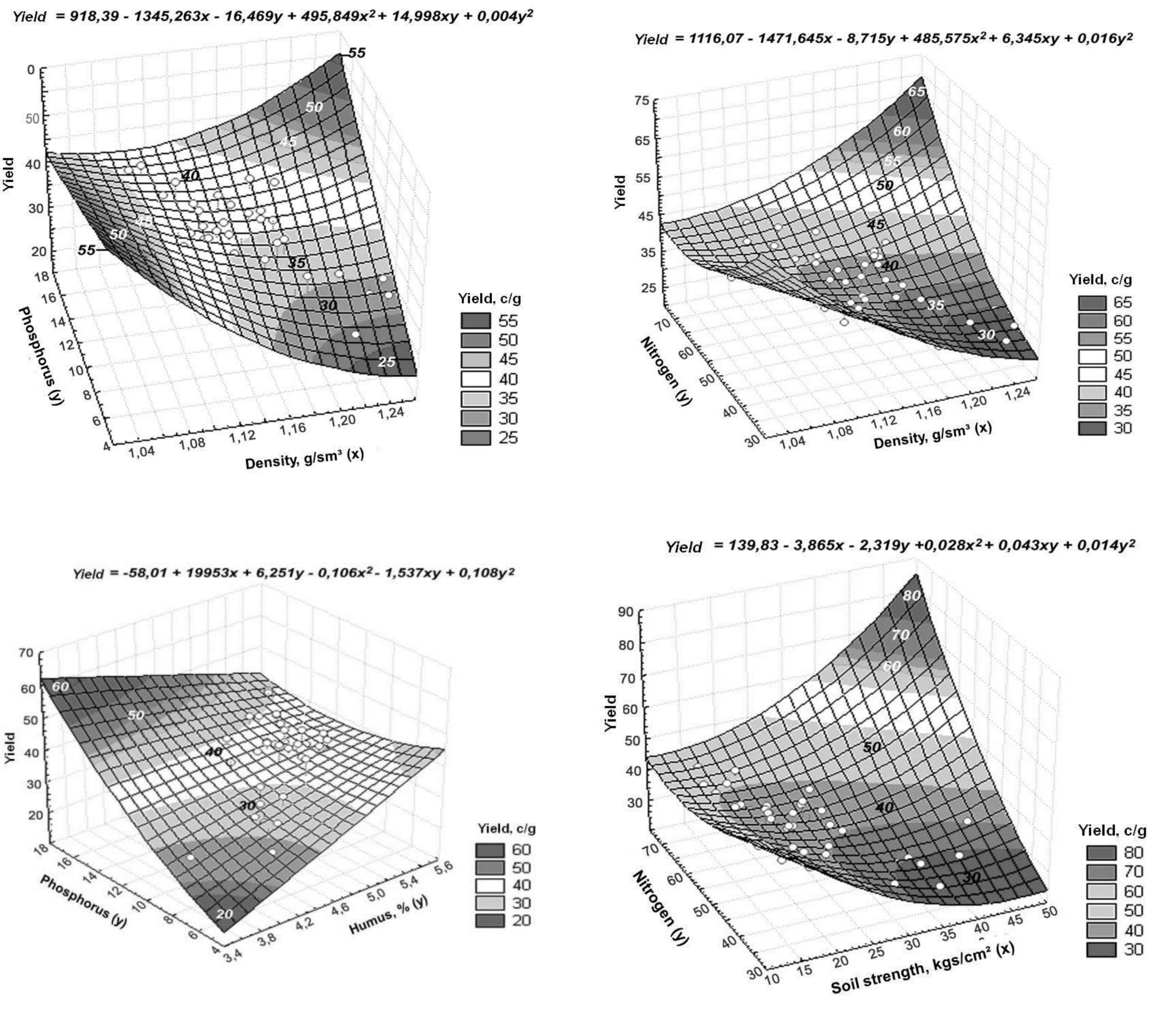


Fig.2. Examples of typical nonlinear dependence of yield on soil properties

We can show forecast of many other scientists about the inevitability of soil deterioration in an unbalanced and too intensive system of agriculture. Unfortunately, expert forecasts do not affect the change of agricultural strategy, because the current system of intensification remains unchanged - only increases the power and weight of machine-tractor units, increases the number of their passages in the field, increases the area of melioration land, where there is a deterioration of structural composition, bulk density, and the compaction is moving deeper and deeper, worsening the conditions for the viability of plant roots throughout the depth of the root layer.

Expert forecasts include forecasts made on the basis of agrochemical certification results. Although 8-9 rounds of such observations have already been conducted, their importance for forecasting the humus state and nutrient regime is devalued due to ignoring the spatial heterogeneity of soil properties and unsuccessful methods of soil sampling. However, the significant reduction of humus content in arable soils and significant transformations of the nutritional regime established on the basis of passportization deserve attention.

An example of extrapolation forecasts, which are a "forecast" in time or the calculation of possible future values, can be forecasting changes in the humus state of arable soils. For this purpose, relevant data were collected for more than 100 years, since the research of V.V. Dokuchaev. The model simulates the dynamics of humus content in soils as a stationary process with elements of inertia, recovery (after the external factor is suspended) and scattering. These elements of the methodology best determine the essence of the interaction of soil with external factors that have a physical or socio-economic nature. In particular, the model is able to compare the inertia of the soil as a body of nature that maintains its modal parameters in space and time (a body that dissipates external loads) and dynamic external factors that can increase, weaken or disappear altogether. Data processing is carried out using differential equations, which are complicated at each subsequent stage. As a result of the analysis, high-order equations were obtained, which could describe even inconspicuous changes in a long range of indicators. We were most interested in the current stage, after 1990, when the effect of external loads on the soil became weaker, as well as the coming and distant years. It was found that the content of humus in the soil decreased from the end of the XIX century and almost to 60 - 70 years of XX century. Then there was a noticeable slowdown in losses (until the late 80's), after which, despite the known cataclysms in the agricultural sector of the country - stabilized. In the first deficit period, the loss of humus reached almost 22% of the initial amount, taken as 100%, in the second - the loss was less than 5%.It is this dominant place of mineralization processes in chernozems during most of the XX century, which has been replaced by stabilization, and proves the achievement of simple reproduction of soil fertility in the 90s of the XX century (after almost 25 years of successful chemicalization). The absence of a decrease in the humus content in the soil over the next 10 to 15 years indicates the inertia of the soil itself. How much inertia will work is unclear, but 2 scenarios can be envisaged. The first scenario is the conservation of the humus stock under the condition of simple reproduction, the second scenario is the continuation of the reduction provided that the deficit balance is preserved, i.e. the current socio-economic condition of the agricultural sector.

The main regularity of the dynamics of humus content in the chernozems of Ukraine for more than 130 years and possible scenarios for its further development are shown in Fig. 3.

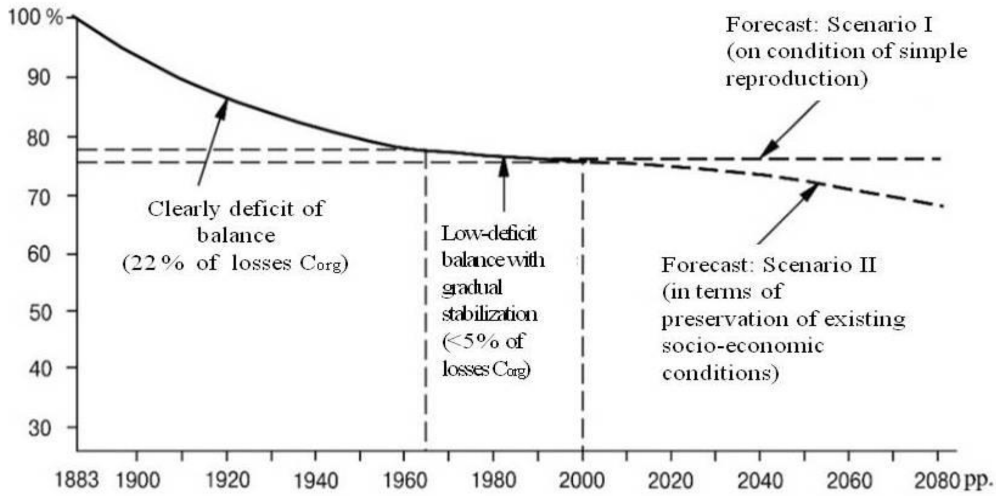


Fig. 3. Dynamics of humus content in chernozems of medium and heavy loam granulometric composition for 1983–2000 and forecast of its changes up to 50–80 years of the XXI century

It was conducted research at special laboratory equipment for implement interpolation predictions. This made it possible to simulate various static loads on samples of intact structure. Samples of typical heavy loam chernozem, southern silty-clay chernozem and soddy-podzolic sandy loam soils were researched. Values of static loads varied from 0 (control) up to 100 kPa. The samples were kept under load until the deformation ceased. The obtained results are shown in Fig. 4.

Deformation of the researched soils is described by exponential dependences. However, if in the soddy-podzolic soil of silty granulometric composition there is a rapid deposition of the curve with a slight increase in density, in chernozem typical heavy loam density increase does not end and will continue with a further increase in load. Thus, the mechanical stability of the soil of silty granulometric composition is significantly higher compared to chernozem, unable to withstand even a small load.

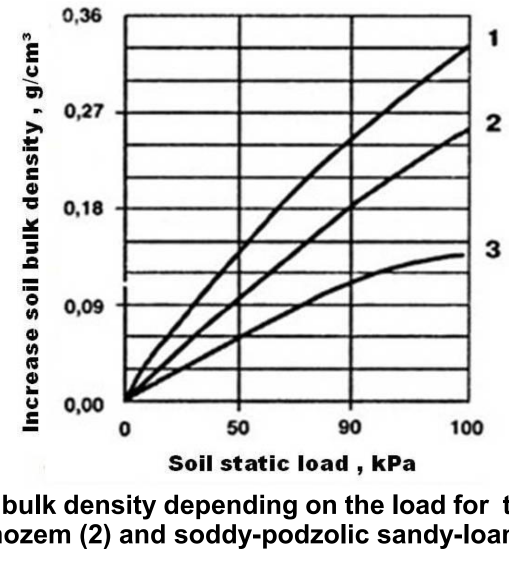
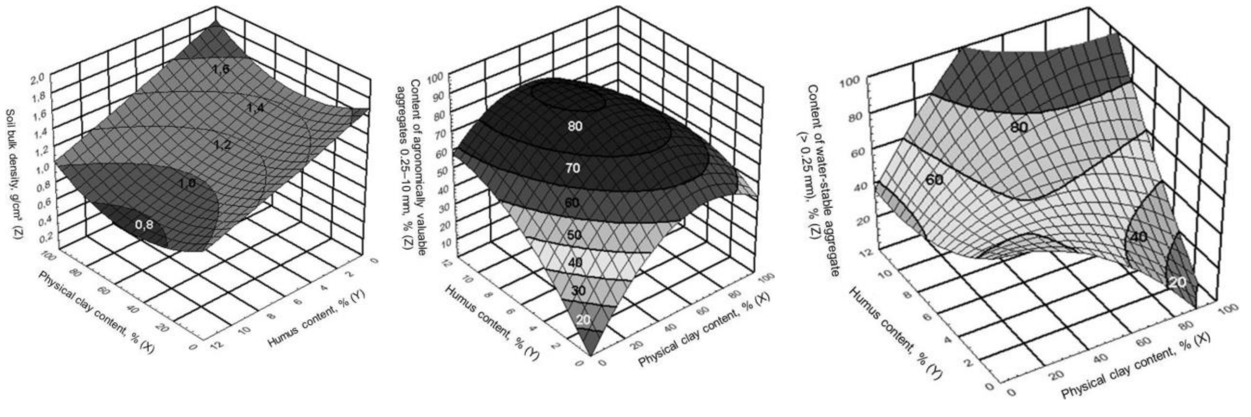


Fig. 4. Increasing the soil bulk density depending on the load for typical heavy-loam chernozem (1), southern silty-clay chernozem (2) and soddy-podzolic sandy-loam soils (3)

The dependences are described by the following equations:
for typical chernozem: $\Delta P = 0,5926\ (1 - e^{-0,0081u})$;
southern chernozem: $\Delta P = 0.5924\ (1 - e^{-0.0055u})$;
soddy-podzolic soil: $\Delta P = 0,1958\ (1 - e^{-0,0123u})$,
where u - is the parameter of exponential dependence in determining the increase in soil bulk density; ΔP - increase bulk density, g / cm3; χ - static load on the soil, kRa.

The parameter u is defined as follows: $u - 105.56 - \sqrt{11142 - 111.11\ \chi}$ at $\chi < 100$ $u = \chi$ at $\chi \geq 100$.

Examples of intrapolation forecasts can be pedotransfer models built to determine the properties of soils based on the combined effect of humus and physical clay content (Fig. 5).



a *b* *c*

Fig. 5. Pedotransfer models of quadratic form to determine the properties of soils according to the content in the soil of physical clay and humus: a - bulk density ; b - content of agronomically valuable aggregates 0.25–10 mm in size; c - the content of water-stable aggregate> 0.25 mm

Forecasting the state of arable soils of Ukraine. *Forecasting of changes in the humus state*, carried out by comparing the humus content in the times of V.V. Dokuchaev (1882) with the current state, indicates that the loss of humus over this almost 130-year period reached 22 % in the forest-steppe, 19.5 % - steppe and almost 19 % - in the Polissya zones of Ukraine.

The loss of humus is considered to be the most significant leading degradation process that needs to be stopped. Regarding organic carbon and humus, a lot has been accumulated information - about stocks, geography of distribution, role in formation of properties and modes of soil, dynamics under the influence of any agrotechnologies. The first reports on the content of humus in soils appeared in the middle of the XIX century. Regarding carbon and humus in the literature there is unique information, databases, various maps. These are the most popular indicators in the research, except for countries with sandy soils, where humus is extremely low and its role is limited. The main regularity of anthropogenic dynamics is determined - in the conditions of real management the carbon content in the soil decreases, especially in the tropics and subtropics for almost 100 - 130 years from the moment of the first determinations, by 20 - 50%. Unfortunately, approximately the same rate of reduction of humus content is typical for arable soils of developed countries and Ukraine, including chernozems. Possible scenarios of changes in the humus content in arable soils of Ukraine are shown in Fig. 3.

Forecasting changes in the physical condition of soils. According to scientists [17-19], recently the physical properties of soils deserve special attention, negative changes of which are observed everywhere, which leads to physical degradation on arable soils of the country. The latter made topicality the need for detailed research in order to forecast their changes in modern conditions, when you need to specifically know and quantify the development of a particular natural process in order to timely and accurately address their management. The issues of management are always based on preliminary forecast calculations, which are performed on the basis of mathematical models. The forecast modeling procedure is very important in the development of soil resource management systems.

Modern soil physics uses a diverse set of methods to determine agrophysical parameters: direct experimental determinations using a variety of methods [20, 21] and various calculation methods [22]. In general, the implementation of the tasks of pedotransfer modeling, the development of new types of models will allow developing the direction in soil science, related to forecasts, various assessments and soil management.

Forecasting changes in agrochemical condition of soils. Based on the calculations of the balance of nutrients made by a group of leading experts [23], which took into account almost all its revenue and expenditure items, we can conclude that in the last 15 - 20 years the balance of essential nutrients in the soils of country has become persistently deficient. Soil fertility will continue to decrease if radical measures are not taken - first of all, increasing the level of mineral fertilizers, the use of crop by-products and local sources of organic matter.

Except to the transformation of the chemical properties of soils of Ukrainian , the issue of soil pollution by radionuclides and heavy metals is important. In general, they pollute up to 20% of the territory to varying degrees. Pollution is mainly local in the Left Bank Forest-Steppe and Steppe, where large enterprises of the chemical, metallurgical, and mining industries are concentrated. Almost all areas adjacent to these enterprises are polluted 1 - 5 orders of magnitude higher than the background value. This applies to lead, vanadium, copper, nickel, chromium, manganese, zinc, petroleum products and even mercury.

Forecasting changes in physico-chemical properties of soils. Under natural conditions, the pH (actual and potential reaction of the soil solution) varies within the country in a wide range - 4 - 9. For arable land in soils of the soddy process of soil formation, where there is a gradual decalcification, the pH is lower than in virgin soil, for podzolic soils - on the contrary, plowing of virgin land slightly alkalizes the soil solution. Under natural conditions, the pH values are more contrasting, in arable land - converge, align. This fact must be taken into account when assessing changes in pH over time in relation to 2 standards - virgin and arable land.

The pH indicator depends on many conditions and, mainly, on the climate, vegetation, lithological composition of soil-forming rocks, the direction of the soil-forming process to a greater extent than other indicators of soil properties from the impact of human economic activity.

A comparison of map of the pH_{salt} with materials on the lithological composition of soil-forming rocks indicates that these indicators are primarily related to the presence and depth of lime in the soil. The increase in soil acidity of the Polissya zone and the mountainous region of the Carpathians is usually due to the carbonate-free soil-forming rocks. Acidity in Forest-Steppe soils formed on forest rocks rich in calcium carbonate decreases from strongly to weakly podzolic forest-steppe soils and typical chernozems and is consistent with the degree of their leaching.

For soils of steppe and dry-steppe zones of Ukraine the pH is in the range of 6 - 7, in other zones certain regions are distinguished by pH values. Transcarpathian lowlands and Precarpathians are clearly characterized by low pH values. The pH value of soils for this region is 4.4 - 4.7. Similar pH values occur only within the most leached soil massifs of Polissya.

In the soils of the Carpathians, this indicator is even lower or equal to 4.3. When comparing pH values with hydrolytic acidity, mobile aluminum content, granulometric composition data, it can be concluded that extremely low pH values are due to the native lithology of soil-forming rocks formed here during redeposition and hypergenesis of flysch rocks predominating in mountainous rocks. In terms of salt pH, as in other physicochemical parameters, this region is an independent geochemical province.

Polissya occupies a special place in terms of pH values. It is dominated by light soils, there are special climatic conditions (high moisture content) and a pronounced eluvial process and soil gleying processes. pH varies from 4.4 - 4.7 to 7.0 depending on the severity of these processes, soil cultivation and the nature of soil-forming rocks. The main area is soils with pH 4.8 - 5.1 and 5.2 - 5.5. There are small massifs of podzolic forest-steppe soils on forest rocks with pH 5.6 - 5.9 and soils of different genesis at the outlets to the surface of carbonate rocks (6.0 - 6.6 and> 6.6). In the virgin chernozem of the Left-Bank Forest-Steppe of Ukraine, the absorption capacity is 51.0 mg · eq./100 g of soil.

Plowing and long-term use of this chernozem in grain-beet crop rotation without the use of fertilizers lead to a gradual decrease in the absorption capacity: after 12 years - by 5%; 37 years - 9; 52 years - 15 and 100 years - by 24%. A similar pattern is observed in the soils of the Western Forest-Steppe [24]. Especially significantly (by 17 - 26% for 100 years) decreases the content of metabolic calcium in low-crop agriculture, the content of metabolic magnesium decreases more slowly.

Forecasting changes in biodiversity. Although research of biodiversity has been developed and supported in recent years, there are no global estimates of its real impact on the ecological functioning of soils. There are also no agreed research methods, no biodiversity in monitoring programs, even in the most developed countries of Europe and North America. This shortcoming, according to soil researchers, should be addressed because the importance of bacteria, fungi, earthworms and other organisms in regulating soil processes, especially the dynamics of organic matter, sequestration and emissions, is becoming increasingly important. Than less microorganisms in the soil, the worse its properties and regimes. Biodiversity loss is usually observed in conditions of low agricultural culture - non-compliance with crop rotations, fascination with agrochemicals, exceeding the intensity of cultivation. According to a survey of 20 leading European experts, 56% soils of EU have problems with biodiversity [10]. According to them, the factors influencing biodiversity are (in descending order) excessive intensification of agriculture, reduction of organic matter in arable soils, pollution, including gene-molecular organisms, compaction, erosion, climate change, invasive effects (xenobiotics, damage for soils substances). The main conclusion of experts: biodiversity is an important condition for the stability of soils against any negative influences, and its support is a way for them to function properly. Unfortunately, the forecast for biodiversity change will remain negative as long as the current level of agro-industrial relations is maintained.

Thus, the complexity and intensity of the situation, which characterizes the current state of the soil cover of Ukraine, requires the definition of state priorities for technological measures for soil protection. The main ones are: suspending the reduction of humus content and achieving its deficit-free balance; enrichment of soils with nutrients and especially phosphorus; effective protection of soils from erosion; melioration of acid and solonetzic soils; reconstruction of irrigation systems, restoration of irrigation areas to the design level; implementation of measures to prevent man-made soil degradation.

Conclusions

It was generalized that the main cause for the unpopularity of forecasting research is the lack of long series of equidistant observations that can be mathematically processed to identify the dominant trends in the change of the object of research. It is noted that the development of new types of models will allow developing the direction in soil science related to forecasts, various assessments and soil management.

The main forecasting methods (on specific examples of extra- and interpolation models) used in soil science were analyzed. On the example of chernozems, changes in the humus state were forecast. A comparison of humus content was made during the time of V.V. Dokuchaev (1882) with their current state.

It is proved that modern soil physics uses a different set of methods to determine agrophysical indicators: direct experimental determinations using various methods and various calculation methods, in particular pedotransfer modeling.

It is established that the forecast of changes in the basic properties of soils and biodiversity will remain negative. The reasons for this are the preservation of the modern level of relationships in the agrosphere, which is characterized by the development of degradation processes in the current deficient balance of essential nutrients, acidification and contamination of soils with radionuclides and heavy metals.

The main state priorities for technological measures to protect and stabilize the level of fertility of arable soils were outlined.

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