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ANALYSIS OF TRADITIONAL METHODS FOR PREDICTING SOIL PRODUCTIVITY

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A B S T R A C T

The article also discusses modern methods of crop yield assessment and forecasting, including the use of regression analysis based on satellite data. Particular attention is paid to short-term and medium-term forecasts that meet the requirements of simplicity, cost-effectiveness and automation. The proposed approaches allow one to take into account the depth of the forecast, which determines the choice of intuitive or formalized methods. The work contributes to the development of tools for sustainable agriculture and the maintenance of soil ecosystem services.

K E Y W O R D S

Soil, plant, fertility, productivity, forecasting methods.

Introduction

Soils cover a significant part of the earth's surface, but in terms of their usefulness to humans, they are a limited and virtually irreplaceable resource [1]. Today, about 3.2 billion hectares of land are used as arable land, which is about a quarter of the total land area [2, 3]. In general, agricultural lands occupy from 40% to 50% of the entire land area [4].

Despite the key role of soils in ensuring productivity, their functions are sometimes poorly defined or interpreted differently. In the German Soil Protection Act [5], soil productivity is described as "suitability for agriculture and forestry". Among the various soil functions (agriculture, resource use, settlements and transport), agricultural and forestry soils occupy a special place. Firstly, the sustainable use of agricultural soils is necessary to maintain their productive potential in the long term. Secondly, natural soil functions such as habitat, nutrient cycling and biofiltration are not only important for conservation areas. Agricultural soils are also obliged to fulfill these natural functions, for example by supporting ecosystem services [6].

The assessment of the soil productivity function is not limited to land use concepts related to tillage intensity. It covers the ability of soils to support low-input and organic farming methods. Furthermore, even soils located in natural ecosystems can fulfill productive functions. This paper focuses on the analysis of the soil productivity function on agricultural land. The existing approaches and tools for assessing the state of soils in terms of their ability to ensure productivity are considered.

Soils and their limitations for plant growth

Soils are components of terrestrial ecosystems. The productivity of these systems is controlled by natural factors and human activities. The most important external natural factors are solar radiation, which affects temperature and evapotranspiration, and/or precipitation [7]. Soils can support plant growth if climate, as the main factor in soil formation, is within a suitable range. Thus, on a global scale, natural limitations to soil productivity can be divided into three main groups. The first group includes the thermal and moisture regimes of soils. Plants require appropriate soil temperature and moisture for their growth. For most soils, the thermal and moisture regimes are directly dependent on climatic conditions. They set the scope for such limitations as drought, humidity, or too short a growing season, which limit productivity [8].

Globally, soil moisture is the main limiting factor in most agricultural systems. Drylands cover more than 50% of the world's land surface [9]. Available soil water is a prerequisite for plant growth. In all climates suitable for agriculture, the water holding capacity of soils is a critical property for soil functionality, including the productivity function. It is closely related to crop yields [10]. The second group of limitations includes other intrinsic soil deficiencies, mainly due to improper substrates that limit plant rooting and nutrition. These include shallow soils, rockiness, hard subsoil layers, anaerobic horizons, or soils with unfavourable chemical properties such as salinity, alkalinity, acidity, nutrient depletion or pollution, which can cause serious limitations to plant growth or biomass utilisation [11]. The third group includes topography, sometimes considered as an external property of the soil, preventing soil erosion and ensuring accessibility for people and machinery.

There seems to be an interaction between natural limitations of soil productivity and social factors. Historically, many countries with poor soils were generally poorly developed. This led to accelerated soil degradation. Currently, in developing countries, about two thirds of soils have serious limitations for agriculture. Their low fertility (38%), sandy or stony soils (23%), poor soil drainage (20%) and steep slopes (10%) are the main limitations to productivity [12].

Over the past decade, several methods and approaches have emerged for forecasting crop yields, the main ones being:

- the method of analyzing the trend and cyclicality in the dynamics of yield;
- the method based on identifying an analog year;
- modeling the growth of plant biomass;
- the method based on the analysis of synoptic processes;
- regression method using satellite data.

An approach based on regression analysis, in the presence of a sufficiently long series of high-quality satellite data, allows obtaining good results [13].

Currently, work on the development of this approach and the analysis of the possibilities of its application for forecasting the yield of various crops is being carried out quite actively. From the results of the studies presented in [13–17], annual fluctuations in yield are quite accurately predicted by vegetation indices during the growing season, during which all vital processes of plants are maximally manifested [18].

When considering the problem of forecasting, the emphasis is placed on short-term or medium-term forecasts, since long-term forecasting requires the use of statistical analysis methods and expert assessments [19]. Applications that implement forecasting models must meet a number of key requirements:

- relative simplicity;
- cost-effectiveness in calculations;
- the ability to automatically generate forecasts.

The scientific literature presents various classifications of forecasting methods. One of them is based on the degree of formalization, where methods are divided into intuitive and formalized.

To select an appropriate forecasting method in different situations when solving problems, the concept of forecast depth is introduced.

$$\tau = \frac{\Delta t}{t},$$

where,

Δt - is the absolute lead time,

t - is the duration of the forecasting cycle. When the forecasting depth value is less than one, we can say that this value fits into the framework of the evolutionary cycle and the most correct will be the use of formalized methods. If the obtained value becomes close to one, then in order to determine the strength of the forecasting "leap" and the time of its existence, intuitive methods and catastrophe theory are most acceptable [20]. If the forecasting depth value is greater than one, this means that several evolutionary forecasting cycles fit into the forecasting period at once. In this case, intuitive methods are increasingly important.

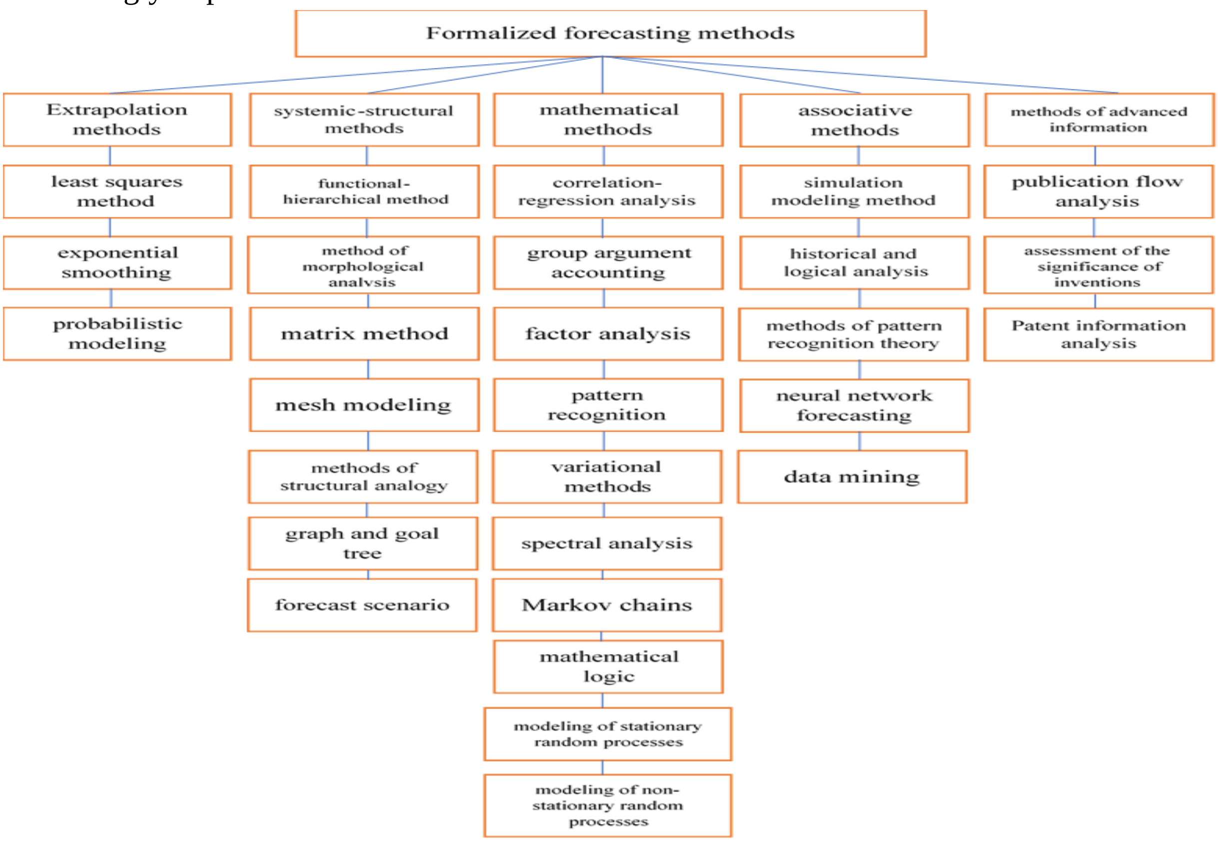

Fig. 1. Classification of formalized forecasting methods

Despite the diversity of formalized forecasting methods, the list presented in Figure 1 is not exhaustive. Among these methods, one of the most common is extrapolation. In the most general sense, extrapolation studies past and present trends in order to transfer them to the future. In extrapolation forecasting, time series are studied and function values are found outside the domain of definition [21, 22]. This uses information about how the function behaves at points lying inside the domain of definition.

Extrapolation can be formal and predictive. Formal extrapolation is based only on the assumption that past and present trends will continue into the future. Predictive extrapolation is based on hypotheses about the further development of the forecast object.

The choice of extrapolation limits largely determines how realistic the forecast will be.

The course of extrapolation is determined by the following steps:

- a specific statement of the problem, consideration of hypotheses about the development of the forecast object, identification of factors that facilitate or hinder the development of the object, establishment of the extrapolation range;
- definition of the system of parameters and standardization of the units of measurement associated with them;
- tabulation of the collected data, data verification;
- detection of development trends in the forecast object.

Conclusion

Soils are a vital but limited resource, the condition and use of which determine the productivity of agricultural lands and the sustainability of ecosystems. Natural limitations of soil productivity, including climatic factors, internal soil properties and topography, significantly affect their ability to support plant growth and ensure crop yields. These constraints require the use of effective management and forecasting methods, especially in the context of increasing pressure on land resources. Modern methods of yield forecasting, such as regression analysis using satellite data, show significant potential for improving the accuracy of short- and medium-term forecasts. At the same time, it is important to take into account the requirements for simplicity, cost-effectiveness and automation of forecasting models.

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