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**THE USE OF DIGITAL TECHNOLOGIES AND GEOGRAPHIC INFORMATION SYSTEMS IN FORECASTING AND PROGRAMMING CROP YIELDS**  
**ВИКОРИСТАННЯ ЦИФРОВИХ ТЕХНОЛОГІЙ ТА ГЕОГРАФІЧНИХ ІНФОРМАЦІЙНИХ СИСТЕМ У ПРОГНОЗУВАННІ ТА ПРОГРАМУВАННІ ВРОЖАЙНОСТІ СІЛЬСЬКОГОСПОДАРСЬКИХ КУЛЬТУР**

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The current stage of development in the agricultural sector is characterised by profound transformation, driven by the introduction of digital technologies, big data analysis tools and automated management systems. In the context of climate change, unstable weather conditions and the growing anthropogenic pressure on agroecosystems, improving the accuracy of yield forecasting and the efficiency of production process programming in crop farming is of particular importance.

Yield forecasting and programming are interrelated components of modern agricultural management, ensuring scientifically sound planning of agricultural production. Traditional approaches, based on statistical generalisations, are gradually giving way to integrated digital models capable of accounting for a significant number of factors in real time.

Forecasting crop yields is a complex systemic process based on the analysis of the interaction between biotic and abiotic factors. Key factors influencing crop yield include climatic conditions, the agro-physical and agro-chemical properties of soils, the genetic potential of crops, and cultivation technologies [5, 8].

Modern approaches to forecasting involve the use of: statistical models, mathematical modelling, plant growth simulation models, and machine learning algorithms.

A distinctive feature of modern models is their ability to account for non-linear dependencies and complex interrelationships between factors. This ensures greater forecast accuracy compared to traditional methods.

Yield programming, in turn, involves actively influencing the yield formation process by optimising agronomic practices. It is based on determining a target yield level and developing a system of measures to achieve it [8].

An important condition for effective programming is taking into account the farm's resource potential and environmental constraints.

The effectiveness of yield forecasting depends to a large extent on the quality and completeness of the information available. In modern conditions, the information base is formed through the integration of various data sources: meteorological observations, soil surveys, remote sensing results, field sensor data, and historical agronomic data [1, 8].

The use of digital platforms allows this data to be consolidated into a single system and utilised to build predictive models.

Of particular importance is the spatio-temporal analysis of data, which ensures that the dynamics of changes in crop growing conditions are taken into account.

Geographic Information Systems (GIS) play a key role in modern agricultural production, ensuring the integration, processing and visualisation of spatial data. The use of GIS in yield forecasting allows for: detailed mapping of fields, analysis of spatial soil heterogeneity, modelling of yield distribution, and zoning of territories [1].

GIS provides the basis for differentiated management of agrotechnological processes. This is a crucial element of yield programming, as it allows technologies to be adapted to the specific conditions of each field plot.

Earth remote sensing (ERS) technologies are one of the most effective tools for monitoring the condition of crops. They provide timely information on plant development and the state of agrocenoses.

The main applications of ESR include: determining vegetation indices, assessing plant biomass, identifying stress factors, and forecasting yield [1, 2].

Satellite data and data from unmanned aerial vehicles (UAVs) enable the collection of information with high spatial and temporal resolution, which significantly improves the accuracy of forecasts.

Sensor technologies and the Internet of Things (IoT) ensure continuous monitoring of environmental parameters. The use of sensors allows data to be obtained on: soil moisture and temperature, microclimatic conditions, and nutrient levels [3].

Integrating this data into forecasting systems enables a rapid response to changes in growing conditions and the adjustment of agronomic practices.

Artificial intelligence and machine learning algorithms open up new possibilities for analysing agricultural data. They enable the identification of hidden patterns, the construction of highly accurate predictive models, and the optimisation of management decisions [1].

The use of neural networks, regression methods and cluster analysis allows for the consideration of complex interrelationships between factors and improves the reliability of forecasts.

Yield programming is implemented through a precision farming system, which involves a differentiated approach to field management. The main elements are: variable fertiliser application rates; adaptive irrigation systems; management of crop density; and optimisation of the timing of agricultural operations.

Field zoning is a fundamental element of yield programming, allowing for the spatial heterogeneity of fields to be taken into account and ensuring the efficient use of resources [1].

The main idea behind precision farming is to account for field heterogeneity, which allows for: optimising fertiliser application; improving water use efficiency; reducing resource consumption; and increasing crop yields [5, 6].

The use of digital technologies in yield forecasting and programming provides significant economic and environmental benefits. In particular: a 15–25% increase in yield [4], a reduction in costs for fertilisers and resources [7], a reduction in negative environmental impact, and increased stability of agricultural production.

The environmental benefit is reflected in the reduction of excessive agrochemical use and the rational use of natural resources.

Despite the significant benefits, the introduction of digital technologies in the agricultural sector is accompanied by a number of challenges: substantial capital expenditure, insufficient digital competence among specialists, limited access to high-quality data, and imperfect regulatory frameworks [5].

Addressing these issues requires a comprehensive approach at the level of government policy and the education system.

The further development of crop forecasting and programming is linked to: the integration of artificial intelligence technologies, the development of big data analysis systems, the automation of agricultural production, and the introduction of digital management platforms.

These technologies are expected to become an integral part of modern agricultural production.

Thus, crop yield forecasting and programming is a key factor in improving the efficiency of agricultural production. The application of digital technologies, geographic information systems and artificial intelligence contributes to an increase in the accuracy of forecasts, the rational use of resources and

the stabilisation of production processes. In the long term, the development of these approaches will ensure the establishment of a highly efficient, competitive and environmentally balanced agricultural sector.

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## ІННОВАЦІЙНІ РЕСУРСОЗБЕРІГАЮЧІ ТЕХНОЛОГІЇ В АГРАРНОМУ СЕКТОРІ: ЄВРОПЕЙСЬКИЙ ДОСВІД ТА УКРАЇНСЬКІ ПЕРСПЕКТИВИ INNOVATIVE RESOURCE-SAVING TECHNOLOGIES IN THE AGRICULTURAL SECTOR: EUROPEAN EXPERIENCE AND UKRAINIAN PROSPECTS

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Сучасний розвиток аграрного сектору відбувається в умовах посилення екологічних викликів, серед яких деградація ґрунтів, зниження родючості та зміни клімату. За оцінками міжнародних організацій, значна частина сільськогосподарських земель зазнає негативного антропогенного впливу, що зумовлює необхідність переходу до сталих моделей виробництва. У цьому контексті особливого значення набувають ресурсозберігаючі та екологічно безпечні технології, які забезпечують ефективне використання природних ресурсів за мінімального впливу на довкілля.

Метою дослідження є аналіз європейського досвіду впровадження ресурсозберігаючих технологій та оцінка перспектив їх застосування в Україні.

За даними FAO [3], понад 33% ґрунтів у світі перебувають у стані деградації. Ресурсозбереження в аграрному секторі передбачає впровадження інноваційних підходів до ведення господарства, зокрема мінімального або нульового обробітку ґрунту, використання технологій точного землеробства, біологізації виробництва та альтернативної енергетики. Такі підходи