ГЕОІНФОРМАТИКА

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AGROCHEMICAL ANALYSIS OF SOILS IN PRECISION FARMING TECHNOLOGIES: A CASE STUDY OF THE CHERNIHIV REGION

(Представлено членом редакційної колегії д-ром геол. наук, ст. дослідником О.І. Меньшовим)

Background. ***Precision agriculture aims to create a comprehensive decision-support system that enhances the efficiency and sustainability of agricultural practices. It is based on the principle that fields are not homogeneous and consist of various zones with distinct characteristics. Variability in soil, terrain, climatic conditions, and other factors results in different plant requirements across different field zones. Precision agriculture allows for consideration of this variability, enabling an individualized approach for each field section.***

A research presents a comprehensive approach to analyzing all key stages of agrochemical surveys, from the preparatory phase to laboratory analysis, the development of agrochemical maps, as well as the creation of fertilizer requirement maps and task maps for agricultural machinery. Particular attention is paid to the potential use of remote sensing data and geographic information technologies for processing and visualizing results.

Methods. ***Soil sampling begins with determining the configuration and area of elementary zones. Several soil sampling strategies are considered, allowing each agricultural enterprise to choose the most suitable one based on its goals and specific field conditions.***

Agrochemical soil properties can vary significantly even within small field areas, necessitating a meticulous approach to sampling for analysis.

Results. ***Developed agrochemical maps serve as additional visual materials that modern laboratories provide along with agrochemical soil reports. These maps, available in both paper and digital formats, illustrate various levels of humus content, nutrient levels in the soil, and soil solution pH.***

Conclusions. ***Agrochemical soil analysis provides essential information for optimizing the processes of differential fertilizer and seed applications. Based on the data obtained about soil type, macro- and micronutrient content, organic matter levels, moisture levels, and other key indicators, the nutrient requirements of elementary zones can be accurately determined. This enables the development of effective agronomic strategies tailored to specific field conditions.***

Keywords: ***precision agriculture, agrochemical soil analysis, soil sampling scheme, geographic information technologies, agricultural automation, soil mapping.***

Background

***Relevance of the research topic*:** The United Nations Commission on Population and Development reported that the Earth's population reached 7.7 billion in 2019 and continues to grow. According to projections, by 2050 it will have reached 9.7 billion, and by the end of the century, it will have increased to approximately 11 billion people (Commission on Population and Development, 2019). In this regard, there is a threat that, given the existing natural resources, arable land, and agricultural technologies, the production of the required amount of food for the world's population may prove insufficient. Increasing the amount of land available for food production is not feasible, as deforestation or wetland drainage poses a risk of ecological catastrophe. Moreover, the productivity of agricultural crops is approaching biological limits (Morgun et al., 2010). The problem is further exacerbated by the uneven development of agriculture across countries and continents, the irrational use of natural resources, and the continuous increase in the cost of seeds, mineral fertilizers, plant protection products, machinery, and other agricultural production resources.

The world faces a challenge of how to feed itself amid the growing global population and the imbalance between food supply and demand. To meet this challenge, food production must increase by at least 70 %. Thus, there is an urgent need to improve the efficiency of agricultural production, particularly in plant cultivation. This can be achieved by increasing yields through the implementation of advanced resource-saving technologies, which will enable more efficient use of arable land, natural material, and economic resources, while also reducing environmental pressure on the natural environment (NPS). One such technology that can ensure high profitability in agriculture is the precision farming system (Tsyhanenko, 2015).

Additionally, Ukraine's agriculture, like that of many other countries, faces challenges caused by climate change, including more frequent droughts, heavy rains, and other extreme weather events that negatively impact agricultural productivity, especially in areas of risky farming, where traditional agricultural methods are becoming less effective. Given that most of Ukraine's cultivated land is already in this zone, and considering the damages caused by the Russian aggression, the situation is becoming even more complicated.

The solution to this situation lies in the use of innovative land cultivation methods and optimization of available resources, primarily through the application of precision farming technologies.

Precision farming aims to create a comprehensive decision-making support system that enhances the efficiency and sustainability of agricultural practices. It is based on the principle that fields are not uniform and consist of different areas with varying characteristics. Variability in soils, topography, climate conditions, and other factors results in different plant needs across different parts of a field. Precision farming allows for the consideration of this variability and the application of an individualized approach to each area. This technology promotes environmental sustainability by ensuring the rational use of resources, reducing soil and groundwater pollution, and decreasing the use of fertilizers and pesticides through precise control of every stage of agricultural production. A 2021 study found that farmers using precision technologies achieved a 4 % increase in yield and a 7 % improvement in fertilizer application efficiency. Additionally, these practices led to a 9 % reduction in herbicide and pesticide use, contributing to the sustainable development of agriculture (Association of Equipment Manufacturers, 2021). A study by the U.S. Government Accountability Office (GAO) revealed that precision farming technologies can improve resource management through the precise application of resources such as water, fertilizers, and micronutrients, leading to increased yields and reduced environmental impact (U.S. Government Accountability Office, 2024).

One of the fundamental tools of precision agriculture is agrochemical soil analysis, which requires priority study for further differential management of agricultural land, increasing crop yields, efficient resource utilization, and ensuring the environmental sustainability of natural ecosystems.

Previous studies in the field of precision agriculture and soil sampling methodology have significantly influenced the evolution of modern nutrient management strategies in agricultural systems. A literature review conducted by the authors highlights the transformation of sampling technologies and their integration into practical farming applications. Notable contributions have been made by researchers such as Qin Zhang, Dennis Ess, Margaret Oliver, Thomas Bishop, Ben Marchant, D. Kent Shannon, David E. Clay, Newell R. Kitchen, and John F. Shanahan. It is also important to recognize the significant contributions of Ukrainian scientists, including L. Moldovan, L. Novakivsky, B. Parkhaver, P. Sabliuk, and A. Tretiak. Challenges related to the implementation of precision agriculture technologies are explored in the works of L. Aniskevych, D. Voitiuk, V. Haram, M. Makarenko, O. Tkachenko, and M. Tsyhanenko**.**

The goal of this paper is to analyse, summarize, and evaluate the application of agrochemical soil analysis as a foundation for solving precision agriculture tasks, as well as to explore the potential of geoinformation technologies as a platform for visualizing spatial agricultural challenges and facilitating effective decision-making.

Presentation of Main Material. The technology of agrochemical soil analysis consists of three main stages: sample collection, laboratory (desk) analysis, and the issuance of recommendations adapted to the realities of Ukraine.

The data processing stage is crucial in the research process, as it involves the analysis, interpretation, and integration of laboratory (desk) results into field management decisions. The study includes spatial pattern analysis, the creation of cartographic models, and the preparation of agronomic recommendations for optimizing fertilizers use and increasing crop yields. The effectiveness of these solutions depends on the quality of this stage. Therefore, the preparatory stage (document analysis and selection of the sampling scheme) and the field stage– determining sampling routes and collecting soil samples– are of primary importance.

Methods

The research was conducted by the authors on a field covering an area of 309.6 hectares, located near the village of Berizka in the Varvynska Territorial Community of the Pryluky district, Chernihiv region, based on data from the agricultural company Kernel (Fig. 1). The soils of the field are predominantly represented by typical low humus chernozems and degraded light loamy chernozems, which have high agricultural potential but require special attention to maintaining their fertility and structure.

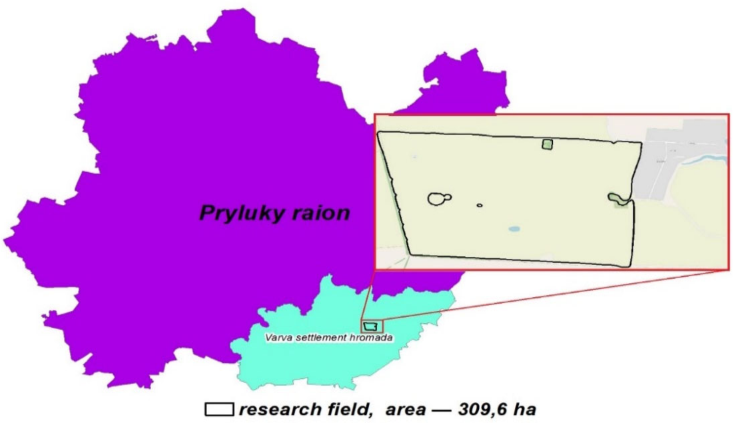


Fig. 1. Location of the Studied Field with an Area of 309.6 hectares

The relief is heterogeneous, with an elevation difference of 20 meters and gentle slopes (gradient up to 4°). Combining a digital elevation model (Fig. 2(a)) with a topographic *wetness index (Fig. 2(b)), calculated as ln (a/tan β), where* "*a*" *is the local upslope area per unit contour length and "tan β"* is the local slope angle (Beven, & Kirkby, 1979), allows for predicting the risks of water erosion within the field. Under such conditions, runoff flows are formed, which can lead to the formation of gullies or soil washout.

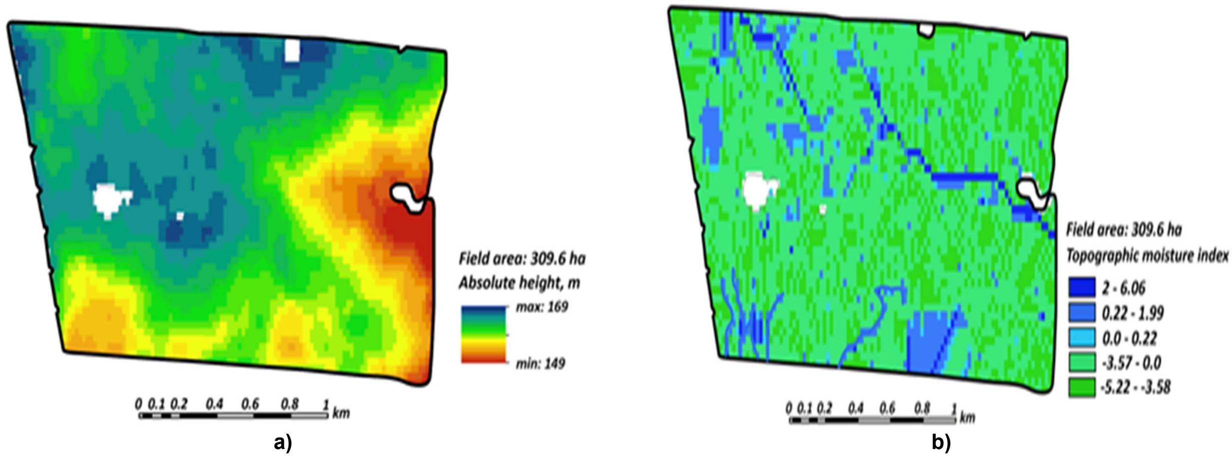


Fig. 2. Digital Elevation Model (a) and Topographic Wetness Index Map (b), of the Studied Field with an Area of 309.6 ha

Soil sampling begins with determining the configuration and area of elementary plots. There exist several soil sampling strategies, with each agricultural enterprise to select the most suitable one based on the specific field's goals and characteristics. When creating a zonal sampling scheme (Fig. 3), historical data (such as soil agroproduction group maps and yield maps for at least the past three years, topographic maps), data from soil conductivity monitoring devices, meteorological information, and remote crop monitoring data (various vegetation indices, including NDVI, EVI, and SAVI) are used. Each of these data types can be applied individually or in combination, with weighted influence coefficients (Brovarets, 2018).

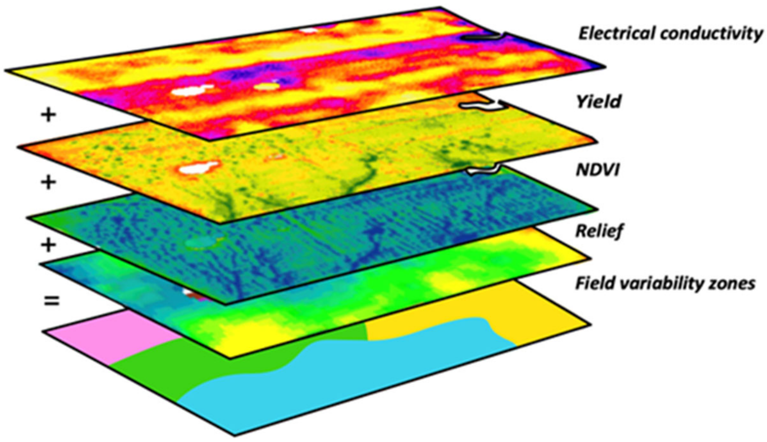


Fig. 3. Field Zoning Based on Variability Parameters of Soil Conditions and Crops

Soil sampling is conducted using a mobile automated system consisting of a navigation system, a field computer, an automatic soil sampler, and a high-clearance vehicle equipped with this technology. Once the equipment is connected, the operator traverses the field along a given sampling route. The location of each borehole is recorded using a navigation receiver with coordinating referencing. Automated soil samplers ensure a standardized sampling depth, which is a critical requirement for obtaining reliable agrochemical analysis results. The high level of automation and integrated control systems minimize the influence of human error reducing the risk of inaccuracies during this initial and critically important stage of research. Due to the equipment's high operational speed, each sample can be collected in 10–15 seconds, even on dense soil types, significantly reducing the time required for fieldwork.

In modern precision agriculture, automated soil samplers mounted on tractors and vehicles are becoming an essential tool for speeding up the process and enhancing the accuracy of agrochemical analysis (Fig 4).

Yield maps are created based on data collected by optical or mechanical sensors mounted on grain harvesters. These systems account for the time delay required to move the harvested mass from the header to the grain elevator. The measurement error of modern sensors typically does not exceed 5 %. Yield is calculated with reference to the harvester's position in the field using GPS equipment (Shevchenko, 2019).

The yield map of the studied 309.6 ha corn field for 2020 indicates uneven soil erosion, leading to reduced yields in eroded areas and increased yields in accumulation zones. The average grain yield per hectare of the field is 8.14 t/ha (Fig. 5).

In the absence of sufficient historical data, geomorphological features of the area, slope gradient information, soil color, and texture from satellite or aerial imagery can be used to delineate zones.

The agrochemical properties of soil can vary significantly even within small field areas requiring a meticulous approach to sample collection for analysis. The sampling scheme and grid density directly affect the accuracy of nutrient content assessments. Tab. 1 presents a comparison of soil sampling approaches developed by the authors.

Fig. 4. Automatic Soil Sampler AgriSoilSample by the Ukrainian Company Agrilab
(Soil Sampler AgriSoilSample, 2024)

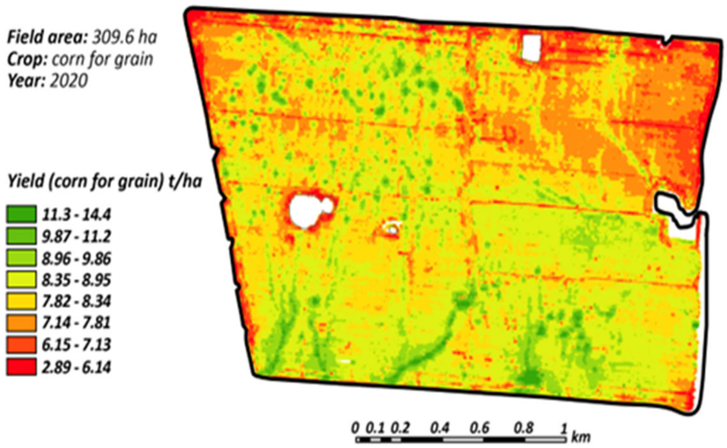


Fig. 5. Yield Map of the Field Studied as of 2020

Table 1

Comparison of Approaches to Soil Sampling

Sampling Scheme	Methods Of Sampling	Advantages	Disadvantages
Grid Scheme (sampling by cells)	sampling from various points within cells using transects	- need for fewer soil samples compared to point-based methods - no restrictions on the size of the elementary plot (cell) - requiring no detailed information about the field - low cost	- less accurate reflection of variability within the field, as it smooths out minor variations within cells
Grid Scheme (sampling by points)	sampling from the center of each cell or at grid line intersections	- providing detailed information on soil variability by adjusting grid density - ensuring accurate results for complex zones - requiring no detailed information about the field	-need for many samples and a dense grid - high cost - for cartographic development, additional GIS analysis (e.g. interpolation) is required
Zonal Scheme	taking several soil samples within boundaries of each defined zone	- covering areas with higher variability using fewer samples - being less time-consuming and labor-intensive due to fewer samples	- need for data on field productivity and yield from previous years - spatial information must be available to define zones - requiring professional knowledge of agronomy and GIS for defining zones

In the grid-sampling scheme, the elementary plots are land parcels of equal size, typically rectangular or square in shape. The maximum area of these plots depends on the client's preferences for agrochemical field surveys, but it should not exceed the allowable areas determined by natural zones and types of agricultural land. For example, the maximum area of an elementary plot on non-irrigated lands of the forest-steppe zone is 15 hectares, while on irrigated lands of Transcarpathia it is 2 hectares (Yatsuk, & Balyuk, 2019).

Soil sampling can also be performed at the intersections of grid lines. To create a composite sample, 8–15 samples from an area located approximately 5–10 meters from the intersection point are randomly combined (Singh, Caughman, & Park, 2020). The results are visualized using interpolation, a mathematical method used for spatial prediction of parameter values at unknown points based on data obtained at known coordinates. The accuracy of the map created through interpolation depends on several critical factors. Firstly, the sampling grid density plays a key role: fewer sampling points increase the risk of predicting errors, particularly in the fields with high variability. Secondly, a heterogeneous relief and the geographical features of the field can complicate predictions. Additionally, the choice of interpolation algorithm (for example: kriging or inverse distance weighting) significantly impacts the accuracy of the raster surface.

The grid strategy is further divided into two subtypes: cell sampling and point sampling (Austin, Gatiboni, & Havlin, 2020). The cell approach involves collecting several dozen soil samples from various points within each cell following a specific route. For elongated and narrow elementary plots, sampling routes for composite samples are laid along the plot or in a zigzag pattern at set intervals. If the plot is square-shaped, the most optimal sampling pattern is a checkerboard layout. On very large fields, point samples are placed diagonally (Fig. 6). On slopes, sampling is conducted in the upper, middle, and lower parts of the field.

The point approach involves selecting a single point for soil sampling from each elementary plot, typically at its center (Fig. 7).

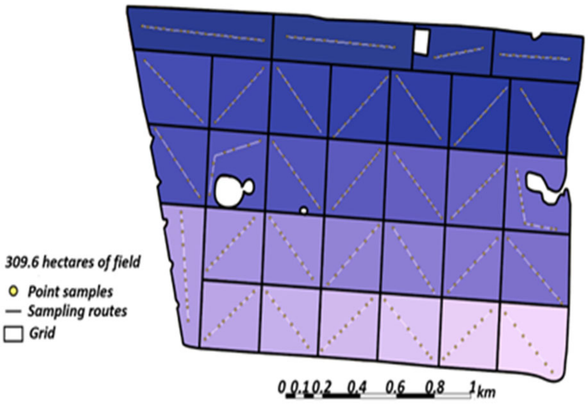


Fig. 6. Grid-based Soil Sampling Scheme with Diagonal Movement at a Grid Density of 10 ha

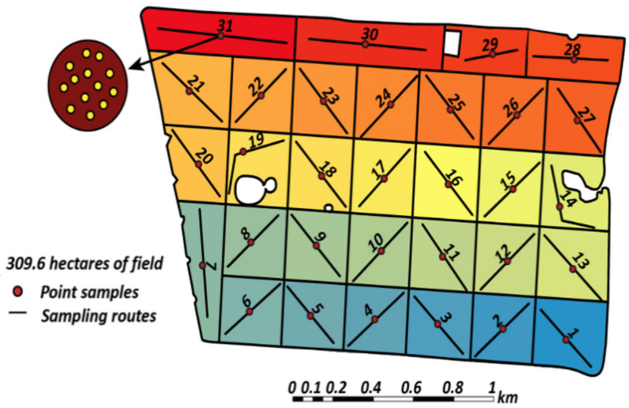


Fig. 7. Point-based Soil Sampling Scheme at a Grid Density of 10 ha

Reducing the size of the soil sampling grid increases the accuracy of determining the agrochemical variability of the field. However, this entails a considerable rise in financial costs. Specifically, as of 2024, the average cost of analysing a single soil sample in Ukrainian agricultural laboratories ranges from 1,500 to 2,500 UAH (Where to Conduct Soil Analysis..., 2024).

Since ensuring data comparability requires soil sampling to be conducted at the same geographic coordinates each time, it is essential to incorporate historical and statistical field data at the initial stage. This includes previous agrochemical analysis results, terrain features, and soil condition variability. Based on this information, an optimal sampling scheme and grid density should be established to balance the accuracy of the collected data with the cost-effectiveness of the survey.

Results

Table 2 and Fig. 8 present the results of the laboratory stage of agrochemical analysis of the 309.6-hectare cultivated field for the year 2020 provided by the agricultural company Kernel. The values of the parameters were determined using methodologies selected by KernelLab. The buffer pH soil determination method was developed by Frank J. Sikora, an associate professor from the university of Kentucky (Sikora, 2005); and the method for determining potassium, calcium, magnesium, and sodium content was devised by D. Warncke and J. R. Brown (Warncke, & Brown, 1988). Additionally, international standards localized for Ukraine, such as DSTU ISO 10390 (DSTU ISO 10390: 2019), DSTU ISO 14870 (DSTU ISO 14870: 2005), DSTU 4289:2004 (DSTU 4289: 2004, 2004), DSTU 4115-2002 by the Chirikov method (DSTU 4115-2002, 2002), DSTU 3866-99 (DSTU 3866-99, 1999) were applied. The sampling grid density under the cell-based sampling scheme was 10 hectares, with composite sample values averaged for the studied field.

The interpretation of the results obtained is a key stage in agrochemical analysis, as the effectiveness of subsequent agronomic decisions depends on the accurate understanding of these data. Indicator values should be presented in a convenient and comprehensible format, which allows for a clear assessment of soil conditions and the development of recommendations.

Agrochemical maps are additional visual materials that modern laboratories provide along with the agrochemical soil report. These maps, available in both paper and electronic formats, illustrate different levels of humus content, nutrient availability in the soil, and soil solution reaction (Fig. 9). The classification of soils based on agrochemical indicators involves color gradations representing the content of mobile nutrient compounds in milligrams per kilogram of soil, humus percentage, and acidity or alkalinity levels based on pH values. For instance, the agrochemical analysis of the studied field in 2020 showed that the soil had a slightly acidic to near-neutral reaction, a medium to low organic matter content, and a predominantly sufficient level of mobile phosphorus and potassium, with some areas exhibiting elevated values of these indicators.

Agrochemical soil analysis provides essential information for optimizing the process of variable-rate fertilizer and seed application. Based on the obtained data regarding soil type, macro- and micronutrient content, organic matter levels, moisture status, and other key parameters, it is possible to precisely determine the nutrient needs of specific field sections. This enables the development of an effective agronomic strategy tailored to the field's specific conditions. The maps in Fig. 10 indicate a significant demand for phosphorus and potassium fertilizers in the studied field as of 2020. Most areas required applications of 60–85 kg/ha of P_2O_5 and K_2O, with localized zones showing lower or minimal fertilization needs.

Table 2

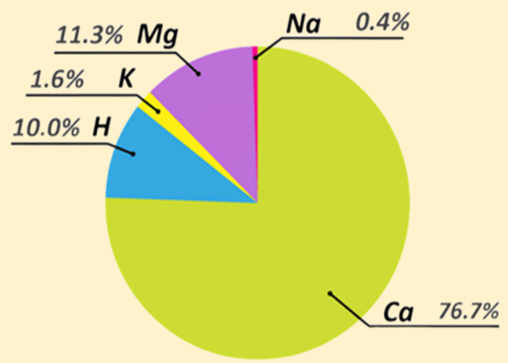
Agrochemical Survey of the Investigated Field

Indicator	Method	Min Value	Max Value	Average Value	Standard Deviation
pH (KCl), unit	DSTU ISO 10390:2019, IDT	5.1	6.6	5.7	0.28
buffer pH, unit	Sikora method (Sikora,2005)	6.5	7.1	6.8	0.15
organic matter, %	DSTU 4289:2004	3.2	4.2	3.7	0.22
mobile Phosphorus (P_2O_5), mg/kg	DSTU 4115-2002 (by Chirikov's method)	114.0	215.7	142.9	17.65
exchangeable potassium (K), mg/kg	Chirikov's method	94.5	179.3	121.2	17.66
exchangeable calcium (Ca), mg/kg	*selected testing methods ("Recommended chemical soil test procedures for the Central North Region. Chapter 7: Potassium and other Basic Cations" by D. Warncke and J.R. Brown; "Midwest Laboratories Calculating Cation Exchange Capacity and the Percent Base Saturation") At- pH=7.0 (Ward, R. C. n.d.), (Midwest Laboratories. n.d.)*	2603.6	3668.9	2984.3	178,54
exchangeable magnesium (Mg), mg/kg		225.3	286.9	263.8	10.49
exchangeable sodium (Na), mg/kg		14.8	33.5	20.1	4.21
copper (Cu), mg/kg	DSTU ISO 14870:2005	0.55	0.74	0.62	0.06
zinc (Zn), mg/kg	DSTU ISO 14870:2005	0.47	2.69	0.89	0.72
manganese (Mn), mg/kg	DSTU ISO 14870:2005	25.0	48.8	34.4	7.17
iron (Fe), mg/kg	DSTU ISO 14870:2005	33.0	75.1	53.8	12.92

Cation Exchange Capacity (CEC)
Laboratory Methodology *(Warncke and Brown, 1998; Raymond C. Ward, n.d.; Midwest Laboratories Calculating, n.d.)*
at pH=7.0

19.4 mg Eq/100g

Base Saturation



Salinization Degree
(DSTU 3866-99 "Soils. Classification of Soils by the Degree of Secondary Salinization")
$(K + Na)/(Ca + Mg + K + Na)$
2.27%
non-saline

Fig. 8. Results of Agrochemical Survey of the Field Studied according to Kernel Agro company Data

The amount of fertilizer application is determined based on the planned crop rotation, target yield, and agrochemical condition of the soil. This process is carried out by creating prescription maps for agricultural machinery, including spreaders, sprayers, or fertilizer applicators. A prescription map is a cartographic representation that contains information about variable fertilizer application rates or seeding rates. These data are integrated with controllers installed on agricultural equipment and used in conjunction with navigation systems to precisely regulate the application rate in different field zones. The application process operates offline, adapting to the specific characteristics of each area (Zatserkovnyi, & Vorokh, 2024). Based on the quantitative soil indicators of the studied field in 2020, the prescription maps (Fig. 11) illustrate a differentiated approach, prescribing varying amounts of complex (NPK), nitrogen-phosphorus, and potassium fertilizers per hectare at different stages of field treatment in the following planting season.

A promising direction in modern agricultural production is the development of sensors for real-time determination of soil physicochemical properties (Sokolik, 2024). The most widely used are electrical and electromagnetic sensors, which allow for the assessment of soil conductivity revealing heterogeneity in texture and other properties. At the same time, optical sensors are being developed to implement remote monitoring algorithms, and electrochemical devices can evaluate pH and ion content in the soil solution. Mechanical, acoustic, and pneumatic sensors are used to assess the physical state of the soil, particularly its compaction. Although the commercial application of many of these devices is still in its early stages, their potential to reduce the costs of agrochemical analysis and improve the accuracy of differentiated fertilizer applications is significant.

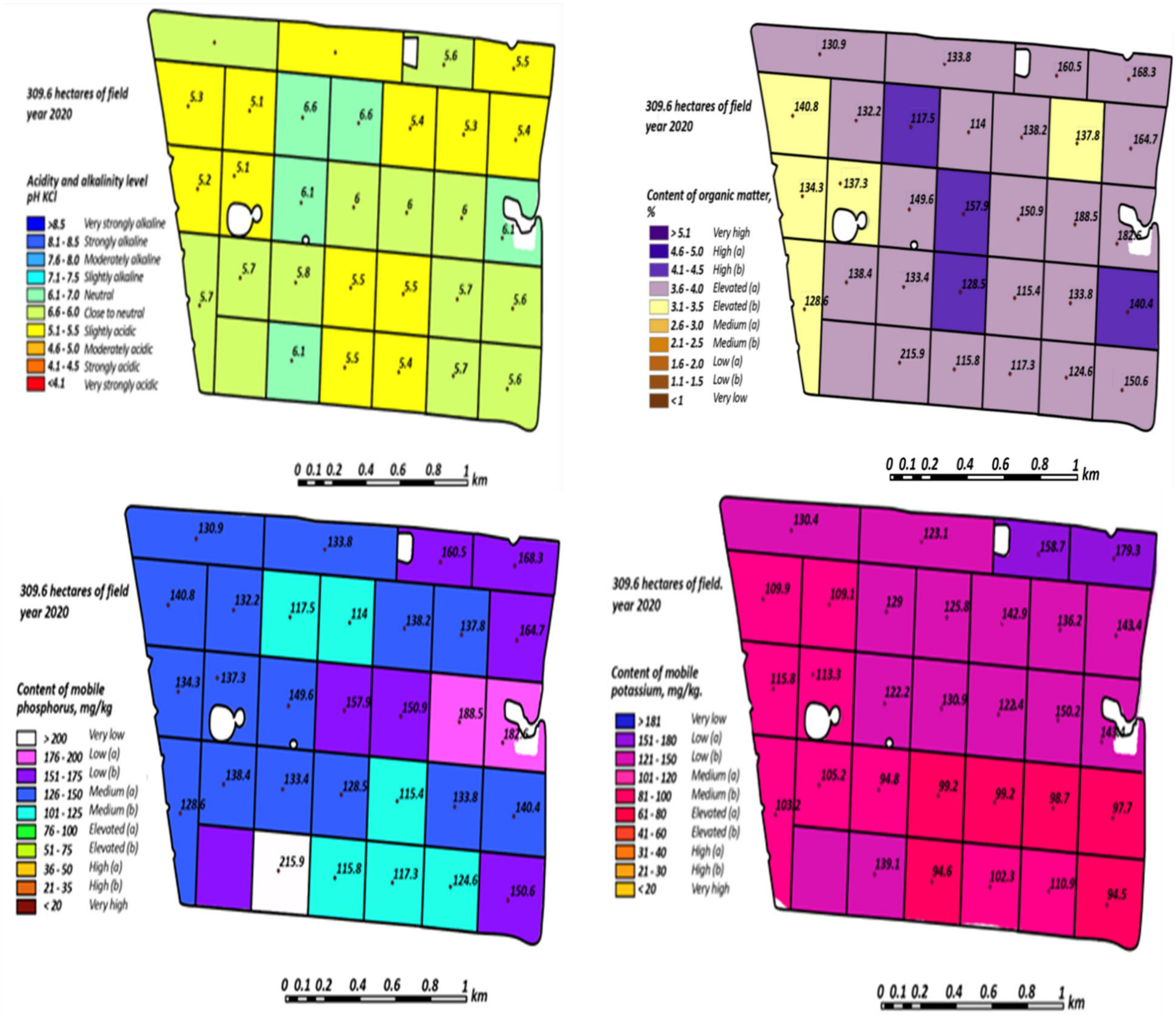
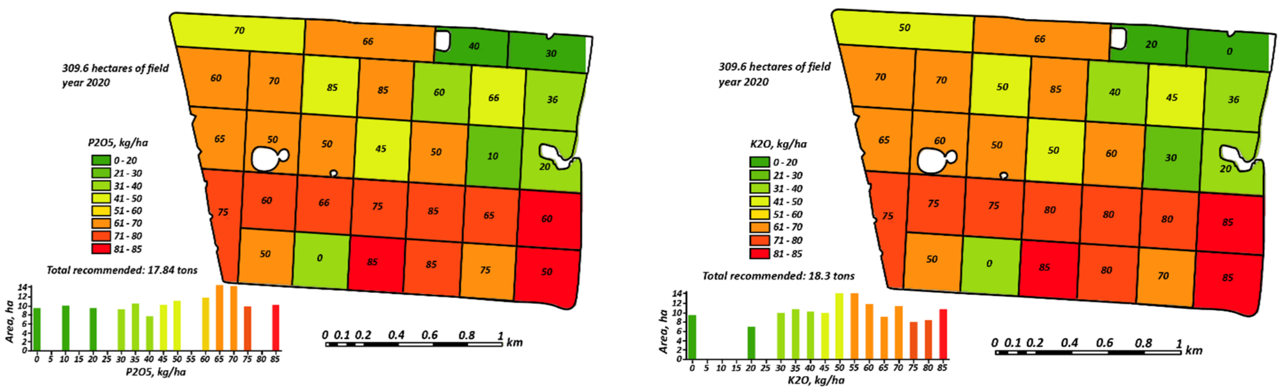


Fig. 9. Cartograms of Soil Acidity and Selected Indicators of the Studied Field



a) b)

Fig. 10. Cartographic Assessment of Elementary Plots' Need for Available Phosphorus (a) and Potassium (b) Based on Agrochemical Analysis

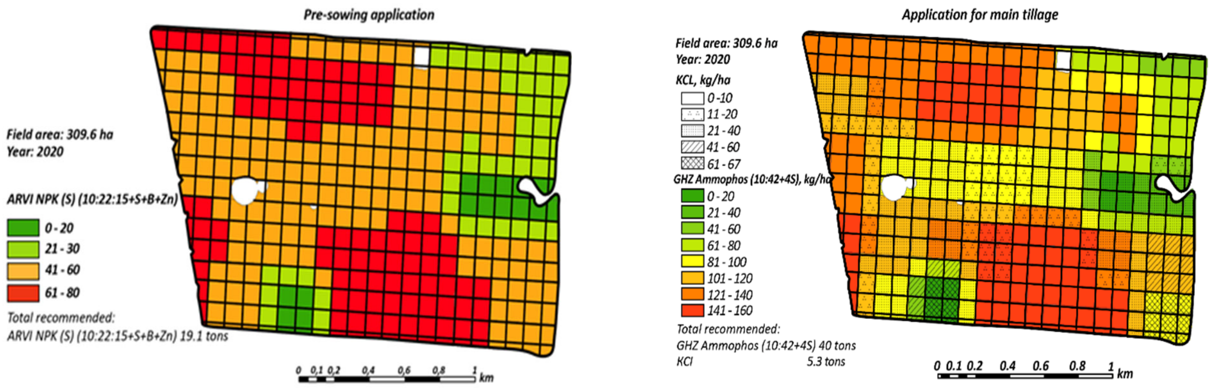


Fig. 11. Task Maps for Agricultural Machinery for Applying Compound Fertilizers to the Field Studied at Different Cultivation Stages

Discussion and conclusions

Agrochemical soil analysis and the implementation of precision farming technologies are essential tools for increasing the efficiency and environmental sustainability of agricultural production. The presented research highlights the importance of a comprehensive approach to soil analysis, which includes careful sample collection, laboratory testing, spatial data interpretation, and the development of recommendations to optimize agronomic practices. In particular, the agrochemical analysis of soil pH in the studied field, covering an area of 309.6 ha in 2020, ranged from 5.1 to 6.6, with an average value of 5.7, indicating a slightly acidic reaction. The average organic matter content was 3.7 %, while the levels of mobile phosphorus and exchangeable potassium were 142.9 mg/kg and 121.2 mg/kg, respectively. Considering the results of the agrochemical soil survey, the terrain, and the average corn yield in the studied field in 2020, which amounted to 8.14 t/ha, with a maximum yield of 14.4 t/ha in certain areas, soil nutrient requirements for the 2021 planting season were determined. The recommendations included applying up to 40 tons of ammonium phosphate and 5.3 tons of potassium fertilizer during primary field treatment, as well as 19.1 tons of NPK(S) during pre-sowing treatment. Variable-rate fertilizer application was carried out according to the developed prescription maps.

Modern methods enable the consideration of diverse soil properties and climatic conditions, ensuring an individualized approach to managing each field section. Specifically, the use of agrochemical maps, variable-rate fertilization systems, and the development of real-time sensors provide new opportunities for more precise and cost-effective farming.

The implementation of geoinformation technologies and remote sensing facilitates the efficient visualization of soil analysis results, the creation of prescription maps for agricultural machinery, and informed decision-making. This approach minimizes resource losses, reduces environmental impact, and enhances crop yields.

Despite the promising prospects, challenges related to the high cost of technology and agrochemical soil analysis must be considered. Future research should focus on expanding the potential of remote sensing data, land cover analysis methods, and real-time soil property detection sensors.

Authors' contributions: Vitalii Zatserkovnyi – conceptualization, methodology, writing; Viktor Vorokh – remote sensing data processing, methodology, search for optimal solutions to the problem; Olga Hloba – geoinformation analysis, data processing, writing; Tetiana Mironchuk – data analysis and processing, writing (review and editing); Iryna Siuiva– data analysis and processing.

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АГРОХІМІЧНИЙ АНАЛІЗ ҐРУНТІВ У ТЕХНОЛОГІЯХ ПРЕЦИЗІЙНОГО ЗЕМЛЕРОБСТВА НА ПРИКЛАДІ ЧЕРНІГІВСЬКОЇ ОБЛАСТІ

Вступ. ***Прецизійне землеробство спрямоване на створення комплексної системи підтримки прийняття рішень, що підвищує ефективність і стійкість сільськогосподарських методів. Воно ґрунтується на принципі, що поля не є однорідними та мають різні ділянки з різними характеристиками. Різноманітність ґрунтів, рельєфу, кліматичних умов та інших факторів призводить до того, що потреби рослин на різних ділянках поля відрізняються. Точне землеробство дає змогу врахувати цю різноманітність і застосовувати індивідуальний підхід до кожної ділянки.***

Представлено комплексний підхід до аналізу всіх ключових етапів агрохімічного обстеження: від підготовчого етапу до лабораторного аналізу, створення агрохімічних картограм і розробки карт потреби в добривах та карт завдань для сільськогосподарської техніки. Особливу увагу приділено можливостям використання даних ДЗЗ та геоінформаційних технологій для обробки та візуалізації результатів.

Методи. ***Відбір ґрунту починається з визначення конфігурації та площі елементарних ділянок. Розглянуто кілька стратегій відбору проб ґрунту, кожне агропідприємство обирає найкращу для себе, залежно від мети та особливостей конкретного поля.***

Агрохімічні властивості ґрунту здатні істотно змінюватися навіть на невеликих ділянках поля, що потребує ретельного підходу до відбору проб для аналізу.

Результати. ***Розроблені агрохімічні картограми – додаткові наочні матеріали, які сучасні лабораторії видають разом з агрохімічним звітом ґрунту. Це зображення на паперових та електронних носіях різних рівнів вмісту гумусу, поживних речовин у ґрунті та реакції ґрунтового розчину.***

Висновки. ***Агрохімічний аналіз ґрунту забезпечує інформацією, необхідною для оптимізації процесу диференційованого внесення добрив та насіння. На основі отриманих даних про тип ґрунту, вміст макро- та мікроелементів, органічної речовини, рівень зволоженості та інші ключові показники можна точно визначити потреби елементарних ділянок у поживних речовинах. Це дає змогу розробити ефективну стратегію агротехнічних заходів, адаптовану до конкретних умов поля.***

Ключові слова: ***прецизійне землеробство, агрохімічний аналіз ґрунту, схема відбору проб, геоінформаційні технології, автоматизація сільського господарства, картографування ґрунту.***

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