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Baseline assessment and comparative analysis of soil properties: A case study from an agricultural research farm in western Ukraine

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ABSTRACT

Soil monitoring at the Educational and Research Production Farm "Nauka" of the West Ukrainian National University was conducted to establish baseline characteristics of soil quality and evaluate the suitability of soils for agricultural production. The study was based on the assessment of physical, chemical, and biological soil properties in two experimental fields (Fields 7 and 8). Soil samples were analysed for pH, electrical conductivity, organic matter content, nutrient availability, cation exchange capacity, and the abundance of ecological and functional groups of soil microorganisms. The results showed that both fields were characterised by favourable soil conditions for agricultural use. Soil pH values indicated predominantly neutral conditions, with average values of 6.7 in Field 7 and 7.2 in Field 8. Electrical conductivity ranged from 14 to 42 mS/m in Field 7 and from 14 to 29 mS/m in Field 8, confirming the absence of salinity constraints. Organic matter content was stable and reached 3.1% in Field 7 and 3.2% in Field 8, indicating favourable conditions for maintaining soil fertility. Chemical analysis revealed differences in nutrient availability between the fields. Field 7 contained higher concentrations of nitrogen (7.5 mg/kg), phosphorus (18.6 mg/kg), potassium (133.9 mg/kg), manganese (14.2 mg/kg), and iron (45.7 mg/kg), while Field 8 showed higher calcium (3875.6 mg/kg), magnesium (138.4 mg/kg), and cation exchange capacity (23.3 mg-eq/100 g). The assessment of soil biological activity demonstrated active microbial processes in both fields. The abundance of oligonitrophilic and nitrogen-fixing bacteria reached an average of 2.88×10^7 CFU/g in Field 7 and 2.29×10^7 CFU/g in Field 8. Field 7 generally exhibited higher microbial activity, including greater abundance of phosphate-mobilising bacteria, pedotrophs, and cellulolytic microorganisms, whereas Field 8 showed stable microbial functioning under lower nutrient availability conditions. The obtained results provide baseline information for further soil monitoring and support the development of sustainable soil management strategies for improving fertility and agricultural productivity.

Keywords: soil monitoring, soil fertility, soil chemical properties, soil microorganisms, nitrogen-fixing bacteria, agricultural productivity.

INTRODUCTION

Soils are among the most important natural resources, underpinning ecosystem functioning and sustaining agricultural productivity (Zeiss et al., 2026). They perform a wide range of essential functions (Wadoux et al., 2026, 2026a), including providing a medium for plant growth, contributing to the natural water cycle (Lechevallier, et al., 2025), regulating temperature and moisture regimes, and serving as habitats for diverse biological communities. Soil quality therefore has a direct influence on agricultural output (Perović et al. 2025) and the overall ecological condition of landscapes. However, intensive land use, climate change (Marques-dos-Santos et al. 2026) and environmental pollution (Yang et al., 2024, Smith et al. 2025) are continuously altering soil properties (Coblinski et al., 2025), highlighting the need for systematic monitoring and assessment.

Soil monitoring is a key tool for evaluating soil condition, increasingly supported by machine learning approaches (Zou et al., 2026, Pasut et al., 2026), and for identifying processes such as degradation, salinisation, erosion, and contamination. It also provides a scientific basis for selecting effective agronomic measures (Sreeram et al., 2025) aimed at improving soil properties and maintaining fertility. A variety of methods are used to assess soils (Ndikuryayo et al., 2025), enabling the accurate characterization of their physical, chemical, and biological attributes (Rybalova et al., 2022, Bondar, et al., 2023). These data are essential for developing recommendations for sustainable soil management.

To study soil condition of n western Ukraine, a soil monitoring was launched at the Educational and Research Production Farm 'Nauka' of the West Ukrainian National University. Located in one of the most agriculturally developed regions of Ukraine, this farm represents an appropriate research site, as it encompasses diverse agroclimatic conditions that enable evaluation of a broad range of soil properties.

The objective of the first stage of monitoring was to collect baseline data on the key physical, chemical, and biological properties of soils within the farm. This included the assessment of soil fertility, acidity, organic matter and mineral content, as well as an evaluation of the effects of anthropogenic factors on soil condition. The collected data provide a basis for characterising the current state of the soils and for identifying potential constraints that must be addressed to ensure their sustainable use. Particular attention was also given to soil biological activity, which serves as a sensitive indicator of soil ecological status and fertility.

Soil monitoring at the 'Nauka' farm constitutes an important step toward establishing a robust baseline for further research and for developing effective recommendations to improve soil condition. The results will support the development of sustainable land-use practices, the preservation of soil fertility, and environmental sustainability, which are essential for ensuring food security and environmental protection under conditions of climate change and intensive land use.

Despite the increasing number of studies focused on soil fertility assessment, there is still limited information on the integrated evaluation of agricultural soils that combines physicochemical characteristics with biological indicators, particularly for specific agricultural farms in western Ukraine. Previous studies have mainly focused on individual soil properties or regional comparisons, while comprehensive baseline datasets describing both nutrient status and microbial activity at the field level remain insufficient.

The novelty of this study is the integration of chemical, physical, and biological soil assessments within a single monitoring framework to characterise the current condition of agricultural soils at the Educational and Research Production Farm "Nauka" of the West Ukrainian National University. Unlike studies based mainly on chemical fertility indicators, this research combines nutrient analysis with the evaluation of ecological and functional groups of soil microorganisms, providing a more comprehensive understanding of soil quality and fertility status. The obtained baseline information can serve as a reference for future monitoring and the development of sustainable soil management strategies under changing environmental conditions.

MATERIALS AND METHODS

Soil sampling was carried out according with national standards DSTU 4287:2004 and DSTU ISO 11464:2007 (DSTU 4287:2004, 2007). Samples were collected using a shovel or soil auger. Polyethylene bags were used for sample storage and transport for subsequent chemical and microbiological analyses. Laboratory analyses were performed at the MicroBio Laba Testing Laboratory of the Laboratory Research and Development Centre (Teplodar, Odesa region, Ukraine). The laboratory holds a Certificate of Recognition of Measurement Capabilities No. pt-286/24 dated 01 October 2024. It is accredited in accordance with DSTU EN ISO/IEC 17025 for physical, chemical, and microbiological testing of soils, grain, seeds and plant materials, and is certified under DSTU ISO 10012:2005 (MicroBio Laba, 2026).

The determination of ecological and functional groups of soil microorganisms – including oligonitrophilic and nitrogen-fixing bacteria, phosphate-mobilising bacteria, streptomycetes, pedotrophs, ammonifiers, amylolytic bacteria, micromycetes, oligotrophs, and cellulolytic micromycetes – was conducted in accordance with regulatory document M.TsLDR 7.2-02-13. Based on these data, pedotrophicity, mineralisation-immobilisation, and oligotrophicity indiceswere calculated (MicroBio Laba, MicroBio Laba, 2026).

The following analytical methods were used to determine the chemical properties of the soils. Soil pH (H_2O) and pH (buffer solution) were determined in accordance with M.TsLDR 7.2-01-07 method. Electrical conductivity was measured using M.TsLDR 7.2-01-08 method. Soil organic matter content was determined according to M.TsLDR 7.2-01-10 method. Nitrate nitrogen and sulphur were analysed following M.TsLDR 7.2-01-09 method. Available phosphorus (Bray P1 method) was determined in accordance with M.TsLDR 7.2-01-02 method. Exchangeable potassium, sodium, and magnesium were analysed using M.TsLDR 7.2-01-06 method. The concentrations of zinc, copper, manganese, and iron were determined according to M.TsLDR 7.2-01-05 method, while boron was analysed using M.TsLDR 7.2-01-04 method. Cation exchange capacity (CEC) and base saturation (Ca, Na, Mg) were determined in accordance with M.TsLDR 7.2-01-11 method. These standardised methods ensure accurate determination of the physical and chemical properties of soils, as well as their biological condition, which is essential for environmental monitoring and agronomic research.

Statistical analysis and data processing

Statistical analysis and data visualization were performed using the R programming language (R Core Team) within the RStudio environment. The readxl package was utilized to import raw data from spreadsheets. Data wrangling, including cleaning and transforming the dataset from a wide to a long format, was conducted using the functions provided by the dplyr and tidyr packages.

To ensure a comprehensive approach to soil health assessment and the accurate visualization of multidimensional data, all investigated parameters were conceptually divided into three functional groups: 1) physicochemical and agrochemical parameters; 2) macro- and microelement content; 3) microbiological activity and ecological coefficients. This categorization is methodologically essential as it prevents the confounding of fundamentally different units of measurement (e.g., percentages, mg/kg, and millions of CFU/g) and enables the application of optimal graphical scales for each specific group. From an ecological perspective, this structured approach facilitates a systemic analysis: progressing from the evaluation of baseline fertility conditions and nutrient availability to the biological activity of the soil microbiome, which serves as a crucial bioindicator of overall ecosystem health.

A comparative analysis of the parameter distributions between the studied soil fields was executed using boxplots. This method allowed for the visualization of medians, interquartile ranges, and the identification of potential statistical outliers within each sample group. Graphical visualization of the results was generated using the ggplot2 package. For parameters exhibiting substantial variance or high absolute values (e.g., microbiological activity), a logarithmic scale (log10) was applied to ensure an accurate and comprehensive comparison of the variables within their respective groups.

RESULTS

The first stage of soil monitoring at the Educational and Research Production Farm 'Nauka' of the West Ukrainian National University was conducted to assess the chemical properties of the soils and to evaluate their fertility and capacity to supply essential nutrients to plants. During this stage, laboratory analyses were performed on soil samples collected from two experimental plots – Field 7 (Table 1) and Field 8 (Table 2). The analyses focused on key chemical parameters, including pH, electrical conductivity, organic matter content, and concentrations of macro- and micronutrients (Figure 1). As this represents the initial phase of the research, the results provide a general overview of soil chemical composition. These findings form a basis for further agronomic planning and help determine the need for fertiliser application or adjustments to soil management practices.

Soil pH is a critical parameter that determines the acid-base balance and directly influences nutrient availability to plants. The solubility and plant uptake of many elements depend on pH conditions. According to the results of the first monitoring stage, soil pH in Field 7 ranged from 6.0 to 7.5, with an average value of 6.7. This indicates slightly acidic to neutral conditions, which are generally optimal for most agricultural crops. Such pH levels ensure adequate availability of essential nutrients, including nitrogen, phosphorus, and potassium. In Field 8, pH values ranged from 6.2 to 7.7, with an average of 7.2, also indicating predominantly neutral conditions. However, the wide range of pH values observed in Field 8 suggests spatial variability in soil chemical

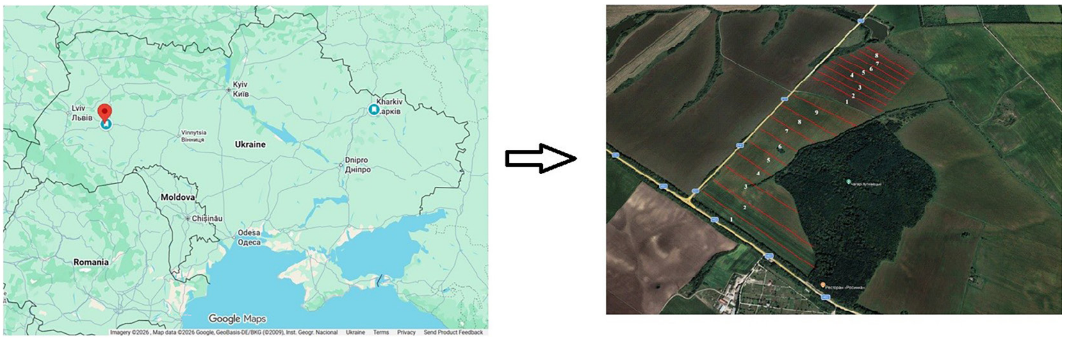

Figure 1. Research flowchart (Ternopil, Ukraine)

Table 1. Chemical analysis of soil samples from Field 7 of the Educational and Research Production Farm 'Nauka'

Characteristics	Units	Number of soil sample									M ± SD
		1	2	3	4	5	6	7	8	9	
pH (H_2O)	pH units	7.5	6.3	6.9	7.2	6.8	6.5	6.1	6	7.2	6.7 ± 0.53
pH (buffer)	pH units	7.2	6.7	7.0	7.2	7.0	6.8	6.6	6.5	7.1	6.9 ± 0.26
Electrical conductivity	mSm/m	30.0	15.0	17.0	22.0	19.0	18.0	16.0	14	42.0	21.4 ± 9.1
Organic content	%	3.2	3.0	3.0	3.0	2.8	3.9	3.0	3.0	2.8	3.1 ± 0.33
Nitrate nitrogen	mg/kg	5.4	9.6	6.5	4.9	6.7	8.2	9.5	7.8	8.8	7.5 ± 1.7
Phosphorus	mg/kg	13.0	15.0	28.0	13.0	8.0	35.0	21.0	22.0	12.0	18.6 ± 8.7
Potassium	mg/kg	142.0	111.0	111.0	150.0	110.0	170.0	136.0	135.0	140.0	133.9 ± 20.3
Calcium	mg/kg	4118	3015.0	3477.0	3669.0	3310.0	3393.0	2616.0	2666.0	3892.0	3350.7 ± 515.2
Sodium	mg/kg	17.0	6.0	8.0	8.0	7.0	7.0	6.0	7.0	7.0	8.1 ± 3.4
Magnezium	mg/kg	146.0	140.0	140.0	156.0	132.0	176.0	130.0	131.0	121.0	140,0 ± 16.7
Sulfur	mg/kg	4.6	3.5	2.0	2.5	2.6	3.1	3.1	3.6	3.2	3.2 ± 0.75
Zinc	mg/kg	0.7	0.5	0.4	0.5	0.5	1.7	0.5	0.8	1.3	0.8 ± 0.,44
Copper	mg/kg	1.0	1.0	0.9	0.9	1.3	2.5	1.1	1.8	1.7	1.4 ± 0.54
Manganese	mg/kg	12.0	14.5	11.9	12.8	10.3	22.7	15.3	16.3	11.8	14.2 ± 3.7
Iron	mg/kg	23.6	44.5	37.0	26.9	38.0	73.3	56.9	60.8	50.0	45,7 ± 16,2
Boron	mg/kg	0.5	0.7	0.6	0.3	0.6	0.7	0.5	0.4	0.2	0.5 ± 0.17
Cation exchange capacity	mg-eq /100 g	22.2	22.3	21.3	20.1	20.4	23.7	21.7	23.2	22.1	21.9 ± 1.2
Base saturation	%										-
H		-	23.6	11.3	0	11.8	20.3	33.1	36.2	5.4	17.7 ± 12.9
K		1.6	1.3	1.3	1.9	1.4	1.8	1.6	1.5	1.6	1,6 ± 0.21
Ca		92.6	66.8	81.7	91.4	81.3	71.6	60.2	57.5	88.2	76.8 ± 13.3
Na		0.3	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2 ± 0.14
Mg		5.5	5.2	5.5	6.5	5.4	6.1	5	4.7	4.6	5.4 ± 0.62

properties, which may require more detailed investigation in subsequent monitoring stages.

Soil electrical conductivity reflects the concentration of dissolved salts in the soil solution and serves as an indicator of soil salinity. Elevated salinity levels may negatively affect plant growth by reducing water availability and impairing nutrient uptake. According to the results of the first monitoring stage, electrical conductivity in Field 7 ranged from 14 to 42 mS/m, with an average value of 21.4 mS/m. These values indicate low to moderate salinity levels typical of agricultural soils and do not suggest salinity-related constraints to crop production. In Field 8, electrical conductivity ranged from 14 to 29 mS/m, with an average of 23.3 mS/m, reflecting conditions comparable to those observed in Field 7. Overall, the electrical conductivity values recorded in both

Table 2. Chemical analysis of soil samples from Field 8 of the Educational and Research Production Farm 'Nauka'

Characteristics	Units	Number of soil sample								M ± SD
		1	2	3	4	5	6	7	8	
pH (H_2O)	pH units	7.4	7.7	7.7	7.6	6.2	7.2	6.8	7.1	7.2 ± 0.52
pH (buffer)	pH units	7.2	7.3	7.3	7.3	6.6	7.1	6.9	7.1	7.1 ± 0.24
Electrical conductivity	mSm/m	28.0	25.0	23.0	26.0	14.0	29.0	20.0	21.0	23.2 ± 4.9
Organic content	%	3.0	3.0	3.0	3.2	3.3	3.5	3.3	3.4	3.2 ± 0.20
Nitrate nitrogen	mg/kg	5.2	3.2	2.5	4.4	4.7	5	3.7	5.4	4.3 ± 1.0
Phosphorus	mg/kg	5.0	3.0	6.0	7.0	2.0	4.0	6.0	4.0	4,6 ± 1,7
Potassium	mg/kg	134.0	119.0	125.0	130.0	111.0	124.0	114.0	122.0	122.4 ± 7.7
Calcium	mg/kg	3851.0	4620.0	4649.0	4336.0	3031.0	3717.0	3284.0	3517.0	3875.6 ± 607.3
Sodium	mg/kg	7.0	6.0	8.0	7.0	6.0	7.0	9.0	9.0	7.4 ± 1.2
Magnezium	mg/kg	140.0	119.0	123.0	124.0	153.0	150.0	150.0	148.0	138.4 ± 14.1
Sulfur	mg/kg	2.8	3.8	3.1	3.8	4.4	2.5	4.6	3.2	3.5 ± 0.75
Zinc	mg/kg	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.4 ± 0.07
Copper	mg/kg	0.9	0.8	0.8	0.9	1.0	0.9	1.0	0.9	0.9 ± 0.08
Manganese	mg/kg	10.1	7.9	7.6	8.7	16.5	10.9	12	11.3	10.6 ± 2.9
Iron	mg/kg	24.8	16.7	15.7	18.5	40.7	28.3	34.5	26.1	25.7 ± 8.8
Boron	mg/kg	0.4	0.3	0.3	0.4	0,4	0.4	0.4	0.4	0.4 ± 0.05
Cation exchange capacity	mg-eq/100 g	20.8	24.4	24.6	23.1	23,7	21.4	21.6	20.4	22.5 ± 1.7
Base saturation	%									
H		0	0	0	0	30.1	5.6	16.7	5.9	7.3 ± 10.9
K		1.7	1.2	1.3	1.4	1.2	1.5	1.4	1.5	1.4 ± 0.17
Ca		92.6	94.6	94.4	93.9	63.6	86.9	76	86.3	86.0 ± 11.0
Na		0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1 ± 0.05
Mg		5.6	4.1	4.2	4.5	5.3	5.8	5.8	6.1	5.2 ± 0.79

fields fall within ranges considered suitable for most agricultural crops and do not indicate significant salinity risks at this stage of monitoring.

Soil organic matter is key indicator of soil fertility. It supports the development of soil microbial communities, improves soil structure, and enhances water-holding capacity. In Field 7, soil organic matter content ranged from 2.8% to 3.9%, with an average value of 3.1%. This level is considered optimal for maintaining soil fertility, as adequate soil organic matter contributes to nutrient retention, improves soil aeration, and supports stable soil structure. In Field 8, soil organic matter content ranged from 3% to 3.5%, with an average of 3.2%. These values also indicate favourable conditions for sustaining soil fertility. However, continued monitoring is necessary to assess long-term trends in organic matter dynamics and their implications for soil productivity and resilience.

The primary macronutrients – nitrogen, phosphorus, potassium, calcium, and magnesium – are essential for plant growth and determine the soil's capacity to sustain agricultural production. In Field 7, nitrogen content ranged from 4.9 to 9.6 mg/kg, with an average of 7.5 mg/kg. This level is generally adequate for plant development, although supplemental nitrogen fertilization may be required to achieve optimal crop yields. In Field 8, nitrogen content ranged from 2.5 to 5.4 mg/kg, with an average of 4.3 mg/kg. Although slightly lower than in Field 7, these values remain within acceptable limits for most crops but may require agronomic adjustment depending on crop demand. Phosphorus content in Field 7 averaged 18.6 mg/kg, indicating an adequate supply of this nutrient. In contrast, Field 8 showed phosphorus levels ranging from 2 to 7 mg/kg, with an average of 4.6 mg/kg, suggesting a pronounced phosphorus deficiency that should be corrected through appropriate fertilization. Potassium, calcium and magnesium levels in both fields were within ranges considered suitable for agricultural soils and do not currently pose limitations to crop production.

Micronutrients play a crucial role in plant growth and development, despite being required in much smaller quantities than macronutrients.

Even at low concentrations, these elements influence physiological processes. metabolic activity, and plant resistance to environmental stress. In Field 7, zinc concentrations ranged from 0.4 to 1.7 mg/kg, with an average value of 0.8 mg/kg, indicating an adequate supply for normal plant growth. In Field 8, zinc levels ranged from 0.3 to 0.5 mg/kg, with an average of 0.4 mg/kg, which is at the lower threshold of the optimal range and may require attention depending on crop sensitivity. Copper concentrations in Field 7 ranged from 0.9 to 2.5 mg/kg, with an average of 1.4 mg/kg. In Field 8, copper content varied from 0.8 to 1.0 mg/kg, with an average of 0.9 mg/kg. Manganese content averaged 14.2 mg/kg in Field 7 and 10.6 mg/kg in Field 8, indicating moderately higher levels in Field 7, which may favour photosynthetic activity and enzymatic processes. Iron concentrations in Field 7 ranged from 23.6 to 73.3 mg/kg, with an average of 45.7 mg/kg, while in Field 8 they ranged from 15.7 to 40.7 mg/kg, with an average of 25.7 mg/kg. Boron, an essential element for cell wall formation, showed an average concentration of 0.5 mg/kg in Field 7 and 3.3 mg/kg in Field 8, indicating considerable spatial variability, particularly in Field 8.

Cation exchange capacity (CEC, mg-eq/100 g) reflects the soil's ability to retain and exchange cations such as calcium, magnesium, and potassium, and is therefore a key indicator of nutrient-holding capacity and overall soil fertility. The average CEC value was 21.9 mg-eq/100 g in Field 7 and 23.3 mg-eq/100 g in Field 8, suggesting a slightly higher capacity for nutrient retention in Field 8. Base saturation in Field 7 was 76.8% for calcium and 5.4% for magnesium, indicating a predominance of calcium among exchangeable bases. Field 8 exhibited a higher overall base saturation, which is generally associated with improved soil structural stability and favourable conditions for plant growth.

Ecological and functional groups of soil microorganisms play a fundamental role in maintaining soil fertility through the transformation of organic and inorganic compounds. These processes are essential for nutrient cycling, ecological balance, and the stability of agroecosystems. The assessment of biological activity in Fields 7 and 8 provides insight into the intensity of these processes and supports the identification of management practices aimed at improving soil quality.

Oligonitrophilic and nitrogen-fixing bacteria are particularly important for enhancing soil fertility, as they contribute to the fixation of atmospheric nitrogen and its conversion into plant-available forms. High activity of these microbial

Table 3. Determination of ecological and functional groups of soil microorganisms in soil samples from Field 7 of the Educational and Research Production Farm 'Nauka', CFU/g*

Characteristics	Number of soil sample								
	1	2	3	4	5	6	7	8	9
Oligonitrophilic and nitrogen-fixing bacteria	4.55E+07	3.51E+07	2.77E+07	1.63E+07	1.51E+07	3.84E+07	1.71E+07	2.93E+07	3.51E+07
Phosphate-mobilising bacteria	2.15E+06	2.89E+05	1.60E+06	2.54E+05	1.21E+05	1.58E+06	1.30E+06	1.59E+05	1.35E+06
Streptomycetes	1.60E+06	1.72E+06	2.58E+06	2.60E+06	1.88E+06	2.39E+06	2.23E+06	2.62E+06	1.66E+06
Pedotrophs	3.69E+07	2.95E+07	2.46E+07	2.42E+07	2.54E+07	4.60E+07	2.79E+07	2.75E+07	3.20E+07
Ammonifiers	2.34E+07	2.21E+07	2.58E+07	3.33E+07	3.75E+07	3.59E+07	4.34E+07	2.56E+07	2.58E+07
Amylolytic bacteria	2.46E+07	2.64E+07	1.91E+07	3.33E+07	3.33E+07	3.21E+07	4.34E+07	3.60E+07	4.43E+07
Micromycetes	3.32E+04	4.74E+04	2.77E+04	2.96E+04	1.94E+04	4.60E+04	2.67E+04	3.05E+04	3.51E+04
Oligotrophs	4.24E+07	2.64E+07	1.78E+07	3.21E+07	1.88E+07	3.40E+07	2.29E+07	1.83E+07	2.40E+07
Cellulolytic micromycetes	1.66E+03	1.97E+03	1.91E+03	2.06E+03	1.21E+03	1.26E+03	1.43E+03	1.22E+03	1.85E+03
Pedotrophicity index	1.58	1.33	0.95	0.73	1.27	1.28	0.64	1.07	1.24
Mineralisation-immobilisation index	1.05	1.19	0.74	1	0.68	0.89	1.00	1.40	1.71
Oligotrophicity index	1.82	1.19	0.69	0.96	0.89	0.95	0.53	0.71	0.93

groups is a key factor in maintaining adequate nitrogen availability in agricultural soils.

According to the study results, the abundance of oligonitrophilic and nitrogen-fixing bacteria in Field 7 ranged from 1.51E+07 to 4.55E+07 CFU/g, with an average value of 2.88E+07 CFU/g. These values indicate a high potential for biological nitrogen fixation, contributing to the supply of plant-available nitrogen. In Field 8, the abundance of nitrogen-fixing bacteria ranged from 1.24E+05 to 1.84E+07 CFU/g, with an average of 2.29E+07 CFU/g. Although this level is also considerable, it is slightly lower than in Field 7, which may indicate a lower ability of the soil to fix nitrogen in Field 8. This suggests the potential need for targeted management measures, such as optimizing fertilization practices or implementing strategies to stimulate beneficial microbial communities.

Phosphate-mobilising bacteria play an essential role in converting insoluble phosphorus compounds into forms available for plant uptake. High activity of these microorganisms enhances phosphorus availability and contributes significantly to maintaining soil fertility, given the critical role of phosphorus in plant growth and development.

According to the analysis results, the abundance of phosphate-mobilising bacteria in Field 7 ranged from 1.21E+05 to 2.15E+06 CFU/g, with an average value of 9.78E+05 CFU/g. These results indicate relatively high activity of phosphate-mobilising microorganisms, contributing to enhanced phosphorus availability for plant uptake. In Field 8, the abundance of phosphate-mobilising bacteria ranged from 1.24E+05 to 1.35E+06 CFU/g, with an average of 4.73E+05 CFU/g. Although these values are substantial, they are noticeably lower than those observed in Field 7, which may suggest reduced phosphorus mobilisation capacity and the potential need for management measures to improve phosphorus availability in this field.

Streptomycetes play an important role in the decomposition of organic matter and the production of biologically active compounds, including antibiotics that suppress soil-borne pathogens. They also contribute to the improvement of soil structure and overall soil health.

In Field 7, the abundance of streptomycetes ranged from 1.60E+06 to 2.62E+06 CFU/g, with an average value of 2.14E+06 CFU/g, indicating a high level of activity within this microbial group. Such activity may positively influence organic matter decomposition and natural plant protection. In Field 8, streptomycete abundance ranged from 1.43E+06 to 3.06E+06 CFU/g, with an average of 2.09E+06 CFU/g. While the mean value was comparable to that of Field 7, higher maximum values recorded in Field 8 may reflect periods of increased microbial activity under favourable environmental conditions.

Pedotrophic microorganisms play a significant role in the decomposition of organic matter and its transformation into plant-available nutrients. High activity of this microbial group contributes to the maintenance of soil fertility and the stability of nutrient cycling processes.

In Field 7, the abundance of pedotrophic microorganisms ranged from 2.42E+07 to 4.60E+07 CFU/g, with an average value of 3.04E+07 CFU/g. These results indicate a high level of microbial activity and effective organic matter decomposition in this field. In Field 8, the abundance of pedotrophs ranged from 2.89E+06 to 2.79E+07 CFU/g, with an average of 1.79E+07 CFU/g. This lower mean value and wider variability suggest comparatively reduced microbial activity, which may reflect less intensive mineralisation processes in this soil.

Ammonifying microorganisms are responsible for converting organic nitrogen compounds into ammonia, an essential intermediate in the nitrogen cycle and a source of plant-available nitrogen. High ammonifier activity enhances nitrogen turnover and contributes to improved nitrogen availability in agricultural soils.

In Field 7, the average quantity of ammonifiers was 2.80E+07 CFU/g, with a minimum of 2.34E+06 CFU/g and a maximum of 4.34E+07 CFU/g. These results indicate a strong potential for ammonification processes and a high capacity of the soil to supply plants with nitrogen in plant-available forms. In Field 8, the average ammonifier abundance was 2.41E+07 CFU/g, with a minimum of 1.54E+07 CFU/g and a maximum of 3.00E+07 CFU/g. Although slightly lower than in Field 7, these values also reflect a substantial capacity for nitrogen mineralisation and adequate nitrogen availability for crop growth.

Amylolytic bacteria play an important role in the breakdown of carbohydrates, particularly starch, which is a source of energy for plants. High activity of these microorganisms enhances the availability of organic substrates in the soil and supports overall microbial functioning and nutrient cycling.

In Field 7, the average number of amylolytic bacteria was 3.25E+07 CFU/g, with a minimum of 1.91E+07 CFU/g and a maximum of 4.43E+07 CFU/g. These results indicate a high potential for the decomposition of complex carbohydrates and active transformation of organic substrates in the soil. In Field 8, the average number was 2.62E+07 CFU/g, with a minimum of 1.61E+07 CFU/g and a maximum of 3.57E+07 CFU/g. Although this value is also high, Field 7 demonstrates a comparatively greater capacity for carbohydrate degradation.

Micromycetes, as key components of the soil microbiota, play an important role in the decomposition of organic matter and contribute to maintaining biological balance within the soil ecosystem. They are also involved in suppressing certain pathogenic microorganisms.

In Field 7, the average number of micromycetes was 2.19E+06 CFU/g, with a minimum of 2.67E+04 CFU/g and a maximum of 1.94E+07 CFU/g. This wide range suggests considerable variability and a relatively high diversity of micromycetes, contributing to overall soil biological activity. In Field 8, the average number of micromycetes was 1.85E+06 CFU/g, with a minimum of 1.24E+04 CFU/g and a maximum of 1.46E+07 CFU/g. This value was slightly lower, which may indicate lower activity of micromycetes in the soil of this field.

Oligotrophic microorganisms, which are adapted to environments with very low nutrient availability, play an important role in sustaining soil microbial activity under resource-limited conditions. A high oligotroph activity indicates the soil's capacity to maintain stable microbial functioning even when nutrient concentrations are low.

In Field 7, the average number of oligotrophs was 2.63E+07 CFU/g, with a minimum of 1.78E+07 CFU/g and a maximum of 4.24E+07 CFU/g. These results indicate a strong capacity of the soil to support microbial communities under limited nutrient conditions. In Field 8, the average oligotroph number was 2.57E+07 CFU/g, with a minimum of 1.61E+07 CFU/g and a maximum of 3.66E+07 CFU/g. The values are comparable to those observed in Field 7, suggesting a similar resilience of microbial communities and an equivalent ability of the soils in both fields to sustain oligotrophic microorganisms.

Cellulolytic micromycetes play a crucial role in the decomposition of cellulose, a major structural component of plant residues. Their activity contributes to the improvement of soil structure and its enrichment with stable organic compounds.

In Field 7, the average number of cellulolytic micromycetes was 1.49E+04 CFU/g, with a minimum of 1.22E+03 CFU/g and a maximum of 1.21E+05 CFU/g. These results indicate relatively high cellulolytic activity and an active process of plant residue decomposition in this field. In Field 8, the average abundance was 9.02E+02 CFU/g, which is substantially lower than in Field 7. This suggests a reduced capacity for cellulose

Table 4. Determination of ecological and functional groups of soil microorganisms in soil samples from Field 8 of the Educational and Research Production Farm 'Nauka', CFU/g*

Characteristics	Number of soil sample							
	I	II	III	IV	V	VI	VII	VIII
Oligonitrophilic and nitrogen-fixing bacteria	3.94E+07	8.11E+06	1.22E+07	1.50E+07	8.43E+06	1.75E+07	2.19E+07	2.48E+07
Phosphate-mobilising bacteria	1.35E+06	3.48E+05	4.09E+05	5.66E+05	1.24E+05	4.61E+05	2.56E+05	2.67E+05
Streptomycetes	2.34E+06	2.01E+06	1.71E+06	1.66E+06	1.43E+06	1.94E+06	3.06E+06	2.54E+06
Pedotrophs	2.89E+07	1.59E+07	1.28E+07	2.34E+07	2.79E+07	1.56E+07	2.50E+07	1.98E+07
Ammonifiers	2.58E+07	2.50E+07	2.75E+07	1.54E+07	1.61E+07	2.81E+07	3.00E+07	2.48E+07
Amylolytic bacteria	3.57E+07	2.68E+07	1.95E+07	2.46E+07	1.61E+07	2.56E+07	3.00E+07	3.10E+07
Micromycetes	1.91E+04	1.59E+04	1.46E+04	2.71E+04	2.54E+04	2.63E+04	4.38E+04	1.24E+04
Oligotrophs	2.71E+07	2.20E+07	3.66E+07	3.20E+07	1.98E+07	2.69E+07	2.50E+07	1.61E+07
Cellulolytic micromycetes	1.41E+03	1.22E+02	1.22E+02	1.41E+03	1.24E+03	1.25E+03	2.31E+02	1.43E+03
Pedotrophicity index	1.12	0.63	0.47	1.52	1.73	0.56	0.83	0.80
Mineralisation-immobilisation index	1.38	1.07	0.71	1.60	1.00	0.91	1.00	1.25
Oligotrophicity index	1.05	0.88	1.33	2.08	1.23	0.96	0.83	0.65

decomposition and potentially slower turnover of plant residues. Such conditions may justify the implementation of soil management measures, including the incorporation of organic amendments, to enhance biological activity and improve soil structure.

The pedotrophic index in Field 7 (mean value 1.12) was higher than in Field 8 (mean value 0.96), indicating a more intensive transformation of organic matter in the soil of Field 7. This suggests enhanced mineralisation processes and more favourable conditions for microbial activity, which may contribute to improved soil fertility.

The mineralisation-immobilisation index was similar in both fields, with average values of 1.07 in Field 7 and 1.12 in Field 8. These results indicate a comparable balance between nutrient mineralisation and immobilisation processes, reflecting a similar efficiency of organic matter turnover and nutrient availability for plants in both soils.

The oligotrophic index was lower in Field 7 (mean value 0.96) than in Field 8 (mean value 1.13). This may indicate a greater capacity of the soil in Field 8 to sustain microbial communities under low nutrient availability. Such a pattern suggests a higher level of adaptation of the microbiota in Field 8 to nutrient-limited conditions, which may support ecological stability and resilience of the soil system.

Statistical analysis of soil physicochemical, agrochemical and microbiological properties

The comparative statistical analysis revealed pronounced differences in the distribution patterns of soil physicochemical characteristics, nutrient availability, and microbiological activity between Field 7 and Field 8. Boxplot analysis demonstrated differences not only in median values but also in the degree of spatial variability, indicating heterogeneous soil conditions within the studied areas (Figure 2).

Among the physicochemical parameters, the most pronounced differences were observed for base saturation, nutrient availability, and soil acidity indicators. Field 8 showed higher calcium saturation compared with Field 7, with the median value approaching 90%, whereas Field 7 demonstrated a lower median level and a wider interquartile range. This pattern indicates a more stable calcium status in Field 8 and greater spatial heterogeneity of exchangeable calcium distribution in Field 7. The higher calcium saturation was consistent with increased calcium concentrations measured in the elemental composition analysis.

Potassium saturation showed relatively similar distributions between the two fields; however,

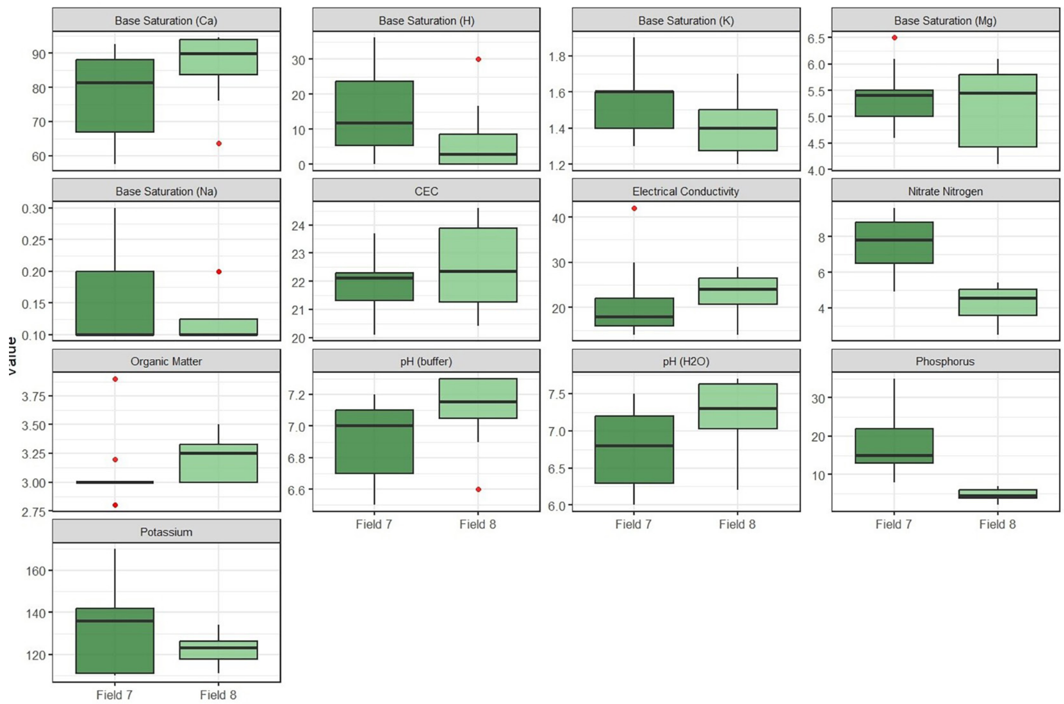

Figure 2. Distribution patterns of physicochemical and agrochemical soil properties in Field 7 and Field 8 based on boxplot statistical analysis

Field 7 tended to exhibit slightly higher values and greater variability. Magnesium saturation demonstrated comparable median values, although Field 8 showed a wider distribution range, suggesting greater spatial heterogeneity of magnesium availability.

The cation exchange capacity (CEC) was slightly higher in Field 8 compared with Field 7. The increased CEC values indicate a greater potential of soils from Field 8 to retain exchangeable cations and regulate nutrient availability. This difference may be associated with variations in soil mineral composition and organic matter stabilization processes.

A clear differentiation between the studied fields was observed for soil nitrogen and phosphorus availability. Field 7 exhibited substantially higher nitrate nitrogen concentrations compared with Field 8, with median values approximately twice as high. This indicates more intensive nitrogen mineralization processes or higher residual nitrogen availability in Field 7. Similarly, available phosphorus concentrations were considerably higher in Field 7, demonstrating improved phosphorus supply conditions compared with Field 8.

Soil reaction parameters also differed between fields. Field 8 demonstrated higher pH values in both water suspension and buffer solution, indicating a shift toward more neutral soil conditions. In contrast, Field 7 showed wider variability of pH values, reflecting greater spatial heterogeneity of soil acidity conditions. The observed differences in pH may influence nutrient mobility and microbial community structure.

Electrical conductivity values were higher in Field 8, suggesting increased concentrations of soluble ions in the soil solution. However, the presence of individual extreme values in Field 7 indicates localized accumulation of soluble salts or nutrient compounds. Organic matter content showed generally similar levels between fields, although Field 7 exhibited greater variability due to isolated high values.

The statistical assessment of macro- and micronutrient concentrations revealed contrasting patterns between the two fields. Field 8 demonstrated higher calcium accumulation, whereas Field 7 showed increased concentrations of several micronutrients, including iron, manganese, copper, and zinc (Figure 3).

Iron content was notably higher in Field 7, where median values exceeded those observed in Field 8. A similar tendency was recorded for manganese and zinc concentrations, suggesting more intensive micronutrient accumulation or different redox and mineralogical conditions in Field 7. Copper distribution followed the

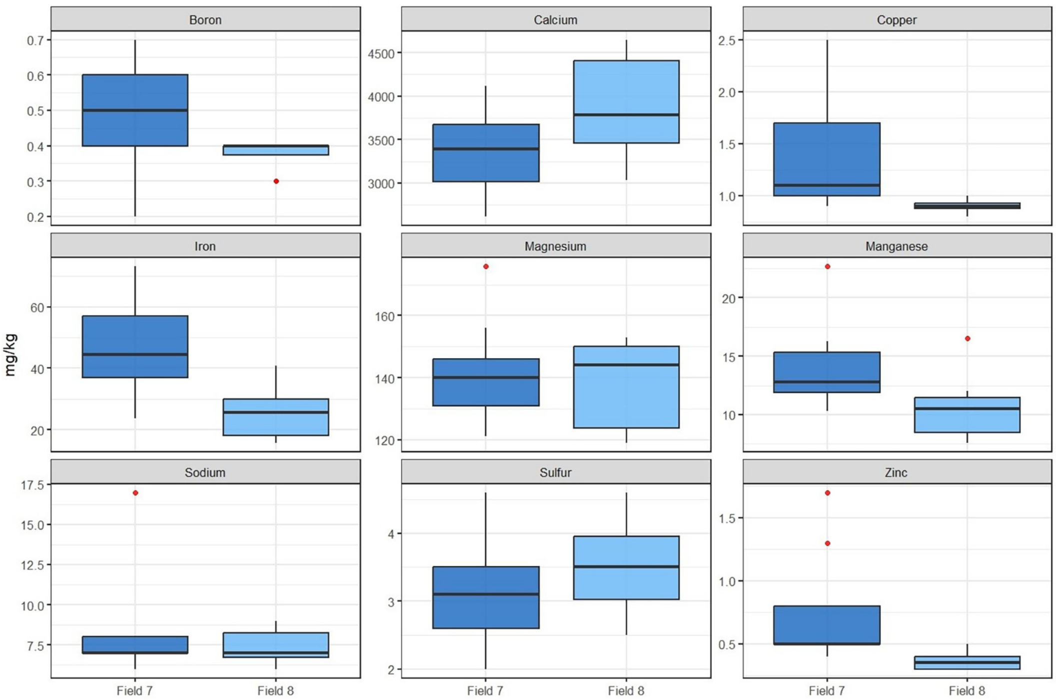

Figure 3. Comparative assessment of macro- and micronutrient concentrations in soils of Field 7 and Field 8 based on statistical distribution analysis

same trend, with higher variability and elevated values in Field 7.

Sulfur concentrations showed a moderate increase in Field 8, whereas boron and sodium contents remained relatively comparable between the studied areas. The observed differences indicate that soil nutrient status was spatially differentiated, reflecting variations in soil-forming processes, nutrient cycling intensity, and possible differences in agricultural management practices.

The microbiological indicators demonstrated substantial differences in functional activity between Field 7 and Field 8. Field 7 generally exhibited higher abundance of major functional microbial groups, including ammonifiers, amylolytic microorganisms, oligotrophs, pedotrophic microorganisms, and phosphate-mobilizing microorganisms (Figure 4).

The abundance of ammonifying microorganisms was higher in Field 7, indicating enhanced transformation of organic nitrogen compounds and potentially greater nitrogen cycling activity. Similar patterns were observed for amylolytic microorganisms, suggesting increased microbial decomposition of carbohydrate-containing organic substrates.

Higher numbers of pedotrophic microorganisms in Field 7 indicate a more intensive utilization of soil organic matter by microbial communities. This finding corresponds with the increased values of ecological coefficients associated with nutrient cycling processes. The pedotrophic coefficient was higher in Field 7, confirming greater microbial activity under conditions of higher organic substrate availability.

The abundance of oligotrophic microorganisms was relatively higher in Field 8, as reflected by increased oligotrophic coefficients. This suggests a greater proportion of microorganisms adapted to nutrient-limited conditions and may indicate lower availability of easily accessible organic compounds compared with Field 7.

The abundance of micromycetes and streptomycetes showed less pronounced differences between fields; however, Field 7 tended to demonstrate higher median values. This indicates that fungal and actinomycete communities were also influenced by differences in soil environmental conditions, although their response was weaker compared with bacterial functional groups.

The statistical analysis demonstrated distinct ecological differentiation between Field 7 and Field 8. Field 7 was characterized by higher biological activity, increased microbial functional diversity, and greater availability of nitrogen and phosphorus forms. These characteristics indicate more intensive nutrient transformation processes and active soil organic matter turnover.

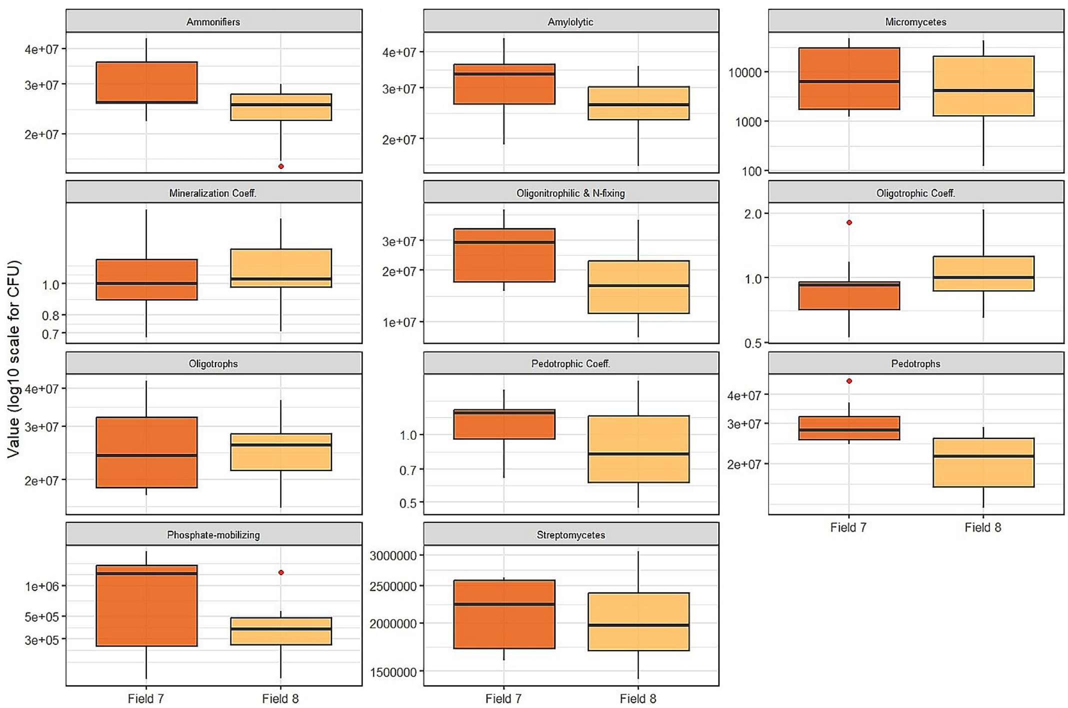

Figure 4. Microbiological activity indicators and ecological coefficients of soils from Field 7 and Field 8 based on statistical distribution analysis

In contrast, Field 8 exhibited more s physicochemical properties, including higher calcium saturation, increased pH values, and greater cation exchange capacity, which reflect improved soil buffering capacity and chemical stability.

Overall, the obtained results confirm that spatial variability of soil properties is controlled by the interaction between physicochemical conditions and biological processes. The differences between fields demonstrate that microbial functional activity responds sensitively to variations in nutrient availability, soil reaction, and elemental composition, emphasizing the importance of integrated assessment of soil chemical and biological indicators for evaluating soil ecological status.

DISCUSSION

The assessment of soil chemical properties (Zhou et al., 2026) is a fundamental component of evaluating soil fertility and its capacity to supply plants with essential nutrients (McGrath et al., 2026). The initial phase of soil monitoring at the Educational and Research Production Farm 'Nauka' of West Ukrainian National University focused on analysing the key chemical characteristics of two experimental plots, Field 7 and Field 8. The determination of parameters such as soil pH, electrical conductivity, organic matter content, and macro- and micronutrient concentrations provides a comprehensive understanding of soil condition, its suitability for agricultural use, and the potential need for corrective management measures. As this monitoring stage represents the baseline assessment, the results primarily reveal general trends and site-specific characteristics. These findings form a foundation for the subsequent development of targeted agronomic strategies aimed at improving soil fertility, optimising fertiliser application, and enhancing conditions for sustainable plant growth.

A comparison of the chemical characteristics of the studied soils in the Ternopil region (according to our data) with those of the Rivne and Lviv regions (Bobunov et al., 2023) reveals substantial differences in the concentrations of major macro- and micronutrients, which directly influence soil fertility and nutrient supply to plants. Potassium, a key macronutrient essential for plant growth, showed pronounced regional variation. The soils of the Lviv region significantly exceeds that of the Ternopil and Rivne regions, indicating more favourable conditions for cultivating potassium-demanding crops. In contrast, potassium levels in the Ternopil region were considerably lower (133.9 mg/kg in Field 7 and 122.4 mg/kg in Field 8), which may constrain crop productivity and suggest the need for potassium fertilisation to optimise soil fertility. The soils of the Rivne region showed intermediate values (1,760 mg/kg in Field 1 and 1,680 mg/kg in Field 2) exceeding those observed in Ternopil but remaining substantially below the levels reported for the Lviv region (3,620 mg/kg in Field 1 and 3,330 mg/kg in Field 2).

The analysis of calcium content further demonstrates the relative advantage of soils in the Lviv region, where concentrations reached 4.510 mg/kg in Field 1 and 4.450 mg/kg in Field 2. Adequate calcium availability supports cell wall stability, root development, and overall plant structural integrity, thereby contributing to stable crop growth. In the Ternopil region, calcium concentrations amounted to 3,350.7 mg/kg in Field 7 and 3875.6 mg/kg in Field 8. These values are

Table 5. Comparison of chemical characteristics in different regions of Ukraine

Characteristics	Units	Ternopil region*		Rivne region**		Lviv region**	
		7	8	1	2	1	2
Potassium	mg/kg	133.9	122.4	3,620.0	3,330.0	1,760.0	1,680.0
Calcium	mg/kg	3,350.7	3,875.6	4,510.0	4,450.0	3,330.0	3,290.0
Sodium	mg/kg	8.1	7.4	140.73	133.51	108.95	102.29
Magnezium	mg/kg	130.0	138.4	3520	3330.0	2060.0	1,980.0
Zinc	mg/kg	0.8	0.4	58.62	57.35	38.42	38.05
Copper	mg/kg	1.4	0.9	10.35	9.58	7.80	7.43
Iron	mg/kg	45.7	25.7	18,560.0	17,360.0	11,590.0	10,150.0
Boron	mg/kg	0.5	3.3	10.72	10.00	8.03	7.77

Note: * the authors' research results; ** the results of Bobunov et al. 2023.

generally satisfactory for most plants agricultural crops and indicate no immediate calcium deficiency. Similarly, soils in the Rivne region contained 3.330 mg/kg in Field 1 and 3.290 mg/kg in Field 2. Although lower than those reported for the Lviv region, these concentrations remain within agronomically acceptable ranges.

In contrast, sodium levels showed a markedly different regional pattern. The soils of the Lviv region exhibited comparatively high sodium concentrations (140.73 mg/kg in Field 1 and 133.51 mg/kg in Field 2). Elevated sodium content may indicate a potential risk of soil salinity, which can adversely affect soil structure, water availability, and nutrient uptake by plants, and may therefore require monitoring and corrective management measures. The soils of the Ternopil region contained substantially lower sodium concentrations (8.1 mg/kg in Field 7 and 7.4 mg/kg in Field 8), suggesting minimal salinity risk and favourable conditions for water and nutrient absorption. In the Rivne region, sodium levels were intermediate (108.95 mg/kg in Field 1 and 102.29 mg/kg in Field 2), indicating favourable conditions for plant growth.

Magnesium concentrations were also markedly higher in the soils of the Lviv region, reaching 3.520 mg/kg in Field 1 and 3.330 mg/kg in Field 2. As magnesium is a central component of chlorophyll and plays a key role in photosynthesis and enzyme activation, such levels provide highly favourable conditions for plant growth. In comparison, the magnesium content in the Ternopil region was considerably lower (130.0 mg/kg in Field 7 and 138.4 mg/kg in Field 8). Although substantially below the values observed in the Lviv region, these concentrations remain within ranges acceptable for most crops, depending on soil type and crop demand. The soils of the Rivne region exhibited intermediate magnesium levels (2.060 mg/kg in Field 1 and 1.980 mg/kg in Field 2), exceeding those in the Ternopil region, but remaining lower than in the Lviv region.

The analysis of micronutrients also revealed pronounced regional differences. Zinc concentrations in the soils of the Lviv region (58.62 mg/kg in Field 1 and 57.35 mg/kg in Field 2) were substantially higher than those recorded in the Ternopil region (0.8 mg/kg in Field 7 and 0.4 mg/kg in Field 8). The Rivne region showed intermediate zinc levels (38.42 mg/kg in Field 1 and 38.05 mg/kg in Field 2), which are generally considered adequate for supporting plant growth and enzymatic functions. A similar pattern was observed for copper. In the Lviv region, copper concentrations reached 10.35 mg/kg in Field 1 and 9.58 mg/kg in Field 2, supporting normal plant metabolic processes. The Rivne region displayed moderate copper levels (7.80 mg/kg in Field 1 and 7.43 mg/kg in Field 2), whereas the Ternopil region had considerably lower concentrations (1.4 mg/kg in Field 7 and 0.9 mg/kg in Field 8).

Iron concentrations were markedly higher in the soils of the Lviv region, reaching 18,560 mg/kg in Field 1 and 17,360 mg/kg in Field 2. Iron is essential for chlorophyll synthesis, photosynthetic electron transport, and various enzymatic processes; therefore, such levels indicate a strong capacity of these soils to support physiological plant functions. In contrast, the Ternopil region exhibited substantially lower iron concentrations (45.7 mg/kg in Field 7 and 25.7 mg/kg in Field 8), which limits the effectiveness of plant development. The soils of the Rivne region showed intermediate but comparatively high iron levels (11,590 mg/kg in Field 1 and 10,150 mg/kg in Field 2), which are generally sufficient to meet plant nutritional requirements.

Boron analysis revealed a different regional pattern. The highest boron concentrations were recorded in the Rivne region (10.72 mg/kg in Field 1 and 10.00 mg/kg in Field 2), indicating a substantial presence of this micronutrient, which plays a critical role in plant cell growth. The Lviv region also demonstrated adequate boron levels (8.03 mg/kg in Field 1 and 7.77 mg/kg in Field 2), supporting normal plant growth and development. In contrast, boron concentrations in the Ternopil region were considerably lower (0.5 mg/kg in Field 7 and 3.3 mg/kg in Field 8), potentially limiting crop productivity, particularly for boron-sensitive species.

Overall, the comparative analysis of soils from the Ternopil, Rivne, and Lviv regions indicates clear regional variability in macro- and micronutrient status (Labbilta et al., 2024; Zhou et al., 2025). The soils of the Lviv region demonstrate consistently higher concentrations of most nutrients, suggesting comparatively favourable conditions for agricultural production. The Rivne region generally exhibits intermediate nutrient levels, supporting diverse cropping systems but potentially requiring targeted fertilisation strategies. In contrast, the soils of the Ternopil region show the lowest concentrations of several essential elements, highlighting the need for corrective agronomic measures, including balanced fertiliser application and long-term soil fertility management. The assessment of soil conditions in Field 7 and Field 8 was performed using an integrated approach combining indicators of chemical fertility, physicochemical limitations, and biological functioning of the soil system. This approach reflects the current shift in soil science from the interpretation of individual soil parameters toward a multifunctional assessment of soil processes, where pH, electrical conductivity (EC), organic matter content, nutrient availability, and cation exchange capacity (CEC) are considered as interconnected components of soil functioning together with microbial ecological and functional characteristics (Panek et al., 2026; Zheng et al., 2026). Such an integrated perspective provides a more reliable understanding of soil quality because the interaction between chemical conditions and biological processes determines nutrient cycling, productivity potential, and ecosystem stability rather than any single parameter alone.

The differentiation between Field 7 and Field 8 observed in this study indicates that soil functional status was shaped by the interaction of physicochemical properties and microbial activity. Field 7 demonstrated higher biological activity, including greater abundance of functional microbial groups involved in nitrogen transformation, organic matter decomposition, and phosphorus mobilization. These characteristics suggest more intensive nutrient turnover and a higher capacity for microbial regulation of biogeochemical processes. In contrast, Field 8 was characterized by higher pH values, calcium saturation, and cation exchange capacity, indicating a more buffered soil environment with greater chemical stability. Similar relationships between soil physicochemical conditions and microbial functional organization have been described as key drivers of soil multifunctionality and ecosystem performance (Grijalva-López et al., 2026). Therefore, differences between the studied fields should be interpreted as the result of complex interactions between nutrient availability, soil chemical equilibrium, and microbial functional potential.

The obtained results emphasize that conventional indicators of soil fertility alone are insufficient for a complete evaluation of soil ecological status. Chemical parameters provide information about resource availability and environmental constraints, whereas microbial functional groups reflect the intensity of transformation processes responsible for nutrient release, organic matter turnover, and maintenance of soil fertility. The combination of these indicators allows a more comprehensive assessment of whether soils possess not only sufficient nutrient reserves but also the biological capacity required for sustainable functioning under field conditions.

A major challenge in contemporary soil microbiome research is determining how accurately microbial taxonomic composition and predicted functional profiles represent actual ecosystem activity and long-term soil resilience. Although molecular approaches provide valuable information about microbial diversity and functional potential, they do not always directly correspond to real-time biochemical processes occurring in soils. Recent studies have demonstrated that microbial community structure should be interpreted together with measurements of functional activity, enzymatic processes, and environmental responses to distinguish potential microbial capabilities from realized ecosystem functions (Li et al., 2026; Zhakypbek et al., 2026). Consequently, future approaches to soil quality assessment should integrate microbiome-based methods with direct measurements of microbial activity and long-term monitoring of soil processes. Such a combined framework will improve the accuracy of ecological evaluations and contribute to a more realistic understanding of soil resilience under changing environmental conditions.

CONCLUSIONS

The first stage of soil monitoring at the Educational and Research Production Farm "Nauka" of the West Ukrainian National University established a comprehensive baseline dataset describing the current physicochemical and biological status of agricultural soils. The obtained results confirm that both investigated fields possess favourable characteristics for agricultural production; however, the identified differences demonstrate that soil fertility is determined not only by nutrient concentrations but also by the interaction between chemical properties, nutrient cycling processes, and microbial functional activity.

Field 7 was characterised by higher availability of nitrogen, phosphorus, manganese, and iron, as well as increased abundance of major functional microbial groups involved in organic matter transformation, nitrogen cycling, and phosphorus mobilisation. These characteristics indicate a higher intensity of biological processes and greater potential for active nutrient turnover. In contrast, Field 8 demonstrated higher calcium content, greater cation exchange capacity, and more stable physicochemical properties, suggesting enhanced buffering capacity and improved resistance of the soil system to external disturbances. At the same time, the lower availability of nitrogen and phosphorus in this field indicates the need for targeted nutrient management practices to maintain optimal crop productivity.

The obtained findings highlight the importance of applying an integrated approach to soil quality assessment. The combined evaluation of chemical indicators and microbial functional characteristics provides a more complete understanding of soil fertility than the analysis of individual parameters alone, as biological activity reflects the actual capacity of soils to maintain nutrient cycling and ecosystem functions. Therefore, microbial indicators should be considered as essential components of long-term agricultural soil monitoring programmes.

As this study represents the first stage of monitoring, the results should be interpreted as a reference baseline rather than a final assessment of soil condition. Further investigations should focus on the analysis of temporal changes in soil properties, seasonal dynamics of microbial communities, and the identification of factors responsible for spatial variability within agricultural fields. Future research should also include the development of spatial soil quality maps, assessment of the effectiveness of different fertilisation and soil management strategies, and integration of microbiological indicators with modern molecular approaches and predictive modelling methods.

The continuation of systematic monitoring at the "Nauka" farm will provide essential information for developing evidence-based recommendations for sustainable land management, maintaining soil fertility, and improving the resilience of agricultural ecosystems under changing climatic conditions and increasing anthropogenic pressures.

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