AGROCHEMICAL SOIL MONITORING IN A MIXED ORCHARD: BASELINE–TO–FIVE-YEAR CHANGE AND IMPLICATIONS FOR FERTILITY MANAGEMENT

Petronela-Bianca (PAVEL) VECERDEA[1], Ioana Maria ARCAȘ[2], Ion BARBU[1]

[1]"Lucian Blaga" University of Sibiu, Faculty of Agricultural Sciences, Food Industry, and Environmental Protection, 5-7 Ion Ratiu, 550371 Sibiu, Romania
[2] Agrochemical and Pedological Studies Office, Sibiu (OSPA Sibiu), Str. Someșului, nr. 49, 550003 Sibiu, Romania

author email: petronela.pavel@ulbsibiu.ro

Corresponding author email: petronela.pavel@ulbsibiu.ro

Abstract
Agrochemical soil monitoring represents the foundation for rational nutrient management in perennial fruit systems. This study documents fertility changes over a five-year interval (2019–2024) in a 2.2 ha mixed orchard located at the Rusciori Teaching and Experimental Farm (Sibiu County, Romania). Soil sampling followed the national agrochemical cartography methodology, using a composite baseline soil sample (approximately 30 subsamples homogenized) and additional row-level composite samples to evaluate both overall soil status and species-related variation. Initial baseline results (2019) showed moderately acidic soil, critically low nitrogen and phosphorus availability, and very high mobile potassium (440 ppm K_2O). After five years, improvements in humus, nitrogen, and phosphorus levels were observed, while mobile potassium decreased markedly to 219 ppm K_2O, identifying potassium as the dominant emerging limiting factor. These findings highlight the importance of periodic soil diagnostics in orchard systems and support species-adapted potassium management strategies, particularly on clay-loam soils prone to K fixation and extraction-driven depletion.
Key words: agrochemical monitoring; orchard soil; potassium depletion; nutrient management; mixed fruit system

INTRODUCTION

Perennial orchards represent long-term agroecosystems with a significant contribution to regional food security, economic resilience and landscape sustainability (Rusu et al., 2023; Radulov et al., 2013). Unlike annual crops, fruit trees remain in the same location for decades, which makes systematic soil fertility assessment essential for sustaining productivity and orchard longevity. Continuous nutrient extraction, when not balanced by fertilization based on soil diagnostics, leads to progressive nutrient depletion, reduced tree vigor and lower fruit quality (Chiurciu, et al., 2022). Therefore, agrochemical soil monitoring functions as a core decision-support tool in orchard nutrient management, guiding fertilization based on measured fertility dynamics rather than empirical interventions (Rusu et al., 2023).

At European level, orchard fertilization strategies are increasingly shaped by sustainability policies. The European Green Deal and the Farm to Fork Strategy aim to reduce mineral fertilizer use by at least 20% while maintaining productivity, emphasizing improved nutrient-use efficiency and data-supported management (EC, 2020; Dunchev, 2025). Achieving these goals requires precise soil diagnostic tools and periodic monitoring to ensure balanced nutrient supply and avoid unnecessary inputs. Recent studies in Central Romania highlight the strong influence of water and nutrient stress on crop performance and support the need for management practices grounded in soil analysis (Drăghici et al., 2024).

In Romania, orchard soil evaluation follows the national agrochemical cartography system coordinated by the National Research-Development Institute for Soil Science, Agrochemistry and Environmental Protection – ICPA Bucharest, based on the official methodological handbook (Dumitru et al., 2011). This framework establishes standardized procedures for sampling, laboratory analysis and interpretation thresholds used in fertilization recommendations for perennial plantations. Transylvanian Plateau soils commonly exhibit slightly acidic pH, low humus content and limited nitrogen and phosphorus reserves, which underlines the importance of continuous diagnostic-based fertilization planning (Drăghici et al., 2024). Advances in smart horticulture have introduced remote sensing and digital decision-support instruments to orchard management (Iagăru et al., 2022; Boșcoianu et al., 2024). However, while such tools increasingly complement field monitoring, physical soil diagnostics remain the indispensable foundation of nutrient planning in perennial systems due to their ability to directly quantify chemical trends such as potassium fixation and long-term depletion — that cannot be accurately inferred from visual assessment or remote-sensing data alone.

The mixed orchard at the Rusciori Teaching and Experimental Farm (Sibiu County, Romania) represents a diverse system with species exhibiting distinct rooting depths and nutrient demands. This study aimed to assess soil fertility evolution between the baseline assessment (2019) and the five-year follow-up (2024), identify emerging limiting nutrients, and characterize row-level variability associated with different fruit species. The results provide empirical evidence supporting periodic agrochemical monitoring as a foundation for adaptive fertilization strategies in mixed orchards, particularly on clay-loam soils prone to nutrient fixation and extraction-driven depletion.

MATERIALS AND METHODS

Study Site and Orchard Description

The research was conducted at the mixed orchard block of the Rusciori Teaching and Experimental Farm (45°46′12″ N, 24°05′41″ E). The location is situated approximately 7 km west of Sibiu, within the Transylvanian Plateau, with an altitude ranging between 400 and 450 m. The terrain is characterized by a gentle, undulating relief. The regional climate is temperate-continental, typically showing a mean annual temperature of 8–9 °C and annual precipitation of 650–750 mm, often peaking in late spring and early summer (ANM, 2020; Bogdan & Marinică, 2007). These climatic characteristics are generally recognized as suitable for pome and stone fruit cultivation (Coman et al., 2014).

The area's soils are predominantly classified as brown eumezobasic luvisols and chernozems (Florea & Munteanu, 2012; USDA, 2022). They possess a loam to clay-loam texture and exhibit medium inherent fertility. Regional agricultural challenges often include a slightly acidic reaction, low humus content, and an imbalance in nitrogen and phosphorus supply (Rusu et al., 2023). Previous studies highlight that the effective use of widespread soil types, such as Albic Luvisols, requires constant management to improve fertility through appropriate technological measures (Uribeetxebarria et al., 2018; Radulov et al. 2013).

The orchard block covers 2.2 ha and was established between 2016 and 2017. It is organized into 23 rows containing nine distinct fruit species: apple (*Malus domestica Borkh.*), pear (*Pyrus communis L.*), plum (*Prunus domestica L.*), sweet cherry (*Prunus avium L.*), sour cherry (*Prunus cerasus L.*), blackcurrant (*Ribes nigrum L.*), raspberry (*Rubus idaeus L.*), aronia (*Aronia melanocarpa L.*), and hazelnut (*Corylus avellana L.*). The final two species share a single mixed row.

Soil Sampling and Laboratory Analysis

Soil sampling followed the national agrochemical cartography standards applied in Romanian perennial systems (Dumitru et al., 2011; Rusu et al., 2023; Dana et al., 2008). To establish the baseline fertility status, a composite agrochemical soil sample was collected in 2019 by homogenizing approximately 30 soil cores per depth, representing the orchard area. This approach reflects the official Romanian diagnostic protocol for perennial plantations, where composite samples characterize block-level fertility for medium-term trend assessment rather than inferential statistical comparison. The diagnostic framework for evaluating orchard land suitability and guiding fertilization planning is further detailed in Dana et al. (2008), which outlines a national expert system methodology.

Analytical determinations were performed in laboratory triplicate to ensure measurement precision, while the field-level composite reflects the standardized monitoring methodology used in orchard agrochemical surveillance programs.

Row-level composite samples were also collected in 2024 to evaluate spatial variability associated with different fruit species. Sampling depths included 0–20 cm and 20–40 cm, with an additional 40–60 cm layer assessed for redox evaluation. Soil pH was measured in aqueous suspension; hydrolytic acidity (Ah), exchangeable bases (Sb), and base saturation (V%) were determined by standard titrimetric methods. Organic carbon was quantified by wet oxidation ($K_2Cr_2O_7$ + H_2SO_4), and humus content was calculated by conversion. Available phosphorus (P-AL) and potassium (K-AL) were determined using the Egner–Riehm DL extraction method, widely applied in Central and Eastern Europe and directly linked to national fertilizer recommendation systems (Adamczewska et al., 2024; Karklins et al., 2015). The Nitrogen Index (IN) was calculated according to national guidelines. Electrical conductivity (EC) and oxidation–reduction potential (ORP) were recorded for salinity and aeration assessment.

Soil texture was determined using the pipette method and classified according to the Romanian Soil Taxonomy System (Florea & Munteanu, 2012), with reference to USDA texture classes for international comparability. This methodology enabled both temporal assessment (2019 vs. 2024) and spatial characterization (row-level variability), supporting a robust interpretation of nutrient dynamics in mixed orchard conditions.

RESULTS AND DISCUSSIONS

The first agrochemical assessment was carried out in 2019, establishing the baseline soil fertility once the orchard had passed the establishment phase. The follow-up sampling in 2024 enabled a five-year comparison under constant orchard management. This two-point monitoring approach follows the Romanian agrochemical diagnostic system for perennial crops, which prioritizes medium-term trend detection over annual variability (Dumitru et al., 2011). As this study adheres to the national soil surveillance protocol, the purpose was agronomic diagnosis rather than inferential testing. The orchard-area composite soil sample, prepared from approximately 30 soil cores to characterize overall site fertility, follows the national diagnostic protocol for perennial systems rather than an inferential experimental design. Analytical triplicates ensured laboratory precision.

Temporal evolution of fertility indicators

Table 1 summarizes the comparative analytical results obtained from the block-composite samples collected in 2019 (baseline) and 2024. Soil reaction showed a clear trend of improvement, shifting from 5.86 (moderately acidic) to 6.40 (slightly acidic). This trend was accompanied by a decrease in hydrolytic acidity (from 5.21 to 4.35 me/100 g soil) and a notable increase in base saturation (from 67.9% to 83.6%), indicating partial correction of soil acidity and enhanced cation balance.

Organic matter status improved significantly, with humus content rising from 1.90% to 5.50%. This increase was reflected in the Nitrogen Index (IN), which improved from 1.08 (very low) to 4.60 (satisfactory). According to national reference standards (Madjar., & Davidescu, 2015; Dumitru et al., 2011), IN values of 4.1–6.0 correspond to a good nitrogen supply potential. A similar positive shift was recorded for available phosphorus, which increased from 30 to 70 ppm.

In contrast, mobile potassium recorded a pronounced decrease, from 440 ppm (very high supply level) to 219 ppm, placing it within the lower sufficiency range for orchard soils. These interpretations are derived from the Egner–Riehm DL extraction method and evaluated against Romanian agrochemical sufficiency classes used for fertilizer recommendations (Dumitru et al., 2011; Adamczewska et al., 2024). This observed depletion suggests a rapid transition toward potassium limitation under orchard conditions, consistent with long-term biological extraction and K fixation in clay-loam soils.

Calcium and Magnesium Status and Soil Texture

The analysis showed that exchangeable calcium levels remained stable, ranging between 780–950 ppm, with magnesium similarly consistent, recorded between 150–210 ppm. This stability yielded a Ca:Mg ratio of 4.2–5.0.

Table 1. Agrochemical characteristics of orchard soils at Rusciori (Block-Composite Sample, n=3)

Parameter	**Year 2019**	**Year 2024**
pH (H_2O)	5.86	6.40
Electrical conductivity (µS/cm)	92.57	59.41
Hydrolytic acidity, Ah (me/100 g soil)	5.21	4.35
Base saturation degree, V (%)	67.93	83.60
Organic carbon (%)	0.70	2.02
Humus (%)	1.90	5.50
Nitrogen index (I_N)	1.08	4.60
Mobile phosphorus P-AL (ppm)	30	70
Mobile potassium K-AL (ppm)	440	219

This figure falls precisely within the recommended optimal range of 4–6 for perennial crops (Nguyen, 2017).

Maintaining this ratio is vital for preserving soil structural stability and reducing the risk of nutrient antagonisms. The adequate calcium status is particularly important for promoting fruit firmness and storability in pome fruits like apple and pear. Conversely, magnesium availability is essential for supporting chlorophyll synthesis, particularly in plum and small fruit species.Granulometric analysis (Table 2) classified the soil texture as clay loam, characterized by 33.8% clay, 17.4% silt, and 48.8% sand.

Table 2. Particle-size distribution of soils in the Rusciori orchard

Soil particle fraction	Diameter class	% fraction
Coarse sand	>0.2 mm	11.4
Fine sand	0.2 – 0.02 mm	37.4
	Total sand	48.8
Silt 1	0.02 – 0.01 mm	6.6
Silt 2	0.01 – 0.002 mm	10.8
	Total silt	17.4
Clay	<0.002 mm	33.8

This textural class offers advantages regarding nutrient retention and Cation Exchange Capacity (CEC). However, it simultaneously presents two major challenges: it increases the inherent susceptibility to soil compaction and it contributes significantly to the fixation of exchangeable potassium (K) (Nguyen, 2017). This specific textural constraint provides a partial explanation for the drastic observed decline in mobile K reserves (Table 1), especially when combined with the high nutrient extraction rates typical of mature fruit trees (Kuzin, 2021; Tagliavini, 2002).

Spatial Variability and Redox Status

Row-specific analytical values (Figure 1) documented localized spatial variability across the orchard block. These observations are used here to suggest potential species-related effects on soil chemistry rather than to support precision-agriculture interventions. Soil pH levels varied from 6.4 to 7.3. Slightly lower values (≈6.5) were recorded beneath blackcurrant and raspberry, reflecting a possible localized acidifying influence from these species. Conversely, higher alkalinity was observed near sour cherry (7.3) and pear (7.1).

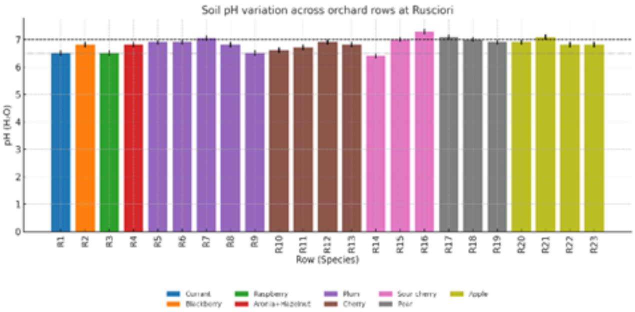

Figure 1. Variation of soil pH across orchard rows in the Rusciori orchard (2024).

Electrical conductivity (EC), a general indicator of salinity, remained very low across the entire block, ranging from 57 μS/cm (in rows R12 and R15, planted with sour cherry) to 123 μS/cm (plum, R7). Chloride levels were also consistently low (0.013%–0.048%), well below any threshold for salt-sensitive fruit trees. Although the variation was limited, these differences suggest minor localized variation in nutrient uptake and soil solution composition associated with different fruit species.

The Oxidation–Reduction Potential (ORP) remained strongly positive, consistently between +320 and +370 mV, confirming well-aerated conditions. Such a favorable redox status is important as it prevents reductive stagnic processes and supports the stability of nitrate and phosphate (Chiurciu, et al., 2022). When considered together with the observed improvement in base saturation and reduction in hydrolytic acidity, these results support the interpretation of improved soil chemical balance, despite the concurrent emergence of potassium depletion as a key constraint.

Management Implications and Future Strategy

The overall fertility dynamics confirm a management success in building nitrogen, phosphorus, and organic matter reserves over the five-year period. However, the pronounced decline in mobile potassium suggests that this nutrient has emerged as the primary potential limiting factor for high-demand species (Strik, 2021; Rusu et al., 2023). Exchangeable calcium and magnesium levels remained adequate, but continued monitoring is essential to prevent potential future imbalances, particularly antagonistic interactions with potassium (Nguyen, 2017).

A short nutrient balance supports this finding: the 221 ppm reduction in K-AL between 2019 and 2024 corresponds to ~663 kg K ha^{-1} depleted from the topsoil layer, indicating extraction-driven decline under perennial cropping.

The need for adaptive, site-responsive management is supported by the temporal shift in constraints (from N/P to K) and the spatial variability observed across rows (Uribeetxebarria et al., 2018). Periodic liming is required to stabilize soil reaction within the optimal range (pH 6.5–7.0). Targeted K fertilization should be prioritized, especially for high-demand species such as apple and plum (Strik, 2021). While the current data does not support full-scale Variable Rate Technology (VRT) implementation, it supports a shift toward row-specific nutrient application aligned with species extraction demand. Maintaining the practice of shredding and incorporating pruning residues remains essential to sustain the documented increase in humus content, buffer soil acidity, and enhance nutrient cycling efficiency (Chiurciu, et al., 2022).

Agrochemical monitoring thus fulfills its dual role: tracking the evolution of overall temporal changes and identifying row-level variability and nutrient imbalances. This evidence supports the view that uniform, blanket fertilization is inefficient (Uribeetxebarria et al., 2018) and that adaptive, site-specific strategies are necessary to sustain productivity while meeting the environmental goals of the European Green Deal (EC, 2020; Dunchev, 2025).

CONCLUSIONS

Agrochemical monitoring of the mixed orchard block at Rusciori revealed significant changes in fertility status over the period 2019–2024. The initial baseline (2019) reflected critical deficits in humus, nitrogen, and phosphorus, balanced by very high mobile potassium reserves. Systematic management over the five years improved pH, humus, nitrogen, and phosphorus status. However, a marked depletion of potassium reserves reduced them to potentially limiting levels (down to 219 ppm K_2O).

The predominant clay-loam texture enhances cation exchange capacity but also presents a risk of compaction and localized potassium fixation. These findings indicate that orchard sustainability requires three coordinated, diagnosis-driven management measures:
(i) corrective liming to stabilize pH and secure Ca and Mg availability;
(ii) prioritized, targeted potassium fertilization aligned with species-specific demand; and
(iii) continued organic matter management

through residue incorporation to maintain soil structure.

The Rusciori case reinforces the principle that systematic agrochemical monitoring is the diagnostic foundation for adaptive management in perennial systems and supports compliance with the resource-efficiency objectives of the European Green Deal **(Dunchev, 2025).**

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