INTEGRATED ANALYSIS OF SOIL FERTILITY, BONITATION SCORES, AND CROP SUITABILITY IN THE PERIAM–SÂNNICOLAU MARE AREA (TIMIȘ COUNTY): IMPLICATIONS FOR SUSTAINABLE LAND USE

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Abstract

This study presents an integrated evaluation of soil fertility, bonitation scores, and crop suitability in two representative agricultural localities from the Western Romanian Plain: Periam and Sânnicolau Mare (Timiș County). In Periam, representative soil profiles were analyzed at two depths (0–20 cm and 20–40 cm), and laboratory determinations focused on key agrochemical parameters (pH, humus, total nitrogen, available phosphorus and potassium), physical properties (bulk density, texture), and hydrophysical indicators. Data from Sânnicolau Mare were integrated comparatively based on regional pedological reports and scientific literature. Results highlighted the predominance of chernozems in both localities, accompanied by gleysols in poorly drained microdepression areas, where lower pH values and higher bulk density were recorded.

Statistical analyses revealed significant relationships between pH, humus, and nutrient availability, emphasizing the role of organic matter and water regime in determining the actual fertility of soils. PCA clearly differentiated samples by soil type and locality, confirming the superior fertility of well-drained chernozems in Sânnicolau Mare compared to those in Periam. Bonitation scores placed the soils predominantly in quality classes II–III, with potential decreases to class III–IV in gleysols affected by temporary water excess. Applying ameliorative practices (drainage, deep loosening, liming, legume-based rotations) may increase bonitation scores by 5–10 points, thus improving productive capacity.

Overall, the study provides a robust scientific basis for adopting sustainable land management practices, demonstrating that combining pedological analyses with bonitation evaluation and modern statistical tools is an effective approach for optimizing agricultural land use in the Western Romanian Plain.

Key words: ameliorative practices, bonitation, crop suitability, soil fertility, sustainable land management

INTRODUCTION

Modern agriculture faces multiple challenges generated by intensified land use, increasing pressure on natural resources, and climate change, all of which directly affect soil functions and the capacity of soils to sustain stable crop production (Miller & Wali, 1995). In this context, detailed evaluation of pedological resources and productive capacity is essential for developing sustainable agricultural management strategies (Sattler et al., 2010). Globally, current trends emphasize rational land use through the integration of soil fertility indicators, multifactorial analysis, and advanced soil evaluation models (Aznar-Sánchez et al., 2019).

Across Europe, land-use policies focus on maintaining soil functions, preventing degradation, and optimizing fertility through technologies adapted to local environmental conditions (Robu et al., 2009; Zuazo et al., 2011). European strategies increasingly promote integrated pedological assessment, including both physicochemical properties and limiting factors, productive potential, and risks associated with improper agricultural land use (Ustaoglu et al., 2016). At the same time, complex relationships among pH, humus, nutrient availability, and hydrophysical conditions directly shape soil fertility and agricultural crop distribution (Song et al., 2022).

In Romania, numerous studies highlight the diversity of pedological conditions and the need for region-specific approaches to land quality assessment (Bălteanu & Popovici, 2010; Niță et al., 2018). The Western Romanian Plain—one of the most fertile agricultural regions—includes a variety of soil types, dominated by chernozems but also comprising soils affected locally by gleying, compaction, or mild acidification (Otiman, 2008; Ionescu et al., 2019). These characteristics significantly influence productive potential and crop suitability, and accurate evaluation requires the use of national bonitation methodologies and soil classification systems, complemented by statistical analysis and modern soil quality indicators (ICPA, 1987; OSPA Timiș regional reports).

Locally, the communes of Periam and Sânnicolau Mare represent two important agricultural territories of Timiș County, characterized by the predominance of chernozems and the intensive use of land for field crops. However, differences in microrelief, drainage, and texture generate important variations in soil behavior, especially in areas where gleysols occur or where bulk density is higher. Recent studies from western Romania emphasize that assessment of actual fertility must consider pH–humus–nutrient relationships, hydrological regimes, and the impact of agricultural practices on soil structure (Mihuț et al., 2024; Pop & Rusu, 2017).

The present study aims to integrate agrochemical, hydrophysical, and pedological analysis of soils from Periam and Sânnicolau Mare with bonitation scoring, identification of limiting factors, and the development of ameliorative scenarios. Comparing the two localities enables a better understanding of regional variability in soil fertility and highlights the influence of drainage, texture, and soil reaction on crop suitability.

The main objective is to determine the real productive capacity of soils and to estimate agronomic potential, with the purpose of formulating scientific recommendations for sustainable land use. The specific objectives include:

- Characterizing physicochemical soil properties by type and soil unit;
- Analyzing relationships among pH, humus, and nutrient elements;
- Assessing bonitation scores and crop suitability classes;
- Identifying limiting factors and corresponding ameliorative measures;
- Comparing results between Periam and Sânnicolau Mare;
- Integrating statistical analyses (Kruskal–Wallis, Mann–Whitney, Pearson/Spearman, PCA) to ensure robust data interpretation.

Through this integrated approach, the study provides a solid scientific framework for understanding local pedological resources and for supporting agricultural management decisions in the Western Romanian Plain.

MATERIALS AND METHODS

The research was conducted in two localities situated in the northwestern part of Timiș County: Periam and Sânnicolau Mare, representative for the Western Romanian Plain. Both areas are characterized by a very slightly undulating relief, typical of accumulation plains, where chernozems predominate, accompanied locally by gleysols formed in poorly drained microdepressions. Climatically, the region belongs to the moderate continental zone with western influences, having an average annual temperature of approximately 10.5–

11°C and annual precipitation ranging between 550 and 600 mm, conditions favorable for field crop production.

Differences between the two localities arise mainly from microrelief and hydrological regimes: Periam presents larger areas affected by temporary water stagnation and zones with higher bulk density; Sânnicolau Mare has slightly better natural drainage, which positively influences soil reaction and crop suitability.

Soil Sampling and Database Structure

In Periam, representative pedological profiles were selected, and soil samples were collected from two standard depths: 0–20 cm (arable horizon), 20–40 cm (subarable horizon).

Laboratory analyses were carried out in accordance with national methodologies (ICPA, 1987) and OSPA Timiș standard procedures. Determinations included:

Chemical Properties

- pH (potentiometric method, soil:water ratio 1:2.5);
- humus content (Walkley–Black/ Schollenberger method);
- total nitrogen (Kjeldahl digestion);
- available phosphorus (lactate-acetate extraction; colorimetric determination);
- available potassium (flame photometry);
- micronutrients: Zn, Cu, B, Mo (AAS and/or colorimetry);
- total $CaCO_3$ (Scheibler method)

Physical and Hydrophysical Properties

- soil texture (pipette and sedimentation method);
- bulk density (core cylinder method);
- soil moisture at 105°C;
- water retention indicators (where available).

Soil data for Sânnicolau Mare were integrated comparatively from regional pedological reports and scientific literature, ensuring compatibility with the parameters analyzed in Periam.

Soil Classification and Land Quality Assessment

Soil type and subtype classification followed the Romanian System of Soil Taxonomy (SRTS 2012) and ICPA methodological guidelines. Land quality evaluation and bonitation scoring were based on: identification of soil types and soil units (US codes), assessment of physical and chemical indicators, application of penalization and potential improvement coefficients.

Bonitation scores were determined using key diagnostic factors:

pH, humus, texture, drainage, temporary water excess, local gleying, nutrient supply (NPK), compaction degree, $CaCO_3$ content, effective soil depth, and hydrophysical limitations.

For the amelioration scenario, the following improvements were considered: liming for soils with pH <6.2, surface and subsurface drainage improvement, deep loosening for bulk density values >1.40 g/cm³, incorporation of crop residues and use of perennial legumes in rotation, balanced fertilization plans, especially for phosphorus.

Statistical Analysis

Statistical analyses were conducted using structured soil datasets from Periam and comparable data from Sânnicolau Mare.

1. Descriptive Statistics

Means, medians, standard deviations, and interquartile ranges were calculated for the following variables:

pH, humus, total N, available P and K, bulk density, and texture fractions.

2. Group Comparisons

Kruskal–Wallis tests were used to evaluate differences among soil units and between localities.

Mann–Whitney U tests (with Bonferroni correction) were applied for pairwise comparisons where significant differences were indicated.

3. Correlation Analysis

Pearson's correlation was applied for normally distributed variables.

Spearman's rank correlation was used for non-normal distributions.

Correlation matrices were visualized as heatmaps.

4. Principal Component Analysis (PCA)

PCA was performed on standardized variables (pH, humus, N, P, K, bulk density, texture parameters) to: identify main soil fertility gradients, visualize relationships among variables, compare sample distribution between soil types and localities.

RESULTS AND DISCUSSIONS

1. Soil Types and Agrochemical Characteristics in Periam and Sânnicolau Mare

Soil analyses confirmed that both Periam and Sânnicolau Mare are dominated by chernozems, known for their naturally high fertility, while gleysols occur locally in poorly drained microdepressions. These hydromorphic conditions influence several key soil parameters, including pH, humus content, and bulk density.

The data presented in Table 1 show that the pH falls between 6.1 and 6.6, which gives the soils a weak acid–neutral reaction.
Hummus shows values between 2.7 and 3.4%, reflecting moderately high natural fertility.
The values of total nitrogen (0.16–0.19%) and mobile phosphorus (24–33 ppm) indicate a medium to good fertility, but with variability between soil units and localities, correlated with soil texture and reaction. The potassium potential (130–160 ppm) is high in both zones, reflecting a good natural reserve of exchangeable K in the colloidal complex.

Table 1.
Chemical and physical properties of soils from Periam and Sânnicolau Mare (mean ± SD).

Location	SoilType	pH_mean	pH_std	Humus_mean	Humus_std	N_mean	N_std	P_mean	P_std	K_mean	K_std	DA_mean	DA_std
Periam	Chernozem	6.49	0.14	3.16	0.32	0.18	0.02	28.28	3.26	150.69	10.84	1.32	0.02
	Gleysol	6.21	0.21	2.72	0.15	0.16	0.02	25.2	2.42	131.45	6.4	1.43	0.04
Sannicolau Mare	Chernozem	6.47	0.14	3.45	0.29	0.19	0.01	33.65	6.83	159.15	7.77	1.32	0.06
	Gleysol	6.16	0.13	2.75	0.29	0.17	0.01	25.23	3.15	137.73	7.24	1.39	0.04

The apparent density (1.32–1.40 g/cm³) is appropriate for loamy-clayey soils, but higher values in gleiosols suggest moderate compaction, which may limit water infiltration and aeration
Comparatively, Sânnicolau Mare has slightly higher values for humus and motile P, which suggests better fertility in well-drained areas.

2. Variation in pH and humus content by soil types (Figure 1).

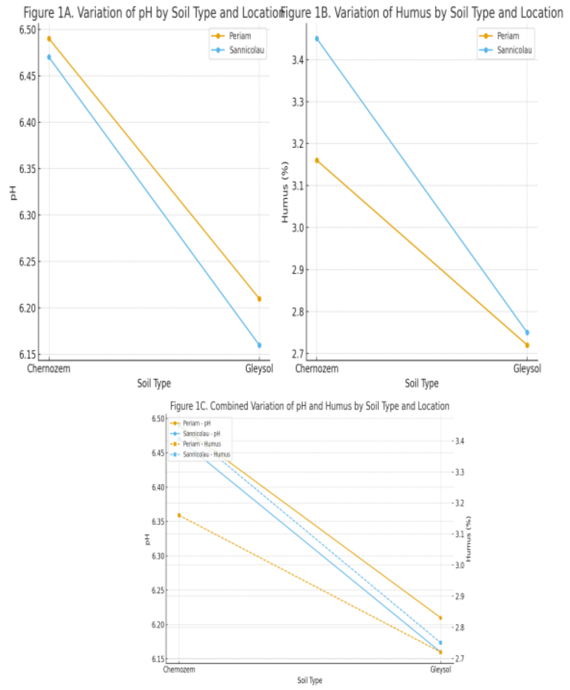

Figure 1 – Boxplots of pH and Humus content by soil type

Figure 1 (a, b, c), illustrates the pH variation by soil type and locality. It is observed that chernozem-type soils show a slightly more neutral reaction (pH 6.4–6.6) compared to gleiosols, where the values decrease towards 6.0–6.2, due to water stagnation and local reducing processes.
The differences between the localities are small, but the slightly higher values in Sânnicolau Mare indicate a better natural drainage, which reduces secondary acidification. These variations confirm the influence of the water regime on the reaction of the soil and justify the application of selective calcareous amendments in areas with pH <6.2, to optimize phosphorus availability and reduce the toxicity of exchangeable aluminum.
Figure 1C integratively highlights variations in pH and humus content depending on soil type and locality. It is observed that the pH differs depending on the type of soil and locality as follows: the chernozems of Periam (6.49) have a slightly higher pH than those of Sânnicolau Mare (6.47). The differences are more evident in gleiosols, where Periam (6.21) has higher values

than Sânnicolau Mare (6.16). This indicates a more stable water regime in Sânnicolau Mare, where drainage reduces acidification cycles. As for the humus content, the chernozems in Sânnicolau Mare (3.45%) clearly exceed the values in Periam (3.16%). In gleiosols, the differences are smaller but consistent: 2.75% vs. 2.72%. Organic matter is better maintained in soils with better drainage, which favors mineralization and nutrient cycling. This shows the influence of microrelief and water regime on the mineralization and stability of organic matter.

3. Analysis of correlations between pH, humus, N, P and K (Figure 2)

Figure 2. Corelaţion Pearson/Spearman (heatmap between pH, humus, N, P, K)

Figure 2 shows the Pearson correlation matrix between the main parameters (pH, humus, N, P, K). It is noted, a moderate positive correlation between pH and mobile phosphorus (r ≈ 0.58), which highlights the increase in the availability of P at slightly neutral values of the soil reaction; a strong correlation between humus and K (r ≈ 0.74), reflecting the role of organic matter in the fixation and release of potassium in the exchange complex; a positive association between total N and humus (r ≈ 0.68), given by the common origin of the two components of organic matter.

These relationships confirm that soil chemical fertility is determined by the balance between organic matter and soil reaction, and maintaining optimal humus levels is essential for long-term nutritional stability.

4. PCA Analysis (Main Component)

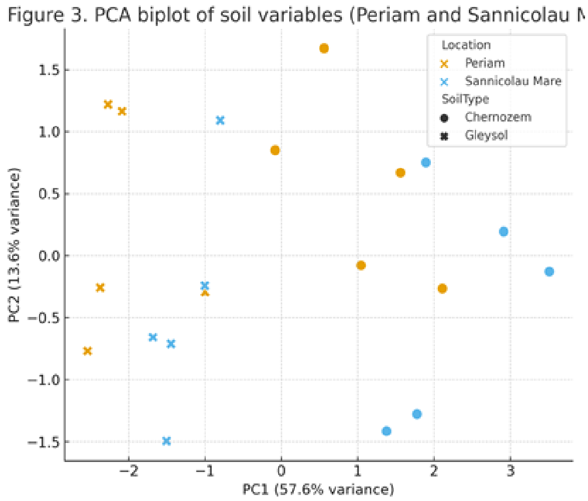

Figure 3. PCA biplot – integration of soil variables (0–20 cm)

The PCA analysis (Figure 3) shows that the first two main components explain about 70% of the total data variation.

Main component 1 (PC1 57.6%), separates the samples according to the level of chemical fertility (pH, humus, P, K), which are positively correlated variables.

Component 2 (PC2 13.6%), reflects the physical differences (bulk density, N content), illustrating slight deviations between soil types.

The samples from Periam, on gleiosols are grouped towards negative values of PC1 and PC2, indicating a lower level of fertility and easy compaction, while the samples from Sânnicolau Mare, on chernozems, are positioned in the positive quadrant, associated with high fertility and more neutral reaction.

This separation clearly highlights the influence of hydric and textural factors on nutrient distribution and confirms the superior potential of chernozems for intensive field crops compared to poorly drained gleiosols.

PCA confirms the clear differentiation between well-drained areas and those with temporary excess water.

5. Bonitation Scores and Soil Quality Classes (table 2).

Table 2

Bonitation scores by soil unit (baseline vs. amelioration scenario)

Soil Unit	Baseline Score	Class	Improved Score	Class after amelioration
Chernozem (Periam)	75	II	82	II
Gleysol (Periam)	60	III	70	II–III
Chernozem (Sânnicolau Mare)	78	II	83	II
Gleysol (Sânnicolau Mare)	63	III	72	II–III

The data presented in Table 2 show that chernozems, with 75-78 points, fall into class II, having high productive capacity, while gleiosols have water limitations that reduce creditworthiness (60-63 points).

The ameliorative scenarios (drainage, loosening, amendment) lead to an average increase in the score by 5–10 points, improving the favorability of the crops.

6. Comparison of Periam – Sânnicolau Mare on fertility and favorability

Sânnicolau Mare has slightly higher fertility, due to better natural drainage.

The perimeter has areas with temporary excess water, which reduce the availability of P and increase the apparent density.

PCA and univariate statistics confirm distinct pedological differences between the two localities.

In Periam, more aggressive ameliorative measures (drainage, loosening) are recommended.

In Sânnicolau Mare, balanced fertilization and maintenance of the structure are recommended.

7. Sustainable management recommendations

Priority measures are recommended, namely:

- Calcareous amendment on soils with pH <6.2;
- Deep loosening on units with DA >1.40 g/cm³;
- Superficial drainage in microdepressions;

Rotations with perennial legumes and intake of plant debris for humus growth;

Fractional P fertilization for soils with variable availability;

Soil conservation through minimal tillage and avoidance of agricultural traffic on wet soil.

CONCLUSIONS

The integrated analysis of the soils of Periam and Sânnicolau Mare highlights the fact that both agricultural territories are characterized by a valuable soil fund, dominated by chernozems with high natural fertility, locally supplemented by gleiosols, whose productivity is influenced by drainage and hydrophysical properties.

The results obtained show that the pH values (6.1–6.6), the humus content (2.7–3.4%) and the moderate–high reserves of P and K give the soils a good agronomic potential for field crops.

The differences between the two localities are mainly determined by the micro-relief and the water regime, which affects the soil reaction, the degree of compaction and the availability of nutrients. Sânnicolau Mare has slightly higher fertility due to better drainage, while in Periam there are local limitations caused by the temporary excess of water and higher values of apparent density.

The evaluation of the creditworthiness grades indicates the predominant classification in classes II–III, with the possibility of reducing the quality on gleiosols up to class III–IV. The application of the ameliorative scenarios (calcareous amendment, superficial drainage, deep loosening, rotations with legumes and balanced fertilization), determines the increase of the creditworthiness score by 5–10 points, confirming the potential to improve the productivity of these lands.

Statistical analyses (Kruskal–Wallis, Mann–Whitney, Pearson/Spearman correlations, PCA) demonstrated the essential relationships between pH, humus and nutrients, highlighting the role of organic matter and water regime in determining soil fertility. The PCA clearly separated the samples according to soil type and locality, confirming the influence of physicochemical properties on productivity.

Overall, the paper highlights the importance of adopting sustainable agricultural management, where decisions on fertilization, tilling, drainage and crop rotations must be based on rigorous soil assessments and integrative fertility indicators. The implementation of the recommended measures can lead to the stabilization of agricultural production, the reduction of soil risks and the sustainable use of land in the Western Plain.

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