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SUSTAINABLE MANAGEMENT OF SOIL RESOURCES IN THE NORTH-WESTERN AREA OF THE ARAD PLAIN

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Abstract. *This paper provides an integrated pedological assessment of soils and agricultural land in the north-western sector of the Arad Plain (Arad County), with the aim of supporting the sustainable management of natural resources and the long-term development of local agriculture. The methodological approach combines field observations with laboratory analyses and the interpretation of pedo-structural data in order to identify, delineate, and classify the main soil types within the study area. The results indicate the predominance of pedological units such as Fluvisols (alluvial soils), Chernozems, Eutric Cambisols, Preluvosols, Vertisols, Pelosols, and Gleysols, each characterized by distinct morphological features and functional properties shaped by the geomorphological setting, hydrological conditions, and local climatic regime. These physico-geographical controls directly influence soil agricultural suitability and require differentiated management measures tailored to the constraints and potential of each unit. In terms of land use, agricultural areas account for approximately 90% of the investigated perimeter and are dominated by arable land, whereas pastures and hayfields occupy relatively small shares. Morphological analyses reveal pronounced variability of pedogenetic horizons, reflecting the dynamics of soil formation and evolution. At the same time, assessments of fertility, structural condition, and water-holding capacity provide relevant indicators for designing efficient agricultural practices with reduced environmental impact and compatible with local conditions. By systematizing and interpreting these data, the study contributes to the completion and updating of the regional pedological database, offering scientific support for land management decisions. The findings can be used both by authorities responsible for land-use planning and conservation measures and by agricultural producers seeking to optimize farming practices. Overall, the assessment supports responsible land-use planning, promotes sustainable agriculture, and strengthens the basis for long-term economic development under conditions of environmental protection in the study region.*

Keywords*: soil resource; sustainable management; Arad Plain; pedogenetic processes; land fund.*

INTRODUCTION

Pedology, as a core domain of soil science, has undergone a significant transition from empirical assessments of “land” and fertility to an explanatory and predictive scientific framework capable of describing pedogenetic processes, quantifying physical, chemical, and biological properties, and supporting evidence-based land management decisions. Along this trajectory, pedological research-focused on the knowledge, characterization, and classification of soils-has become an indispensable tool for the rational use of natural resources and for achieving sustainable development goals, especially in regions dominated by intensive agriculture (BOCIOACĂ, 2015; BAIZE & TCHOUNDJEU, 2016).

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The first modern attempts at soil systematization emerged in the late nineteenth and early twentieth centuries through contributions from European and North American schools (e.g., THAER, BIRNBAUM, KNOOP; DOKUCHAEV; STORIE), which introduced differentiation criteria based on morphology, composition, and mineralogy. In Romania, the development of pedology as an applied discipline accelerated during the first half of the twentieth century through the institutionalization of research and the initiation of systematic soil surveying, which enabled the production of pedological maps and the establishment of terminology adapted to local conditions. Subsequently, the standardization of taxonomic classification was strengthened through national soil classification systems, notably the Romanian System of Soil Taxonomy (SRTS), updated in successive editions, which has provided a coherent framework for inventorying, evaluation, and land-use planning.

At the international scale, the need for a common language to facilitate comparison and communication led to the adoption of the World Reference Base for Soil Resources (WRB) as a global reference standard. WRB, coordinated by the International Union of Soil Sciences (IUSS) working group, was first published in 1998 and has been periodically revised, reflecting the dynamic nature of soil taxonomy and its continuous adaptation to methodological advances and new datasets (DINER ET AL., 2018).

A major turning point in pedology has been driven by the digital transformation of soil mapping. The integration of remote sensing, Geographic Information Systems (GIS), and pedological databases has enabled a shift from static maps to multi-scale spatial products that can be updated rapidly and that improve the identification of areas vulnerable to soil degradation (ŠIMANSKÝ ET AL., 2018). GIS allows the correlation of pedological information with environmental variables (relief, lithology, hydrology, land use) and supports the modelling of processes in space and time (PACHECO ET AL., 2017). In addition, machine learning approaches (such as Random Forest, Support Vector Machines, or neural networks) make it possible to classify and predict the spatial distribution of soils and key edaphic properties under conditions of high heterogeneity or incomplete observational coverage, contributing to the production of high-resolution digital soil maps (SANTOS ET AL., 2020).

The relevance of these approaches is particularly evident in intensively cultivated plains, where pedo-hydrological conditions and anthropogenic pressures may vary substantially at local scales. A representative case is the north-western part of Arad County, especially the administrative territories of Curtici town and Olari commune, located within the Arad Plain-a sector of the Western Plain characterized by a flat surface, subsidence tendencies, and a dense network of drainage canals and hydro-ameliorative works historically developed to control excess water. In such a setting, agricultural productivity and ecosystem stability depend not only on the intrinsic fertility of soils, but also on water regime dynamics within the soil profile, susceptibility to compaction, and risks such as seasonal hydromorphism, localized salinization/sodification, or structural degradation.

Therefore, a rigorous introduction to pedological studies in this area should connect the conceptual evolution of pedology to its practical relevance by emphasizing:(1) standardized inventory and taxonomic classification (SRTS/WRB) as a basis for comparison and knowledge transfer; (2) modern mapping (GIS, remote sensing, modelling) as a tool for spatial characterization; and (3) the integration of results into agricultural land management, in order to adapt technologies to the specific local conditions of Curtici and Olari. In this way, pedology becomes not merely a descriptive discipline, but a scientific foundation for planning, preventing degradation, and ensuring the sustainable use of soil resources in a strategically important agricultural area of the Arad Plain.

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MATERIAL AND METHODS

The study aimed to compile a detailed set of pedological information to serve as a scientific basis for recommending technological and land-management measures adapted to local conditions in the north-western part of Arad County, with a focus on the administrative territories of Olari commune and Curtici town. The operational objectives were as follows:

- identifying, delineating, and inventorying the soil–land units (TEO) within the investigated area;
- carrying out the morphological, physical/hydrophysical, and chemical characterization of these units, in correlation with geomorphological and hydrological conditions and with land use;
- assessing the limiting/restrictive factors (natural and anthropogenic) that influence agricultural productivity potential and the stability of agroecosystems.

The investigated area is located in the low-plain sector of Arad County, within a predominantly flat relief featuring landforms typical of plains (gently undulating interfluves, microdepressions, and areas with contrasting drainage conditions), where land use is mainly agricultural (primarily arable). The documentary material included:

- existing pedological and cartographic data (archives and databases) from O.S.P.A. Arad;
- up-to-date cartographic supports (plans/topography, orthophotos), used for orientation and verification of unit boundaries;
- data obtained from field investigations and laboratory analyses.

The delineation of soil–land units was performed through field soil mapping, using transects and point checks in representative areas of Olari and Curtici, with attention to the relationships among microrelief - drainage - agricultural land use - parent materials. In key locations, pedological profiles were excavated and/or auger borings were carried out, positioned to capture local variability (flat surfaces versus microdepressions, areas showing signs of hydromorphism, and zones potentially affected by anthropogenic modifications such as levelling or land-improvement works).

Morphological descriptions were completed for each profile in accordance with the Romanian System of Soil Taxonomy (SRTS, 2012) and the Methodology for Pedological Studies (ICPA, Vol. I–III, 1987), including: horizon sequence, thickness, colour, estimated texture, structure, porosity, consistency, reaction to HCl (carbonates), presence of concretions, redox features indicative of gleying/stagnogleying, as well as diagnostic elements for pedogenetic processes (e.g., clay illuviation, vertic properties).

Depending on the objectives and soil type, laboratory analyses targeted parameters such as: texture (particle-size distribution), bulk density and structural indicators, pH, electrical conductivity (salinity), carbonates ($CaCO_3$), humus/organic carbon, and agrochemical indicators relevant for the cultivated layer (plant-available macronutrients). For soils with potential halomorphic/hydromorphic features, additional indicators related to salt regime and internal drainage were also considered, as appropriate.

The morphological and analytical data were integrated into a unified database and correlated with field position, resulting in the delineation and description of soil–land units. Taxonomic classification was performed primarily according to SRTS (2012), and where useful for comparability, correspondence to an international system (WRB) was established at the level of principal groups/qualifiers. Limiting factors affecting productivity were interpreted based on the combined influence of key properties (hydromorphism, compaction, salinization/sodification, soil reaction, water-holding capacity) and local land-use conditions, in order to formulate a pedo-functional diagnosis relevant for the management of agricultural land in Olari and Curtici.

RESULTS AND DISCUSSIONS

1. NATURAL CONDITIONS FOR THE FORMATION AND EVOLUTION OF SOILS IN THE NORTH-WESTERN ARAD PLAIN

1.1. Geomorphology

The investigated perimeter, corresponding to the administrative territories of Curtici town and Olari commune, lies within the Arad Plain (a sector of the Western Plain), which is characterized by a predominantly flat relief, low altitudinal variation, and micro-relief fragmentation generated by the alternation of positive and negative landforms. In the field, natural levees/ridges (elongated micro-elevations with relatively better drainage) and microdepressions/backswamps are frequently observed, together with traces of abandoned meanders or former flow paths-features typical of plains shaped by alluvial accumulation. From a genetic standpoint, the area is influenced by the Mureș river system and is associated with a “younger” plain surface built through depositional processes toward zones with subsidence tendencies, which explains the frequency of poorly drained areas and shallow negative microforms.

Microrelief differences directly control the soil profile’s air–water regime: better-aerated conditions prevail on ridges with a lower risk of water stagnation, whereas microdepressions create environments favourable to hydromorphism (seasonal stagnation, gleying/stagnogleying), affecting soil structure, reaction, and salt mobility.

1.2. Geology and lithology of surface deposits

Lithologically, the Curtici–Olari area consists of deposits of variable age and grain-size composition, arranged in successions controlled by meso- and microrelief. In negative landforms (depressions and low inter-ridge areas), fine-textured materials (clay loam to clay) generally occur within the first ~1.0–1.3 m, followed by layers with medium to moderately fine textures (clay loam, silty clay loam) down to approximately 1.0–1.8 m. At greater depths, deposits shift to medium textures (loam, silt loam, locally sandy loam), and in some sectors coarser accumulations (sand, loamy sand) occur, particularly in association with positive landforms or palaeochannels.

This stratification explains: pronounced variability in permeability and internal drainage; a predisposition to moisture excess in areas with compact clays; and favourable conditions for processes such as vertic properties (where shrink–swell clays are present) or textural differentiation influencing colloid migration and aggregate stability.

1.3. Climate

The climatic regime is moderate temperate-continental, with relatively mild winters and seasonal dynamics influenced by air-mass circulation: westerly inputs with oceanic nuances (often continentalized by the time they reach the plain) and easterly continental influences, periodically overlain by warmer southern advections. In climatic classification terms, the area falls within the temperate Cfbx domain (with regional particularities), supporting a variable interannual water balance and alternating wetter and drier periods during the growing season.

Pedogenetic implications. Seasonal wet–dry alternation and episodes of precipitation surplus play a major role in: intensifying water stagnation in microdepressions; triggering water-stress during warm periods on soils with degraded/compacted structure; and influencing organic matter and structural dynamics, with direct effects on fertility and workability.

1.4. Hydrography and hydrogeology

The Curtici–Olari area (north-western Arad Plain) belongs to the Mureș River basin, which acts as the main regional collector. In the plain, the natural valley network is weakly expressed, and runoff is largely controlled by canals and drainage/desiccation works, amplified by intensive agricultural land use and the need to limit excess water in low-lying zones. In microdepressions, temporary water accumulations (ponding/waterlogging) may occur during periods of high precipitation, indicating slow external drainage and low permeability of fine deposits.

Pedogenetic implications. Groundwater level and fluctuations, together with temporary stagnation of rainfall water, control the distribution of soils with hydromorphic features (gleyic/stagnic), as well as the risk of structural degradation and compaction when agricultural traffic occurs on wet soils.

1.5. Vegetation

From a phytogeographical perspective, the area lies in the forest-steppe to steppe transition zone, and the potential vegetation (in the absence of human influence) would have been dominated by forest-steppe communities, with forests of *Quercus spp*. (oaks) and associated species (e.g., *Carpinus*, *Fraxinus*, *Populus*, *Betula*), currently preserved only fragmentarily (isolated trees, small patches, shelterbelts). At present, agricultural land overwhelmingly dominates the territories of Curtici and Olari, and spontaneous vegetation persists mainly along field margins, canal banks, and within microdepressions.

In low-lying areas with moisture excess, hygrophilous plant assemblages develop, with indicator species of persistent wetness such as *Phragmite*s (reed), *Carex* (sedge), *Scirpus* (bulrush), *Juncus, Poa* palustris, Typha (cattail), etc.

Pedogenetic implications. Vegetation patterns—especially hygrophilous elements—confirm the presence of microzones with surplus water regime, serving as natural indicators for delineating soil–land units and interpreting hydromorphism processes.

2. SOIL-FORMING PROCESSES IN THE INVESTIGATED AREA

In the north-western Arad Plain (the administrative territories of Curtici and Olari), soil-forming processes are mainly controlled by the very weakly dissected relief, alluvial deposits with variable textures, the moderate temperate-continental climatic regime, and the dynamics of surface and groundwater. Microrelief, expressed by the alternation between natural levees/ridges and microdepressions, generates local differences in drainage and soil-profile aeration. On slightly elevated surfaces with more permeable parent materials (sandy loam/loam), pedogenetic processes associated with a more balanced air–water regime predominate, including humification and the development of soil structure in the upper horizon, as well as gradual decarbonation where carbonates occur at shallow depth. By contrast, in low-lying areas dominated by fine-textured deposits (clay loam/clay) and reduced internal drainage, hydromorphism becomes more pronounced: seasonal water stagnation leads to stagnogleying and/or gleying, with the occurrence of redox mottling (marmorization), structural changes, and decreased permeability.

Under wet–dry alternation conditions (wetter springs and warmer summers), soils with a high clay content may exhibit shrink–swell phenomena, resulting in vertic properties (cracks, prismatic aggregates, and characteristic microrelief). At the same time, groundwater mineralization and summer evaporation may locally favour salt accumulation and processes of salinization/sodification, particularly within microdepressions. Anthropogenic interventions (drainage, desiccation, and agricultural operations) modify these processes by partially reducing moisture excess; however, they also increase the risk of compaction and structural degradation when field traffic takes place outside the optimal moisture range.

3. LAND FUND OF THE STUDY AREA

Table 1.

Land fund status in the study area

Land-use category	Curtici Town (ha)	Olari Commune (ha)	NW Arad Plain (ha)	% of total agricultural land	% of total area
Arable land	6,500	3,461	9,961	89.79	81.52
Pastures	186	897	1,083	9.76	8.86
Hayfields	0	50	50	0.45	0.41
Vineyards	0	0	0	0	0
Orchards	0	0	0	0	0
Total agricultural land	6,686	4,408	11,094	100	90.79
Forests	10	0	10	–	0.08
Water bodies	0	128	128	–	1.05
Other categories	510	477	987	–	8.08
Total area	7,206	5,013	12,219	–	100

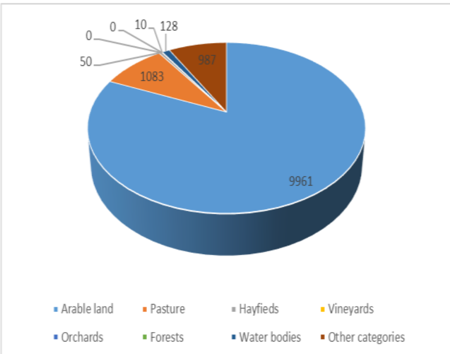

Figure 1. Distribution of land-use categories in the NW Arad Plain

Based on the data presented in Table 1 and Figure 1, agricultural land use clearly dominates in the NW Arad Plain (Curtici + Olari). Out of a total of 12,219 ha, agricultural land amounts to 11,094 ha, i.e. 90.79% of the area. Within agricultural land, arable land is overwhelming: 9,961 ha, representing 89.79% of total agricultural land and 81.52% of the total area. Pastures have a secondary share (1,083 ha = 9.76% of agricultural land; 8.86% of the total area), while hayfields are almost negligible (50 ha = 0.45% of agricultural land; 0.41% of the total area). The complete absence of vineyards and orchards suggests a clear specialization toward field crops (cereals, oilseeds, and industrial crops), typical of highly mechanized plain regions.

A comparison between the two administrative units highlights two distinct land-use patterns. Curtici is strongly dominated by arable land: out of 6,686 ha of agricultural land, 6,500 ha are arable, i.e. 97.22% of agricultural land (approximately 90.20% of the UAT total area). Pastures are marginal (about 2.78% of agricultural land). Olari shows greater diversification: arable land covers 3,461 ha (approximately 78.52% of agricultural land), while pastures are substantial (897 ha, about 20.35% of agricultural land). In addition, the water bodies category appears only in Olari (128 ha = 2.55% of the total area), indicating the presence of canals/depression zones or surfaces with a more active hydrological regime.

Overall, the very small share of forests (10 ha = 0.08% of the total area) reflects an almost continuous agricultural landscape, which implies increased pressure on soils (compaction, declining organic matter, and vulnerability to both excess and deficit of moisture). The Curtici–Olari contrast (arable land versus pasture/water) also suggests distinct local pedo-hydrological conditions in Olari that may limit arable land in certain microzones and justify a detailed pedological analysis at the level of soil–land units.

4. SOIL RESOURCES IN THE STUDY AREA

Soil resources identified within the total agricultural land of the NW Arad Plain

Table 2.

Soil class	Soil type	Curtici Town (ha)	Olari Commune (ha)	NW Arad Plain area	
				ha	%
Cernisols	*Chernozem*	4,728	1,109	5,837	52.61
	Phaeozem	201	–	201	1.82
Cambisols	*Eutric Cambisoil*	599	55	654	5.89
Vertisols	*Vertisol*	247	2,001	2,248	20.27
	Pelosoil	905	1,136	2,041	18.40
Hydrisols	*Gleysoil*	–	71	71	0.64
Salsodisols	*Solonetz*	–	36	36	0.32
Anthrisols	*Anthrosoil*	6	–	6	0.05
TOTAL			6,686	4,408	11,094

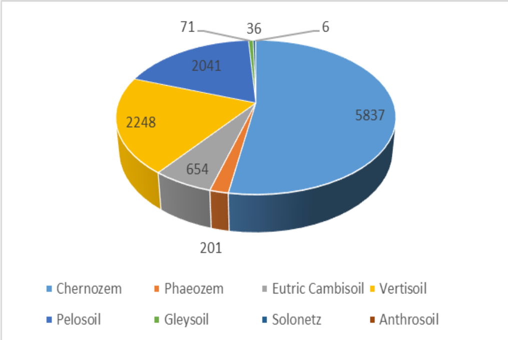

Figure 2. Distribution of soil resources by soil type in the study area

The data collected and presented in Table 2 describe the soil-resource structure for the total agricultural land of the NW Arad Plain (Curtici + Olari), amounting to 11,094 ha. The results highlight a pedological structure dominated by soils with high agricultural potential, but also including a substantial component of heavy soils with physical and hydrological constraints.

4.1. Overall structure by soil types/classes

Cernisols (Chernozem + Phaeozem): 5,837 + 201 = 6,038 ha, i.e. 54.43% of the total (52.61% + 1.82%). This high share confirms the character of an intensively cultivated plain, where soils with a well-developed humus horizon traditionally support arable crops.

Vertisols (Vertisol + Pelosol): 2,248 + 2,041 = 4,289 ha, i.e. 38.67% of the total (20.27% + 18.40%). This is a very high proportion, indicating the wide extent of clay-rich parent materials and shrink–swell processes; these increase the risk of compaction, difficult workability, slow internal drainage, and seasonal alternation between moisture excess and deficit.

Cambisols (Eutric Cambisol): 654 ha (5.89%)—a secondary component, suggesting lithological/geomorphological transitions or sectors with different evolutionary conditions.

Problematic soils in terms of spatial extent are limited, yet ecologically significant:

Gleysol (Hydrisols): 71 ha (0.64%), indicating microzones with shallow groundwater and/or waterlogging.

Solonetz (Salsodisols): 36 ha (0.32%), reflecting localized sodification (risk of degraded structure and very low permeability).

Anthrosol (Anthrisols): 6 ha (0.05%), very small areas locally affected/modified by human activity.

4.2. Implications for agricultural management and pedogenetic discussion

The high share of Chernozems at the overall level suggests strong potential for field crops; however, almost 40% of the area is occupied by Vertisols and Pelosols, which have narrow “workability windows,” are sensitive to compaction, and exhibit an oscillating moisture regime. The presence of Gleysols and Solonetzs—even though limited—matters for planning, because these areas require targeted measures (drainage, reduction of traffic on wet soil, chemical/structural amelioration, and adaptation of land use).

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4.3. Pedogenetic discussion (soil–environment relationships)

The soil-resource structure of the NW Arad Plain (Curtici–Olari) reflects the strong control exerted by alluvial parent materials and the lowland microrelief (ridges–microdepressions) on the soil air–water regime and pedogenetic processes. The dominance of Cernisols (Chernozems + Phaeozems = 54.43%) indicates areas with relatively good drainage and a more favourable air–water balance, where humification and organic matter accumulation have produced a well-developed A horizon with high natural fertility. These soils are typical of more stable geomorphological sectors (interfluves/slightly elevated areas) where water stagnation is limited.

The very high share of Vertisols (Vertisols + Pelosols = 38.67%) confirms the extensive occurrence of clay deposits with shrink–swell properties, which induce vertic features (cracks, prismatic structure, characteristic microrelief) and generate an oscillating moisture regime: excess moisture during wet periods and deficit during the warm season. In microdepressions or on fine, poorly permeable deposits, water stagnation favours hydromorphism, reflected in the local presence of Gleysols (0.64%), while in places where groundwater mineralization and salt redistribution are more pronounced, Solonetzs occur (0.32%), characterized by degraded structure and very low permeability. The differentiated distribution by administrative unit confirms this control: Curtici is dominated by Chernozems (≈73.7% of its agricultural land), whereas Olari is dominated by Vertisols/Pelosols (≈71.2%), implying more difficult workability and higher vulnerability to compaction and temporary moisture excess.

CONCLUSIONS

The paper highlights that the investigated area in the north-western Arad Plain (the administrative territories of Curtici and Olari) belongs to a lowland plain sector formed by Mureș River accumulations toward zones with subsidence tendencies, where microrelief (ridges–microdepressions) and the lithological succession (alluvial deposits with variable textures, locally covered by a thin loess-like mantle) decisively control the soil air–water regime and pedogenetic processes. The alternation between better-drained surfaces and low-lying areas with slow drainage explains the simultaneous occurrence of soils with high fertility and soils with physical/hydrological constraints, confirming the major role of the natural setting in pedological diversity.

From a land-use perspective, the area is characterized by a clear dominance of agricultural use: agricultural land totals 11,094 ha (90.79%) out of 12,219 ha, and arable land is the main component (9,961 ha; 81.52% of the total). The very low share of forests (0.08%) outlines an almost continuous agricultural landscape, which increases pressure on soils and requires practices oriented toward conserving soil structure and water resources.

The identified soil resource confirms a significant agricultural potential, but also a marked vulnerability to physical degradation and hydrological imbalance. Across the entire agricultural area, Cernisols (Chernozems and Phaeozems) account for 54.43%, underpinning high productivity through the presence of a humus-rich horizon and a relatively favourable air–water regime on geomorphologically more stable surfaces. At the same time, Vertisols (Vertisols and Pelosols) cover 38.67%, indicating the extent of clay deposits affected by shrink–swell processes, which result in short workability windows, increased compaction risk, and a seasonal alternation of moisture excess and deficit. The presence-even if limited-of Gleysols (0.64%) and Solonetzs (0.32%) confirms microzones with excess water and/or sodification, which are relevant for suitability zoning and for selecting appropriate land uses.

Comparatively, two pedo-functional patterns can be distinguished: the Curtici area is dominated by Chernozems and shows a very high degree of arable-land use, whereas Olari is dominated by Vertisols/Pelosols and includes areas with a more active water regime (including water surfaces), which justifies greater land-use diversification (a higher share of pastures) and the need for stricter measures to prevent compaction and improve local drainage.

The results support the conclusion that sustainable land management in Curtici and Olari must be based on zoning of soil–land units and the application of differentiated technologies: conservation practices and maintenance of organic matter on Chernozems, and rigorous timing of tillage, reduced traffic on wet soils, drainage measures, and structural amelioration on Vertisols/Pelosols and in hydromorphic or sodic microzones. Integrating pedological mapping with modern tools (GIS/monitoring) provides the necessary framework for optimizing productivity, reducing degradation risks, and increasing the resilience of agroecosystems in the north-western Arad Plain.

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