AN INTEGRATED NDVI, SAVI AND LAI BASED APPROACH FOR ASSESSING GRASSLANDS IN THE POIANA RUSCĂ MOUNTAINS

Loredana COPĂCEAN[1], Nicolae Marinel HORABLAGA[1,2], Cristian BOSTAN[2], Christianna ISTRATE-SCHILLER[1], Ionel SAMFIRA[1,2], Veronica SĂRĂȚEANU[1], Carmen DURĂU[1], Dorin RECHIȚEAN[2], Luminița COJOCARIU[1,2]*

[1]University of Life Sciences "King Mihai I" from Timisoara, 300645, 119, Calea Aradului, Timisoara, Romania
[2]Agricultural Research and Development Station Lovrin, 307250, 200, Principala, Lovrin, Romania
**Corresponding author: luminita_cojocariu@usvt.ro*

Abstract

This study evaluates the condition of grassland vegetation in the protected areas of the Poiana Ruscă Mountains (altitudes >500 m) using vegetation indices derived from Sentinel-2A imagery acquired in June 2024. NDVI, SAVI and LAI were applied to assess photosynthetic activity, vegetation cover and leaf density. NDVI values ranged from 0.32 to 0.75 (mean 0.59), indicating vigorous vegetation, while SAVI varied between 0.28 and 0.63 (mean 0.48), showing good plant coverage with minimal soil influence. LAI values ranged from 0.9 to 2.3 (mean 1.96), suggesting high biomass accumulation potential. Classification into five classes showed that most surfaces were in the "good" or "very good" vegetation state (72% according to NDVI, 77% SAVI, 65% LAI). Vegetation development was most favorable below 1100 m. Results highlight the usefulness of combining indices for ecological monitoring and sustainable pasture management.

Keywords: NDVI, SAVI, LAI, mountain grasslands, altitudinal analysis, vegetation classification.

INTRODUCTION

Grasslands are key ecosystems for maintaining biodiversity (CĂLUȘERU et al., 2013; KACHLER et al., 2023; GIGANTE et al., 2024), ecosystem services (COJOCARIU et al., 2010) and agro-pastoral activities (COPĂCEAN et al., 2020; VIDICAN et al., 2020), while also being highly sensitive to land-use changes and climate change (XIONG et al., 2019). In this context, remote sensing methods have become essential tools for monitoring vegetation status, biomass, and degradation processes on a regional and global scale (AYVAZYAN et al., 2024), providing synoptic and repeatable information over time at low cost compared to classic ground based monitoring. Numerous studies synthesize the role of remote sensing in estimating essential grassland parameters, aerial biomass, primary productivity, vegetation cover, and Leaf Area Index (LAI) and highlight the usefulness of satellite imagery (Sentinel, Landsat, MODIS) in assessing the condition and management of natural and cultivated grasslands (REINERMANN et al., 2020; WANG et al., 2022; BANGIRA et

al., 2023). The application of remote sensing techniques in the study of grasslands is mainly based on multispectral optical data, supplemented, increasingly, by radar sensors and high spatial resolution platforms (UAVs), which allow detailed capture of the structure of the vegetation carpet and its seasonal dynamics (TARAVAT et al., 2019; VERRELST et al., 2019; SIMON et al., 2020). These technologies make it possible to continuously monitor the functional parameters of vegetation, including seasonal growth, drought effects, grazing intensity or degradation processes, being particularly useful in mountainous or hard to reach areas (SIMON et al., 2021). Recent reviews highlight the shift from simple thematic mapping to the assessment of ecological processes and grassland management, through the integration of satellite imagery time series and indicators derived from them (ALI et al., 2017; YAN et al., 2025). Among the indicators derived from remote sensing, vegetation indices play a central role, providing a quantitative characterization of the state of the vegetation carpet based on the spectral contrast between the red and near-infrared domains. The Normalized Difference Vegetation Index (NDVI) is the most widely used index in grassland studies, being recognized for its ability to restore vegetation vigor, coverage, and productivity dynamics, including in the modeling of aboveground biomass and primary productivity (BALATA et al., 2022; SERRANO et al., 2024; WANG et al., 2025). NDVI is frequently used for monitoring grassland production, predicting vegetation status, and assessing response to climate variability in various regions (XUE and SU, 2017; PANG et al., 2020; MILAZZO et al., 2024; ZHAO and QU, 2024). However, NDVI can be significantly influenced by soil reflectance, especially in areas with sparse or discontinuous vegetation cover. To mitigate this limitation, Huete (1988) proposed the Soil-Adjusted Vegetation Index (SAVI), which introduces a soil background correction factor into the index formula, thus reducing variations induced by soil brightness and moisture. SAVI is especially recommended for grasslands with variable grassland density or in early stages of regeneration, being successfully used in monitoring vegetation growth and production conditions in different types of grasslands and crops (WANG et al., 2024). On the other hand, the Leaf Area Index (LAI) is a fundamental structural parameter, defined as the ratio between the total leaf area and the corresponding land area, which can be directly correlated with the photosynthetic potential and biomass accumulation. Remote sensing LAI estimation has been intensively developed for both agricultural crops and forests and grasslands, with studies showing close relationships between LAI, aerial biomass and grassland productivity. The integration of multispectral and, more recently, radar or UAV data, allows for detailed spatial maps of LAI, useful in assessing the conservation status of ecosystems and in planning pastoral use (WANG et al., 2019; XU et al., 2020; WU et

al., 2025).The literature highlights the advantages of combining several remote sensing indices in grassland analysis, as each index captures a different facet of vegetation status: NDVI is sensitive to photosynthetic vigor, SAVI reduces soil influence in areas with partial cover, and LAI describes leaf density and biomass accumulation capacity. Recent studies on estimating biomass, productivity and grassland degradation show that models based on combined sets of indices, including NDVI, SAVI and LAI, are more accurate than those using a single index, making them particularly useful for grassland resource management on a regional scale (PANG et al., 2020; BU et al., 2022; WANG et al., 2022; MĂGUREANU et al., 2023; PANEK-CHWASTYK et al., 2024). In this context, the mountain grasslands of the Poiana Rusca Mountains, located in protected areas and at altitudes above 500 m, represent an appropriate framework for the application and testing of an integrated approach based on NDVI, SAVI and LAI. The aim of this study is to assess the vegetation status of the grasslands in the Poiana Rusca Mountains, located at altitudes above 500 m and included in protected areas, through an integrated approach based on remote sensing indices (NDVI, SAVI and LAI). By combining information on vegetation vigor (NDVI), soil influence (SAVI) and leaf density (LAI), the analysis aims to highlight spatial variations of the vegetation cover and identify areas with high productive potential or susceptible to degradation. The results obtained are intended to support the effective monitoring and sustainable management of mountain pastoral ecosystems.

MATERIAL AND METHOD

1. Study area

The study area includes the grasslands of the Poiana Ruscă Mountains (Figure 1), whose limits were defined according to the Mountain Law no. 197/2018 and the geomorphological delimitation made by Posea and Badea (1984). According to the Mountain Law, they fall into Mountain Group 8 and also integrate some depressions and marginal hilly areas. The analysis is focused exclusively on grasslands located above 500 m altitude and overlapping protected areas, which total an area of 3319.13 ha, according to Corine Land Cover (CLC 2018) data (COPERNICUS LAND MONITORING SERVICE, 2022).

2. Research methodology

The workflow applied in the research is shown in Figure 2. The satellite imagery used for grassland vegetation analysis comes from the Sentinel-2A platform, acquired in June 2024 (COPERNICUS OPEN ACCESS HUB, 2025).

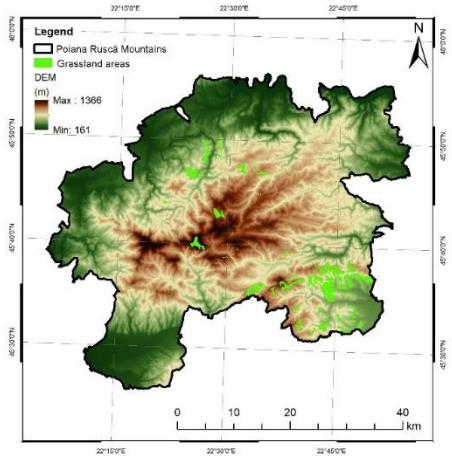

Fig. 1. Spatial distribution of grasslands in the Poiana Ruscă Mountains by relief units (Posea and Badea, 1984; Law nr. 197/2018; Geospatial, 2021; Copernicus Land Monitoring Service, 2022; Ministry of Agriculture and Rural Development, 2025)

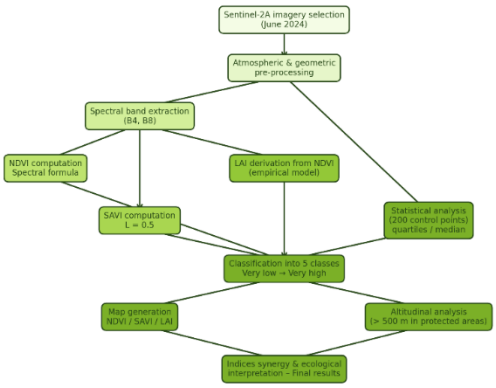

Fig. 2. Research methodology

The period of active vegetation for mountain grasslands was selected in order to obtain relevant values of vegetation indices.

Calculated vegetation indices

Three remote sensing indices were calculated as follows:

- NDVI, according to relation 1, widely used to estimate vegetation vigor (BALATA et al., 2022; SERRANO et al., 2024):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

where: NIR - near-infrared band (for Sentinel-2A, B8); RED - red stripe (B4);

- SAVI, according to relation 2 (HUETE, 1988); reduces the effects of soil brightness in areas with low vegetation cover; L = 0.5 is used (WANG et al., 2024):

$$\mathrm{SAVI} = \left(\frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED} + \mathrm{L}}\right) \times (1 + \mathrm{L})$$

where "L" is a correction factor for the influence of the soil;

- LAI was derived from NDVI based on empirical relations reported in the literature (BAJOCCO et al., 2022):

$$\mathrm{LAI} = \mathrm{a} \times \mathrm{NDVI} + \mathrm{b}$$

where: a and b are coefficients determined by local linear regression; the statistical correlation

was verified by the coefficient of determination R^2. The geospatial data processing was done with the ArcGIS for Desktop software, version 10.8, and the statistical data processing was done in the IMB SPSS program.

Establishment of thresholds for classification of vegetation indices In order to ensure a realistic classification of the consistency of grassland vegetation, the thresholds for classification in classes were defined based on the distribution of the values of the indices calculated in control points (200 points) located in the Poiana Rusca Mountains. The LAI, NDVI and SAVI values (minimum, maximum, median and quartiles) were statistically analyzed, and the thresholds were established so as to reflect both the literature on the usual ranges of these indices for grassland ecosystems, and the local reality captured in the datasets (Table 1).

Table 1.

Classification thresholds of the NDVI, SAVI and LAI indices for the grasslands of the Poiana Ruscă Mountains

Class	LAI	NDVI	SAVI
Very weak	< 1.0	< 0.35	< 0.30
Weak	1.0 – 1.5	0.35 – 0.45	0.30 – 0.40
Moderate	1.5 – 1.9	0.45 – 0.55	0.40 – 0.48
Good	1.9 – 2.1	0.55 – 0.62	0.48 – 0.55
Very good	> 2.1	> 0.62	> 0.55

The classes were divided into five categories: very weak, weak, moderate, good and very well vegetated, corresponding to the distribution of the values recorded: the values below the lower quartile were considered "weak", those around the median, "moderate", and those above the upper quartile, "good" and "very well" vegetated. This approach allowed locally calibrated thresholds to be defined.

Benchmarking and exporting results After calculating the indices and classifying the areas in the defined vegetation classes, the thematic maps of NDVI, SAVI and LAI were superimposed to allow the spatial assessment of the vegetation consistency, the identification of areas of interest (e.g. with high productive potential or with little vegetation) and the generation of statistics on altitudinal floors and for the protected areas concerned. In this way, the integration of data at the surface level and the preparation for ecological and agronomic interpretation was ensured.

RESULTS AND DISCUSSIONS

1. Evaluation of the grasslands in Poiana Ruscă through the NDVI, SAVI and LAI indices

The analysis of the vegetation indices at the level of the Poiana Ruscă Mountains highlights a good general condition of the vegetation carpet, with spatial differentiations related to altitude and local environmental conditions.

NDVI values (Figure 3), ranging from –0.22 to 0.76 and an average of 0.59, indicate well-represented vegetation with large areas where potential productivity is high. The relatively concentrated distribution of values suggests that most areas are covered with vigorous vegetation, but there are also limited areas where grass mat is less frequent or in a state of regeneration. The results provided by the SAVI index (Figure 3), which vary between –0.23 and 0.78, with an average of 0.50, confirm the trends captured by the NDVI, but bring added relevance by reducing the influence of soil in areas with partial cover. Thus, land with lower vegetation density is better differentiated, and the spatial structure of the grass carpet is more clearly outlined. The LAI index (Figure 3), with values between –0.91 and 2.62 and an average of 2.03, completes the overall picture, highlighting the leaf density of the vegetation. The high level of the average reflects a well-developed grass carpet with a high productive potential. At the same time, the existence of lower values, located especially in marginal areas or at higher altitudes, also shows the vulnerabilities of ecosystems, where climatic and edaphic conditions limit the development of vegetation. The interpretation of the NDVI, SAVI and LAI values for the entire region of the Poiana Ruscă Mountains highlights an extensive and vigorous vegetation cover, with the predominance of well-forested areas and dense grass cover, which reflects a good state of mountain ecosystems and a high productive potential of plant resources (Figure 3).

1.1. Analysis of grasslands in Poiana Ruscă Mountains based on NDVI values

The NDVI values for the grasslands of the Poiana Ruscă Mountains (figure 4) vary between 0.22 and 0.76, with an average of 0.59, which reflects a well-developed vegetation carpet and a good overall vegetation condition. The distribution of values is relatively close, dominated by the high positive range, which indicates that most grasslands have a consistent degree of cover and adequate vegetative vigor for their agronomic use. The Kruskal–Wallis test confirmed the existence of significant differences between the NDVI values of the grasslands of the Poiana Ruscă Mountains on altitudinal levels ($H = 63.08$; $p < 0.001$), which shows that the degree of coverage and vigor of the vegetation cover vary with altitude. The highest values are specific to the range 701-1100 m, where moderate temperatures and a relatively balanced rainfall regime support the development of dense and productive vegetation. At higher altitudes, above 1300 m, post-hoc tests showed a significant decrease in NDVI values, associated with limiting the growing season and reducing accumulated biomass. From an agronomic point of view, the grasslands on the lower and middle floors are the most valuable, having a dense and productive grass carpet, while those on the upper floors are characterized by a lower forage potential and are mainly used for summer grazing.

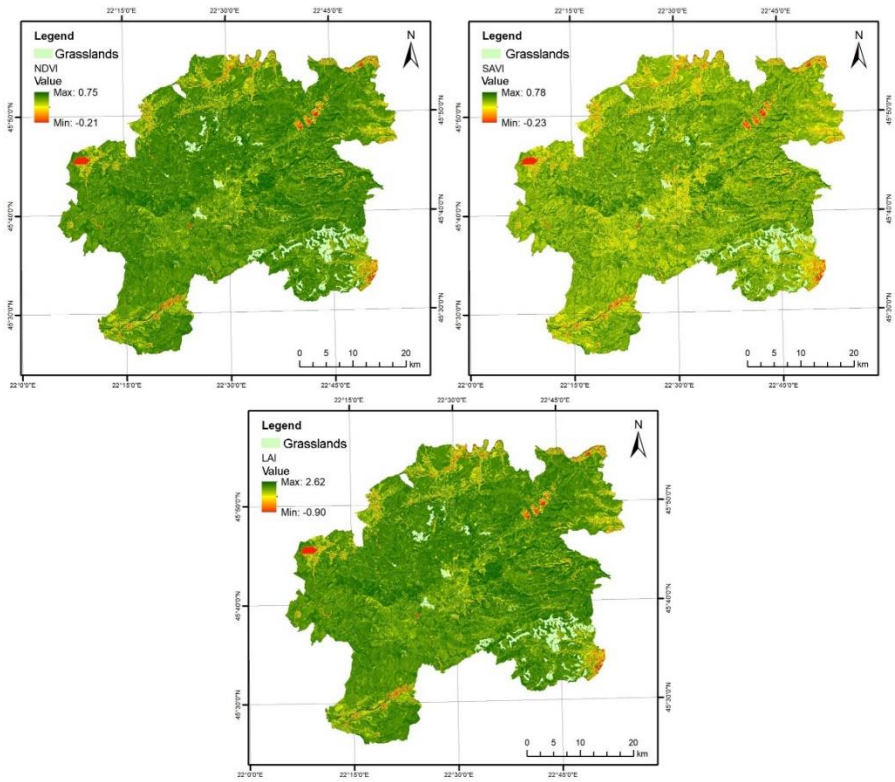

Fig. 3. Spatial representation of the indices NDVI (A), SAVI (B) and LAI (C) in the Poiana Ruscă Mountains

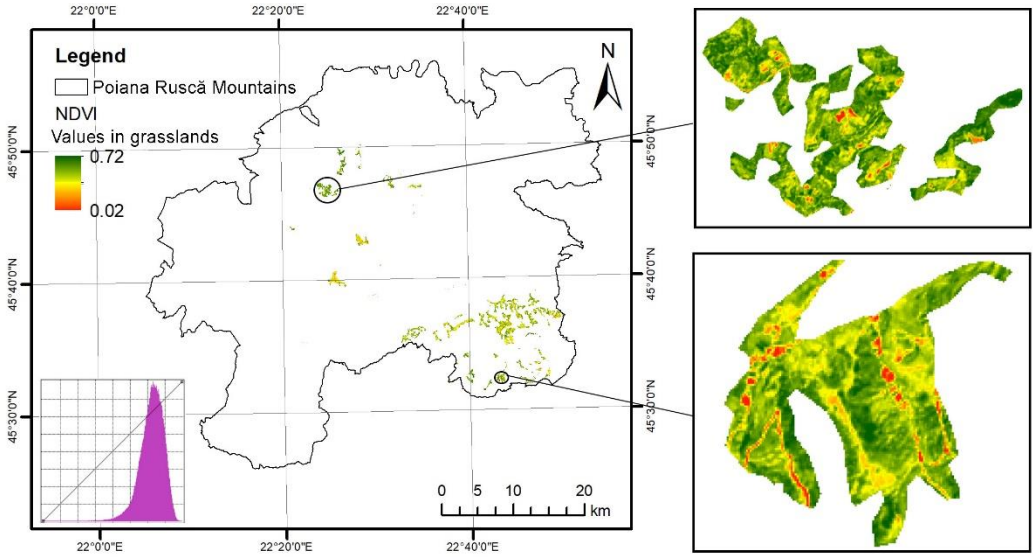

Fig. 4. Distribution of NDVI values in the meadows of the Poiana Rusca Mountains, with details for two representative areas

The classification of the NDVI map for the grasslands of the Poiana Ruscă Mountains shows that most of the area falls into the "high" and "very high" coverage classes (Table 2). About 47% of the grasslands have a dense vegetation carpet, and 22.7% have a very high cover, which indicates an excellent state of vegetation and a great forage potential. Together, these two classes account for almost 70% of the area, confirming the importance of these grasslands as an agricultural and pastoral resource

Table 2.

Distribution of grasslands in the Poiana Rusca Mountains by cover classes, according to NDVI values

Classes of grasslands with cover	Surface (ha)	% of total
Very weak	12.57	0.3
Weak	92.00	2.7
Moderate	896.32	26.9
Large	1564.31	47.1
Very Large	755.03	22.7

The "moderate" class of coverage comprises 26.9% of the surface, representing areas where the vegetation carpet is well developed, but with a lower density, possibly due to edaphic conditions or more intense exploitation. In contrast, grasslands with poor and very poor cover are extremely small in extent (below 3%), which shows that degraded areas or areas with sparse vegetation are marginal and do not significantly affect the pastoral landscape of the region.

Overall, the structure of the NDVI classes demonstrates that the grasslands of the Poiana Ruscă Mountains have a very high degree of vegetation cover, which reflects a good conservation of the grass cover and a considerable agronomic potential.

1.2. Analysis of grasslands in the Poiana Ruscă Mountains based on SAVI values

The SAVI values obtained for the grasslands in the Poiana Ruscă Mountains vary between 0.03 and 0.71 (Figure 5), with a mean of 0.48 and a standard deviation of 0.06, which shows a tight distribution around moderate and high values. This situation reflects uniform vegetation with good density and a low degree of degraded areas or with scarce vegetation.

Compared to NDVI, SAVI values are slightly more temperate, but confirm the same general picture of a well-represented carpet, with the difference that this index more clearly highlights areas where soil influence is stronger and vegetation is more discontinuous.

The statistical analysis of the SAVI values on altitudinal levels in the Poiana Ruscă Mountains shows significant differences ($H = 65.77$; p

< 0.001), with higher values at low and medium altitudes and a clear decrease above 1300 m. From an agronomic point of view, it confirms that the most productive grasslands are located at lower and medium altitudes, where the climate favours the accumulation of biomass, while at high altitudes, low temperatures and the short growing season limit vegetation density and productivity.

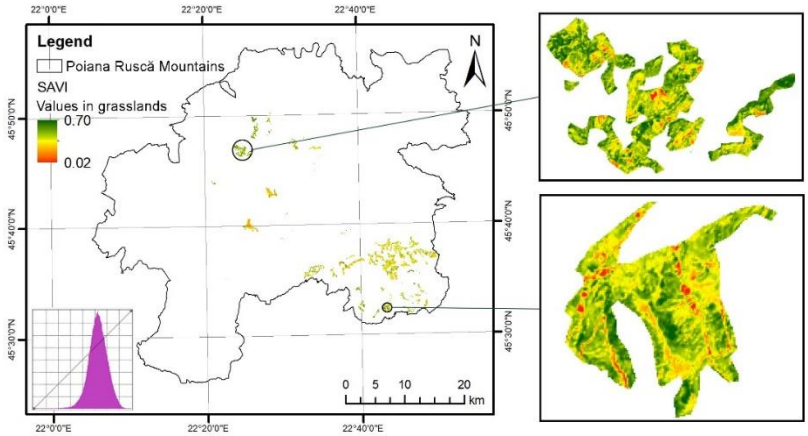

Fig. 5. Distribution of SAVI values in the meadows of the Poiana Rusca Mountains, with details for two representative areas

The classification of SAVI values for the meadows of the Poiana Ruscă Mountains (Table 3) highlights a predominance of vegetation carpet with moderate and high cover, which together represent almost 80% of the total area. Grasslands with moderate cover occupy the largest share, 41.2% (1369.39 ha), followed by those with high cover, 36.1% (1199.09 ha), which shows a good general condition of vegetation. Grasslands with very high cover are present on 12.6% of the area (420.11 ha), indicating areas with high biomass density, favorable for mowing and intensive grazing. On the other hand, the areas with poor or very poor cover are reduced, totaling only 9.9%, which confirms that the degradation of vegetation has a limited and punctual character.

Table 3.

Distribution of grasslands in the Poiana Rusca Mountains by cover classes, according to SAVI values

Classes of grasslands with cover	**Surface (ha)**	**% of total**
Very weak	21.85	0.6
Weak	309.79	9.3
Moderate	1369.39	41.2
Large	1199.09	36.1
Very Large	420.11	12.6

Overall, the data suggest that the grasslands of Poiana Ruscă have a high productive potential, especially in low and medium altitude areas, where climatic conditions support the development of a consistent grass carpet.

1.3. Analysis of grasslands in the Poiana Ruscă Mountains based on LAI values

For the analysis of the grasslands in the Poiana Ruscă Mountains based on LAI values, the statistics indicate values between 0.03 and 2.50 (Figure 6), with an average of 1.96 and a standard deviation of 0.21, on a total area of 3319.13 ha.

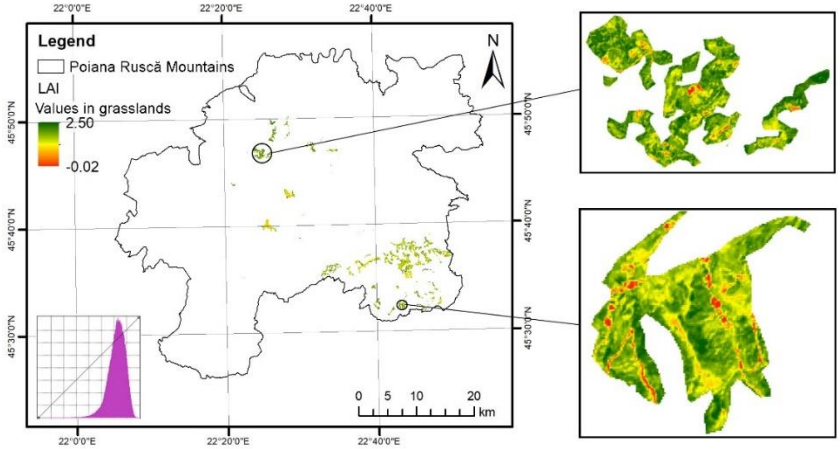

Fig. 6. Distribution of LAI values in the meadows of the Poiana Rusca Mountains, with details for two representative areas

The LAI distribution shows a strong concentration of values around the average, which suggests that most grasslands are characterized by a relatively high leaf density, favorable to photosynthetic processes and biomass accumulation. From an agronomic point of view, these results reflect a considerable productive potential, grasslands with LAI values close to 2 indicating a well-developed grassy structure with a consistent and uniform cover.

Compared to the NDVI and SAVI values, LAI brings a more detailed picture of vegetation density, highlighting areas where grass mat plays an important role in ecosystem stability and in supporting agro-pastoral activities.

The results for the analysis of the LAI values in the Poiana Ruscă Mountains show statistically significant differences between the altitudinal levels ($H = 63.08$; $p < 0.001$). The average values are higher at low and medium altitudes: between 701–900 m (1.99) and 901–1100 m (1.93), followed by the range of 501–700 m (1.88), suggesting a high leaf density and a well-developed grass carpet.

At higher altitudes, between 1101–1300 m and 1301–1500 m, the average values gradually decrease to 1.85 and 1.66 respectively, indicating limitations related to

lower temperatures and short vegetation period.

From an agronomic perspective, these results confirm that the most productive grasslands with the best regenerative capacity are located at low and medium altitudes, where the climate favors the accumulation of biomass. At high altitudes, grasslands have less cover and are more suitable for extensive grazing with low productivity and shorter use period.

The classification of LAI values for the grasslands in the Poiana Ruscă Mountains (Table 4) shows a very good general condition of the vegetation, with the predominance of the large and very large cover categories, which together account for 65.2% of the area (2167.35 ha). Grasslands with moderate cover occupy 31.7% (1054.29 ha), which confirms the existence of large areas with constant leaf density and high productivity. The areas with poor and very poor cover are almost insignificant, representing only 2.8% of the total, which shows that the degradation of the vegetation is punctual and does not affect the entire area.

Table 4.

Distribution of grasslands in the Poiana Ruscă Mountains by cover classes, according to LAI values

Classes of grasslands with cover	Area (ha)	% of total
Very weak	5.98	0.1
Weak	92.61	2.7
Moderate	1054.29	31.7
Large	1267.27	38.1
Very Large	900.08	27.1

From an agronomic point of view, the distribution of these classes reflects a pastoral resource of great value, with a compact and uniform grass cover, which supports both intensive grazing and mowing, being characteristic of favorable climatic conditions and efficient land management.

Compared to NDVI and SAVI, which mainly indicate variations in vigor and vegetation cover, the LAI values in the Poiana Ruscă Mountains highlight more clearly the differences in leaf density, confirming the general trend of higher grassland productivity at low and medium altitudes and a gradual reduction in vegetation cover with increasing altitude.

2. Synergy of vegetation indices in grassland assessment

The integrated analysis of the NDVI, SAVI and LAI indices highlights a clear convergence of the results, confirming a very good general state of the vegetation carpet in the Poiana Rusca Mountains. All three indices indicate predominantly high values of vegetation, both from the perspective of photosynthetic vigor and foliar density, with spatial

differences strongly correlated with the altitudinal gradient.

NDVI and SAVI revealed similar distributions of areas with rich vegetation, but SAVI provided a more nuanced differentiation in areas with less cover, by diminishing the influence of the soil. Thus, areas classified with poor and very poor coverage are reduced for all indices, but are slightly more clearly distinguishable in the SAVI analysis. LAI complements the other two assessments with additional information on biomass and foliar structure, highlighting a high density of herbaceous vegetation on most of the investigated area, where grasslands are well developed and with high productive potential.

As for the variation on altitudinal levels, all three indices indicate maximum values at low and medium altitudes (701–1100 m), where climatic conditions favor vegetation development, followed by a gradual decrease with the increase in altitude, above 1300 m. This pattern confirms that environmental variables are a major determinant of grass carpet productivity.

The similarities between NDVI, SAVI and LAI in spatial distributions robustly validate the observation that grasslands with high agronomic potential are predominantly located in the lower and middle levels of mountains.

The integration of the three indices allows a more complete picture of the state of the vegetation, indicating both its vitality and the capacity for biomass production and regeneration.

The comparative results demonstrate that the grasslands of the Poiana Ruscă Mountains are in a very good ecological and productive state, with large areas characterized by a dense and uniform vegetation cover, which underlines their importance as a pastoral and ecological resource. Altitudinal differences are obvious and must be taken into account in sustainable land management strategies.

Overall, the results obtained for the grasslands of the Poiana Ruscă Mountains confirm that the combined use of the NDVI, SAVI and LAI remote sensing indices is a robust and extremely useful tool for ecological and agronomic analyses, as it allows a fine spatial quantification of the state of the vegetation carpet and the productive potential along the altitudinal gradient, in full agreement with the conclusions formulated in the specialized literature on the estimation of biomass and grassland productivity (SCHAEFER and LAMB, 2016; REINERMANN et al., 2020; ANDREATTA et al., 2022; WANG et al., 2022; NETSIANDA and MHANGARA, 2025)

CONCLUSIONS

The grasslands in the Poiana Ruscă Mountains register high values of vegetation indices, with an average NDVI of 0.59 and a

cumulative share of almost 70% of the areas classified in the "high" and "very high" cover classes, which indicates a well-developed and extremely valuable vegetation carpet from a productive point of view.

The SAVI values, with an average of 0.48, confirm this trend, 77.3% of the area being in the moderate and high cover classes, demonstrating a consistent plant development even in areas where the soil influence could be more pronounced. At the same time, the LAI distribution, with an average of 1.96 and over 65% of grasslands framed in high and very high levels of foliar density, highlights a high capacity for biomass accumulation and an increased vitality of the herbaceous vegetation. The observed altitudinal differences (with maximums in the lower floors and a gradual decrease above 1300 m) reveal the decisive influence of climatic conditions on the structure of the mountain vegetation.

Overall, remote sensing means prove effective in rapidly assessing and monitoring the state of the vegetation carpet, providing a solid basis for supporting measures for the conservation and sustainable use of pastoral resources.

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