Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

REMOTE ASSESSMENT OF THE FRACTION OF ABSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION (fAPAR) FOR MOUNTAIN GRASSLANDS

Margareta MAGUREANU[1], Loredana COPACEAN[1], Despina-Maria BORDEAN[1], Luminita COJOCARIU[1, 2]

[1]University of Life Sciences "King Mihai I" from Timisoara, 119 Calea Aradului Street, Timisoara, Romania
[2]Agricultural Research and Development Station Lovrin, 200 Principala Street, Lovrin, Romania

Corresponding author email: luminita_cojocariu@usvt.ro

Abstract

The work focused on the analysis of the vegetation cover of the grasslands according to the Fraction of Absorbed Photosynthetically Active Radiation (fAPAR index), in five different stages, during the same year (2022), on altitudinal levels, from three groups of mountains. 110 grasslands located in different environmental conditions were studied, from: the Banat Mountains, the Poiana Ruscă Mountains and part of the Southern Carpathians. Five Sentinel 2 satellite scenes were used, acquired on the following dates: 22.03, 16.05, 15.07, 08.09, 18.10 and the Digital Elevation Model, classified into 8 altitudinal levels, from 53-2473 m. The results show that the fAPAR values are different, lower in March when the vegetation is still stagnant and does not use solar radiation, maximum in July when the vegetation is very well represented and uses maximum solar radiation, and from August, a downward trend, along with the reduction of the physiological activity of the plants in the grasslands. Also, differences in average fAPAR values by mountain groups and similarities in altitudinal steps between mountain groups were noticed.

Key words*: fAPAR, grasslands, seasonal variation, spatial variation.*

INTRODUCTION

fAPAR, acronym for *Fraction of Absorbed Photosynthetically Active Radiation* (Myneni & Williams, 1994; Epiphanio & Huete, 1995), is the remote sensing index that expresses the fraction of solar radiation absorbed by living leaves (Wang et al., 2016), in the electromagnetic spectrum ranging between 400-700 nm, for photosynthetic activity, meaning it refers only to the green and living elements of the vegetation canopy. In this context, previous research (Field et al., 1995; Zhang et al., 2015) has demonstrated that the primary productivity, gross or net, of plants is closely related to the fAPAR values.
fAPAR is one of the Essential Climate Variables (ECV) recognized by the Global Climate Observing System (GCOS) (GCOS, 2006), and when applied to satellite images, fAPAR, with values between 0 and 1 (Yang et al., 2014), is a biophysical variable used in ecosystem analysis, in various climate models, in estimating primary productivity of vegetation or crop yield (Sellers et al., 1996; Fensholt et al., 2004; Viña & Gitelson, 2005; Qin et al., 2018), at regional or global scales (Xiao et al., 2016).
In recent decades, both fAPAR and other remote sensing indices have been successfully applied in pasture analysis, with various objectives, among the most important being the assessment of vegetation status, spatiotemporal monitoring of surfaces, analysis of vegetation cover distribution, productivity estimation and so on (Rossini et al., 2012; Chen et al., 2017; Pu et al., 2020; Noumonvi & Ferlan, 2020; Šandera & Štych 2020; Xu et al., 2023).
In this context, the aim of the study was to analyze pasture vegetation based on fAPAR index values and identify developmental patterns over time and space under different environmental conditions.

MATERIALS AND METHODS

Study area

The study area (Figure 1) is located in southwestern Romania, covering parts of five counties: Caraş-Severin (with the largest share), Hunedoara, Gorj, Mehedinţi, and Timiş. Geographically, according to the geomorphological zoning conducted by Posea & Badea (1984), the study area overlaps with the Retezat - Godeanu Group in the Southern Carpathians (Retezat Mountains, Godeanu Mountains, Ţarcu Mountains, Cernei Mountains, Mehedinţi Mountains, Vâlcan Mountains), Poiana Ruscă Mountains, and Banat Mountains (Almăj Mountains, Semenic Mountains, Locva Mountains, Anina Mountains, Dognecei Mountains, and the associated depression areas). The altitude varies between 54 and 2473 m; the complexity of relief conditions (Rusu, 2007; Caluseru et al., 2015) imposes variability in environmental factors across the territory, which is reflected in the distribution of pasture vegetation.

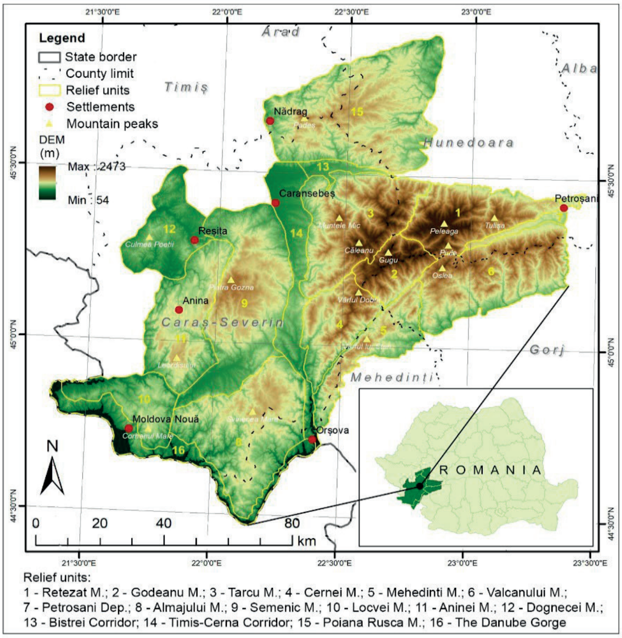

Figure 1. The location of the study area (processing after Posea & Badea, 1984; EEA-DEM, 2023; Geospatial, 2023)

In the analyzed area, with a total surface of 1,112,683 hectares (11,126.83 km²), forested areas predominated, covering approximately 70% of the territory, followed by grasslands, accounting for 14.75% (CLC, 2023). The other land use categories have proportions below 5%. Grasslands, totaling 164,092 hectares, are spread across the entire analyzed area, in all forms and relief units, with the largest areas found in hilly and mountainous regions.

The working methodology

For the analysis of the area of interest through remote sensing, Sentinel 2 satellite images from the year 2022 were used, downloaded for free from the Copernicus Open Access Hub platform. Five Moments of observation (M) were established, noted as M1...M5: on 22.03, 16.05, 15.07, 08.09, and 18.10. Considering the large extent of the study area, four satellite scenes were downloaded for each M, with the indicators 34TER, 34TFR, 34TEQ, and 34TFQ. In the first stage, the satellite scenes were processed in the SNAP software, and the following operations were applied (Figure 2):

1. Mosaicking the four scenes from each Moment (M);
2. Extracting the area containing the area of interest (Subset);
3. Resizing the spatial resolution to 20 meters for all spectral bands (Resampling);
4. Generating fAPAR images using the algorithm implemented in the software.

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

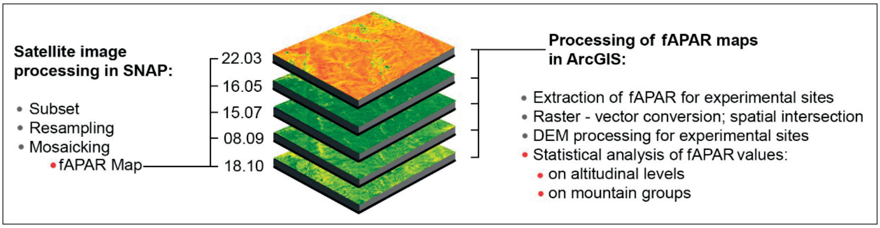

Figure 2. The workflow (Original diagram)

The second stage of the workflow involved processing geospatial data in ArcGIS according to the following algorithm:

1. Extraction of the area of interest from the fAPAR images based on a specific contour for each observation moment;
2. Classification of the Digital Elevation Model (DEM) with a spatial resolution of 25 meters (EEA, 2023) into 8 altitude classes: 53-300 m, 301-600 m, 601-800 m, 801-1000 m, 1001-1200 m, 1201-1400 m, 1401-1600 m, 1601-2473 m;
3. Selection of grassland test surfaces - from the Corine Land Cover database (2018 edition), 110 representative grassland surfaces were selected, located in areas with different environmental conditions and relief units;
4. Extraction of images and numerical values of fAPAR from each Moment for the selected grassland surfaces, which were subsequently used in the statistical analysis of the results;
5. Conversion of fAPAR maps for grasslands into vector format and spatial intersection of two datasets;
6. Statistical analysis of fAPAR values on altitude classes and mountain groups. The data were statistically evaluated using PAST Version 2.17c software (Hammer et al., 2001).

RESULTS AND DISCUSSIONS

Although fAPAR can be applied through in situ procedures, one of the most efficient ways to determine this index is the determination and representation on high spatial resolution photogrammetric images (Copăcean et al., 2020; Simon et al., 2020) or on satellite images, on a global or regional scale, depending on the needs of the studies (Liang & Wang, 2019; Jin et al., 2022; Cojocariu et al., 2024).

The analysis of grassland vegetation dynamics across the temporal moments M1 - M5 is based on the fAPAR values

For the study area, in the year 2022, five fAPAR images were generated; the images from the beginning (22.03) and from the end of the period (18.10) are presented in Figure 3.

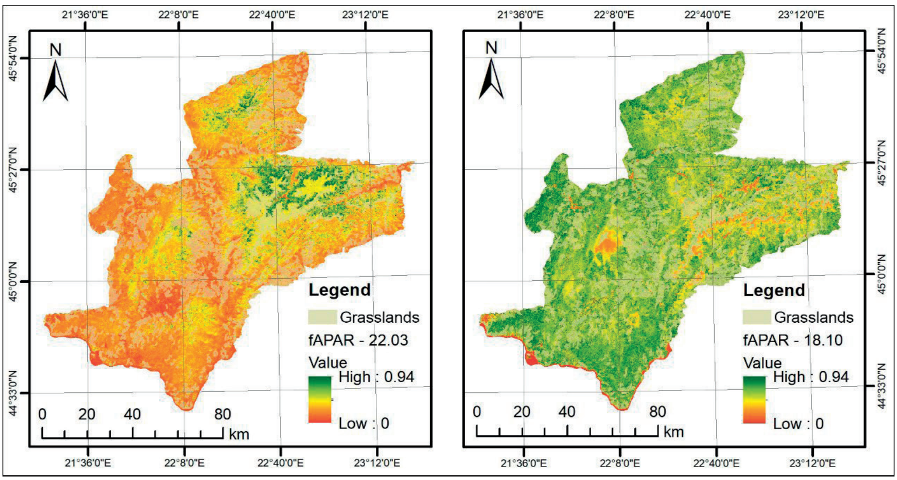

Figure 3. The spatial distribution of fAPAR values across different temporal moments

To analyze the changes produced during the considered period, the fAPAR values were classified into four equal classes, depending on the minimum and maximum value of the index.
In M1 (March), for the selected grasslands, the fAPAR index ranged from 0 to 0.93, with the average value being very low at 0.15. In M1, 77% of the fAPAR values were between 0 and 0.25 (Figure 4), indicating that plants utilized only 25% of visible light to produce biomass. This suggests a low vegetation cover. The obtained results also agree with other studies (Jarocinska & Zagajewski, 2009).

The transitions matrix 22.03 - 16.05

fAPAR	0.00-0.25	0.26-0.50	0.51-0.75	0.76-1.00	Total (ha)
0.00-0.25	138	2246	5101	1134	8619
0.26-0.50	193	1387	712	201	2493
0.51-0.75	0	5	36	5	47
0.76-1.00		0	4	0	5
Total (ha)	331	3639	5853	1341	11164

The transitions matrix 16.05 - 15.07

fAPAR	0.00-0.25	0.26-0.50	0.51-0.75	0.76-1.00	Total (ha)
0.00-0.25	20	51	186	74	331
0.26-0.50	99	1445	1795	303	3642
0.51-0.75	188	1605	3456	605	5854
0.76-1.00	17	127	454	753	1351
Total (ha)	324	3228	5891	1735	11164

The transitions matrix 15.07 - 08.09

fAPAR	0.00-0.25	0.26-0.50	0.51-0.75	0.76-1.00	Total (ha)
0.00-0.25	40	184	98	2	324
0.26-0.50	33	2155	1022	21	3230
0.51-0.75	2	873	4939	82	5896
0.76-1.00	0	26	966	738	1731
Total (ha)	74	3239	7025	843	11164

The transitions matrix 08.09 – 18.10

fAPAR	0.00-0.25	0.26-0.50	0.51-0.75	0.76-1.00	Total (ha)
0.00-0.25	26	47	2	0	74
0.26-0.50	45	1317	1860	15	3237
0.51-0.75	23	1509	5243	249	7024
0.76-1.00	14	158	548	115	835
Total (ha)	108	3032	7652	380	11164

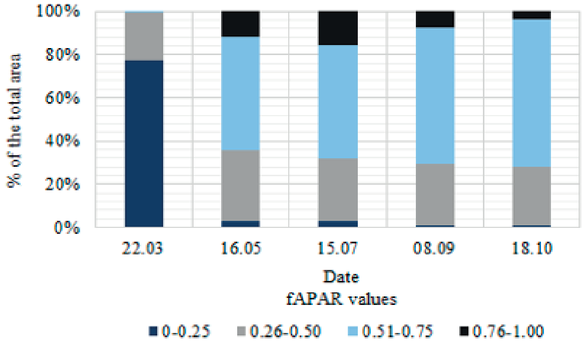

Figure 4. The variation of fAPAR values across M1 – M5

In M2 (May), in the analyzed grasslands, fAPAR values ranged from 0 to 0.94, with an average of 0.55. At this moment, compared to M1, there is an increase in the percentage of radiation utilized by plants, indicating a higher biomass "quantity" and consequently a higher degree of soil cover. In this scenario, 32% of fAPAR values fell between 0.26 and 0.50, and 52% fell within the range of 0.51-0.75.
In M3 (July), the fAPAR index ranged from 0 to 0.94, with an average of 0.57. This period corresponds to the peak vegetation period in grasslands. In grasslands, vegetation is mosaic, and therefore in M3, there are four classes of fAPAR index values: 0-0.25 (3%); 0.26-0.50 (29%); 0.51-0.75 (53%); and 0.76-1.0 (16%).
In September (M4), it is observed that the fAPAR index values remain within the same limits as in M3, as a result of vegetation recovery after the rains at the end of summer.
Surprisingly, for the analyzed area, in October (M5), 69% of fAPAR index values fell between 0.51-0.75, indicating that plants use visible radiation to a large extent (between 51-75%). This suggests a good state of grassland vegetation.
To analyze the variations in fAPAR values in the defined temporal moments, Principal Component Analysis (PCA) was applied. This was done using the correlation matrix, without considering the grouping of the data values. The main components, with a Joliffe cut-off at 0.7, are presented in Table 1.

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

Table 1. Distribution of principal components based on PCA

PC	Eigenvalue	% variance
1	2.62473	52.495
2	1.61062	32.212
3	0.482899	9.658
4	0.217262	4.3452
5	0.0644861	1.2897

From Figure 5, it can be observed that the M1 vector exhibits the highest influence on the polygonal area described by the data values corresponding to the Southern Carpathian Mountains (CM), indicating that in M1 (March), the greatest variation of the fAPAR index is observed, regardless of the altitude class.

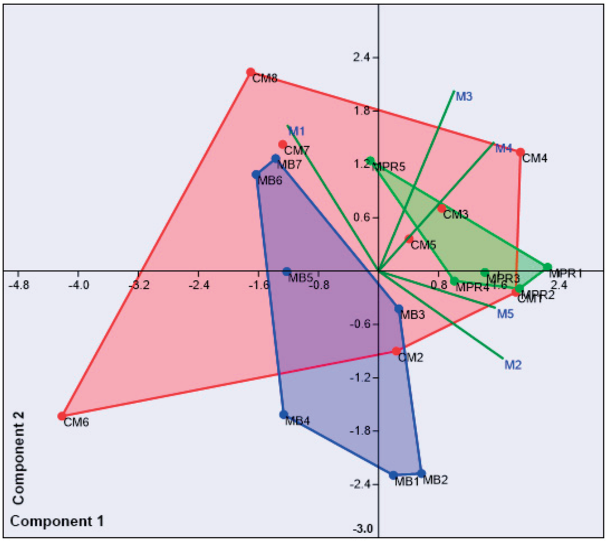

Figure 5. Graphical representation of the distribution of data values on principal components - PCA

The fAPAR index remained quite stable during intensive vegetative growth and with the onset of senescence, a situation also noted in other studies (Viña & Gitelson, 2005; Zhang et al., 2014; Sakowska et al., 2016).

The analysis of the fAPAR index across altitude classes within the analyzed mountain groups

Between the three mountain groups analyzed in the study, there are differences and many similarities across altitude classes, as presented in Figure 6.

Cluster analysis was performed using the Ward algorithm, with Euclidean distances as the similarity measure. As a result of the cluster analysis, a significantly strong correlation coefficient of 0.7886 was obtained.

The cluster analysis (Figure 6) highlights two large groups, A and B:

- Group A consists of CM6, CM8, CM7, MB6, MB7 – they are the upper floors of the high mountains, where the fAPAR values are similar and suggest that the vegetation has similar "behavior", independent of the mountain groups (CM and MB);
- Group B includes three different subgroups of which: B1 (MPR3, CM1, MPR2, CM4 and MPR1); B2 (MB4, MB1, MB2); B3, consisting of B3.1 (CM3, CM2, MB3, MPR4) and B3.2 (MB5, CM5, MPR5).

According to the cluster analysis, similarities were observed between different altitudinal steps, within the three groups of mountains. Within the same mountain group, the fAPAR index has similar values on several altitudinal levels.

The results show that the fAPAR values present a high degree of similarity from altitudes above 1001 m, in all the considered mountain units. Below the altitude of 1000 m, the grouping based on similarity is different, most likely under the influence of local conditions, which influence the vegetation of the grasslands.

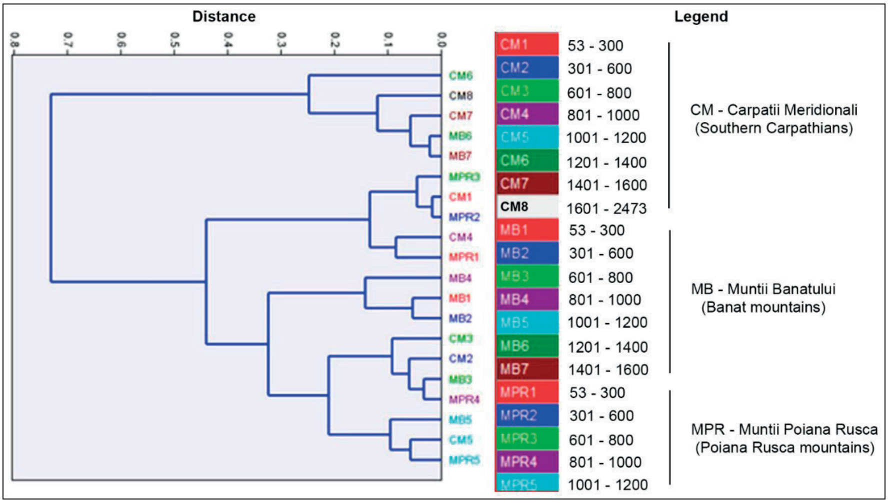

Figure 6. Cluster analysis based on the selection of altitude classes for all mountain groups

CONCLUSIONS

The fAPAR remote sensing index, applied through specific techniques, on satellite images, has demonstrated its usefulness in pratology through the analysis of grassland vegetation. Although they are data conditioned by the spatial resolution, they can be applied on extended surfaces, on altitudinal levels, vegetation seasons, in different periods of time.

The analysis of the fAPAR index, between March and October, shows that the vegetation is very well represented and uses solar radiation to the maximum, in July (average values of 0.57) and that the vegetation is still stagnant and uses solar radiation to a reduced extent, in March (average of 0.15).

In the analyzed area, represented by the Retezat-Godeanu Group, the Poiana Ruscă Mountains and the Banatului Mountains, the fAPAR values showed variations, both from one time point to another, and on altitudinal levels, from one mountain group to another.

Such studies can be used, at different scales, to monitor the state of vegetation, to analyze the degree of vegetation coverage of grasslands and can be included in rural development or management programs, at the regional level.

REFERENCES

ArcGIS Documentation. (2022). https://desktop.arcgis.com/en/documentation/ (accessed on 25.10.2022)

Caluseru, A.L., Cojocariu, L., Borlea, F., Bordean, D-M., & Horablaga, A. (2015). Rural Development of Mountain Areas in Romania, Challenges and Targets for the Year 2020. In *Proceedings of the SGEM 2015 Conference Proceedings*, Albena, Bulgaria, 2, 791–798.

Chen, B.X., Zhang, X.Z., Sun, Y.F., Wang, J.S., & He, Y.T. (2017). Alpine grassland fPAR change over the Northern Tibetan Plateau from 2002 to 2011. *Adv. Climate Change Res.*, *8*, 108–116.

Cojocariu, L.L., Copăcean, L., Ursu, A., Sărăţeanu, V., Popescu, C.A., Horablaga, M.N., Bordean, D.-M., Horablaga, A., & Bostan, C. (2024). Assessment of the Impact of Population Reduction on Grasslands with a New "Tool": A Case Study on the "Mountainous Banat" Area of Romania. *Land*, *13*, 134.

Copăcean, L., Cojocariu, L., Simon, M., Zisu, I., & Popescu, C. (2020). Geomatic techniques applied for remote determination of the hay quantity in agro-silvo-pastoral systems. *PESD*, *14*(2), 89 – 101,

Copernicus Land Monitoring Service - Corine Land Cover (CLC) Database, 2018 Edition, Available online: https://land.copernicus.eu/pan-european/corine-land-cover (accessed on 15.09.2022)

Copernicus Open Access Hub, Available online: https://scihub.copernicus.eu/dhus/#/home (accessed on 11.10.2022)

Epiphanio, J.C.N., & Huete, A.R. (1995). Dependence of NDVI and SAVI on Sun/Sensor Geometry and Its Effect on fAPAR Relationships in Alfalfa. *Remote Sensing of Environment, 51*, 351-360.

European Environment Agency (EEA), 2023, Digital Elevation Model (DEM), https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem (accessed on 13.11.2022)

Fensholt, R., Sandholt, I., Rasmussen, M.S. (2004). Evaluation of MODIS LAI, fAPAR and the relation between fAPAR and NDVI in a semi-arid environment using in situ measurements. *Remote Sens Environ*., *91*(3–4), 490–507.

Field, C.B., Randerson, J.T., & Malmström, C.M. (1995). Global net primary production: combining ecology and remote sensing. *Remote Sens Environ,* 51, 74−88.

GCOS. (2006). Satellite-Based Products for Climate, Supplemental Details to the Satellite Based Component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC; Report GCOS-107 (WMO/TD No. 1338); World Meteorological Organization (WMO): Geneva, Switzerland

Geospatial, 2023, România: seturi de date vectoriale generale – http://geo-spatial.org/vechi/download/romania-seturi-vectoriale (accessed on 18.08.2022).

Hammer, O., Harper, D.A.T., Paul, D.R. (2001). Past: Paleontological statistic software package for education and data analysis. *Palaeontol. Electron*, *4*(9). Available online: https://palaeo-electronica.org/2001_1/past/issue1_01.html.

Jarocinska, A., & Zagajewski, B. (2009). Remote sensing tools for analysis of vegetation condition in extensively used agricultural areas. *International journal*, 1-6.

Jin, H., Li, A., Liang, S., Ma, H., Xie, X., Liu, T., & He, T. (2022). Generating high spatial resolution GLASS FAPAR product from Landsat images. *Science of Remote Sensing*., *6,* 100060, 10.1016/j.srs.2022.100060.

Liang, S., & Wang, J. (2019). Advanced Remote Sensing: Terrestrial Information Extraction and Applications (2e ed.), Academic Press/Elsevier, Cambridge, UK (accesed on 02.02.2024).

Myneni, R.B., & Williams, L.D. (1994). On the Relationship between FAPAR and NDVI. *Remote Sensing of Environment*, *49*, 200-211.

Noumonvi, K.D., & Ferlan, M. (2020). Empirical vs. light-use efficiency modelling for estimating carbon fluxes in a mid-succession ecosystem developed on abandoned karst grassland. *PLoS One*, 15(8):e0237351. doi: 10.1371/journal.pone.0237351.

Posea, G., & Badea, L. (1984). România. *Unităţile de relief (Regionarea geomorfologică)*. Ed. Ştiinţifică şi Enciclopedică, Bucureşti.

Pu, J., Yan, K., Zhou, G., Lei, Y., Zhu, Y., Guo, D., Li, H., Xu, L., Knyazikhin, Y., & Myneni, R.B. (2020). Evaluation of the MODIS LAI/FPAR Algorithm Based on 3D-RTM Simulations: A Case Study of Grassland. *Remote Sens*., *12*, 3391.

Qin, H., Wang, C., Zhao, K., & Xi, X. (2018). Estimation of the fraction of absorbed photosynthetically active radiation (fPAR) in maize canopies using LiDAR data and hyperspectral imagery. *PLoS ONE*, *13*(5), e0197510. https://doi.org/10.1371/journal.pone.0197510.

Rossini, M., Cogliati, S., Meroni, M., Migliavacca, M., Galvagno, M., Busetto, L, et al. (2012). Remote sensing-based estimation of gross primary production in a subalpine grassland. *Biogeosciences*, *9*, 2565–84. 10.5194/bg-9-2565-2012.

Rusu, R. (2007). *Organizarea spaţiului geografic în Banat*. Ed. Mirton, Timişoara.

Sakowska, K., Juszczak, R., & Gianelle, D. (2016). Remote Sensing of Grassland Biophysical Parameters in the Context of the Sentinel-2 Satellite Mission. *Journal of Sensors*, *16*, 10.1155/2016/4612809.

Šandera, J., & Štych, P. (2020). Selecting Relevant Biological Variables Derived from Sentinel-2 Data for Mapping Changes from Grassland to Arable Land Using Random Forest Classifier. *Land, 9*, 420. https://doi.org/10.3390/land9110420.

Sellers, P.J., Randall, D.A., Collatz, G.J., Berry, J.A., Field, C.B., Dazlich, D.A., et al. (1996). A revised land surface parameterization (SiB2) for atmospheric GCMs. Part I: Model formulation. *J. Climate*, *9*(4), 676–705.

Simon, M., Popescu, C.A., Copăcean, L., & Cojocariu, L. (2020). Complex model based on UAV technology for investigating pastoral space. *PESD*, *14*(2), 139 – 150.

Viña, A., & Gitelson, A.A. (2005). New developments in the remote estimation of the fraction of absorbed photosynthetically active radiation in crops. *Geophys Res. Let*.*,, 32*, L17403.

Wang, Y., Xie, D., Liu, S., Hu, R., Li, Y., & Yan, G. (2016). Scaling of FAPAR from the Field to the Satellite. *Remote Sens*., *8*, 310.

Xiao, Z., Liang, S., Wang, T., & Jiang, B. (2016). Retrieval of Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) from VIIRS Time-Series Data. *Remote Sens*., *8*, 351. https://doi.org/10.3390/rs8040351.

Xu, X., Tang, J., Zhang, N., Zhang, A., Wang, W., & Sun, Q. (2023). Remote Sensing Classification of Temperate Grassland in Eurasia Based on Normalized Difference Vegetation Index (NDVI) Time-Series Data. *Sustainability*, *15*, 14973.

Yang, F., Ren, H., Li, X., Hu, M., & Yang, Y. (2014). Assessment of MODIS, MERIS, GEOV1 FPAR products over Northern China with ground measured data and by analyzing residential effect in mixed pixel. *Remote Sens*., *6*(6), 5428–51.

Zhang, Q., Cheng, Y., Lyapustin, A., Wang, Y., Gao, F., Suyker, A., Verma, S., & Middleton, E. (2014). Estimation of crop gross primary production (GPP): fAPAR_{chl} versus MOD15A2 FPAR. *Remote Sensing of Environment*, *153*, 1–6, 10.1016/j.rse.2014.07.012.

Zhang, F., Zhou, G., & Nilsson, C. (2015). Remote estimation of the Fraction of Absorbed Photosynthetically Active Radiation for a maize canopy in Northeast China. *Journal of Plant Ecology*, *8*(4), 429–435, https://doi.org/10.1093/jpe/rtu027.