FORAGE PRODUCTION OF PERMANENT GRASSLANDS IN ROMANIA ACROSS ALTITUDINAL AND SOIL GRADIENTS

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PRODUCȚIA DE FURAJE DIN PAJIȘTILE PERMANENTE DIN ROMÂNIA PE GRADIENȚII ALTITUDINALI ȘI AI SOLULUI

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ABSTRACT

Permanent grasslands represent one of the most important components of Romania's agricultural and ecological landscape. Their productivity is influenced by climatic gradients, soil properties, and topographic variation. This study evaluates dry matter production across vegetation zones, and investigates the role of altitude, soil group, and soil pH in explaining productivity differences. A total of 83 sampling sites were distributed proportionally across Romanian vegetation zones. Aboveground biomass was harvested using standardized 1 m² quadrat sampling. Soil samples were collected from 0-10 cm and 10-20 cm depths for classification and pH determination. The adjusted model was composed of 68 samples after excluding underrepresented soil categories. Simple regression analysis showed that altitude significantly influences dry matter production (R^2=0.091, p=0.009). The ANOVA analysis model which included soil group and soil pH explained 37.3 % of total variance (R^2=0.373, p=0.002). While the soil group did not present a statistically significant independent main effect, interaction patterns suggested that the impact of altitude differs among certain soil types. These findings conclude that altitude is a consistent factor in grassland productivity, while soil characteristics impact productivity responses rather than acting independently.

REZUMAT

Pajiștile permanente reprezintă una dintre cele mai importante componente ale peisajului agricol și ecologic al României. Productivitatea lor este influențată de gradienții climatici, proprietățile solului și variațiile topografice. Acest studiu evaluează producția de materie uscată în diferite zone de vegetație și investighează rolul altitudinii, grupului de sol și pH-ului solului în explicarea diferențelor de productivitate. Un total de 83 de puncte de prelevare au fost distribuite proporțional în zonele de vegetație din România. Biomasa supraterană a fost recoltată folosind eșantionare standardizată în ramă metrică de 1 m². Probele de sol au fost colectate pe adâncimi de 0-10 cm și 10-20 cm pentru clasificare și determinare a pH-ului. Modelul ajustat a fost compus din 68 de probe după excluderea categoriilor de sol subreprezentate. Analiza simplă de regresie a arătat că altitudinea influențează semnificativ producția de substanţă uscată (R^2=0,091, p=0,009). Modelul de analiză ANOVA, care a inclus grupa de sol și pH-ul solului, a explicat 37,3 % din varianța totală (R^2=0,373, p=0,002). Deși grupa de sol nu a prezentat un efect principal independent semnificativ statistic, modelele de interacțiune au sugerat că impactul altitudinii diferă între anumite tipuri de sol. Aceste constatări concluzionează că altitudinea este un factor consistent în productivitatea pajiștilor, în timp ce caracteristicile solului influențează răspunsurile la productivitate, mai degrabă decât să acționeze independent.

INTRODUCTION

Romanian permanent grasslands cover an area of approximately 4.8 million hectares (*Dragomir, 2005; Eliott et al., 2024; Motcă et al., 1994*) (almost 3.3 million ha are used for grazing and 1.5 ha in hayfield regime), Romania occupying, the 5th place in Europe after France, Great Britain, Spain and Germany, excluding the European part of the Russian Federation (*Elliott et. al., 2024; Kingler et al., 2025; Schils et al., 2022*).

These areas, which represent 33 % of the agricultural area (*Maruşca et al., 2010*), include a wide range of habitats that vary greatly in terms of their management, agricultural productivity, socio-economic value (*Maruşca et al., 2025*) and nature conservation status, which reflect the effects of traditional practices and the impact of recent management (*Dragomir et al., 2009*).

This makes the land resources for grasslands in Romania extremely varied in all aspects: physical-geographic; climatic; hydrographic; soil depth; soil types and their physico-chemical properties (*Mocanu et al., 2021; Rotar and Carlier, 2010; Vîntu et al., 2004*).

Pastures and meadows are considered not only a source of grazing and hay for herbivores, but they play a multifunctional ecological and socio-economic role, forming an ecosystem that provides habitats for flora and fauna (*Ali and Kaul, 2025; Nemera et al., 2018*; *Nicoară et al., 2020*). Meadows, being components of the landscape, are crossed by tourist routes, which must be maintained in good condition to provide a pleasant appearance (*Iacob, 2015*). Pastures, as part of the environment, interact with other environmental processes, for example, climate change (*Kemp and Michalk, 2005*).

Grasslands are an essential element of sustainable agricultural systems (*Dragomir et al., 2009; Kuzel et al., 2009; Peters, 2008*) represented by: animal welfare, fodder provision, soil quality and optimal use of low-productive land, especially for the production of biomass (*Prochnow et al., 2008*), a renewable energy source (*Dragomir et al., 2009*).

Permanent grassland (EU-agreed term) includes natural grasslands, semi-natural grasslands and improved grasslands.

Natural grasslands, commonly used as pastures, are dominated by perennial grasses (*Mitev, 2023; Păcurar and Rotar 2014*; *Samuil et al., 2025*) whose floristic composition has not been modified to improve the efficiency of livestock products (*Horablaga et al., 2025; Rotar and Carlier, 2010*).

Semi-natural grasslands can be defined as habitats created at low intensity, with traditional agriculture (*Macholdt et al., 2023; Qiao et al., 2025; Roukos et al., 2017*).

The study aims to evaluate the variation in dry matter production of permanent grasslands in Romania in relation to altitude and soil group.

Grasslands are found on all landforms, respectively from the altitude of the Danube Delta and the plains, to the altitude of 2,500 m on the alpine plateaus of the Carpathian Mountains (*Doniţă et al., 2005; Ţucra et al., 1987; Vîntu et al., 2004)*.

Improved grasslands are more intensively maintained and have a high productive potential. These grasslands have been modified by sowing more nutrient-rich grasses or forage legumes, by using fertilizers (*Kovacs, 1979; Rotar and Carlier, 2010*), other amendments (*Rotar and Carlier, 2010; Vîntu et al., 2004*) and sometimes irrigation (*Sărăţeanu et al., 2025; Vîntu et al., 2004*) to support more intensive grazing (*Nemera et al., 2018; Van Del Pol et al., 2018*).

Forage plants in grasslands intensify the photosynthesis process in ecosystems and introduce a greater amount of organic matter into the soil (*Ye et al., 2024; Zhang et al., 2024*), maintaining active biological life in the soil (*Schneider and Thurner, 2024; Schneider and Thurner, 2025*).

The roots of grassland forage plants, which act as a binder in the presence of organic matter, stop the process of destroying the granular structure of soils, in most cases leading to their improvement (*Dragomir et al., 2009; Maruşca et al., 2010; Mocanu et al., 2021*).

In addition to the main role of providing fodder for cattle and sheep, grasslands have a number of important functions in rural development and the environment, reflected in: carbon sequestration in soils (*Dragomir et al., 2009*), symbiotic nitrogen fixation (*Dragomir et al., 2009*), landscape quality, biodiversity conservation (*Van Eekeren et al., 2018*), soil fertility improvement, flood and landslide prevention, water resource management and even as part of a nation's cultural heritage (*Dragomir et al., 2009; Maruşca et al., 2010; Peters, 2008*).

Research Hypotheses

H1: Altitude significantly affects dry matter production in permanent grasslands.
H2: Soil group explains differences in dry matter production.
H3: The relationship between altitude and dry matter production varies across soil groups.
H4: Soil pH (0-10 cm layer) significantly influences dry matter production.

MATERIALS AND METHODS

To determine the annual biomass production of grasslands (for 2025), a methodology based on the main landforms (plain area, hill area, mountain area, alpine area) was used, correlated with the zonal distribution of permanent grassland areas in Romania.

In this sense, the estimation of the annual biomass productivity per hectare was carried out through direct measurements from all vegetation floors, which reflected the situation in the field regarding the vegetation in those specific areas.

Samples of plants were taken from a surface unit (1 m^2), which could be extrapolated to the hectare level, to determine the dry matter content (DM, %). The samples were taken from each representative area, avoiding the edges or atypical portions (swamps, hummocks, stones, pits, animal excrements etc.). The entire amount of green mass, delimited by the 1m^2 metric frame placed on the ground, was cut at a height of 3 cm, harvested in three repetitions for each sample (*Nemera et al., 2018; Păcurar and Rotar, 2014*); the aerial biomass production was established as the average of these repetitions. After establishing the production of aerial biomass, prototypical samples of 200 g were taken, packaged in a bag with an identification label, for laboratory investigations (establishing the percentage of dry matter).

Table 1 presents a distribution of grassland surface by vegetation area, the percentage of participation in the Romanian grassland area for all vegetation zones, the counties with large areas.

Table 1

Grassland areas in Romania, by vegetation zone

No.	Name of vegetation zones	Participation percentage, (%)	Counties with important grassland area
1	Zone 1- Alpine grassland zone (alpine proper)	0.15	Argeș, Brașov, Dâmbovița, Prahova
2	Zone 2- Juniper zone (lower alpine)	1.70	Argeș, Brașov, Harghita, Prahova, Caras Severin
3	Zone 3- Rare forest zone (boreal-subalpine)	0.40	Alba, Argeș, Brașov, Buzău, Gorj, Prahova, Vâlcea
4	Zone 4- Spruce and mixed forest zone	7.25	Alba, Argeș, Bistrița Năsăud, Brașov, Covasna, Harghita, Maramureș, Prahova, Suceava, Vâlcea,
5	Zone 5- Beech forest zone	13.90	Alba, Argeș, Bistrița Năsăud, Brașov, Cluj, Covasna, Prahova, Suceava, Vâlcea
6	Zone 6- *Quercus petraea* forest zone	38.81	Alba, Argeș, Brașov, Cluj, Covasna, Harghita, Gorj, Sibiu, Suceava, Vrancea, Vâlcea
7	Zone 7- Oak, sessile oak and oak forest area (including oak hybrids)	5.61	Argeș, Bihor, Caraș Severin, Dolj, Mehedinți, Sălaj, Timiș
8	Zone 8- Forest-steppe subzone	9.31	Alba, Bacău, Botoșani, Buzău, Cluj, Iași, Neamț, Mureș, Timiș, Vaslui
9	Zone 9- Antesteppe subzone	3.82	Buzău, Călărași, Constanța, Galați, Tulcea, Vaslui
10	Zone 10- Danubian steppe subzone	1.92	Brăila, Buzău, Caraș S., Constanța, Galați, Ialomița, Tulcea
11	Zone 11- River side, delta and river plain vegetation	13.56	Arad, Bihor, Brașov, Galați, Timiș, Harghita, Iași, Suceava, Vaslui
12	Zone 12- Salt marsh vegetation (halophilous)	1.27	Arad, Brăila, Buzău, Constanța, Iași, Tulcea
13	Zone 13- Sand vegetation (arenicola)	0.70	Brăila, Constanța, Dolj, Olt, Satu Mare, Tulcea
14	Zone 14- Lake and swamp vegetation (hydrophilic)	1.13	Brăila, Dolj, Mehedinți, Suceava, Timiș, Tulcea
15	Zone 15- Locally distributed vegetation	0.08	Bihor, Buzău, Constanța, Dolj, Timiș, Galați, Gorj, Mehedinți, Satu Mare
16	Zone 16- Waters	0.52	Arad, Brăila, Cluj, Constanța, Timiș Vâlcea Galați, Ilfov, Neamț, Tulcea
TOTAL		**100.00**	

The number of samples taken was established based on the percentage of participation of the grassland area in the vegetation zone, compared to the total area recorded by APIA (Payments and Intervention Agency for Agriculture), which uses the LPIS (Land Parcels Identification System).

For sampling, itineraries were established to cover areas in the counties with a large region of the different vegetation zones. *Table 2* shows the geographical coordinates of the sampling points, grouped by vegetation area.

Table 2

Geographic coordinates, soil type and pH level, grouped by vegetation zone

No.	Sample code	Altitude (m)	Latitude Longitude	Soil type	pH	
					0-10 (cm)	10-20 (cm)
1.	Zone 1- Alpine grassland zone (alpine proper)					
	1.1	1997.80	45.403551 25.446147	Prepodzol	4.5	4.3
	1.2	1884.77	45.590832 24.626494	Podzols	4.3	4.7
2.	Zone 2- Juniper zone (lower alpine)					
	2.1	1654.88	45.324079 25.463617	Dystric Cambisol	4.7	4.4
	2.2	1638.55	45.584675 24.641339	Podzols	5.7	6.1
3.	Zone 3- Rare forest zone (boreal-subalpine)					
	3.1	1115.80	45.424733 25.359453	Prepodzol	4.8	4.9
	3.2	1557.16	45.297817 23.675945	Districambosol	5.0	4.8
4.	Zone 4- Spruce and mixed forest zone					
	4.1	767.00	45.722218 26.002334	Gleyic aluviosol and Saline and sodic aluviosol	5.7	5.5
	4.2	1130.10	45.973032 26.351990	Prepodzol	4.8	5.0
	4.3	830.08	45.675897 25.970099	Hyperdistric Luvisols	5.7	5.4
	4.4	637.89	45.562969 26.180329	Districambosol	5.8	5.7
	4.5	688.70	46.102542 25.897556	Eutric Cambisol	5.2	5.3
	4.6	1038.33	45.307116 25.519913	Districambosol	5.5	5.7
	4.7	844.59	45.516098 25.516020	Hyperdistric Luvisols	6.0	6.6
	4.8	951.30	45.607778 25.549982	Districambosol	6.6	7.4
5.	Zone 5- Beech forest zone					
	5.1	842.77	45.516094 25.516023	Hyperdistric Luvosols	5.3	5.4
	5.2	1205.48	45.228848 23.687941	Districambosol	4.3	4.5
	5.3	529.26	45.707868 24.570616	Gleyic aluviosol and Saline and sodic aluviosols	4.9	4.8
	5.4	1071.38	45.424109 25.245461	Districambosol	7.4	7.4
	5.5	1264.37	45.436954 25.269119	Rendzinas	5.0	5.1
	5.6	737.95	45.258935 25.637577	Nigrosol	7.2	7.6
	5.7	393.33	45.443359 26.306933	Eutricambosols	7.4	7.6
	5.8	475.50	45.424765 26.298660	Eutricambosols	7.5	7.7
	5.9	601.49	45.625100	Stagnic Albic Luvisol	5.5	5.7

No.	Sample code	Altitude (m)	Latitude	Soil type	pH	
			Longitude		0-10 (cm)	10-20 (cm)
			25.505808			
	5.10	767.00	45.722218 26.002334	Gleyic aluviosol and Saline and sodic aluviosol	5.9	6.0
	5.11	375.87	46.202485 26.527223	Entic aluviosols	6.6	6.6
	5.12	365.61	46.207955 26.542920	Entic aluviosols	7.4	7.5
6.	Zone 6- *Quercus petraea* forest zone					
	6.1	408.12	46.182940 26.491610	Preluvisol	5.7	5.7
	6.2	343.40	46.213594 26.617809	Stagnic Luvisol	7.4	7.6
	6.3	519.40	46.506500 26.810714	Stagnant Luvisols	5.4	5.3
	6.4	306.40	46.697741 27.165618	Stagnant Luvisols	5.9	5.6
	6.5	450.02	45.758545 24.570632	Aluviosol	4.5	4.6
	6.6	492.40	45.180405 24.689269	Entic aluviosol	5.8	5.8
	6.7	691.53	45.566625 25.413530	Stagnant Preluvisols	5.8	6.0
	6.8	1600.30	45.296216 23.684175	Prepodzol	4.4	4.6
	6.9	490.55	45.151828 23.789130	Eutricambosols	7.4	7.8
	6.10	372.88	45.251836 24.348738	Typical Eutricambosol	7.1	7.0
	6.11	409.08	45.660075 24.281065	Cambic Chernozems and/or Cambic Phaeozems	5.7	5.9
	6.12	413.88	45.704763 24.268907	Typical Luviosol and Lamellar Luvisols	5.4	5.6
	6.13	587.94	45.767132 23.955206	Preluvosol	7.7	7.7
	6.14	590.11	45.767578 23.954937	Preluvosol	7.8	7.7
	6.15	544.56	45.826953 23.858012	Stagnant Preluvosols	7.9	8.1
	6.16	290.90	46.116451 23.535210	Eutricambosols	5.8	6.1
	6.17	361.90	46.102630 23.432994	Aluviosol	7.6	7.8
	6.18	479.46	46.121307 23.198304	Districambosol	5.5	5.6
	6.19	478.80	45.792024 23.610403	Districambosol	5.2	5.0
	6.20	477.72	45.866755 23.586296	Districambosol	5.4	5.2
7.	Zone 7- Oak, sessile oak and oak forest area (including oak hybrids)					
	7.1	296.79	44.927456 25.353536	Stagnant albic Luvosols	5.4	5.4
	7.2	506.85	45.777500 25.069822	Gleyic aluviosol and Saline and sodic aluviosol	5.4	5.5
	7.3	134.60	44.612086		7.4	7.6

No.	Sample code	Altitude (m)	Latitude Longitude	Soil type	pH	
					0-10 (cm)	10-20 (cm)
			26.073203	Reddish Preluvosols and Slightly Eroded Reddish Preluvosols		
	7.4	309.77	45.045664 25.894004	Albic Luvisols	7.7	7.3
	7.5	97.60	44.523786 26.046181	Reddish Preluvosols and Slightly Eroded Reddish Preluvosols	7.0	6.5
	7.6	291.09	44.756494 25.016387	Aluviosol	5.4	5.6
8.	Zone 8- Forest Steppe subzone					
	8.1	277.05	45.014818 25.964286	Stagnant albic Luvosols	6.7	6.7
	8.2	156.05	46.631813 27.598806	Entic aluviosols	7.8	8.0
	8.3	96.59	46.653773 27.743410	Entic aluviosols	7.5	7.9
	8.4	321.58	46.300300 24.302225	Gleysol	7.7	8.0
	8.5	300.05	46.480381 24.044490	Geoerodic Regosols	7.9	7.8
	8.6	343.22	46.119058 23.610978	Pararendzinic phaeozems	8.0	8.1
	8.7	345.56	46.489734 23.782724	Pararendzinic phaeozems	7.6	7.8
	8.8	362.30	45.877016 23.877425	Pararendzinic phaeozems	7.6	7.8
	8.9	323.78	45.911414 23.730724	Chernozemoid phaeozems	6.6	7.6
	8.10	315.11	46.126721 24.247215	Pararendzinic phaeozems	7.5	7.5
9.	Zone 9- Antesteppe subzone					
	9.1	128.87	45.125113 26.755680	Cambic Chernozems and/or Cambic Phaeozems	7.5	8.1
	9.2	11.88	45.314088 28.144321	Lakes or Ponds	7.7	7.8
	9.3	133.95	45.277594 28.145526	Typical Chernozem and/or Calcareous Chernozems	7.9	8.0
	9.4	170.62	46.206490 27.505355	Cambic Chernozems and/or Cambic Phaeozems	6.1	5.9
	9.5	99.05	45.065652 26.979095	Typical Chernozem and/or Calcareous Chernozems	8.0	8.9
10.	Zone 10- Danubian steppe subzone					
	10.1	54.11	44.232703 28.216307	Typical Chernozem and/or Calcareous Chernozems	8.3	8.3
	10.2	94.81	44.205359 28.310702	Cambic Chernozems and/or Cambic Phaeozems	7.5	7.7
11.	Zone 11- River side, delta and river plain vegetation					
	11.1	99.48	46.619668 27.701397	Gleyic alluviosols and Saline and sodic alluviosols	7.5	7.8
	11.2	150.62	46.741808 27.768757	Aluviosol	8.2	8.3
	11.3	159.29	46.862766 27.802862	Aluviosol	7.7	7.9

No.	Sample code	Altitude (m)	Latitude	Soil type	pH	
			Longitude		0-10 (cm)	10-20 (cm)
	11.4	469.50	45.802355 24.815174	Batygleic and/or saline and/or sodic alluviosols	4.9	5.0
	11.5	439.72	45.799757 24.768362	Stagnant Preluvosols	5.4	5.8
	11.6	464.00	45.776758 24.632622	Allosols	5.5	5.7
12.	Zone 12- Salt marsh vegetation (halophilous)					
	12.1	73.51	45.016056 26.824280	Solonetz	7.9	8.6
	12.2	104.12	44.996816 26.876758	Solonetz	7.5	8.3
13.	Zone 13- Sand vegetation (arenicola)					
	13.1	128.30	44.237161 23.849938	Typical Preluvosols and Lamellar Preluvosols	5.7	5.7
14	Zone 14- Lake and swamp vegetation (hydrophilic)					
	14.1	34.21	45.074696 29.113621	Gleiosol	7.7	8.0
	14.2	32.94	45.069586 29.103068	Kastanoziom	8.0	8.3
15	Zone 15- Locally distributed vegetation					
	15.1	56.19	44.135939 23.893123	Solonetz	7.4	7.9
16	Zone 16- Waters					
	16.1	64.27	43.994860 28.153237	Aluviosol	7.4	8.0
	16.2	556.35	45.767534 25.481324	Relict Gleiosol	5.7	5.4
TOTAL: 83 samples						

Soil samples were collected from the same aerial biomass sampling points at depths of 0-10 cm and 10-20 cm to determine soil type and acidity level (pH value) (*Vlad et al., 2014*). Table 2 presents the results of laboratory chemical analysis of soil samples from different vegetation zones.

Statistical analyses were conducted using SPSS Version 26. From the initial dataset of 83 samples (Figure 1), soil groups represented by fewer than three cases were excluded from the adjusted analysis in the ANOVA model, in order to avoid unstable variance estimates. The final multivariate analysis was therefore conducted on 68 observations, while the analysis of regression was performed on 73 observations for the cases where data was available.

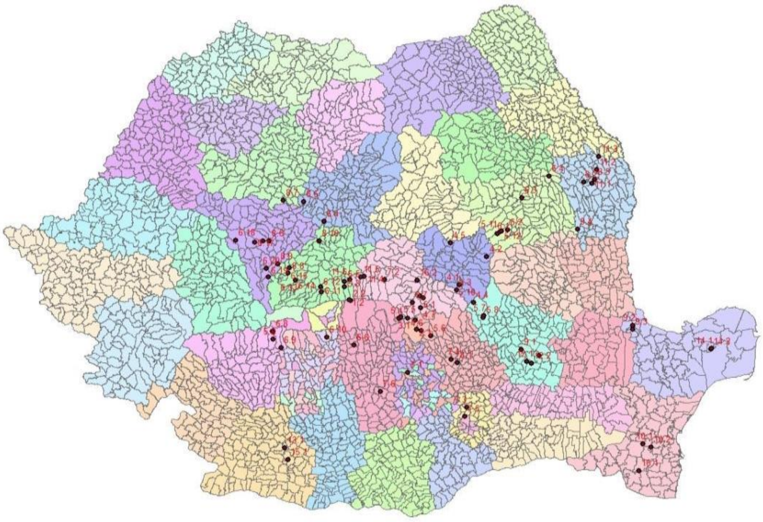


Fig. 1 - Map of Romania with the distribution of aerial biomass and soil sampling points

RESULTS

The determination of the volume of aerial biomass (DM, t/ha) was carried out by direct measurements on different types of grasslands representative of all vegetation levels.

Vegetation mass samples were taken from a surface unit, which could be extrapolated to the hectare level. For each vegetation area, a different number of samples were taken, depending on the percentage of participation of the grassland area in the total area of grasslands in Romania. The final biomass value represented the average of these samples.

Table 3 presents the results regarding the average production of dry matter (DM) per surface unit for the samples collected from different vegetation areas, establishing the average of dry matter (DM, t/ha).

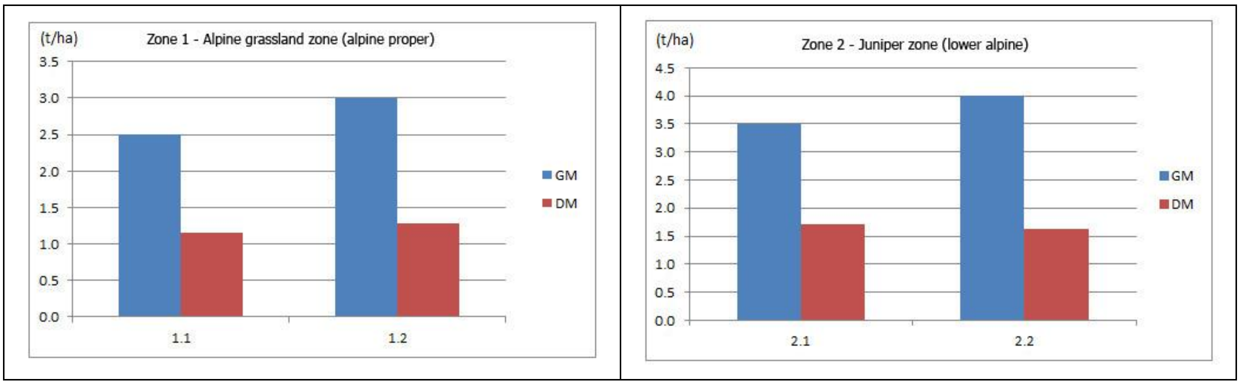
Table 3

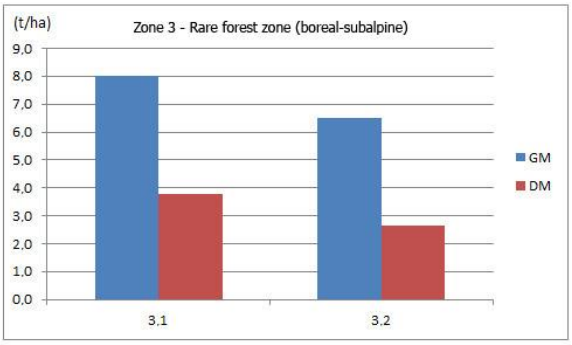
Results regarding dry matter production per unit area for samples collected from different vegetation zones

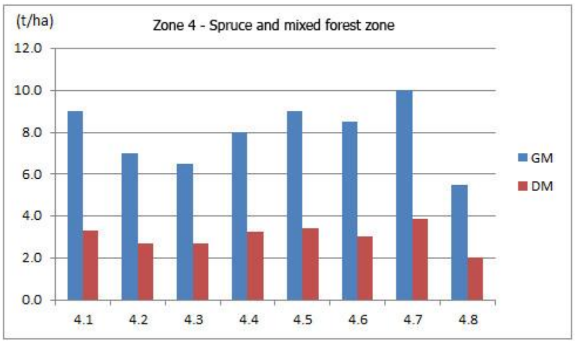
No.	Name of the vegetation area	Average DM (t/ha)
1	Zone 1- Alpine grassland zone (alpine proper)	1.224
2	Zone 2- Juniper zone (lower alpine)	1.676
3	Zone 3- Rare forest zone (boreal-subalpine)	3.194
4	Zone 4- Spruce and mixed forest zone	3.044
5	Zone 5- Beech forest zone	2.968
6	Zone 6- *Quercus petraea* forest zone	3.118
7.	Zone 7- Oak, sessile oak and oak forest area (including oak hybrids)	3.709
8.	Zone 8- Forest Steppe subzone	3.100
9.	Zone 9- Antesteppe subzone	2.158
10.	Zone 10- Danubian steppe subzone	2.434
11.	Zone 11- River side, delta and river plain vegetation	3.566
12.	Zone 12- Salt marsh vegetation (halophilous)	5.148
13.	Zone 13- Sand vegetation (arenicola)	1.824
14	Zone 14- Lake and swamp vegetation (hydrophilic)	2.842
15	Zone 15- Locally distributed vegetation	2.160
16	Zone 16- Waters	7.680

According to the data in Table 3, the DM amount of above ground biomass, expressed in t/ha, has values between 1.224 (Alpine grassland zone) and 7.680 (Waters).

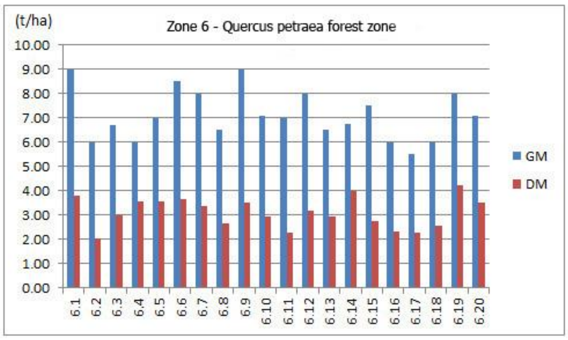
Figure 2 graphically represents the green mass (GM) and dry matter (DM) productions per hectare. It is observed that the values determined for both GM and DM had relatively uniform values for each altitudinal zone.

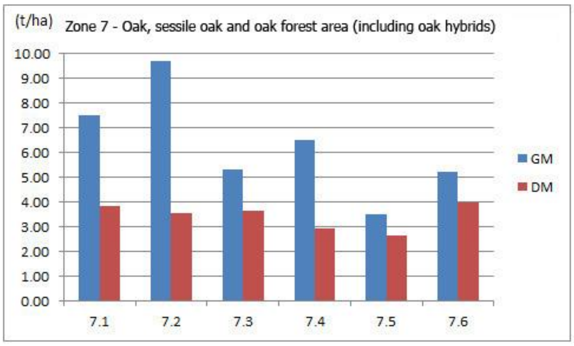


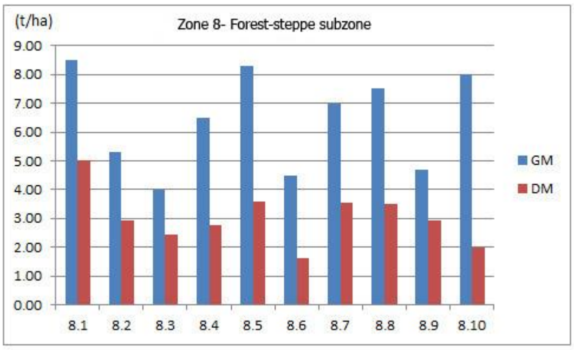

(t/ha)
Zone 3 - Rare forest zone (boreal-subalpine)
9,0
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
3.1
3.2
GM
DM

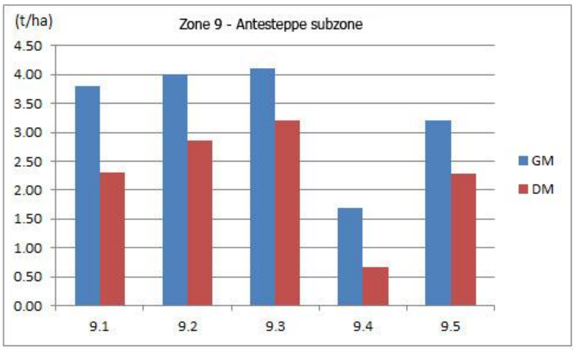

(t/ha)
Zone 4 - Spruce and mixed forest zone
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
GM
DM

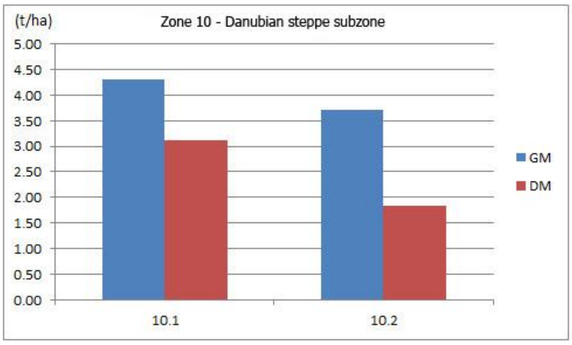

(t/ha)
Zone 5 - Beech forest zone
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
5.10
5.11
5.12
GM
DM

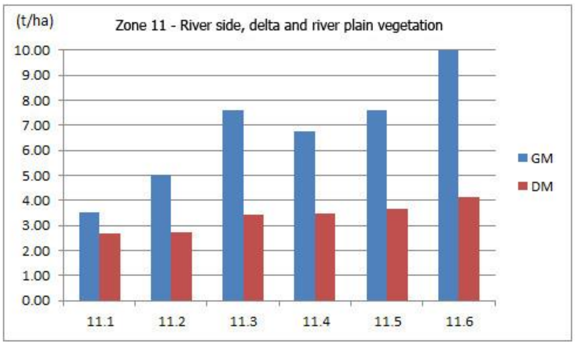

(t/ha)
Zone 6 - Quercus petraea forest zone
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
6.10
6.11
6.12
6.13
6.14
6.15
6.16
6.17
6.18
6.19
6.20
GM
DM

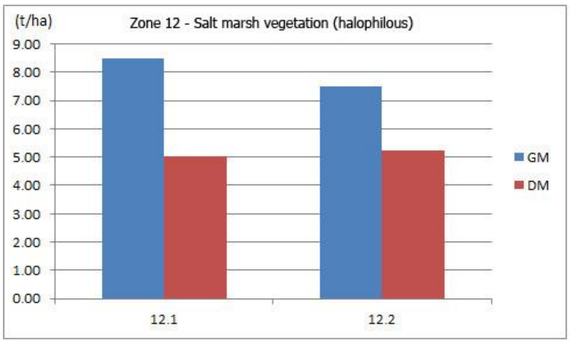

(t/ha)
Zone 7 - Oak, sessile oak and oak forest area (including oak hybrids)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
7.1
7.2
7.3
7.4
7.5
7.6
GM
DM


(t/ha)
Zone 8- Forest-steppe subzone
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
8.1
8.2
8.3
8.4
8.5
8.6
8.7
8.8
8.9
8.10
GM
DM


(t/ha)
Zone 9 - Antesteppe subzone
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
9.1
9.2
9.3
9.4
9.5
GM
DM


(t/ha)
Zone 10 - Danubian steppe subzone
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
10.1
10.2
GM
DM


(t/ha)
Zone 11 - River side, delta and river plain vegetation
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
11.1
11.2
11.3
11.4
11.5
11.6
GM
DM


(t/ha)
Zone 12 - Salt marsh vegetation (halophilous)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
12.1
12.2
GM
DM

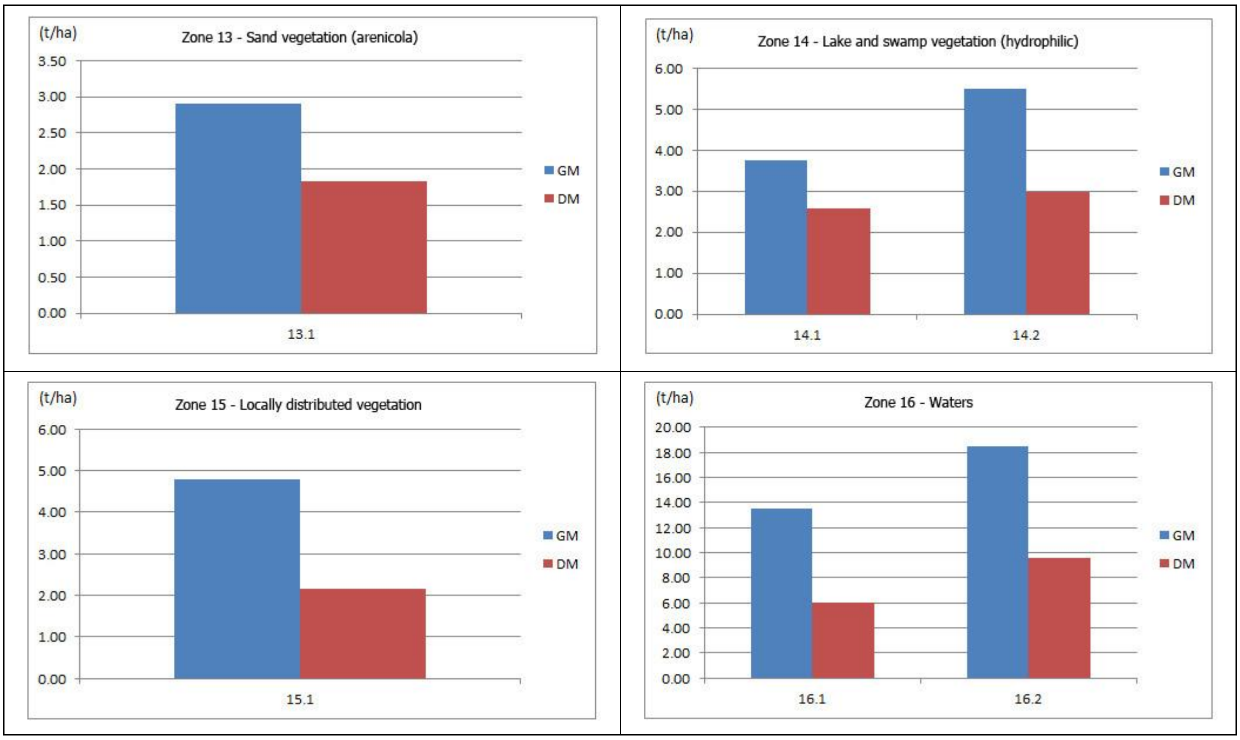


Fig. 2 - GM and DM production on each altitudinal zone

Figure 3 graphically shows the DM yield, in t/ha, for all altitudinal zone. It can be seen that most altitudinal zone achieved a DM production that was grouped in the range of 2-4 t/ha, with the exception of the first 2 zone, which achieved a yield below 2 t/ha, and respectively zone 12 and zone 16, where a production of over 5 t/ha was recorded.

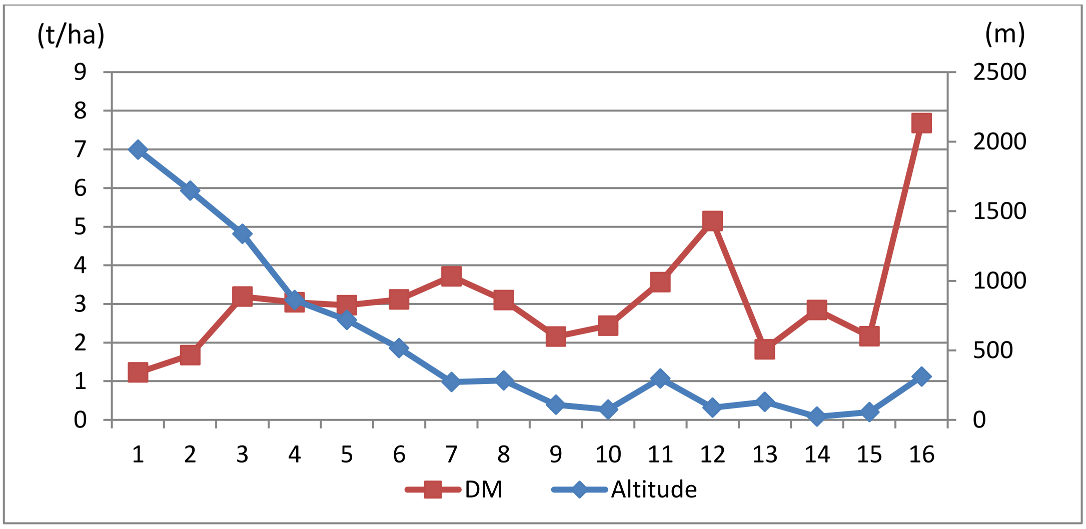


Fig. 3 - Average DM production on all altitudinal zone

Descriptive analysis

Dry matter production varied across soil groups. Mean values ranged from 2.19 t/ha in Podzols/ Prepodzols, to 3.25 t/ha in alluvial soils. Although these differences can be easily identified following sample collection, the independent effect of the soil group did not reach statistical significance in the adjusted model (Table 4).

Table 4

Descriptive statistics for soil groups

Descriptive Statistics			
Dependent Variable: DM			
Soil Group	Mean	Std. Deviation	N
Cambisols (Districambosol, Eutricambosol etc.)	2.938562500000001	.678424859877644	16
Luvisols / Preluvisols	3.207461764705883	.744523255498404	17
Chernozems / Phaeozems	2.748169230769231	.733494839091836	13
Alluvial soils (Aluviosols etc.)	3.247456250000000	.548022122386496	16
Podzols / Prepodzols	2.193166666666667	1.016080000131223	6
Total	2.976299264705882	.756662888052644	68

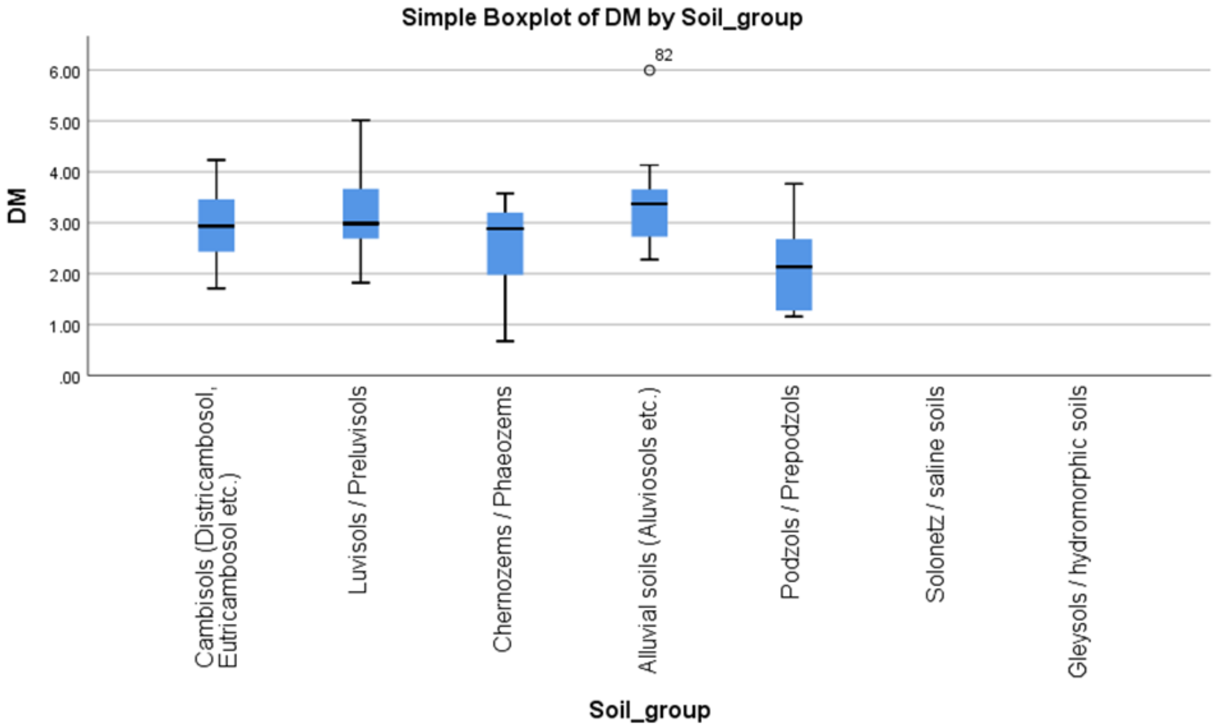


Fig. 4 - Box plot reflecting the Dry Matter values in different soil types

A simple linear regression model was applied to 73 observations, to determine whether altitude alone can predict dry matter production (Figure 5). Our model yielded significant results, F(1, 72)=7.225, p=0.009, R^2=0.091 (Table 5). This indicates that altitude can explain approximately 9 % of the total variation in productivity. The region coefficient (B=-0.001) suggests that dry matter production decreases as altitude increases. Although the effect is moderate, it confirms that the altitudinal gradient plays a measurable role in grassland productivity.

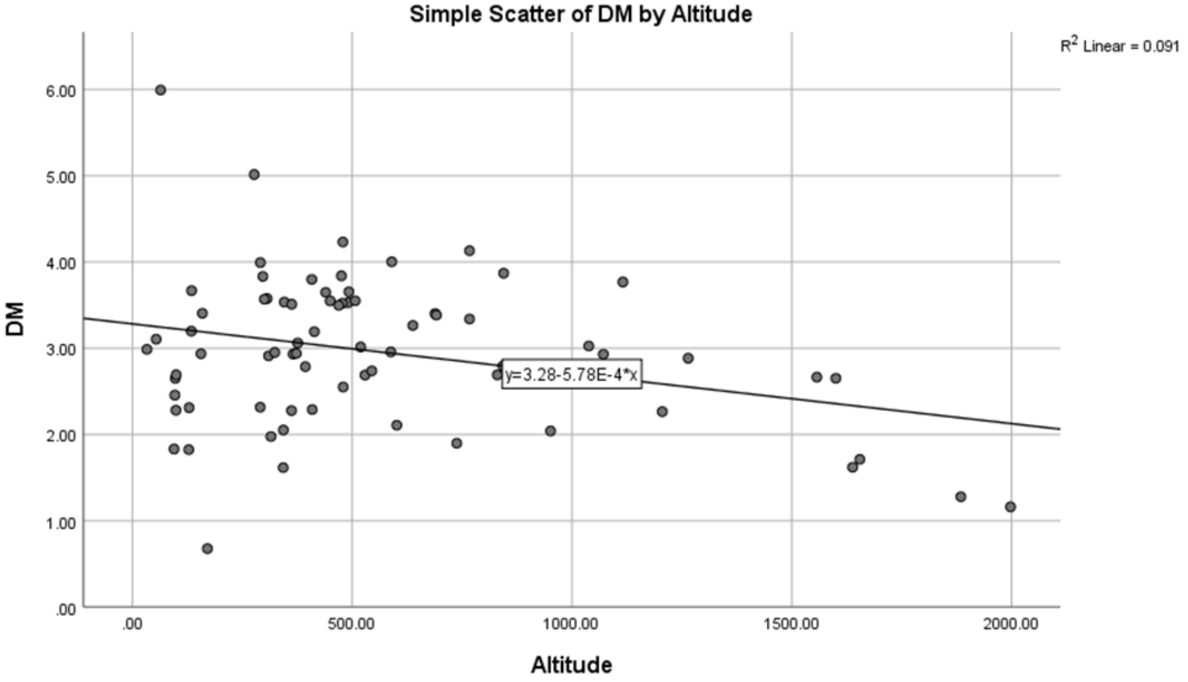


Fig. 5 - Scatter Plot with regression line showing dry matter production depending on altitude

Table 5

Regression results

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.302[a]	.091	.079	.833386132752013

a. Predictors: (Constant), Altitude

The ANOVA model was constructed on 68 observations (Table 6), including soil group and soil pH, while maintaining altitude as a continuous predictor. The overall model was statistically significant, with F(10, 57)=3.395, p=0.002, R²=0.373. As it can be seen from the data (Table 6), this model explained 37.3 % of the total variance in dry matter production, representing a substantial increase compared to altitude alone (9 %). This indicates that combining soil classification and interaction terms improves the explanatory power of this effect. The model includes altitude, soil group and soil pH, with the ANOVA analysis explaining 37.3 % of total variance. Altitude remained a significant predictor (p=0.044), while soil group and soil pH did not show significant independent main effects. The soil group and the altitude interaction had a score close to the significance level (p=0.076), suggesting that productivity responses to altitude may differ among certain soil types.

Table 6

Results of ANOVA analysis

Tests of Between-Subjects Effects

Dependent Variable: DM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.319[a]	10	1.432	3.395	.002	.373
Intercept	15.978	1	15.978	37.883	.000	.399
Soil_group	3.270	4	.817	1.938	.116	.120
Altitude	1.797	1	1.797	4.260	.044	.070
pH_0_10	.496	1	.496	1.177	.283	.020

Soil_group * Altitude	3.772	4	.943	2.236	.076	.136
Error	24.041	57	.422			
Total	640.728	68				
Corrected Total	38.360	67				
a. R Squared = .373 (Adjusted R Squared = .263)						

Main effect of Altitude: altitude remains statistically significant in the adjusted model F(1, 57)=4.260, p=0.044, which confirms that the negative altitudinal gradient persists even after controlling for soil group and pH (Table 6).

Main effect of Soil group: the independent main effect of soil category did not reach statistical significance F(4, 57)=1.938, p=0.116. However, the absence of significance suggests that soil classification alone does not fully explain productivity variation when altitude is accounted for. Of course, this does not imply that soil types are not relevant, but rather that their impact may be mediated through other environmental aspects (Table 6).

Main effect of Soil pH: the soil pH was not statistically significant F(1, 57)=1.177, p=0.283, which means that the pH variation within the sampled range does not independently determine biomass production.

Interaction between Soil Group and Altitude: this interaction approached statistical significance F(4, 57)=2.236, p=0.076 (Table 6). In certain types of soil, the decline in dry matter productivity along the altitudinal gradient may be steeper or moderate compared to other soil types. The moderate effect size indicates that soil characteristics may influence how productivity responds to altitude.

Results confirm that altitude represents a consistent structural driver of grassland productivity in Romania. The observed negative relationship aligns with ecological expectations related to shorter growing seasons and lower mean temperatures at higher elevations. The lack of a statistically significant independent soil group effect indicates that soil classification alone does not dominate productivity patterns at national scale. Instead, soil types appear to interact with topographic gradients. The increase in explained variance from 9 % (altitude alone) to 37 % (combined model) highlights the importance of considering multiple environmental variables simultaneously. The non-significant effect of pH suggests that within the observed variability range, pH may not represent a primary limiting factor for biomass production.

Overall, the findings indicate that grassland productivity patterns are shaped by interacting environmental gradients rather than single isolated factors. Although the soil group did not exhibit a statistically significant independent main effect, the observed interaction effects suggest that pedological context can influence productivity along altitudinal levels. These findings should be interpreted with caution due to sample size constraints in certain soil categories.

CONCLUSIONS

The determination of dry matter production per unit area was carried out by direct measurements on different types of grasslands representative of all vegetation areas. The samples of above ground biomass were taken per unit area, which was extrapolated to the hectare level, for each sample 3 harvests were made from different points of the location.

Dry matter production varied across vegetation zones. The lowest values were those recorded in alpine grasslands (1.224 t/ha), reflecting harsher climatic conditions and shorter vegetation periods. Intermediate forest and forest steppe areas recorded values of between 2.5 to 3.5 t/ha. The highest values were found in halophilous and hydromorphic environments. These descriptive differences suggest that environmental gradients could influence biomass production.

This study shows that altitude influences dry matter production, while soil group alone does not pose a dominant independent effect. Soil-altitude interaction suggests differentiated productivity responses. Soil pH was not a significant independent predictor. Results highlight the role of altitudinal gradients in shaping permanent grassland productivity in Romania. Future empirical research integrating multi-year climatic indicators and nutrient analyses could further analyze and refine knowledge of grassland productivity determinants.

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