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The Biomass Productivity and Quality Indices of Some Permanent Grasslands

Adrian-Ilie Nazare[1], Victor Ţîţei[2], Ana Guţu[2], Costel Samuil[1], Aliona Miron[2], Mihal Gadibadi[2], Andrea Andreoiu[3], Vasile Vîntu[1]

[1]"Ion Ionescu de la Brad" University of Life Sciences, Iaşi, 3 Mihail Sadoveanu Alley, Romania
[2]"Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, Chişinău, 18 Pădurii Street, Republic of Moldova
[3]Research-Development Institute for Grassland, Braşov, 5 Cucului Street, Romania
[*]Corresponding author. E-mail: vic.titei@gmail.com

ABSTRACT

An appropriate grassland management is crucial to support biodiversity, to ensure adequate forage quantity and quality, supporting domestic livestock production, and to provide multi-purpose feedstock for the circular economy. The study was conducted on permanent pastures dominated by *Festuca valesiaca* and *Elytrigia repens* in the Moldavian Forest Steppe regions of Romania and the Republic of Moldova. Biomass productivity ranged from 1.59 to 7.93 t/ha dry matter. The dry matter quality indices were as follows: 85-91 g/kg crude protein (CP), 382-424 g/kg crude fiber (CF), 86-89 g/kg ash, 415-450 g/kg acid detergent fiber (ADF), 658-753 g/kg neutral detergent fiber (NDF), 44-60 g/kg acid detergent lignin (ADL), 355-416 g/kg cellulose, 241-303 g/kg and hemicellulose (HC). Forage quality was characterized by digestibility (DMD) of 53.8-56.7%, digestible energy (DE) of 10.76-11.28 MJ/kg, metabolizable energy (ME) of 8.84-9.26 MJ/kg, and net energy for lactation (NEl) of 4.86-5.26 MJ/kg. Fertilization treatments, either mineral ($N_{100}P_{100}$ kg/ha) or organic (30 t/ha sheep manure every 2 years), can significantly improve the biomass production and forage quality in *Festuca valesiaca*-dominated grasslands. Additionally, the biomass harvested from these grasslands can serve as a raw material for biofuel production, with a gross energy value of 17.5-18.3 MJ/kg, a biochemical methane potential (BMP) of 305-333 l/kg VS, and a theoretical ethanol potential of 433-523 l/t VS.

Keywords: biochemical methane potential, biomass productivity, energy value, *Elytrigia repens* grasslands, *Festuca valesiaca* grasslands, fertilization treatments, fodder values, theoretic ethanol potential.

INTRODUCTION

Climate change, from a broad perspective, affects crop production, livestock production and the socioeconomic structure, negatively impacting energy and food security, as well as the rate of economic development. Natural and semi-natural grasslands worldwide are true "green oceans" of great importance for life on Earth and have been the subject of detailed research over time. Grassland management is crucial to ensure adequate forage quantity and quality, supporting domestic livestock production (Hopkins and Holz, 2005; O'Mara, 2012; Samuil and Vîntu, 2012; Rotar et al., 2020; Wróbel et al., 2025). Additionally, several countries have utilized grassland biomass as feedstock for a circular economy, including for renewable energy production (Mähnert et al., 2002, 2005; Tilman et al., 2006; Rösch et al., 2009; Jungers et al., 2013; Dubrovskis et al., 2018; Joseph et al., 2018; Brandhorst et al. 2024).

In the Republic of Moldova, grasslands cover 333.4 thousand hectares, or 9.8% of the total area of the country. Of this, 331.3 thousand hectares are pastures, and 2.1 thousand hectares are hayfields. In Romania, pastures and hayfields cover 4.828 million hectares, of which 3.272 million hectares are pastures and 1.556 million hectares are hayfields. This represents 20.3% of the country's total area and 33% of its agricultural land. The floristic composition is extremely varied and rich, where all species characteristic of the suballiance, alliance, order and class can be found (Postolache, 1995; Chifu et al., 2006; Lazu, 2014; Maruşca and Burescu, 2021).

In Romania and Republic of Moldova, the association formed by *Festuca valesiaca*

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Schleich. ex Gaudin dominates most grasslands in the steppe and forest-steppe zones, particularly on arid slopes with varying inclines, from gentle to steep (5-45%), and southern exposure. The majority of the land occupied by these phytocenoses is rugged, with severe erosion and landslides (Samuil et al., 2019). Grasslands with *Elytrigia repens* (L.) Desv. ex Nevski (syn.: *Agropyron repens* (L.) P. Beauv., *Elymus repens* (L.) Gould) and *Festuca valesiaca* in the Republic of Moldova are under-researched from both quantitative and qualitative perspectives, with most knowledge coming from geobotanical studies. According to geobotanical research (Miron, 2009; Lazu, 2014; Postolache, 2024), plant communities dominated by *Elytrigia repens* have been classified into three associations and two vegetation classes:

1. Class *Molinio-Arrhenatheretea* R. Tx. 1937, order *Potentillo-Polygonetalia* R. Tx. 1947, alliance *Potentillion anserinae* R. Tx. 1947, association *Rorippo austriacae-Agropyretum repentis* (Timar 1947) R. Tx. 1950.
2. Class *Artemisietea vulgaris* Lohmeyer et al.ex von Rochow 1951, order *Agropyretalia repentis* Oberd et al. (1967), alliance *Convolvulo arvensis-Agropyrion repentis* Gors 1966, association *Convolvulo-Agropyretum repentis* Felfoldy, 1943, association *Lepidio-Agropyretum repentis* T. Muller et Gors 1966.

The communities of the *Rorippo austriacae-Agropyretum repentis* association are widely distributed across the Republic of Moldova (Miron, 2007; 2009; Postolache, 1995; 2024). Numerous grasslands dominated by *Elytrigia repens* are also found in Romania, particularly in the Bârlad floodplain, the floodplains of the Prut and Siret rivers and their tributaries (Chifu et al., 2006). These grasslands, dominated by *Elytrigia repens* and accompanied by halophytic species, mark the transition towards saline grasslands.

The primary goal of this study was to evaluate the productivity of permanent grasslands dominated by *Festuca valesiaca* and *Elytrigia repens* in the Moldavian Forest Steppe on both sides of the Prut River. The study also aimed to evaluate the effects of organic and mineral fertilizers on productivity of *Festuca valesiaca* grasslands. Assess the quality indices of the grassland biomass as livestock feed and explore its potential as raw material for biofuel production as a renewable energy source.

MATERIAL AND METHODS

The research was conducted on permanent grasslands dominated by *Festuca valesiaca* and *Elytrigia repens* in the Central Zone of the Republic of Moldova. In Romania, the experiment was carried out from 2023 to 2025 on a *Festuca valesiaca* plant association located within the Moldavian Forest Steppe, Ezareni testing aria. A monofactorial experiment was established in 2024 using the randomized block design, with three replications. The following variants of experimental treatments were applied: V_1 - unfertilized (control), V_2 - $N_{50}P_{50}$ kg/ha annually, V_3 - $N_{75}P_{75}$ kg/ha annually, V_4 - $N_{100}P_{100}$ kg/ha annually, V_5 - 10 t/ha sheep manure annually, V_6 - 20 t/ha sheep manure annually and V_7 - 30 t/ha sheep manure annually (applied every two years). Harvesting was conducted at heading-flowering stage of the dominant grasses. Biomass productivity was assessed by measuring the total dry phytomass from 10 m² plots, with five replications. In the Republic of Moldova, the harvested phytomass was air-dried directly in the field. The dry matter content was determined by oven-drying the samples at 105°C until a constant weight was achieved. For chemical analysis, biomass samples were chopped into 1.5-2.0 cm pieces, dried in a forced-air oven at 60°C, and then milled using a beater mill with a 1 mm sieve. Biochemical parameters, including crude protein (CP), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), and acid detergent lignin (ADL), were determined using near-infrared spectroscopy at the Research-Development Institute for Grassland, Brașov, Romania. Forage analyses were conducted by the *AgroLab* Laboratory at the University of Life

Sciences "Ion Ionescu de la Brad", Iași, Romania. The total nitrogen content was analyzed using the Kjeldahl method (SR ISO 13325/1995), and crude protein (CP) content was calculated by multiplying the total nitrogen by the conversion factor of 6.25. The cell wall content (ADF and NDF) of the samples was determined using the FibreBag System, 36-place (Gerhardt Analytical Systems). The concentrations of hemicellulose (HC), cellulose (Cel), total digestible nutrients (TDN), relative forage quality (RFQ), digestible energy (DE), metabolizable energy (ME), and net energy for lactation (NEl) were calculated according to standard procedures. The carbon content of the substrates was determined using an empirical equation from Badger et al. (1979). Biochemical methane potential was calculated based on the equations provided by Dandikas et al. (2015). The theoretical ethanol potential (TEP) was calculated using the method proposed by Goff et al. (2010), considering the conversion of cellulose and hemicellulose into hexose (H) and pentose (P) sugars. The energy value of dry biomass was measured according to standardized protocols at the Scientific Laboratory of Biosolid Fuel, Technical University of Moldova.

RESULTS AND DISCUSSION

Between 2020 and 2025, new research was conducted on the flora, vegetation, productive potential, and economic value of grasslands in the Central Zone of the Republic of Moldova. New distribution sites for grasslands dominated by *Elytrigia repens* and *Festuca valesiaca* were identified, and the productivity and quality of their biomass (hay) were assessed.

Grasslands with *Elytrigia repens* were found in small areas along the floodplains of minor rivers in the communes of Puțintei, Donici, Ghetlova (Orhei district) and Săseni (Călărași district). These grasslands occur on alluvial, moderately alkaline, moderately salinized soils, typical bog soils, or on chernozemoid and leached chernozem soils. The identified phytocenoses were classified within the *Rorippo austriacae-Agropyretum repentis* association (Timar 1947, R. Tx. 1950). The floristic composition of these phytocenoses is relatively poor in species diversity. *Elytrigia repens* provides good ground cover. Alongside it, *Poa pratensis*, a typical meadow species, is frequently encountered. *Poa pratensis* is a valuable forage plant with wide distribution in the study area, thriving under similar conditions, often coexisting with common couch *(Elytrigia repens)* communities. Other frequent but less abundant species that contribute to hay production and quality include *Lolium perenne*, *Alopecurus pratensis*, *Elytrigia intermedia*, *Festuca pratensis*, *Plantago major*, *Plantago lanceolata*, *Taraxacum officinale*, *Achillea millefolium* and *Convolvulus arvensis*. Some ruderal, undesirable, or low-value species are also present, including *Rumex confertus*, *Dipsacus fullonum*, *Eryngium campestre*, *Centaurea solstitialis*, *Carthamus lanatus*, *Artemisia absinthium*, *Tragopogon dubius* and *Galium humifusum*. The prevalence of these species, along with the absence of valuable Fabaceae, indicates an advanced stage of degradation in the grasslands due to unregulated grazing and lack of a proper management. Based on the research, hay production from grasslands dominated by *Elytrigia repens* in the Central Zone of the Republic of Moldova ranges from 4.7 t/ha to 7.93 t/ha of dry matter.

The meadows dominated by *Festuca valesiaca* in the Republic of Moldova have a significantly wider distribution compared to those dominated by *Elytrigia repens*, being identified in most of the studied sites. Based on geobotanical descriptions, the phytocenoses were classified into the *Poo angustifoliae-Festucetum valesiacae* association (Zinöcker in Mucina et Kolbek, 1993). Biomass production in these grasslands was assessed by evaluating hay production across 12 *Festuca valesiaca* grasslands in the communes of Ivancea, Puțintei, Ghetlova, Morozeni, Peresecina, Donici (Orhei district), Codreanca (Strășeni district) and Săseni (Călărași district). The results indicate that grassland productivity is influenced by site characteristics, precipitation levels, management practices and the state of the vegetation cover. Hay production in the *Festuca valesiaca* grasslands ranged from 1.59 t/ha of dry matter on the Codreanca grassland to a maximum of 3.83 t/ha on the Ghetlova and Morozeni grasslands.

The phytodiversity of permanent *Festuca valesiaca* grasslands in the Moldavian Forest Steppe, Romania, has been studied over several decades, with observed changes attributed to pedo-climatic conditions and the application of certain pratotechnical measures (Samuil et al., 2010, 2019; Vîntu et al., 2017; Nazare et al., 2021, 2023). In the Moldavian Forest Steppe, Romania, dry matter production in permanent *Festuca valesiaca* grasslands during the 2021-2023 period varied from 1.6 to 4.5 t/ha (Samuil et al., 2025).

Several studies have described the productivity of permanent grasslands. According to Yagi et al. (2007) the mean annual dry matter yields of *Elymus repens*-dominant grasslands over five years ranged from 8490 to 13150 kg/ha in meadow conditions and from 4230 to 11750 kg/ha in simulated pasture. Grzelak and Gaweł (2019) found that communities dominated by *Agropyron repens* contained 14-29 species, with productivity ranging from 2.8 to 4.5 t/ha of dry matter and a fodder value score of 3.9 to 6.4. Miron et al. (2023) reported a dry matter productivity of *Elymus repens* grasslands ranging from 4.72 to 9.31 t/ha, while grasslands dominated by *Festuca valesiaca* produced 1.59 to 3.77 t/ha of dry matter. Burescu et al. (2022) indicated that the economic value and productive potential of grasslands in the *Agrostio-Festucetum valesiacae* association ranged from 6.13 to 9.32 t/ha of green mass, with 47.39% to 63.21% pastoral value and a grazing capacity of 0.51 to 80 livestock units (cattle)/ha.

Traditionally, grassland biomass has been utilized as forage for grazing, freshly cut feed, or conserved as hay or silage, and is primarily fed to ruminants for the production of milk and meat. The quality of ruminant forage is commonly assessed based on its usable energy content (measured as net energy for lactation, NEL) and protein content. The biochemical composition and nutritional value of forages from the studied unfertilized grasslands are summarized in Table 1. The forage dry matter content ranged from 85-91 g/kg CP, 415-457 g/kg ADF and 658-753 g/kg NDF. The nutritional parameters included 533-566 g/kg DDM, 514-561 g/kg TDN, RFV=66-80, RFQ=70-83, with energy concentrations of 8.76-9.26 MJ/kg ME and 4.78-5.26 MJ/kg NEl. Notably, the forage from the *Festuca valesiaca* grassland in the Central Zone of the Republic of Moldova exhibited higher levels of crude protein and lower concentrations of structural carbohydrates compared to the forage from the Moldavian Forest Steppe in Romania, resulting in improved digestibility, nutritional value and energy content. In contrast, the forage from *Elytrigia repens* grassland showed no significant differences in crude protein, acid detergent fiber, digestibility, or energy concentration when compared to the *Festuca valesiaca* forage from the Moldavian Forest Steppe, Romania.

Several studies have reported varying results regarding grassland forage quality. According to Yagi et al. (2001), the hay of *Elytrigia repens* contained 241 g/kg CP, 528 g/kg NDF, 295 g/kg ADF, 2.4 g/kg Ca and 3.9 g/kg P; *Dactylis glomerata* hay contained 194 g/kg CP, 525 g/kg NDF, 239 g/kg ADF, 2.9 g/kg Ca and 3.2 g/kg P; and *Lolium perenne* hay contained 224 g/kg CP, 521 g/kg NDF, 283 g/kg ADF, 5.3 g/kg Ca, and 2.4 g/kg P. Postolache-Cujbă (2009) reported that the forage from *Festuca valesiaca* meadows, when used for grazing, had 12.8-15.9% CP and 18.2-22.55% CF, while hay from the same meadows contained 14.3-17.1% CP and 19.4-21.9% CF. Maheri-Sis et al. (2008) reported the chemical composition and nutritive value of hay from *Agropyron repens* (quackgrass) harvested at late maturity, which included 950 g/kg DM, 887 g/kg OM, 8.9% CP, 1.44% EE, 34.30% CF, 66.0% NFE, 8.96% NFC, 69.60% NDF, 38.30% ADF, 5.70% ADL, 11.2% ash, 43.54% ODM and 6.58 MJ/kg ME. Yagi et al. (2007) reported the annual forage quality of *Agropyron repens*-dominated pastures, with values ranging from 202-287 g/kg CP, 484-584 g/kg NDF, 57.1-62.6% TDN, 2.1-

2.6 g/kg Ca and 3.1-4.5 g/kg P. Tambe and Rawat (2009) reported that *Festuca valesiaca* fodder was characterized by 11% CP, 81% NDF, 41% ADF, 57% DDM, and an RFV of 65. Samuil and Vintu (2012) found that the dry matter from unfertilized permanent grasslands with *Festuca valesiaca* contained 90.1 g/kg CP and 242.2 g/kg CF. Jankowska-Huflejt (2014) noted that the hay from organic grasslands contained 10.75% CP, 2.98% EE, 30.59% CF, 7.31% ash, 0.64% Ca, and 0.25% P. Vintu et al. (2017) reported that forage from non-fertilized *Festuca valesiaca* grasslands had 7.8% CP, 75.2% NDF, 46.8% ADF and an RFV of 65. Boob et al. (2019) noted that the nutritive value of lowland hay meadows ranged from 6.80-13.50% CP and 4.46-5.81 MJ/kg NEl. Ashibokova and Lapenko (2021) reported that grass stands dominated by sod-steppe species *Stipa pulcherrima*, *Festuca valesiaca* and *Festuca rupicola*, which reached 60 cm in height, had an average protein content of 10.8%. Miron et al. (2023) noted that hay from grasslands dominated by *Elymus repens* contained 6.62-11.79% CP, 1.31-2.47% EE, 30.78-37.17% CF, 40.64-53.01% NFE, 4.31-6.82% sugars, 1.40-1.79% starch, 7.12-7.69% ash, 0.27-0.49% Ca, 0.16-0.21% P, 4.40-9.0 mg/kg carotene, with energy concentrations of 17.94-18.22 MJ/kg GE, 8.05-9.73 MJ/kg ME, and 4.39-5.50 MJ/kg NEl. For the hay from grasslands dominated by *Festuca valesiaca*, the quality ranged from 7.85-12.20% CP, 1.99-3.15% EE, 29.92-40.78% CF, 40.42-49.03% NFE, 2.41-5.37% sugars, 1.78-2.93% starch, 6.79-8.44% ash, 0.31-0.48% Ca, 0.13-0.20% P, 3.45-29.00 mg/kg carotene, and energy concentrations of 18.17-18.41 MJ/kg GE, 7.93-9.48 MJ/kg ME, and 4.28-9.48 MJ/kg NEl. In our previous study, Nazare and Țîței (2025) we found that *Festuca valesiaca* forages contained 8.5-9.2% CP, 8.6-9.5% ash, 44.4-44.6% ADF, 73.8-75.4% NDF, 5.5-5.8% ADL, 8.9 MJ/kg ME and 4.9 MJ/kg NEl.

Table 1. Productivity, biochemical composition and nutritional value of forages from the unfertilized grasslands

Indices	*Festuca valesiaca* grassland		*Elytrigia repens* grassland Central Zone, Republic of Moldova
	Central Zone, Republic of Moldova	Moldavian Forest Steppe, Romania	
Crude protein, g/kg	91.00	86.00	85.00
Minerals, g/kg	89.00	-	86.00
Crude fibre, g/kg	382.00	-	424.00
Acid detergent fibre, g/kg	415.00	457.00	450.00
Neutral detergent fibre, g/kg	658.00	722.00	753.00
Acid detergent lignin, g/kg	60.00	-	44.00
Cellulose, g/kg	355.00	-	416.00
Hemicellulose, g/kg	243.00	265.00	303.00
Digestible Dry Matter, g/kg	566.00	533.00	538.00
Total Digestible Nutrients, g/kg	561.00	514.00	543.00
Relative Feed Value	80	69	66
Relative Forage Quality	83	70	70
Digestible energy, MJ/ kg	11.28	10.67	10.76
Metabolizable energy, MJ/ kg	9.26	8.76	8.84
Net energy for lactation, MJ/ kg	5.26	4.78	4.86
Productivity, t/ha dry matter	1.59	4.50	7.93
Crude protein, kg/ha	144.69	387.00	674.05
Metabolizable energy, GJ/ ha	14.72	39.42	70.10
Net energy for lactation, GJ/ ha	8.36	21.51	38.54

The permanent grasslands respond well to fertilization, making it an important management practice for these ecosystems. Dry matter yields were influenced by climatic conditions, as well as the type and level of organic and mineral fertilization. Fertilizer application rates and types significantly impacted yields and quality of forage (Samuil et al., 2010; Vîntu et al., 2017; Adamovics et al., 2019; Cirebea et al., 2020; Ranta et al., 2021; Samuil et al., 2025; Canișag et al., 2026).

Impact of fertilization on the productivity, biochemical composition, nutritional and energy value of forages from *Festuca valesiaca* dominated permanent grassland are presented in Table 5. As expected, the biomass yield data from our study showed considerable annual variation. During the study period (2024-2025), total biomass production responded positively to both mineral and sheep manure applications. Biomass production significantly increased with the addition of nitrogen-phosphorus (NP) mineral fertilizers or sheep manure across all treatments. In 2024, the vegetation of permanent grasslands was significantly affected by the prolonged drought that dominated the Ezareni testing area from September-October 2023 to July-August 2024 (Figure 1).

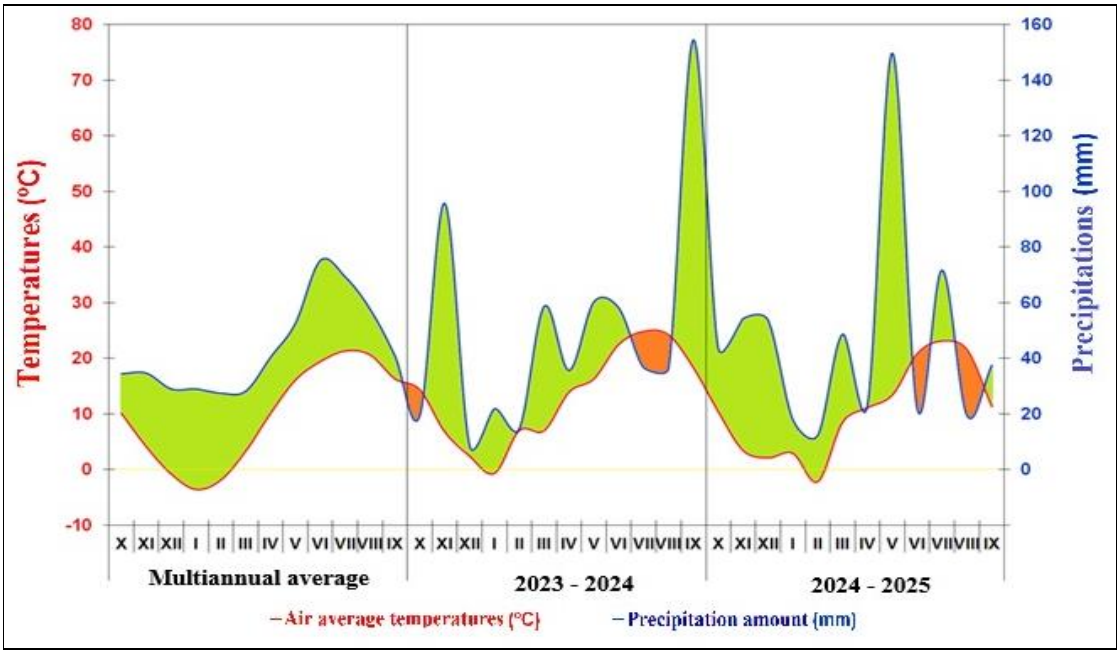

Figure 1. Climadiagram for the Agricultural Periods 2023-2025, in the Moldavian Forest Steppe, Romania

As a result, productivity was reduced, and the impact of fertilization on production was minimal. The production data analysis revealed that in 2024, dry matter yield in the unfertilized control was 2.71 t/ha, while the highest yield, 4.75 t/ha, was recorded at the $N_{100}P_{100}$ fertilization rate (Table 2), with statistically significant differences. In 2025, production varied according to fertilizer dose and type. Yields in 2025 were higher than those of the previous year, ranging from 6.73 t/ha in the unfertilized control to 11.76 t/ha with $N_{100}P_{100}$ fertilization, with statistically significant differences. Mineral and organic fertilizers applied at different doses resulted in higher yields in the second year (2025) of the study, due to more favorable climatic conditions for biomass accumulation, with very significant differences in production.

Table 2. Impact of fertilization on the productivity, biochemical composition, nutritional and energy value of forages from *Festuca valesiaca* dominated permanent grassland, in 2024-2025, Moldavian Forest Steppe, Romania

Indices	Variant						
	V_1 - unfertilized (control)	V_2 - $N_{50}P_{50}$	V_3 - $N_{75}P_{75}$	V_4 - $N_{100}P_{100}$	V_5 - 10 t/ha sheep manure	V_6 - 20 t/ha sheep manure applied annually	V_7 - 30 t/ha sheep manure applied every two years
2024							
Crude protein, g/kg	91.20	107.10	120.30	124.50	97.30	106.10	112.70
Acid detergent fibre, g/kg	350.50	342.80	331.40	318.70	341.70	340.40	342.30
Neutral detergent fibre, g/kg	541.70	553.10	550.60	531.30	577.20	566.40	531.70
Hemicellulose, g/kg	191.20	210.30	219.20	212.16	235.50	226.00	189.40
Digestible dry matter, g/kg	615.96	621.96	631.15	640.73	623.36	623.83	622.35
Total Digestible Nutrients, g/kg	632.92	641.54	654.21	668.39	642.80	644.33	642.17
Relative feed value	106	105	107	112	100	102	109
Relative Forage Quality	110	117	120	124	106	108	115
Digestible energy, MJ/ kg	12.16	12.26	12.43	12.60	12.29	12.30	12.27
Metabolizable energy, MJ/ kg	9.98	10.07	10.21	10.35	10.09	10.10	10.08
Net energy for lactation, MJ/ kg	6.00	6.09	6.22	6.36	6.10	6.12	6.09
Productivity, t/ha dry matter	2.71	3.93	4.21	4.76	3.07	3.75	3.98
Crude protein, kg/ha	247	421	507	593	299	398	449
Metabolizable energy, GJ/ ha	27.04	39.58	42.98	49.27	30.98	37.88	40.12
Net energy for lactation, GJ/ ha	16.26	22.72	26.19	30.27	18.73	22.95	24.23
2025							
Crude protein, g/kg	103.10	107.80	110.30	131.50	115.10	128.10	131.70
Acid detergent fibre, g/kg	381.40	370.80	368.50	362.10	381.70	379.70	375.10
Neutral detergent fibre, g/kg	597.30	591.30	588.80	592.10	615.20	611.40	603.60
Hemicellulose, g/kg	215.90	220.50	220.30	230.00	233.50	231.70	228.50
Digestible dry matter, g/kg	591.89	600.15	601.94	609.92	591.66	593.21	596.80
Total Digestible Nutrients, g/kg	598.62	610.39	612.99	620.08	598.26	600.42	605.68
Relative feed value	91	94	95	96	89	91	92
Relative Forage Quality	95	99	100	101	92	94	95
Digestible energy, MJ/ kg	11.73	11.87	11.91	12.05	11.73	11.75	11.92
Metabolizable energy, MJ/ kg	9.63	9.75	9.78	9.89	9.63	9.65	9.70
Net energy for lactation, MJ/ kg	5.65	5.76	5.79	5.87	5.65	5.67	5.72
Productivity, t/ha dry matter	6.73	9.31	10.56	11.76	8.74	9.34	10.35
Crude protein, kg/ha	694	1004	1165	1546	1006	1196	1363
Metabolizable energy, GJ/ ha	64.81	90.77	103.28	116.31	84.17	90.13	100.40
Net energy for lactation, GJ/ ha	38.02	53.63	61.14	69.03	49.39	52.96	59.20

The crude protein (CP) content of forage typically varies depending on plant species composition and fertilization practices. In our study, mineral fertilization of *Festuca valesiaca* grasslands at the tested doses resulted in an increase in crude protein content, reaching 12.45% in 2024 and 13.15% in 2025, compared to the unfertilized control, with statistically significant differences. Similarly, organic fertilization, as shown in Table 2, significantly increased crude protein content in both years, with the highest values of 11.27% in 2024 and 13.17% in 2025 observed in the variant fertilized with 30 t/ha of sheep manure applied every two years. The application of mineral and organic fertilizers produces significant changes in the concentration of acid detergent fibre (ADF), neutral detergent fibre (NDF), and hemicellulose (HC) in the fodder obtained from *Festuca valesiaca* grasslands. Analysing the data for 2024 and 2025, a slight increase in NDF values is found in most fertilized variants, as a result of the change in the ratio between stems/leaves and nutrient availability. Thus, in 2024, the NDF content of the forage varied between 54.17% in the unfertilized variant and 57.72% in the variant fertilized with 10 t/ha of sheep manure applied annually, and in 2025, the values for the same variants ranged between 59.73% and 61.52%. In both years, the ADF content shows a slight decrease from 35.05% to 31.87% in 2024 and from 38.14% to 36.21% in 2025. The hemicellulose level also increases significantly, except in the variant fertilized with 30 t/ha of sheep manure (applied every two years) in 2024, where a negligible decrease is observed compared to the control variant. It is well known that hemicellulose is more easily assimilated by animals compared to cellulose, and increasing hemicellulose content has a positive effect on animal nutrition and energy value. The application of fertilizers in our study had a positive effect on the digestibility and energy supply of the feed, with all fertilized variants recording statistically significant increases compared to the control variant. In 2025, it was observed that the forage from permanent grassland primarily consisting of *Festuca valesiaca* has lower digestibility and energy content than in 2024. Consequently, the RFQ values ranged from 101.44 to 123.78, indicating good feed quality in the mineral-fertilized variant with $N_{100}P_{100}$. In contrast, the unfertilized variant showed values between 94.89 and 110.13, reflecting medium feed quality.

Climate change, increasing dependence on oil and other fossil fuels, rising energy prices and other factors have made national economies more vulnerable. The development of renewable energy sources (RES) has become a priority. Bioenergy is promoted as a sustainable alternative to non-renewable energy, aiming to reduce greenhouse gas emissions and mitigate climate change. The use of biomass for energy places growing demand on ecosystem services. Over the past two decades, the potential of grasslands for bioenergy has gained significant attention. Harvested biomass from grasslands, particularly when surplus to livestock requirements, is increasingly viewed as a viable alternative land-use option.

The quality indices of biomass for solid fuels from the studied grasslands in the Republic of Moldova are presented in Table 3. Ash content is a key factor in determining biomass quality, as higher ash levels reduce fuel quality, particularly for solid fuels. The biomass from the studied grasslands has an optimal energy value but higher ash content, which may require blending with wood biomass for the production of densified solid biofuels such as pellets or briquettes. The energy value of biomass from *Festuca valesiaca* grasslands is higher than that from *Elytrigia repens* grasslands.

Table 3. Biomass quality indices for solid fuels from studied grasslands in the Republic of Moldova

Indices	Grasslands	
	Festuca valesiaca	*Elytrigia repens*
Ash, %	8.90	8.60
Gross calorific value, MJ/kg	18.00	17.80
Net calorific value, MJ/kg	16.00	15.90

Several studies have quantified the bioenergy potential of herbage from grasslands. Florine et al. (2006) reported that cool-season grasslands in southern Iowa can produce 0.75 to 8.24 t/ha of biomass, with ash content ranging from 5.85% to 11.81%, chlorine from 0.08% to 0.76%, sulphur from 0.07% to 0.34%, and a higher heating value (HHV) ranging from 17.69 to 19.46 MJ/kg. Heinsoo et al. (2010) found that the energy value of biomass samples from mesic meadows was 18.6 MJ/kg, while biomass from wooded meadows had a value of 18.1 MJ/kg. Melts (2014) observed significant differences in calorific values among functional groups in grasslands: 16.9 MJ/kg for grasses, 17.2 MJ/kg for sedges and rushes, 17.1 MJ/kg for legumes, and 16.5 MJ/kg for other forbs. Joseph et al. (2018) reported that solid fuel derived from grassland biomass had 3.54-4.74% ash and a lower heating value ranging from 17.56 to

17.94 MJ/kg. Kizekova et al. (2018) found that the gross energy of grassland biomass varied from 17.49 to 18.88 MJ/kg. Waliszewska et al. (2021) noted that *Agropyron repens* biomass contained 7.0% ash and a HHV of 19.25 MJ/kg.

The use of plant biomass for biomethane production is crucial in replacing natural gas, supporting the transition from a fossil-based to a bio-based economy. Grassland biomass serves as a feedstock in biogas generators to produce methane for heat and electricity, while residual biomass (digestate and fugate) can be used as valuable fertilizers. This approach is proposed as a means of achieving stabilization in ways that support the provision of ecosystem services in organic grassland systems. The quality indices of grassland substrates and their biochemical methane potential are presented in Table 4. In the substrates derived from the studied grasslands, the carbon-to-nitrogen (C/N) ratio ranged from 34.76 to 37.34, the concentration of acid detergent lignin ranged from 44 to 60 g/kg, and the concentration of hemicellulose ranged from 243 to 303 g/kg. The biochemical biogas potential ranged from 569 to 662 L/kg of organic dry matter, while the biomethane potential ranged from 304 to 333 L/kg of organic dry matter. It was found that the substrate from *Elytrigia repens* grasslands contained a higher concentration of hemicellulose and a lower level of acid detergent lignin, contributing to a higher biochemical methane potential.

Table 4. Quality indices and biochemical biomethane potential of biomass substrates from studied grasslands in the Republic of Moldova

Indices	Grasslands	
	Festuca valesiaca	*Elytrigia repens*
Crude protein, g/kg	91.00	85.00
Nitrogen, g/kg	14.56	13.60
Minerals, g/kg	89.00	86.00
Organic matter, g/kg	911.00	914.00
Carbon, g/kg	506.11	507.78
Ratio carbon/nitrogen	34.76	37.34
Acid detergent lignin, g/kg	60.00	44.00
Hemicellulose, g/kg	243.00	303.00
Biogas potential, L/kg	569.00	662.00
Biomethane potential, L/kg	304.00	333.00

Several studies have quantified the biogas and methane potential of herbage from both natural and sown grasslands. Mähnert et al. (2002) reported methane yields from grass substrates ranging from 310 to 360 L/kg VS. Kaparaju (2003) found that specific methane yields from grass hay substrates varied from 270 to 350 L/kg VS. Mähnert et al. (2005) observed biogas yields from seven species of perennial grasses, ranging from 591 to 929 L/kg VS. Amon et al. (2007) noted that specific methane yields from hill grasslands ranged from 128 to 221 L/kg VS, while yields from valley regions ranged from 190 to 392 L/kg VS. Melts (2014) found that the average methane yield from wooded and dry to mesic meadows was approximately 0.30 m^3/kg VS after 46 days. Meyer et al. (2014) reported methane yields from roadside grass substrates ranging from 220 to 390 L/kg VS. Țîței (2016) found that the gas-forming potential of fermentable organic matter from introduced grass species *Agropyron desertorum* and *Agropyron sibiricum* ranged from 399 to 454 L/kg VS. Mattioli et al. (2017) reported biogas production from grass biomass collected from public parks, which ranged from 600 to 650 m^3/t. Dubrovskis et al. (2018) found that grass hay pellet substrates achieved 666 L/kg VS of biogas or 355 L/kg VS of methane. Boob et al. (2019) reported methane yields from unfertilized hay meadows ranging from 283 to 290 L/kg VS. French (2019) found that biomass from unimproved grasslands had 24.1% cellulose, 22.9% hemicellulose, 10.3% lignin and a biogas yield of 625.1 m³/t, while biomass from restored grasslands had 22.1% cellulose, 24.7% hemicellulose, 12.5% lignin, and a biogas yield of 657.9 m³/t. Biomass from improved grasslands had 26.4% cellulose, 14% hemicellulose and 1.3% lignin, yielding 437.5 m³/t of biogas, while the biomass from grasslands managed for conservation had 23.4% cellulose, 23.5% hemicellulose, 11.2% lignin, yielding 527.2 m³/t of biogas and 268.5 m³/t of methane. Meserszmit et al. (2021) reported methane yields from substrates of semi-natural mountain and lowland hay meadows ranging from 244 to 249 L/kg VS. Skripsts et al. (2021) found that hay substrates from semi-natural grasslands contained 928 g/kg dry matter and 6.02% ash, with biomethane potential varying from 289.91 to 378.81 L/kg VS depending on enzyme treatment. Brandhorst et al. (2024) observed specific methane yields from hay substrates of orchard meadows ranging from 265 to 293 L/kg, depending on the cutting period. Miron and Ţîţei (2025) reported that the substrates from the investigated hay grasslands had C/N ratios of 21.86-29.43, 43-44 g/kg ADL, 222-253 g/kg HC and a biochemical methane potential of 334-342 L/kg VS.

Second-generation bioethanol derived from lignocellulosic feedstocks is a sustainable alternative fuel for transportation and has the potential to replace fossil fuels. Ethanol yields vary among plant species due to differences in cell wall composition, which affect both carbohydrate content and the efficiency of enzymatic hydrolysis.

The cell wall composition and theoretical ethanol potential of biomass substrates from the studied grassland are presented in Table 5. As previously mentioned, the concentration of structural carbohydrates in the biomass substrates from the studied grasslands varies considerably. The substrate from *Elytrigia repens* grasslands exhibited higher levels of cellulose and hemicellulose, and lower levels of lignin, compared to *Festuca valesiaca* grassland biomass. Theoretical ethanol yields from hexose sugars averaged 315 L/t for the *Elytrigia repens* substrate, compared to 268 L/t for the *Festuca valesiaca* substrate. Theoretical ethanol yields from pentose sugars were lower across all studied grassland biomass substrates, with values of 208 L/t for *Elytrigia repens* and 167 L/t for *Festuca valesiaca*.

Table 5. Cell wall composition and theoretical ethanol potential of biomass substrates from studied grasslands

Indices	Grasslands	
	Festuca valesiaca	*Elytrigia repens*
Acid detergent fibre, g/kg	415.00	450.00
Neutral detergent fibre, g/kg	658.00	753.00
Acid detergent lignin, g/kg	60.00	44.00
Cellulose, g/kg	355.00	416.00
Hemicellulose, g/kg	243.00	303.00
Theoretical ethanol potential	434.68	522.89
- from hexose sugars, L/ ton	268.00	315.07
- from pentose sugars, L/ton	166.68	207.82

Jungers et al. (2013) noted that biomass yields from conservation grasslands in Minnesota, USA, ranged from 0.5 to 5.7 t/ha, with 63.5-81.6% NDF, 15.3-22.0% Klausen lignin, 318-494 g/kg IVTD, 1-12 g/kg rhamnose, 14-40 g/kg arabinose, 45-203 g/kg xylose, 1-25 g/kg mannose, 4-21 g/kg galactose and 185-378 g/kg glucose. Theoretical ethanol conversion efficiency was estimated at 450 L/t of biomass.

CONCLUSIONS

The dry matter productivity of the unfertilized permanent grasslands studied ranged from 1.59 to 4.5 t/ha in the grasslands with *Festuca valesiaca* and from 4.7 to 7.93 t/ha in the grasslands with *Elytrigia repens*, indicating significant differences in productivity between the two species.

Compared to the grasslands with *Elytrigia repens*, the biomass from the grasslands with *Festuca valesiaca* had a lower content of structural carbohydrates, accompanied by higher concentrations of crude protein, digestible dry matter and energy value. These characteristics suggest that *Festuca valesiaca* biomass may be particularly advantageous in terms of nutritional quality.

The application of different doses and types of fertilizers enhanced both the productivity and forage quality of *Festuca valesiaca*-dominated grasslands, helping to optimize the balance between yield and nutritional value. Both *Festuca valesiaca* and *Elytrigia repens* grasslands also demonstrate considerable potential as raw materials for biofuel production, providing a renewable and sustainable energy source. The variation in biomass productivity and nutritional composition between these pastures offers valuable information for optimizing their use both in both livestock feed and bioenergy applications.

The results obtained provide a scientific basis for sustainable management strategies to support the coordinated improvement of the productivity of the studied grasslands and biomass quality indices, under the steppe and forest-steppe conditions in Romania and the Republic of Moldova.

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