

SOIL FERTILITY DYNAMICS ON A SOWN GRASSLAND UNDER THE COMBINED INFLUENCE OF MINERAL FERTILIZATION AND WATER EROSION

Mihaela BĂLAN¹, Oana Alina NIȚU²

¹University of Craiova, Faculty of Agronomy, 19 Libertatii Street, Craiova, Romania

²University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: oanaalinanitu1111@gmail.com

Abstract

This study investigates the temporal dynamics of key agrochemical properties of soil in a sown grassland under the influence of mineral fertilization and water erosion on a slope of 10-15%, at the Preajba Experimental Center, Gorj County. Research was conducted on a stagnic luvisol using three experimental treatments: unfertilized control (N0P0K0), fertilization with N60P60K60, and fertilization with N100P90K60, each replicated three times in a randomized block design. Soil samples were collected from the upper and lower positions of the plots at three distinct time points: pre-fertilization (April), post-fertilization (May), and at the end of the growing season (October). The results demonstrated highly significant increases in hay yield in the fertilized treatments, while soil agrochemical properties exhibited moderate changes, characteristic of soils with high buffering capacity and pronounced chemical inertia. Mineral fertilization induced slight acidification and increases in available phosphorus and potassium, whereas organic matter and total nitrogen evolved gradually. These findings provide a scientific basis for the development of sustainable management strategies for sown grasslands on sloped terrains.

Key words: dynamics, mineral fertilization, sown grassland, water erosion, agrochemical indicators, soil fertility.

INTRODUCTION

Modern agriculture operates under increasing pressures generated by population growth, climate variability, and the depletion of natural resources, while simultaneously being required to reduce its environmental impact (Leoveanu-Soare et al., 2020; Mărin N. et al., 2023, Nițu et al., 2023).

In this context, agricultural production fundamentally relies on soil, water, and atmospheric resources, rendering agroecosystems particularly vulnerable to extreme meteorological phenomena such as drought and unevenly distributed precipitation (Bonea 2020; Cioboată et al., 2025, Nițu et al., 2025). In parallel, to meet crop nutritional requirements, various fertilization strategies and technologies are applied, whose efficiency and limitations vary depending on species, pedological conditions, and agroclimatic factors; consequently, fertilizer use remains a major concern (Cioboată et al., 2025; Prioteasa et al., 2025). Soil degradation processes, particularly erosion and organic matter

depletion, reduce soil stability and its capacity to sustain agricultural productivity (Ailincăi et al., 2008; Popescu et al., 2024). Balanced nutrient management therefore represents a core pillar of sustainable agriculture, enhancing system resilience to climatic and economic pressures. In modern agriculture, soil fertility is the result of the interaction between natural fertility and fertility induced by agrochemical management, including mineral and organic fertilization, soil reaction amendment, and the application of technologies aimed at conserving soil organic matter.

Optimizing fertility is an essential condition for achieving high agricultural productions that are economically efficient and compatible with the principles of sustainable agriculture (Popescu & Balan, 2024).

The application of fertilizers on eroded soils contributes to increased plant density, enhanced aboveground biomass and root system development, thereby improving water infiltration into the soil and increasing the protective capacity of vegetation against erosion processes (Iancu et al., 2009).

Grasslands represent highly complex ecosystems of considerable ecological and economic importance, determined by their global extent and the multiple functions they perform (Rotar, 1997). They support livestock production by providing forage resources with high nutritional value and deliver a wide range of ecosystem services, including soil fertility conservation, carbon sequestration, regulation of the hydrological cycle, climate stabilization, and enhancement of landscape and recreational value (Vargová et al., 2020).

In Gorj County, agriculture and livestock production represent essential components of the local economy, with grasslands constituting a central element of the agricultural system (Balan et al., 2024; Balan & Nițu, 2025). Approximately half of the county's agricultural area (50.07%), corresponding to 122,070 ha out of a total of 243,768 ha, is occupied by pastures and hayfields (Balan & Popescu, 2024), highlighting the strategic importance of these ecosystems. The management of grasslands decisively influences their ecological status, being sensitive to both abandonment and overexploitation (Briemle & Opperman, 2003; Bogdan, 2012).

Mineral fertilization and management intensity induce significant changes in soil fertility, floristic composition, and productivity, with management intensification often being associated with a reduction in plant species diversity.

The floristic composition and productivity of grasslands are the result of complex interactions between edaphic, climatic and technological factors, and their response to mineral fertilization differs depending on the type of grassland and soil conditions (Rotar, 2003; Rotar et al., 2016; Cirebea, 2017). In this context, detailed knowledge of the soil and the processes that influence productive capacity becomes essential for the implementation of sustainable management strategies (Balan et al., 2024; Păcurar, 2005). A balanced approach to fertilization and grassland utilization is required to optimize forage productivity while simultaneously maintaining biodiversity and the functional integrity of grassland ecosystems (Naie et al., 2017).

Soil erosion is one of the main degradation processes, particularly affecting the top layer of

soil (0-30 cm), which is rich in organic matter and biological activity. The removal of this layer leads to significant losses of humus and essential nutrients, such as nitrogen, phosphorus and potassium, with negative effects on physicochemical properties, microbiological activity and nutrient supply capacity (Ailincai et al., 2008; Mușat et al., 2023; Balan et al., 2024; Popescu et al., 2024).

Overall, these transformations lead to a decline in soil fertility and a reduction in the productive potential of grasslands, underscoring the need to assess the impact of erosion on nutrient dynamics as a critical factor in ensuring sustainable land use and the functional integrity of grassland ecosystems (Balan et al., 2024).

The aim of this study was to evaluate the impact of erosion processes on nutrient dynamics and soil fertility in sown grassland ecosystems of Gorj County in relation to the applied management practices. Specifically, the study aimed to: characterize changes in soil physicochemical properties induced by erosion processes and mineral fertilization; analyzing variations in humus content and the main nutrient elements (nitrogen, phosphorus, and potassium) in sown grassland soils; and assess the effects of these changes on the productivity and functionality of sown grassland ecosystems.

MATERIALS AND METHODS

The research was conducted at the Preajba Experimental Grassland Center (Gorj County, Romania), belonging to the University of Craiova. The site is located in the Subcarpathian region, on Bălănești Hill, at an altitude of approximately 300 m, on the highest terrace of the Jiu River (fifth terrace), with south-eastern exposure and a slope of 10-15%. The area is characterized by a humid hilly climate, with mean annual precipitation of 736.9 mm, of which 434.1 mm occurs during the growing season. Mean air temperatures range from -1.1°C in January to 21.9°C in July.

The research was carried out on a Stagnic Luvisol located on land with a slope of 10-15%, developed on fluvial terrace deposits. The groundwater table is situated at depths ranging between 5 and 10 m, and the natural vegetation is represented by an acidophilous grassland. The soil profile at the experimental site is of the Aț-

Ao–El(w)–ElBt–Bt₁(w)–Bt₂(w) type. From a chemical perspective, the soil exhibits a strongly acidic reaction, with pH values ranging from 5.1 to 5.4 throughout the entire profile.

With respect to chemical fertility, the soil is characterized by a very low content of available phosphorus, approximately 6 ppm in the surface horizon, decreasing to about 1 ppm in the underlying horizons. The supply of available potassium is good in the surface A₁ and Ao horizons (174 ppm and 144 ppm, respectively), moderate in the AE₁ (76 ppm) and E₁ (46 ppm) horizons, and low in the Bt₁, BC, and C horizons, where concentrations are below 40 ppm.

The experiment consisted in the placement of an experiment with grassland sown with 3 variants and 3 repetitions, according to the method of isolated blocks, in order to highlight the dynamics of soil fertility under the influence of erosion and mineral fertilization.

The experimental plots were rectangular, measuring 25 m in length (oriented along the maximum slope and runoff direction) and 2.5 m in width, with a total area of 62.5 m². In April, the soil was prepared using a rotary tiller, manually leveled, and manually sown with a grass-legume mixture composed of 60% grasses and 40% legumes, as follows: *Dactylis glomerata* (20%, 210 g), *Lolium perenne* (20%, 228 g), *Phleum pratense* (20%, 228 g), *Trifolium pratense* (15%, 120 g), and *Lotus corniculatus* (25%, 282 g).

Immediately after sowing in April, the experimental plots were fertilized as follows: the control variant V₁ was left as an unfertilized control, the V₂ variant was fertilized with N₆₀P₆₀K₆₀, and the V₃ variant was fertilized with N₁₀₀P₉₀K₆₀.

The experimental variants were mowed after each flowering phase, in order to determine the yields obtained as a result of the application of mineral fertilization. At the same time, to assess changes in soil agrochemical properties under the influence of mineral fertilization and water erosion processes, soil samples were collected using an agrochemical probe, with two composite samples taken for each treatment.

Thus, sample A was collected from the upstream area of the plot, respectively from its upper half, from 10 randomized points, and sample B was taken from the downstream area of the plot,

corresponding to the lower half, also from 10 randomized points. In order to highlight the dynamics of the agrochemical properties of the soil, the collection of samples was carried out in three stages: in April, before the application of fertilizers, two weeks after fertilization and at the end of the vegetation period (October 1).

Laboratory analyses of the soil samples were performed in accordance with ICPA methodology. The following analytical methods were applied for the determination of soil chemical properties:

- pH (potentiometric method in aqueous suspension at soil/water ratio of 1/2.5 - SR 7184 /13-2001);
- Sum of basic exchange basic ions (SB) by hydrochloric acid extraction 0.1 N according to the Kappen method, Chiriță modified;
- hydrolytic acidity, extraction with sodium acetate at pH 8.2;
- base saturation degree, V% (Kappen Schofield method).
- organic matter (humus): volumetric determination (Walkley-Black humidification method, STAS 7184/21-82);
- the nitrogen content, by calculation, based on the humus content and the degree of saturation with bases (IN = humus x V/100);
- mobile phosphorus content (Egner-Riehm-Domingo method and colorimetric molybdenum blue, Murphy-Riley method ascorbic acid reduction);
- mobile potassium content (Egner-Riehm-Domingo extraction and flame photometry);

RESULTS AND DISCUSSIONS

Mineral fertilization had a pronounced and statistically significant effect on hay production in the sown meadow.

The unfertilized control variant (N₀P₀K₀) registered a production of 2.82 t·ha⁻¹, while the application of the N₆₀P₆₀K₆₀ dose increased the production to 5.97 t·ha⁻¹, corresponding to an increase of 110% compared to the control.

The highest production was obtained in the N₁₀₀P₉₀K₆₀ variant (6.65 t·ha⁻¹), which represents an increase of 133.7% compared to the non-fertilized variant. The differences in production between the fertilized and control variants were very statistically significant, as illustrated in Table 1 and Figure 1.

Table 1. Influence of mineral fertilization on hay production

Variant	Dose	Production			Significance
		t·ha ⁻¹	%	±d/mt	
V ₁	N ₀ P ₀ K ₀ (Ct)	2.82	100	—	—
V ₂	N ₆₀ P ₆₀ K ₆₀	5.97	210	3.15	***
V ₃	N ₁₀₀ P ₉₀ K ₆₀	6.65	233.7	3.83	***

DL 5% = 0.259 t·ha⁻¹
DL 1% = 0.426 t·ha⁻¹
DL 0.1% = 0.800 t·ha⁻¹

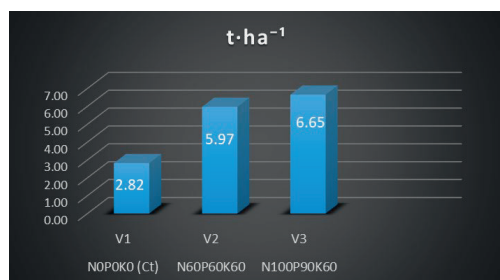


Figure 1. Influence of mineral fertilization on hay production

The values determined for the main soil agrochemical indicators - namely aqueous suspension pH, sum of exchangeable bases (SB), hydrolytic acidity (Ah), exchangeable aluminum (Al), humus content (H), total nitrogen (N), available phosphorus (PAL), and available potassium (KAL) - as well as the calculated fertility indicators, including total cation exchange capacity (T), base saturation degree (V), and nitrogen index (IN), are presented in Tables 2-4. The seasonal dynamics of these parameters reflect the complex interaction between climatic conditions and management practices, requiring an integrative approach to the interpretation of annual variations.

The agrochemical indicator values recorded during the study period indicate a moderate seasonal dynamics of soil reaction and nutrient content, which remained within relatively narrow ranges.

Table 2. Values of the main agrochemical soil indicators in the experimental plots in April

Experimental plots	pH	SB	Ah	T	Al	V %	H %	IN	Nt %	P _{AL} ppm	K _{AL} ppm
		me/100 g sol									
Sown grassland Control (Ct) A	4.90	5.45	5.27	10.72	0.20	50.83	2.82	1.43	0.124	9.20	48.72
Sown grassland Control (Ct) B	5.00	5.51	5.40	10.91	0.40	50.50	2.82	1.42	0.124	9.40	48.55
Sown grassland N60P60K60 A	4.95	5.47	5.21	10.68	0.38	51.22	2.77	1.42	0.122	10.23	49.20
Sown grassland N60P60K60 B	4.97	5.44	5.28	10.72	0.64	49.25	2.87	1.41	0.125	9.11	49.35
Sown grassland N100P90K60 A	4.85	5.28	5.23	10.51	0.44	49.76	2.79	1.39	0.123	8.70	49.70
Sown grassland N100P90K60 B	4.95	5.39	5.35	10.74	0.84	49.81	2.80	1.39	0.124	8.13	48.84

Table 3. Values of the main agrochemical soil indicators in the experimental plots in May

Experimental plots	pH	SB	Ah	T	Al	V %	H %	IN	Nt %	P _{AL} ppm	K _{AL} ppm
		me/100 g sol									
Sown grassland Control (Ct) A	5.07	5.07	5.16	10.23	0.46	49.56	2.84	1.41	0.121	9.15	50.21
Sown grassland Control (Ct) B	5.10	4.67	5.10	9.77	0.72	47.80	2.76	1.32	0.122	9.55	50.03
Sown grassland N60P60K60 A	5.01	4.88	5.08	9.96	0.40	49.00	2.74	1.34	0.123	11.02	50.70
Sown grassland N60P60K60 B	5.04	5.11	5.25	10.36	0.48	49.32	2.87	1.42	0.124	9.20	50.86
Sown grassland N100P90K60 A	5.03	4.78	5.12	9.90	0.40	48.28	2.79	1.35	0.124	9.00	51.22
Sown grassland N100P90K60 B	5.07	5.09	5.21	10.30	0.42	49.42	2.85	1.41	0.125	8.54	50.33

Table 4. Values of the main soil agrochemical indicators in the experimental plots in October

Experimental plots	pH	SB	Ah	T	Al	V %	H %	IN	Nt %	P _{AL} ppm	K _{AL} ppm
		me/100 g sol									
Sown grassland Control (Ct) A	4.95	5.23	5.25	10.48	0.70	49.90	2.81	1.38	0.122	9.21	48.65
Sown grassland Control (Ct) B	5.00	5.15	5.20	10.35	1.12	49.76	2.80	1.37	0.124	9.42	48.40
Sown grassland N60P60K60 A	4.87	5.10	5.12	10.22	0.36	49.90	2.79	1.37	0.123	10.29	49.84
Sown grassland N60P60K60 B	5.03	5.05	5.18	10.23	0.82	49.36	2.78	1.37	0.125	9.18	50.00
Sown grassland N100P90K60 A	4.85	5.21	5.21	10.42	0.40	50.00	2.82	1.40	0.124	8.85	50.35
Sown grassland N100P90K60 B	4.89	5.26	5.28	10.54	0.58	49.90	2.83	1.42	0.125	8.35	49.70

Seasonal fluctuations in humus, nutrients and soil reaction are the result of the complex interaction between climatic factors (amount and intensity of precipitation), erosion processes, peak consumption phenophases of plants, microbiological activity dependent on temperature, aeration and pH, as well as the doses and nature of the fertilizers applied. Some of these factors can act synergistically, favoring nutrient losses, while others have a compensatory effect, contributing to their accumulation in the soil. Overall, the data presented in Tables 2-4 indicate the maintenance of a relative soil homeostasis as an ecological system, despite the concomitant influence of fertilization and erosion processes, which are analyzed in more detail by comparing the initial and final values of the agrochemical indicators presented in Tables 5-9.

Soil reaction (pH) variation

The analysis of soil reaction variation (Table 5) reveals only minor pH changes across all experimental treatments, indicating a good buffering capacity of the soil. In the unfertilized control, soil reaction showed a very slight increase of approximately 0.5%, with minimal differences between upslope and downslope positions, suggesting high pH stability in the absence of mineral fertilization.

Under the N₆₀P₆₀K₆₀ fertilization rate, soil pH exhibited a slight average decrease (approximately 0.2%), with differences between upslope and downslope positions attributable to the physiologically acidifying effect of fertilizers and to local runoff conditions. At the higher fertilization rate (N₁₀₀P₉₀K₆₀), soil reaction decreased by approximately 0.6% on average, with a more pronounced reduction in downslope positions, confirming the cumulative acidifying effect of mineral fertilization.

Table 5. Variation in soil reaction between initial and final soil pH values

Experimental plots	Soil reaction (pH units)		Soil reaction variation (%)	Range of soil reaction variation
	Initial values (April)	Final values (October)		
N ₀ P ₀ K ₀ Mt A	4.90	4.95	1.02	4.85 – 5.10
N ₀ P ₀ K ₀ Mt B	5.00	5.00	0.00	
N ₆₀ P ₆₀ K ₆₀ A	4.95	4.87	-1.62	
N ₆₀ P ₆₀ K ₆₀ B	4.97	5.03	1.21	
N ₁₀₀ P ₉₀ K ₆₀ A	4.85	4.85	0.00	
N ₁₀₀ P ₉₀ K ₆₀ B	4.95	4.89	-1.21	

Variation in humus content

The data presented in Table 6 indicate differentiated variations in humus content

depending on the fertilization level. In the unfertilized control, humus content decreased slightly (approximately 0.5%) as a result of natural organic matter mineralization processes. Under the N₆₀P₆₀K₆₀ fertilization rate, humus content showed an average decrease of approximately 1.2%, with more pronounced differences between upslope and downslope positions, indicating increased spatial variability in organic matter decomposition processes. In contrast, at the higher fertilization rate (N₁₀₀P₉₀K₆₀), humus content increased uniformly by approximately 1.1%, as a result of enhanced plant biomass production and a greater return of organic residues to the soil.

Table 6. Variation in soil humus content between initial and final values

Experimental plots	Humus content %		Humus content variation (%)	Range of variation of humus content
	Initial values (April)	Final values (October)		
N ₀ P ₀ K ₀ Mt A	2.82	2.81	-0.35	2.78-2.83
N ₀ P ₀ K ₀ Mt B	2.82	2.80	-0.71	
N ₆₀ P ₆₀ K ₆₀ A	2.77	2.79	+0.72	
N ₆₀ P ₆₀ K ₆₀ B	2.87	2.78	-3.14	
N ₁₀₀ P ₉₀ K ₆₀ A	2.79	2.82	+1.08	
N ₁₀₀ P ₉₀ K ₆₀ B	2.80	2.83	+1.07	

Variation in total nitrogen content

Variations in total nitrogen content follow a pattern similar to that of humus, which can be explained by the close relationship between these two components, given that about 92-98% of total soil nitrogen is found in organic matter. Thus, according to the data in Table 7, in the control version, the total nitrogen content decreased on average by about 0.8%, as a result of nitrogen consumption by plants.

Table 7. Variation in total soil nitrogen content between initial and final values

Experimental plots	Total nitrogen content %		Total nitrogen content variation (%)	Range of variation in total nitrogen content (%)
	Initial values (April)	Final values (October)		
N ₀ P ₀ K ₀ Mt A	0.124	0.122	-1.61	0.122-0.125
N ₀ P ₀ K ₀ Mt B	0.124	0.124	0.00	
N ₆₀ P ₆₀ K ₆₀ A	0.122	0.123	0.82	
N ₆₀ P ₆₀ K ₆₀ B	0.125	0.125	0.00	
N ₁₀₀ P ₉₀ K ₆₀ A	0.123	0.124	0.81	
N ₁₀₀ P ₉₀ K ₆₀ B	0.124	0.125	0.81	

The application of the N₆₀P₆₀K₆₀ fertilization rate resulted in a slight increase in total nitrogen content (approximately 0.4%), with only minor differences between upslope and downslope

positions. Under the higher fertilization rate (N₁₀₀P₉₀K₆₀), total nitrogen content increased uniformly, confirming the effectiveness of nitrogen inputs through mineral fertilization.

Variation in available phosphorus content

Available phosphorus content exhibited more pronounced variations compared with the other analyzed nutrients (Table 8). In the unfertilized control treatment, available phosphorus increased only marginally (approximately 0.2%). Application of the N₆₀P₆₀K₆₀ fertilization rate resulted in a moderate increase in available phosphorus content (approximately 0.68%). The most substantial increase was observed under the N₁₀₀P₉₀K₆₀ treatment, where available phosphorus content increased by approximately 2.22%. Differences between positions A and B indicate the influence of plot position on phosphorus distribution. The high variability of available phosphorus can be explained by its uneven distribution within the soil profile, with maximum concentrations located in the erosion-prone surface layer, as well as by precipitation processes leading to the formation of sparingly soluble phosphate compounds in the presence of elevated levels of exchangeable aluminum.

Table 8. Variation in available soil phosphorus content between initial and final values

Experimental plots	Available phosphorus content (ppm)		Variation in available phosphorus (%)	Range of variation of mobile phosphorus, ppm
	Initial values (April)	Final values (October)		
N ₀ P ₀ K ₀ Mt A	9.20	9.21	0.11	8.13 – 10.29
N ₀ P ₀ K ₀ Mt B	9.40	9.42	0.21	
N ₆₀ P ₆₀ K ₆₀ A	10.23	10.29	0.59	
N ₆₀ P ₆₀ K ₆₀ B	9.11	9.18	0.77	
N ₁₀₀ P ₉₀ K ₆₀ A	8.70	8.85	1.72	
N ₁₀₀ P ₉₀ K ₆₀ B	8.13	8.35	2.71	

Variation in available potassium content

The data presented in Table 9 indicate a distinct evolution of available potassium content depending on fertilization treatment. In the unfertilized control, available potassium content decreased slightly (approximately 0.23%) as a result of plant uptake. Application of the N₆₀P₆₀K₆₀ fertilization rate resulted in a clear and relatively uniform increase in available potassium content (approximately 1.31%). At the higher fertilization rate (N₁₀₀P₉₀K₆₀), the increase in available potassium was more pronounced (approximately 1.54%), with higher values

recorded in downslope positions, suggesting the influence of transport and redistribution processes within the plot. These increases reflect the compensation of potassium losses through mineral fertilizer inputs.

Table 9. Variation in available soil potassium content between initial and final values

Experimental plots	Available potassium content (ppm)		Variation in available potassium (%)	Range of variation in available potassium content
	Initial values (April)	Final values (October)		
N ₀ P ₀ K ₀ Mt A	48.72	48.65	-0.14	48.40-50.35
N ₀ P ₀ K ₀ Mt B	48.55	48.40	-0.31	
N ₆₀ P ₆₀ K ₆₀ A	49.20	49.84	1.30	
N ₆₀ P ₆₀ K ₆₀ B	49.35	50.00	1.32	
N ₁₀₀ P ₉₀ K ₆₀ A	49.70	50.35	1.31	
N ₁₀₀ P ₉₀ K ₆₀ B	48.84	49.70	1.76	

The results obtained demonstrate that mineral fertilization influences both grassland productivity and the dynamics of the main soil agrochemical indicators, in agreement with numerous studies showing that nutrient availability represents a major limiting factor for grassland ecosystem productivity (Whitehead, 2000; Hopkins & Del Prado, 2007). The yield increases observed in fertilized treatments confirm the role of nitrogen, in combination with phosphorus and potassium, in stimulating plant biomass growth (Radu et al., 2021). The moderate decreases in soil pH observed in the fertilized treatments are consistent with the physiologically acidifying effect of mineral fertilizers, particularly nitrogen-based fertilizers, through nitrification processes and alterations in the ionic balance of the soil adsorption complex (Guo et al., 2010). The relatively low amplitude of the changes indicates that, in the short term, the soil has sufficient buffering capacity to limit the sharp variations in the reaction.

The differences observed between upslope and downslope positions may reflect spatial soil heterogeneity and the influence of microrelief on water redistribution processes (Brady & Weil, 2016). The evolution of humus content reflects the complex interaction between fertilization, biomass production, and mineralization processes. The slight decreases in humus observed in unfertilized or weakly fertilized treatments can be associated with intensified organic matter decomposition and reduced inputs of plant residues. In contrast, appropriate fertilization, by stimulating vegetation growth

and root system development, can increase organic carbon inputs to the soil, thereby promoting the maintenance or even enhancement of humus reserves (Six et al., 2002; Lal, 2004; Acatrinei et al., 2024).

The literature indicates that the effect of fertilization on soil organic matter depends on the balance between residue inputs and the intensity of mineralization, being influenced by pedoclimatic conditions and the duration of treatment application (Chen et al., 2018). In this context, the results obtained suggest that the fertilization-induced increase in biomass production may contribute to humus stabilization.

Total nitrogen dynamics closely follow humus variations, which is consistent with the fact that most soil nitrogen is stored in organic fractions. The slight decreases observed in the control variant can be attributed to nitrogen consumption by plants and slow replenishment through mineralization processes, while the low increases in the fertilized variants are compatible with exogenous nitrogen intake and intensification of its internal cycling (Stevenson, 1994; Brady & Weil, 2016).

The relatively small magnitude of the variations suggests that, in the short term, changes in total nitrogen content are limited and influenced by spatial variability, which requires a cautious interpretation of the results, supported by statistical analysis.

The more pronounced variability of available phosphorus is characteristic of acidic soils, where the availability of this element is strongly controlled by sorption and precipitation processes involving aluminum and iron oxides and hydroxides (Hinsinger, 2001; McLaughlin et al., 2011). Under these conditions, even following fertilization, a substantial proportion of the applied phosphorus may be rapidly immobilized in sparingly soluble forms.

The spatial differences observed between positions A and B can be explained by heterogeneity in exchangeable aluminum content and by the uneven distribution of phosphorus along the soil profile.

The evolution of available potassium primarily reflects the balance between removal through harvest and inputs via fertilization, under conditions of relatively good retention on the soil cation exchange complex.

The increases observed in fertilized variants are consistent with the literature indicating that potassium fertilization can compensate for nutrient losses and maintain adequate soil potassium levels (Sparks, 2003; Havlin et al., 2014).

Overall, the results support the hypothesis that rationally applied mineral fertilization can simultaneously contribute to increasing grassland productivity and maintaining soil fertility. At the same time, the early signals of acidification observed at higher doses underscore the need for long-term monitoring of soil reaction and indicators that control organic matter stability and nutrient availability, as recommended by synthesis studies on sustainable grassland management (Tilman et al., 2002; Lal, 2015).

CONCLUSIONS

The study demonstrates that mineral fertilization represents a key determinant of productivity enhancement in sown grasslands, while simultaneously influencing soil agrochemical functioning. The positive system response to nutrient inputs confirms the importance of fertilization management in grassland ecosystems characterized by limited nutrient availability.

The relatively small changes observed in the main agrochemical indicators indicate short-term functional stability of the soil, despite seasonal variability and the influence of fertilization. This stability suggests the presence of internal regulatory mechanisms that allow the maintenance of soil fertility under climatic and anthropogenic pressures.

Overall, the results highlight the need for an integrated management approach to sown grasslands, in which mineral fertilization is applied rationally and coupled with continuous soil monitoring, as an essential prerequisite for ensuring the sustainability of these ecosystems.

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