LONG-TERM EFFECTS OF MINERAL FERTILIZATION ON BIOMASS PRODUCTIVITY AND AGRONOMIC FACTORS IN HIGH NATURE VALUE GRASSLANDS

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Abstract

High Nature Value (HNV) grasslands play a key role in maintaining biodiversity and ecosystem functionality in mountain regions. This study evaluates the long-term effects of mineral fertilization on the agronomic characteristics and biomass productivity of a semi-natural grassland in the Apuseni Mountains, after 17 consecutive years of annual NPK applications (0; $50N25P_2O_525K_2O$; $100N50P_2O_550K_2O$; $150N75P_2O_575K_2O$ kg/ha). Biomass yield increases mainly through the expansion of two species with high competitive capacity: Agrostis capillaris, whose cover rises from 11% in the control to 64.6% under high fertilization, and Trisetum flavescens, which shows maximal development at moderate doses. Agronomic quality improves with fertilization, shifting from class V (medium) in the unfertilized sward to class VI (good) under the highest treatment, due to the installation of taller species with richer foliage. In contrast, grazing and trampling tolerance decrease progressively as mineral inputs intensify, reflecting the replacement of stress-tolerant species by taller, less resistant ones. Overall, the findings indicate that mineral fertilization enhances biomass production and forage quality but reduces structural complexity and tolerance of the sward to pastoral use. In the context of rising temperatures and decreasing precipitation in the study area, these trends underline the need for careful nutrient management to preserve the ecological stability and multifunctionality of HNV grasslands.

Keywords: HNV grasslands, mineral fertilization, biomass production, agronomic factors, forage quality, long-term experiment, Apuseni Mountains.

INTRODUCTION

In recent decades, Romania's mountainous areas have undergone profound transformations driven primarily by the restructuring of their traditional economic system. The drastic reduction of timber resources—the main source of income for local communities—has led to major changes in the way of life of mountain populations (Rotar et al. 2020; Păcurar et al. 2023). A representative example is the Apuseni Mountains, where logging and wood processing once provided approximately 70% of household income, and the strong dependence of Mote communities on this resource has been documented by several authors (Auch et al., 2001; Rușdea et al. 2011; Gliga et al. 2013; Păcurar et al. 2019).

As forest resources have progressively diminished, local populations have increasingly shifted towards agriculture and livestock husbandry. This transition has directly influenced land use patterns, landscape dynamics, floristic composition, and the phytodiversity of grasslands (Brinkmann et al. 2009; Rotar et al. 2010; Păcurar et al. 2023).

Within this context, the assessment and conservation of High Nature Value (HNV) grasslands have become a major national concern. Romanian specialists are developing management methods based on the use of indicator species, adjusted to local site conditions and the intensity of agro-pastoral practices (Vaida et al. 2017; Sângeorzan et al. 2018; Gaga et al. 2022). At the European level, the use of indicator species to assess HNV grasslands has a long tradition, with numerous studies showing that agricultural intensification in Western Europe leads to biodiversity reduction, a trend revealed by shifts in floristic indicators. In Germany, for instance, the effectiveness of agri-environmental measures has been validated through the monitoring of indicator species (Wittig & Zacharias 2006; Balázsi et al. 2018; Milberg et al. 2020).

Climate change represents an additional threat to grassland ecosystems in the Carpathian Mountains, the most extensive mountain range in Central and Eastern Europe (Sângeorzan et al. 2024). These ecosystems host valuable plant communities with high biodiversity and important indicator species (Vaida et al. 2021). Recent climatic trends, including rising temperatures and declining precipitation, influence vegetation dynamics and the capacity of grasslands to maintain stable structures under increasing anthropogenic pressure.

Many researchers now recommend that Common Agricultural Policy measures across the European Community be evaluated based on outcomes rather than actions, and that lists of species indicative of management intensity be developed. In this context, research on HNV grasslands should be carried out through long-term experiments, as short-term studies may fail to capture or may distort real ecological processes. Authors emphasize that knowledge gained from long-term ecological fertilization experiments must be considered before applying additional nutrients to semi-natural grasslands (Păcurar et al. 2023).

Experiments assessing the effect of mineral fertilization on biodiversity are relatively rare, as mineral inputs applied in optimal quantities are considered, at European level, a viable solution for maintaining and even conserving grassland biodiversity in Romania. The wide diversity of HNV ecosystems in mountain regions has been created and maintained through traditional and sustainable agricultural practices, and altering this equilibrium may generate major changes in floristic composition and agronomic parameters of the vegetation cover.

In this context, the present study analyzes how mineral fertilization, applied continuously for 17 years, influences the floristic composition, biomass productivity, and agronomic factors of a mountain grassland in the Apuseni Mountains, providing essential insights into the long-term evolution of phytocoenoses under current climatic and socio-economic transformations.

MATERIAL AND METHOD

The long-term experiences with mineral fertilizers were studied. The mineral experiment consisted of 4 treatments in 4 replications (T1 control, T2 50N25P25K, T3 100N50P50K, T4 150N75P75K). Mineral fertilizers were applied annually in early spring, using the same type of complex fertilizer, namely NPK (nitrogen, phosphorus, potassium) 20:10:10. For the floristic analysis, data from long-term experiments established in Ghețari (Apuseni Mountains, Romania) were used, at an elevation of 1130 m, founded in 2001, using the random blocks method, will be used. The floristic studies were performed according to the Braun-Blanquét method modified by Păcurar and Rotar (2014). This paper presents data from three experimental years (2015, 2016, 2017), but highlights the cumulative effect of mineral inputs 17 years after the placement of the experiments.

Mineral fertilizers were applied annually in early spring, when the snow cover melted, usually around April 15-20. Mineral fertilization was performed on the same day in all experimental variants. The PC-ORD software, version 7 (www.pcord.com), was used to process the floristic data obtained in the experimental fields. For processing, the data obtained were entered in the form of two matrices. The first matrix contained data on vegetation, while the second matrix contained the experimental variants. PC-ORD software (version 7) was used for vegetation classification and ordination, as well as for randomization tests.

In this paper, the ordering was performed in two dimensions because it provides a clear picture of the phenomenon. The ordering of the floristic surveys of the experimental data was performed using the Principal Coordinates Analysis (PCoA) method. This method is widely used in ordering statistics, even outside the fields of ecology and agronomy. It has been tested over time and has always been adjusted by specialists in statistical processing. (PECK, 2010; Păcurar și Rotar 2014).

Regarding the temperatures recorded at the Ghețari station over the last 17 years, the following aspects can be observed: the multi-year average was around 5.8^{0}C, with a maximum value of 7.7^{0}C recorded in 2012 and 2015 (Gliga et. al 2013), and a minimum value of 3.2^{0}C recorded in 2005 (Apahidean et. al., 2005, Barbara et. al 2006); Table 2 also shows an upward trend in average annual temperatures, particularly between

2012 and 2017 (Brinkmann *et. al.*, 2009; Morea *et. al.*, 2014).

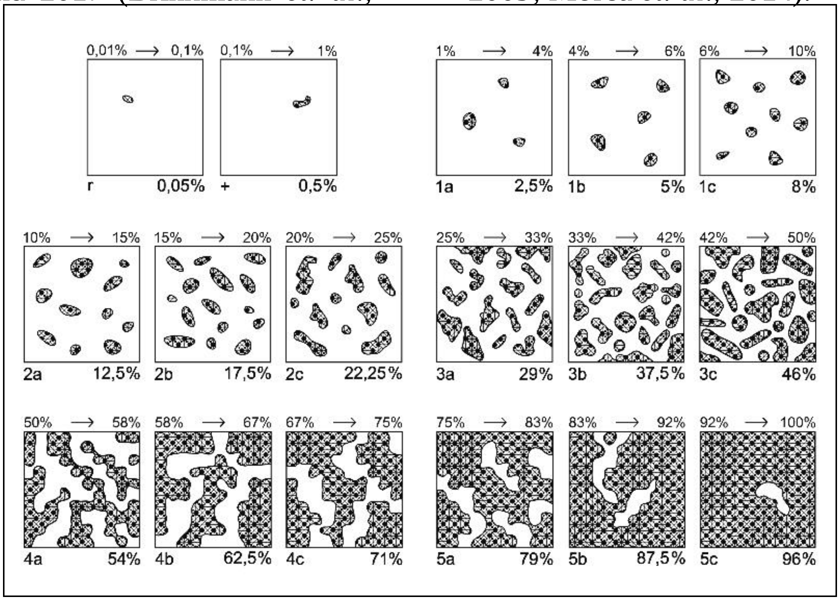


Figure 1. Scheme of appreciation of abundance-dominance by method Braun-Blanquet, using three sub-notes Pacurar and Rotar, 2014)

Table 1.

Scale of appreciation of abundance-dominance Braun-Blanquet, completed Tüxen and Ellenberg (1937), modified with three sub-notes and three sub-ranges byPăcurar and Rotar, (2014)

Nota	Coverage interaval (%)	Central value of class (%)	Sub-note	Sub-interval (%)	Central-adjusted value of sub-interval (%)
5	75 – 100	87.5	5c	92 – 100	96
			5b	83 – 92	87.5
			5a	75 – 83	79
4	50 – 75	62.5	4c	67 – 75	71
			4b	58 – 67	62.5
			4a	50 – 58	54
3	25 – 50	37.5	3c	42 – 50	46
			3b	33 – 42	37.5
			3a	25 – 33	29
2	10 – 25	17.5	2c	20 – 25	22.25
			2b	15 – 20	17.5
			2a	10 – 15	12.5
1	1 – 10	5	1c	6 – 10	8
			1b	4 – 6	5
			1a	1 – 4	2.5
+	0.1 – 1	0.5	-	-	0.5
r	0.01 – 0.1	0.05	-	-	0.05

Note: system Braun-Blanquet, completed by Tüxen and Ellenberg (1937), modified with three sub-notes and three sub-intervals (source Pacurar and Rotar, 2014)

Therefore, the context of climate change in the study area (Ghețari Plateau – Poiana Călineasa) has significant effects on the floristic diversity of oligotrophic grasslands in the Apuseni Mountains.

Table 2

The monthly average temperatures recorded at Gheţari weatherstation (2015-2017)

Year	Months												Average
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
2015	0,8	2	4,7	3,8	10,8	13,5	16,5	16,5	12,7	7,7	3,4	-0,2	7,7
2016	-5,4	0,1	1	8	8,7	14,8	16	15,3	10,9	4,6	0,4	-5,4	5,7
2017	-1,8	6	8,3	6,4	10	14,6	15,5	15,3	10,7	7,9	0,6	-3,2	7,5
Mean	-4,5	-2,7	0,2	5,3	10,5	14,5	15,9	15,4	11,3	6,0	1,4	-3,1	5,8

Regarding the average annual precipitation values recorded at the Ghețari weather station, it was found that the multi-year average (over 17 years) was 1042.1 mm, with the maximum recorded in 2001 (1553 mm; Păcurar et. al., 2004) and the minimum was recorded in 2012 (687 mm; Păcurar et. al., 2017), which was considered the driest year in our study area. Comparing the last 5 years (2012-2017; Rotar et. al., 2020) with the multi-year average in terms of rainfall, it is easy to see that the downward trend in precipitation values is complemented by an increase in temperature values, thus foreshadowing a constantly changing climate, which brings with it new challenges in terms of adapting grassland management in the Apuseni Mountains.

Table 3

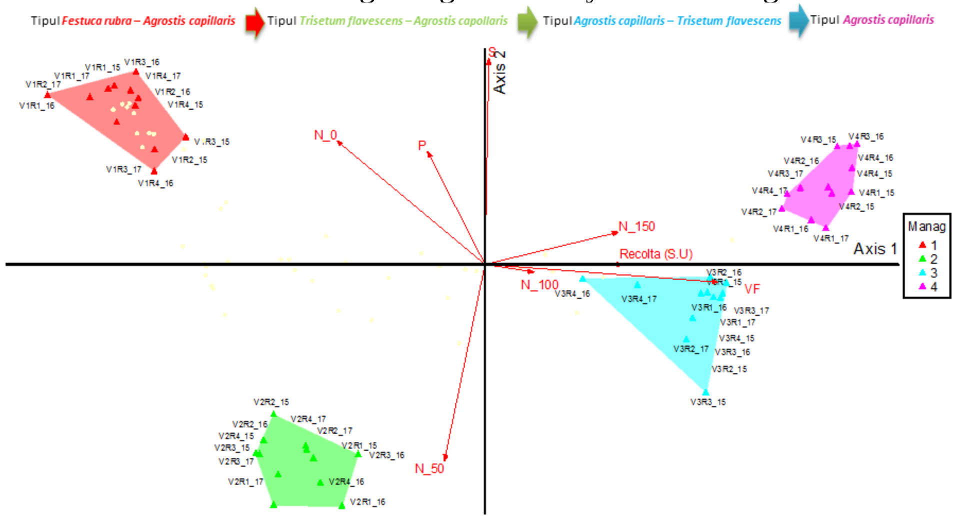
The monthly average precipitations recorded at Gheţari weatherstation (2015-2017)

Year	Months												Average
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
2015	32,6	14,2	23,6	48,6	69,4	78,2	33,8	95	124	38,8	98,4	49,8	706,4
2016	120	111,4	79,4	108,4	67	165,4	58,8	49,4	56	86,6	127	0,2	1030
2017	112	0	86	11,4	116,6	95	37	35	88	100	98	36,2	815,2
Media	67,2	55,9	81,8	77,2	102,4	100,3	137,3	98,4	92,6	86,6	86,5	55,8	1042,1

RESULTS AND DISCUSSIONS

The influence of mineral fertilization on agronomic factors

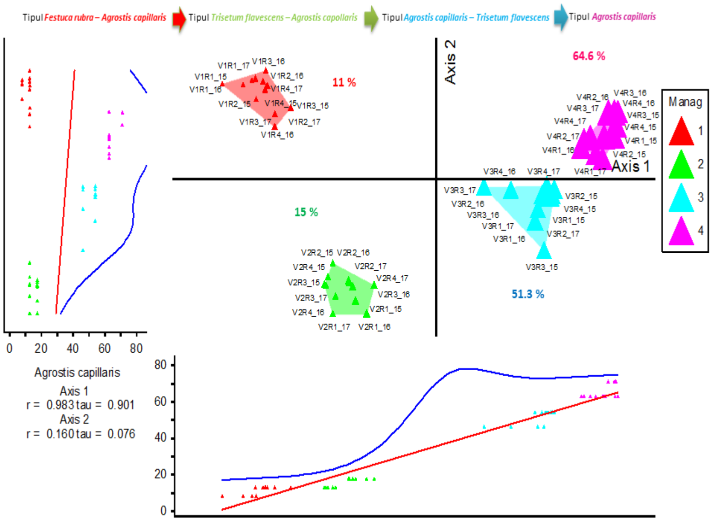
The agronomic factors that correlate with the ordering axes are represented by species tolerance to grazing, trampling, forage value, and yield (Fig. 2). Species preferences in terms of grazing tolerance are inversely proportional to yield and forage value.



1 – V1 (CONTROL); **2** – V2 (50N25P25K); **3** – V3 (100N50P50K); **4** – V4 (150N75P75K); **VF** – Fooder value; **P** – grazing; **S** - crushed

Fig. 2 The influence of mineral fertilization on the agronomic factors

The biomass harvest developed mainly on the basis of two species: *Agrostis capillaris* (Fig. 3) and *Trisetum flavescens* (Fig. 4). The *Agrostis capillaris* species is strongly influenced by the treatments applied and has the highest proportion in the 100N50P50K and 150N75P75K treatments (r = 0.983; Fig. 3). The species increases its share from 11% coverage (control) to 64.6% of the vegetation cover (150N75P75K). Our results are also confirmed by Motcă in 1975, when mineral fertilization of an *Agrostis capillaris* – *Festuca rubra* meadow in the Făgăraş Depression led to a strong establishment of the *Agrostis capillaris* species, which became dominant. Dincă in 1984 shows that mineral fertilization led to an increase in the size of the *Agrostis capillaris* species and lush growth with rich foliage. Our studies are also confirmed by current specialist literature. Thus, the analysis of the effects of mineral fertilization on the floristic composition highlights a clear change in the structure of the vegetation cover with the intensification of nutrient input. The results obtained in the long-term experiment at Ghețari confirm the trends reported in recent literature, according to which *Agrostis capillaris* is one of the most sensitive and reliable indicator species of intense mineral fertilization (Gârda et. al., 2009; Gheţe et. al., 2025). The ecological trend of this species, also identified in other studies, confirms that *Agrostis capillaris* is adapted to nitrophilic conditions, responding favorably to increased nitrogen availability and effectively competing with other species in ecosystems with high nutrient inputs. By integrating these results, the experiment demonstrates that long-term mineral fertilization causes a functional redistribution of species in the plant community: *Agrostis capillaris* emerges as an indicator species of high fertilization intensity, while *Trisetum flavescens* (Gârda et. al., 2010) and other mesotrophic species remain characteristic of low-input variants. This differentiation is essential for understanding the adaptation mechanisms of mountain grasslands to different management regimes.

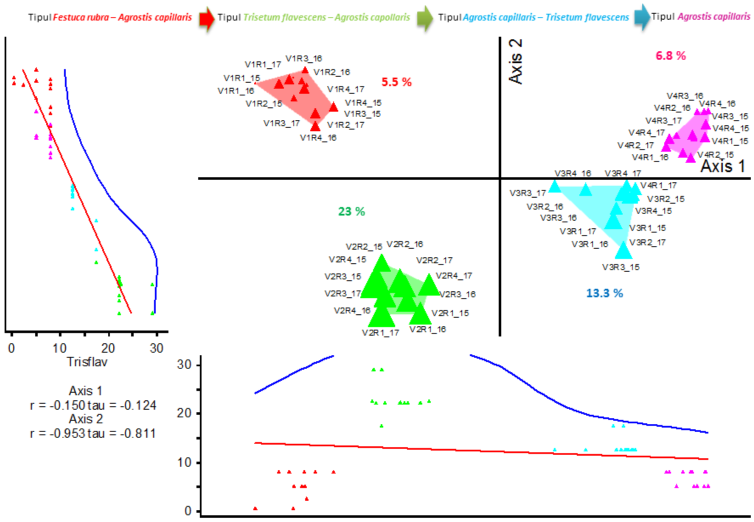


1 – V1 (control); **2** – V2 (50N25P25K); **3** – V3 (100N50P50K); **4** – V4 (150N75P75K); r-correlation coefficient

Fig. 3 The influence of *Agrostis capillaris* species on dry matter

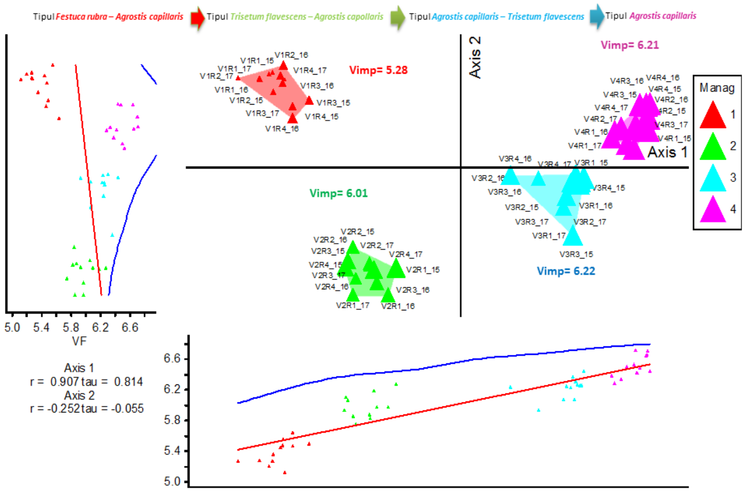
The species *Trisetum flavescens* is influenced by the treatments applied and has the highest proportion in the treatments with 50N25P25K and 100N50P50K (Fig. 4). The species increases its share from 5.5% (control) to 23% in the 50N25P25K treatment, 13.3% in the 100N50P50K treatment, after which it records a decrease in share (6.8%) in the 150N75P75K fertilized variant. Our results are also confirmed by SCHNEIDER in 2011, when he identified the species *Trisetum flavescens* on high-yield grasslands. Feed value is a complex concept that takes into account the following aspects (Vîntu, 2004; Rotar and Carlier, 2010): chemical composition; degree of consumability; palatability (acceptance by animals); degree of toxicity; percentage of leaves and stems; porosity of plant organs and their type; digestibility.

The application of mineral fertilization led to an improvement in forage quality. The phytocoenosis of the control (*Festuca rubra* – *Agrostis capillaris*) falls into class V (Fig. 5), the average category, being a meadow dominated by species with average forage value, supporting 0.81–1.00 UVM/ha, and following mineral fertilization, it falls into class VI quality, good category (V4 – 150N75P75K; *Agrostis capillaris* type), where species with good forage value predominate, supporting 1.01 – 1.20 UVM/ha. This increase in quality can be explained by the installation of new types of pasture as a result of the increased intensity of the system.



1 – V1 (control); **2** – V2 (50N25P25K); **3** – V3 (100N50P50K); **4** – V4 (150N75P75K); r-correlation coefficient

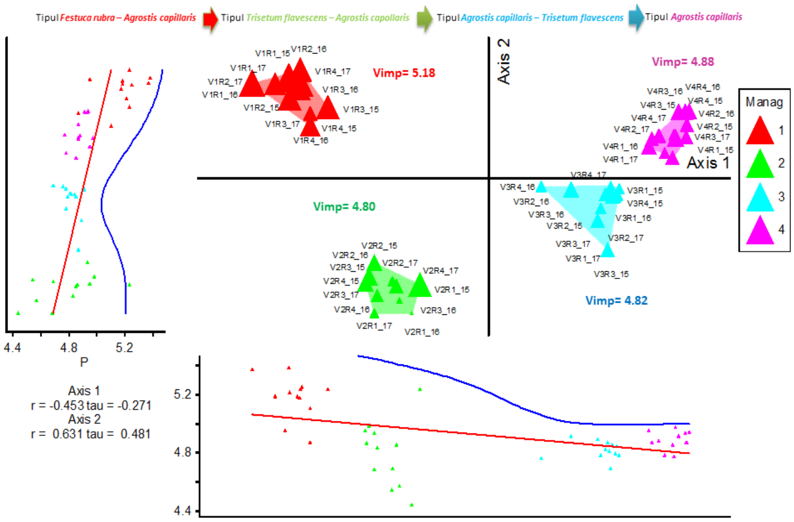
Fig. 4 The influence of *Trisetum flavescens* species on dry matter



1 – V1 (control); **2** – V2 (50N25P25K); **3** – V3 (100N50P50K); **4** – V4 (150N75P75K); r-correlation coefficient; VF – feed value

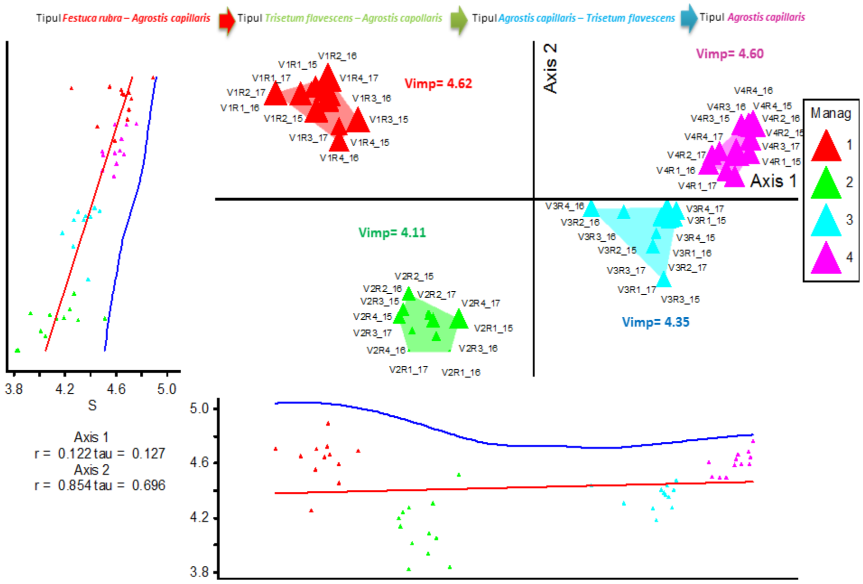
Fig. 5 Influence of mineral fertilization on fodder value

The tolerance of phytocenosis to grazing is inversely proportional to mineral fertilization (Fig. 6). The representative phytocenosis of the control is moderately tolerant to grazing (P=5.18) and is reduced to moderately tolerant to treatment with 150N75P75K (P=4.88). This situation can be explained by the new species (*Agrostis capillaris*) that have been introduced, which are medium to tall in height and have a lower tolerance to grazing compared to the species in the control phytocenosis (*Festuca rubra*).



1 – V1 (control); **2** – V2 (50N25P25K); **3** – V3 (100N50P50K); **4** – V4 (150N75P75K); r **-** correlation coefficient; P **-** grazing

Fig. 6 Influence of mineral fertilization on the tolerance of phytocenoses in grazing



1 – V1 (control); **2** – V2 (50N25P25K); **3** – V3 (100N50P50K); **4** – V4 (150N75P75K); r-correlation coefficient; S – crushed

Fig. 7 Influence of mineral fertilization on the tolerance of phytocenoses in crushed

Tolerance to crushing is inversely proportional to mineral fertilization, with a decrease in the tolerance to crushing of phytocenoses (Fig. 7). While in the control sample the tolerance to crushing is 4.62, following mineral fertilization and the installation of new types of grassland, it is reduced to 4.11 (V2 – *Trisetum flavescens* – *Agrostis capillaris* type), 4.35 in the treatment with 100N50P50K (*Agrostis capillaris* - *Trisetum flavescens type*), there is no change in the agronomic category, all being moderately tolerant to crushing.

CONCLUSIONS

The application of mineral fertilizers increases the fodder value of the vegetation cover, due to the establishment of new types of pasture with superior qualities;

Mineral fertilization causes a slight decrease in the grazing tolerance of phytocenoses;

Overlaying the results regarding the evolution of agronomic, ecological, and natural factors over those specific to vegetation changes leads to a clearer picture of the behavior of newly established pasture types as a result of fertilizer application.

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