GRASSLANDS DOMINATED BY *FESTUCA RUBRA*: ECOLOGY, FUNCTIONING, AND MANAGEMENT

Ioan ROTAR[1] and Ioana GHEȚE[*1]

[1]*Faculty of Agriculture, Department of Plant Crops. University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Manăștur street, 3-5, 400372,Romania*
**corresponding author: ioana.gheţe@usamvcluj.ro*

Abstract

Grasslands dominated by Festuca rubra represent a defining component of mountain landscapes in Romania and across Europe, owing to their characteristic combination of structural stability, floristic diversity, and sensitivity to management changes. This paper provides an integrated bibliographic synthesis on the ecology of Festuca rubra, the functioning of grasslands in which it becomes dominant, and the ways these ecosystems respond to different fertilization regimes and management practices. The analysis of Romanian and European literature highlights the ecological versatility of the species, capable of thriving on low- to moderately fertile soils, under humid mountain conditions, and within traditional mowing and grazing systems. Festuca rubra grasslands maintain a favorable balance between productivity and biodiversity when managed extensively or moderately. However, long-term studies show that intensive mineral fertilization leads to vegetation simplification by promoting nitrophilous species, while the absence of management triggers successional processes that gradually diminish the semi-natural character of the habitat. Belowground interactions—particularly associations with arbuscular mycorrhizal fungi—enhance the resilience of these grasslands and are influenced by soil fertility and land-use practices. Integrating research from Romania, especially from the Apuseni Mountains, with European findings underscores the ecological, agronomic, and cultural value of Festuca rubra-dominated grasslands and highlights the need for sustainable management supported by appropriate agricultural policies.

Keywords: *Festuca rubra; mountain grasslands; biodiversity; fertilization; sustainable management; semi-natural grasslands; succession; agro-ecological conservation.*

INTRODUCTION

Permanent mountain grasslands in Europe represent some of the most valuable agro-pastoral ecosystems, owing to their high biodiversity and the ecosystem services they provide, including forage production, soil protection, carbon storage, and the maintenance of traditional cultural landscapes. In Romania, particularly in the Carpathians, semi-natural grasslands form a central component of the rural landscape, shaped by long-term extensive use, low external inputs, and traditional mowing and grazing practices (Reif et al., 2005; Reif et al., 2008; Rușdea et al., 2011).Within this context, grasslands dominated by *Festuca rubra* hold a distinct position. They occur frequently in humid mountain and hilly areas on low- to moderately fertile soils and are often classified as High Nature Value (HNV) grasslands when managed extensively (Păcurar et al., 2018; Vaida et al., 2021). *Festuca rubra* is characterized by high ecological

plasticity and the capacity to dominate oligotrophic or moderately fertilized grasslands in the Apuseni Mountains and in other European regions (Brinkmann et al., 2009; Gliga et al., 2013). Long-term research conducted in the Apuseni Mountains—particularly in the Gheţari and Gârda de Sus areas—has identified these grasslands as model systems for studying the relationship between biodiversity, fertilization, and management (Auch et al., 2001; Păcurar, 2005; Reif et al., 2005). Findings show that *Festuca rubra* grasslands respond sensitively to input intensity and type, with clear shifts in floristic composition and productivity (Păcurar et al., 2008; Păcurar et al., 2012; Rotar et al., 2003, 2005a, 2005b, 2010). Additional long-term studies conducted over 7–15 years confirm the existence of a productivity–diversity trade-off under moderate use, whereas high fertilization accelerates the decline of oligotrophic species (Păcurar et al., 2008; Vaida et al., 2016, 2017; Păcurar et al., 2014; Rotar et al., 2014; Gaga et al., 2022; Samuil et al., 2025; Gheţe et al., 2025). Beyond agronomic aspects, numerous studies have investigated belowground ecological processes, highlighting the importance of mycorrhizal associations and edaphic indicators in the stability of *Festuca rubra* grasslands (Corcoz et al., 2021; Stoian et al., 2014a, 2014b, 2019; Maruşca et al., 2021, 2022). At the European scale, similar grasslands are recognized as elements of traditional cultural landscapes, tightly linked to extensive use and local identity (Reif et al., 2008; Balázsi et al., 2016, 2018). Recent transformations—whether intensification or abandonment—raise important questions regarding the ecological future and resilience of these systems (Morea et al., 2013; Vaida et al., 2016; Moş & Brînzan, 2024; Sângeorzan et al., 2018b). European and national agricultural policies, including the Romanian RDP 2014–2020 and the National Strategic Plan 2023–2027, incorporate measures targeted at HNV grasslands and extensive systems, reflecting the recognition of their ecological and socio-economic value (PNDR, 2019; PNS, 2023; Sângeorzan et al., 2018a; Rotar et al., 2020). In the Apuseni Mountains, interdisciplinary studies have demonstrated strong connections between *Festuca rubra* grasslands, pastoral landscape structure, and traditional management practices (Gârda et al., 2009, 2010; Rotar et al., 2005a; Păcurar et al., 2015). In this context, the aim of the present paper is to synthesize scientific knowledge regarding *Festuca rubra*-dominated grasslands, with emphasis on species ecology, community functioning, management responses, and implications for the conservation of mountain ecosystems.

ECOLOGICAL CHARACTERIZATION OF *FESTUCA RUBRA*

Festuca rubra L. is one of the most widespread perennial grasses in the temperate zone of Europe and a defining element of mountain,

subalpine, and hilly grasslands. Its ecological plasticity—reflected in the diversity of its growth forms and its tolerance to a wide range of edaphic conditions—explains the central role it plays in numerous semi-natural ecosystems. Both European and Romanian literature recognize it as a keystone species, capable of thriving in oligotrophic as well as moderately fertilized habitats without compromising the functioning of traditional grassland communities.

The taxonomic complex of the species includes rhizomatous forms, which produce a dense turf and high regenerative capacity, alongside tussock forms adapted to different soil conditions. This variability accounts for its wide distribution across Romania and Europe, from the mountain grasslands of the Carpathians to colline and mesotrophic meadows. Studies from the Apuseni Mountains—particularly from the Gheţari, Gârda, and Padiş areas—show that *Festuca rubra* behaves as a stable species in extensively used grasslands, responding predictably to fertilization regimes (Păcurar et al., 2008; Rotar et al., 2003; Morea et al., 2008).

Ecologically, *Festuca rubra* prefers soils of low to moderate fertility, with slightly acidic to neutral pH, and tolerates humid mountain climates and low temperatures. It persists in oligotrophic grasslands, together with *Agrostis capillaris* or *Nardus stricta*, as well as in mesotrophic or moderately fertilized systems (Vîntu et al., 2011a; Samuil et al., 2013). Low doses of organic fertilization enhance turf density without markedly reducing diversity, whereas intensive mineral fertilization favors replacement by nitrophilous grasses such as *Dactylis glomerata* or *Poa trivialis* (Păcurar & Rotar, 2014; Rotar et al., 2014; Vaida et al., 2016).

Morphologically, the rhizomatous form confers resilience to mowing and grazing, enabling rapid recovery of the sward. Its fine, waxy leaves improve drought tolerance and contribute to fodder value. An essential ecological trait of the species is its association with arbuscular mycorrhizal fungi, which enhance nutrient uptake and support ecosystem functioning in low-fertility environments. Studies from HNV grasslands in the Apuseni indicate high levels of mycorrhizal colonization under extensive management, with significant reductions under intensive mineral fertilization (Corcoz et al., 2021; Stoian et al., 2014, 2019).

Due to its moderate competitiveness and tolerance of typical pastoral disturbances, *Festuca rubra* contributes substantially to grassland stability. By maintaining a dense turf and balanced competition levels, it enables the coexistence of mesotrophic and oligotrophic forbs and legumes, making *Festuca rubra*-dominated grasslands some of the most stable pastoral ecosystems in mountain regions (Gârda et al., 2010; Vaida et al., 2021). At the same time, its distribution and vigor accurately reflect soil fertility and land-use history, which is why the species is frequently used as an indicator.

Recent research employing modern technologies—near-infrared (NIR) spectrometry and hyperspectral imaging—has confirmed the

species' importance for assessing forage quality and the condition of semi-natural ecosystems (Dale et al., 2012; Dale et al., 2013b). Moreover, *Festuca rubra* often occurs in habitats that host species of conservation value, such as *Arnica montana*, further emphasizing the ecological and cultural significance of these grasslands (Michler et al., 2005b; Morea et al., 2008, 2013; Vârban et al., 2011; Sângeorzan et al., 2024).

Overall, *Festuca rubra* is one of the most versatile and ecologically relevant species in mountain grasslands. Its capacity to respond to management changes while maintaining the stability of semi-natural ecosystems makes the studies conducted in the Apuseni Mountains a valuable reference for understanding vegetation dynamics in the context of contemporary transformations affecting mountain agriculture.

STRUCTURE AND FUNCTIONING OF *FESTUCA RUBRA*-DOMINATED GRASSLANDS

Grasslands dominated by *Festuca rubra* represent some of the most characteristic and stable semi-natural ecosystems in the mountain regions of Romania and Europe. They arise from the interplay between environmental conditions, agro-pastoral land-use history, and the ecological traits of the dominant species. Depending on soil fertility, mowing frequency, grazing pressure, and successional dynamics, these grasslands range from species-rich mesotrophic communities to more impoverished but highly resilient systems.

In the humid mountain zones of the Apuseni Mountains, where long-term studies have monitored vegetation dynamics under contrasting management regimes, *Festuca rubra* grasslands exhibit a relatively stable floristic composition. The dominance of *Festuca rubra* is accompanied by a consistent assemblage of species—*Agrostis capillaris*, *Trisetum flavescens*, *Lotus corniculatus*, *Anthoxanthum odoratum*, *Poa pratensis*, and *Ranunculus acris*—all typical of Carpathian mesotrophic grasslands (Gârda et al., 2010; Brinkmann et al., 2009). This mixture of species confers high ecological elasticity, as dominant and co-dominant plants respond differently to variations in fertility and land-use pressure.

A defining structural element of these grasslands is the dense sward formed by the rhizomatous system of *Festuca rubra*. This stabilizes the vegetation layer, reduces soil exposure, enhances organic matter accumulation, and maintains a uniform microclimate near the soil surface—conditions that support high companion-species diversity. At the same time, the compact turf limits erosion and contributes to a relatively constant rate of mineralization, particularly in low-input systems (Păcurar & Rotar, 2011; Maruşca et al., 2021).

From an ecosystem functioning perspective, *Festuca rubra*-dominated grasslands are efficient resource users and can maintain high levels of diversity under extensive management. The

moderate growth rate of the dominant species facilitates the coexistence of mesotrophic and oligotrophic grasses and forbs, generating stable and functionally diverse communities. However, increased nitrogen inputs favor competitive grasses such as *Dactylis glomerata* and *Poa trivialis*, reducing structural complexity and biodiversity (Mălinaș et al., 2013; Păcurar et al., 2014; Rotar et al., 2014; Vaida et al., 2016).

Vegetation succession plays a key role in the dynamics of these grasslands. Under irregular management or abandonment, *Festuca rubra* communities may transition toward stages dominated by robust species like *Agrostis capillaris* or *Calamagrostis arundinacea*, and woody vegetation may gradually appear in the absence of mowing or grazing (Păcurar et al., 2015; Gliga et al., 2013). Although *Festuca rubra* often remains present in early successional stages, its competitive ability diminishes over time relative to taller, more aggressive species (Vaida et al., 2016; Moș & Brînzan, 2024).

Belowground interactions further influence grassland functioning. Root colonization by arbuscular mycorrhizal fungi enhances nutrient uptake efficiency and supports ecosystem stability in low-fertility environments. Studies from the Apuseni Mountains show that these symbiotic relationships persist under extensive management but decline significantly under intensive mineral fertilization (Corcoz et al., 2021; Stoian et al., 2014, 2019).

Another key functional attribute is the moderate to good forage value of these grasslands, supported by the fine foliage and rapid regrowth capacity of *Festuca rubra* after mowing or grazing. In traditional pastoral systems, these grasslands provide consistent, balanced forage, which has contributed to their long-term persistence in mountain landscapes (Sima & Păcurar, 2002).

Modern analytical tools—such as near-infrared (NIR) spectrometry and hyperspectral imaging—have demonstrated that forage-quality variation can be accurately monitored and is closely linked to species composition and fertilization regimes (Dale et al., 2012, 2013a).

Overall, *Festuca rubra*-dominated grasslands combine structural stability, resistance to moderate disturbance, and sensitivity to intensification, giving them a central role in sustaining long-term ecosystem functioning and biodiversity (Vîntu et al., 2011b). They can be considered true ecological nuclei within pastoral mountain landscapes, and their responses to management changes serve as key indicators of agro-ecological sustainability in mountain regions.

RESPONSES OF *FESTUCA RUBRA*-DOMINATED GRASSLANDS TO MANAGEMENT AND FERTILIZATION

Grasslands dominated by *Festuca rubra* exhibit a complex ecological behavior, sensitive to fertilization regimes and land-use practices, yet relatively stable under traditional management systems.

Numerous studies from the Apuseni Mountains and other European mountain regions show that the response of this species—and of the communities it dominates—is strongly influenced by the intensity and type of inputs, as well as by mowing and grazing frequency. This sensitivity makes *Festuca rubra* a valuable indicator of management-induced ecological changes.

Under low fertilization regimes, *Festuca rubra* grasslands maintain their traditional floristic and functional structure. Moderate organic fertilization, especially with well-decomposed manure, enhances vegetation cover by stimulating growth and favoring associated mesotrophic species, without major biodiversity losses. Experiments from the Apuseni Mountains show that small annual doses maintain a favorable balance between productivity and diversity, whereas excessive organic inputs produce the first signs of community simplification (Păcurar & Rotar, 2006; Vaida et al., 2017; Morea et al., 2008). In such cases, *Festuca rubra* remains dominant, but oligotrophic species decline gradually, and functional diversity decreases.

Mineral fertilization induces a much faster and more pronounced ecological response (Nazare et al., 2024). Low doses may resemble the effects of moderate organic fertilization, but increasing nitrogen inputs accelerates competition among grasses. Long-term experiments from the Apuseni Mountains show that medium NPK levels visibly shift dominance patterns by promoting nitrophilous species (*Dactylis glomerata*, *Poa trivialis*), which tend to replace *Festuca rubra* in more fertile areas (Păcurar et al., 2014; Rotar et al., 2014; Păcurar et al., 2012). As soil fertility rises, grasslands lose their semi-natural character and species richness declines. These processes are confirmed not only by floristic analyses but also by functional indicators—functional diversity, functional dispersion, and Fourth Corner analysis—highlighting reduced trait variability and the emergence of an ecological "threshold" at medium fertilization levels.

Over the long term, high mineral fertilization results in marked community simplification, transforming grasslands into systems dominated by a few fast-growing, highly competitive species. Studies by Rotar et al. (2003, 2005b) and Păcurar et al. (2012) show that excessive fertilization alters not only floristic composition but also soil properties and root system functioning, reducing mycorrhizal colonization and tolerance to water or mechanical stress. Under such conditions, *Festuca rubra* gradually loses competitiveness and may be replaced in highly fertile zones, although it often remains present within the sward structure.

Management practices—particularly mowing and grazing—play a decisive role in shaping *Festuca rubra* grasslands. Annual mowing at the optimal phenological stage maintains openness and supports regeneration of valuable species. In traditionally mown grasslands, *Festuca rubra* forms a dense, persistent sward, renewing

aerial biomass continuously, which confers a competitive advantage compatible with species coexistence and biodiversity maintenance (Sima & Păcurar, 2002). By contrast, intensive or unregulated grazing reduces biomass and vigor, favoring species tolerant to repeated defoliation, such as *Agrostis capillaris*, or even invasive taxa. Moderate grazing, combined with rotational management, creates a mosaic-like structure that allows *Festuca rubra* to coexist with diverse forbs and legumes of floristic and fodder importance.

Grassland abandonment represents one of the most significant challenges in mountain landscapes. In the absence of mowing or grazing, *Festuca rubra* grasslands enter slow successional pathways characterized by increased vegetation height and density, alongside gradual loss of competitiveness among species adapted to moderate disturbance. In early successional stages, *Festuca rubra* persists, but it is progressively replaced by taller, more robust species or by young woody vegetation. Studies from the Apuseni Mountains show that abandoned grasslands rapidly exhibit biodiversity loss and structural degradation (Păcurar et al., 2015; Vaida et al., 2016; Moș & Brînzan, 2024). Pedoclimatic factors and belowground processes also play a critical role. Research on mycorrhizal colonization under contrasting fertilization regimes shows that symbiotic relationships with soil fungi contribute to the resilience of *Festuca rubra* grasslands. Under moderate organic fertilization, mycorrhizal associations remain active and support diversity, whereas intensive mineral fertilization significantly reduces colonization levels (Corcoz et al., 2021; Stoian et al., 2014, 2019). Thus, the functioning of *Festuca rubra* ecosystems depends not only on aboveground vegetation dynamics but also on belowground processes that regulate nutrient fluxes and long-term stability.

Overall, *Festuca rubra* grasslands exhibit a wide spectrum of responses to management and fertilization. They remain stable and productive under extensive systems and tolerate low-input fertilization but become rapidly sensitive to intensification. Their ecological responses reflect shifts in the balance between biodiversity conservation, productivity, and modern agricultural pressures, making them a valuable reference system for understanding mountain ecosystem functioning and for designing sustainable grassland management practices in Romania and Europe.

SUSTAINABLE MANAGEMENT AND RECOMMENDATIONS FOR *FESTUCA RUBRA*-DOMINATED GRASSLANDS

Festuca rubra-dominated grasslands represent a cornerstone of mountain pastoral landscapes, forming an ecological and agronomic resource whose long-term stability depends on management practices tailored to their specific functioning. Although these grasslands are resilient to moderate disturbances, they remain

vulnerable to intensification, abandonment, and rapid changes in agricultural practices. Effective nutrient management is particularly important in mountain systems, as nitrogen use efficiency strongly influences both productivity and community stability. Recent research on nitrogen use efficiency in temporary grasslands shows that moderate fertilization rates optimize ecosystem performance without causing substantial losses through leaching or volatilization (Mălinaș et al., 2020)—a principle equally applicable to semi-natural *Festuca rubra* grasslands. Sustainable management must therefore aim to balance productivity with biodiversity conservation and ecosystem functionality.

1. Principle of Extensive Use: Annual Mowing and Moderate Grazing

Traditional mowing—performed after flowering but before stems become lignified—supports sward regeneration and promotes the dispersal of valuable species. In *Festuca rubra* grasslands, this timing synchronizes the life cycle of the dominant species with that of companion plants, preventing excessive litter accumulation or the establishment of undesirable species. Studies from the Apuseni Mountains demonstrate that such practices maintain a stable balance between productivity and diversity, supporting both mesotrophic and oligotrophic species (Sima & Păcurar, 2002; Păcurar & Rotar, 2011).

→ Key principle: maintain traditional mowing at optimal phenological stages.

2. Principle of Controlled Grazing

Moderate grazing—especially with cattle or horses—maintains grassland openness and limits excessive competition among grasses. In *Festuca rubra*-dominated grasslands, controlled grazing prevents overdominance of the species and encourages coexistence with ecologically important forbs and legumes. Intensive or irregular grazing weakens the sward and promotes species tolerant to repeated defoliation or even invasive taxa (Rotar et al., 2010; Păcurar et al., 2018).

→ Key principle: use moderate, rotational grazing to maintain structural diversity.

3. Principle of Rational Nutrient Management

Moderate organic fertilization is the most appropriate strategy for maintaining the balance between productivity and species richness. Small annual doses of well-decomposed manure increase soil organic matter, improve soil structure, and support mycorrhizal communities—critical in oligotrophic mountain ecosystems.

In contrast, mineral fertilization—particularly at high nitrogen rates—accelerates vegetation succession, simplifies community structure, and promotes aggressive nitrophilous species (Păcurar et al., 2014; Rotar et al., 2014; Samuil et al., 2025; Gheţe et al., 2025).

→ Key principle: apply moderate, intermittent organic fertilization; avoid high mineral inputs.

4. Principle of Preventing Abandonment

Abandonment rapidly leads to the loss of semi-natural character. In the absence of mowing or grazing, *F. rubra* grasslands evolve toward stages dominated by tall species such as *Calamagrostis arundinacea* or *Deschampsia cespitosa*, followed by the establishment of woody vegetation. Restoring traditional structure afterwards becomes difficult and costly (Păcurar et al., 2015; Vaida et al., 2016; Moș & Brînzan, 2024).
→ Key principle: ensure continuity of use to prevent successional degradation.

5. Principle of Integrating Agricultural Policy Measures

Sustainable management cannot be decoupled from agricultural policy instruments. Payments for High Nature Value (HNV) grasslands, agri-environmental schemes, and measures aimed at preventing abandonment—such as those included in PNDR 2014–2020 and PNS 2023–2027—provide essential economic support for maintaining extensive practices (Balázsi et al., 2018; Rușdea et al., 2011; PNDR, 2019; National Strategic Plan, 2023).
→ Key principle: link economic support with ecologically sound practices.

6. Principle of Integrated and Adaptive Management

The conservation of *Festuca rubra* grasslands requires an approach that harmonizes agricultural techniques with ecological characteristics of the habitat. In mountain regions, local knowledge and traditional practices have played a central role in ecosystem stability. *Festuca rubra* dominates not through aggressiveness, but through adaptability and ecological balance, embodying a functional coexistence between agriculture and nature.
→ Key principle: adopt adaptive, site-specific management grounded in ecological understanding.

CONCLUSIONS

Festuca rubra-dominated grasslands represent a defining component of European and Romanian mountain landscapes, reflecting the persistence of traditional agro-pastoral systems. They form ecosystems that are stable yet sensitive to management changes, and their dynamics serve as a reliable indicator of the overall condition of semi-natural grasslands.

The literature shows that these grasslands perform best under moderate use, where annual mowing or controlled grazing maintains sward structure and supports the conservation of floristic diversity. Low-input organic fertilization provides a sustainable compromise between productivity and biodiversity, whereas intensive mineral fertilization rapidly simplifies the plant community and diminishes ecosystem functionality. At the same time, abandonment remains one of the major threats, accelerating successional processes and undermining the semi-natural character of the habitat.

Through its ecological traits—rhizomatous growth, resilience to moderate disturbance, and strong regenerative capacity—*Festuca rubra* plays a fundamental role in the stability of mountain grasslands. Its association with mycorrhizal networks and its contribution to nutrient cycling emphasize the importance of belowground processes in maintaining ecosystem functioning. Furthermore, the species' compatibility with conservation-relevant flora enhances the value of these grasslands as key habitats.

In the current context of agricultural intensification and socio-economic change, *Festuca rubra* grasslands hold strategic importance for mountain landscapes. They demonstrate that moderate productivity, biodiversity, and cultural value can coexist when management is adapted to local conditions and guided by ecological principles. Agricultural policies targeting HNV grasslands and extensive systems can support the preservation of these ecosystems, but their effectiveness depends on a deep understanding of the mechanisms underpinning grassland stability.

Viewed as a whole, *Festuca rubra*-dominated grasslands are complex and valuable systems that integrate ecological processes, agronomic functions, and cultural identity. Their conservation represents both an ecological responsibility and an opportunity to sustain pastoral traditions and cultural landscapes across the Carpathians and other European mountain regions.

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