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REVIEW ARTICLE

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Diversification increases the resilience of European grassland-based systems but is not a one-size-fits-all strategy

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Abstract

Diversification of grassland-based systems is highly valued in agroecology, organic farming and other forms of regenerative agriculture. For lowlands, mountain and Mediterranean areas, we illustrate that diversification of grassland types, livestock species, products and farm labour allows coping with market, climatic and workforce-related risks. However, diversification is not a one-size-fits-all strategy and the type of diversification strategy should be adapted according to socio-economic, structural, technical and pedoclimatic conditions of each farm. Farmers' technical skills and ability to re-organise and monitor the system must be considered to avoid ineffectiveness of the diversified system. Moreover, it is essential to account for site-specific conditions so that the ecological processes to be optimised can provide the expected benefits. Diversification occurs on different levels, from grassland management to the entire farm activity. There may be trade-offs among these different levels impairing grassland ecosystem services. For instance, if diversification of farm activities dilutes the workforce, simplified grassland management can lead to the loss of vegetation communities of high ecological value. In contrast, case-adapted diversification benefits from local opportunities, available resources and external supports to secure the system and favour sustainable resource management. Diversification thereby preserves grassland ecosystem services and enhances farm socio-economic resilience to withstand perturbations.

KEYWORDS
agroecology, biodiversity, ecosystem services, management, mixed grazing, trade-offs

1 | INTRODUCTION

Grassland-based systems have historically been adapted to local conditions and the use of external inputs was limited. Therefore these systems were inevitably diverse and self-supplied. In the 20th century, agricultural industrialisation and the global market led to systems intensification and specialisation. Specialisation has increased the

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predominance of high-yielding fertilized swards and grass-legume mixtures over less intensively managed grasslands. Although productive, many of these high-yielding grassland-based systems are increasingly vulnerable to climate change (Melts et al., 2018; Stampfli et al., 2018). Fertilized grasslands, which are poorly fragmented and homogeneously managed also favour outbreaks of ground voles and moles (Couval et al., 2014). In uplands, where animals graze on steep slopes and sometimes in more remote areas, grasslands are threatened by partial abandonment due to lack of economic profitability. Forage production for hay and silage is concentrated on mechanizable plots on the farm, and the steep slopes are under-grazed, abandoned or planted with softwoods (Garambois et al., 2020).

Nowadays, the challenge is to replace the old paradigm based on simplification and standardization of production systems for optimising productivity per unit of human labour, with a new paradigm emphasising diversification at field, herd and farm scale to optimise productivity per unit of natural resource and provide a number of ecosystem services (Dardonville et al., 2022; Kremen & Miles, 2012; Wang et al., 2019). Diversification has the potential to reduce the vulnerability of grassland-based systems. Vulnerability not only depends on the exposure and sensitivity to risks, but also on the ability to adapt to or recover from perturbations (Smit & Wandel, 2006). Walker et al. (2004) defined resilience as the capacity of a system to absorb perturbations and reorganize while undergoing changes to maintain its function. Darnhofer (2014) has discussed that resilience covers the buffer, adaptive and transformative capabilities of any system. Buffer capability denotes the ability of a system to assimilate a perturbation without changing its structure or function; adaptive capability that of temporarily adjusting to change while staying in the current stability domain; and transformative capability implies transition to a new system.

Dumont et al. (2020) have demonstrated that production and ecosystem services provided by grassland-based systems are grounded in grassland type diversity and herd (inter-individual, inter-breed or inter-specific) variability (Magne et al., 2016; Ollion et al., 2016). The benefits of diversity can also arise from interactions between system components generating emergent properties at the farm level (Bennett et al., 2009; Steinmetz et al., 2021). At the farm level, it is also possible to adapt the type of product sold to market conditions (Astigarraga & Ingrand, 2011), and to mitigate the effects of climatic variability by temporarily decreasing stocking density (Do Carmo et al., 2016) or modifying herd equilibrium in multi-species farms (Joly et al., 2019; Mace, 1990). On-farm diversity and interactions among system components further enhance system buffer and adaptive capabilities. Transformative capability can be promoted by diversifying feed resources and products. Multi-species livestock farming and product diversification imply changes in sales management and in work organization (Martin et al., 2020). System redesign can even lead to a diversification of farm activities beyond the food-producing role of agriculture (Hansson et al., 2010; López-i-Gelats et al., 2011).

Biggs et al. (2012) have proposed a hump-shaped relationship between the level of system diversity and the resilience of ecosystem services. This suggests that there is a theoretical diversity optimum, below which low diversity limits the buffer and adaptive capabilities of the system. Beyond the optimum, system resilience would be compromised by being too complex. Farmers become unable to monitor and integrate all possibilities and interconnections into their analysis and consequently, the system will 'stagnate'. Based on this concept, we present a critical understanding of the diversification of European grassland-based systems on different levels. We discuss how the diversification of grassland types, livestock, products and farm labour can improve their resilience. Meanwhile, we identify diversification trade-offs and risks leading to poor grassland management and therefore to a decrease in production, biodiversity and ecosystem services. Finally, we briefly discuss how private insurance and public support are complementary levers to consider for achieving resilience.

2 | DIVERSIFICATION OF GRASSLAND TYPES, FEED RESOURCES AND GRASSLAND MANAGEMENT

Diversification in grassland type is here defined in a broad sense, as it summarises diversity of plant species, plant traits, environmental conditions (e.g., wetlands, dry grasslands) and grassland management (e.g., permanent or sown grassland, intensively or extensively used grassland, pasture or meadow). Plant species diversity can increase grassland resilience through various mechanisms (Lüscher et al., 2022), for example by buffering drought events due to a broad range of plant traits (e.g., Grange et al., 2021). However, the diversity of a single meadow or pasture can hardly buffer all potential perturbations to which it is exposed. Diversification of grassland types is therefore needed to further increase resilience. In intensively managed grazing systems, grassland type diversification can be achieved by cultivating drought resistant mixtures (Lüscher et al., 2022), including for instance sainfoin (Kölliker et al., 2017) on some fields of a farm. These resistant mixtures are not the most productive ones in average years, but they reduce the variability of biomass yield in dry years and thereby increase farm resilience. This lever of adaptation can also be found in extensively managed grazing systems, but with some plots having the agronomic potential for being sown and managed more intensively. Farmers can also diversify forage resources by cultivating additional fodder crops such as corn silage and cover crops to increase farm self-sufficiency. In France, it allowed beef and sheep grazing farmers to increase and stabilize the quantity of fodder harvested per livestock unit, but farm income was neither higher nor less variable due to higher stocking density and production costs (Mosnier et al., 2013). Diversification of fodder resources thus does not necessarily increase farm resilience but should be considered as part of global risk management at farm scale.

Fodder type diversification has further advantages and can benefit animal performance as the result of improved pasture nutritive value, of increased daily intake when animals are offered a more diversified diet, and of parasite control thanks to tannin-rich plant species such as sainfoin (Dumont et al., 2020). Another possible source for diversification could be the integration of 'poor agronomic value' grasslands on wet areas (which increases system resilience in dry years) or shallow soils (useful in wet years). Conservation of such semi-natural grasslands with a generally high ecological value would thus also generate benefits for fodder system resilience. In Mediterranean silvopastoral systems, grassland management creates a balanced mix of trees, species-rich pastures and marginal habitats improving animal performance and welfare (Moreno et al., 2018). Silvopastoral systems also preserve and increase biodiversity at farm and landscape scales, especially in transhumant systems. Trees and shrubs providing fodder and shade, favour the adaptation of these ecosystems to climate change and thereby increase their resilience. For instance, leaves and acorns of oak trees are used as forage supplement in Iberian dehesas. In Mediterranean wood pastures, livestock benefits from browsing pollarded trees, shrubs or pruned branches. Releasing domestic pigs in wooded areas (so-called pannaging) is still practised for fattening pigs with acorns, beechmast, chestnuts or other nuts in dehesas and montados. Moreover, the introduction of trees into grassland-based systems increases total carbon sequestration (thanks to carbon storage in branches and trunks) and creates microclimates under the canopy, which limit water evaporation and offer insolation to plants and livestock. This diversification of radiation, micro-topographic parameters (such as slope, exposure, convexity and concavity) and soil parameters (such as pH) enhances the diversity of grassland types (Franca et al., 2016).

Beyond the diversification of fodder system, adapting management intensity can enhance grassland resilience, and biodiversity effects can be modulated by management practises. For instance, Vogel et al. (2012) found that resilience was positively related to plant species richness only in the most intensively managed grasslands. Also the lower the mowing frequency in years of drought events, the higher the biomass yield in the subsequent year. In another study, land-use intensity did not alter either the magnitude of drought effects on biomass yield at the end of drought or the degree of drought recovery on aboveground production recorded 1 year after precipitation exclusion (Stampfi et al., 2018). Some short-term experiments have demonstrated that nutrient applications in semi-natural grasslands can maintain productivity and could therefore be considered as relevant to strengthen system resilience. For example, Nyfeler et al. (2011) demonstrated that if intensively managed grasslands are heavily fertilised, nitrogen yield increases. However, the additional yield is not provided by the grassland ecosystem itself, but by the external input alone, leading to a decrease in nitrogen use efficiency. Short-term study results may also not reflect potential long-term changes, and grasslands are likely to respond to disturbance in site specific ways, so that it can be argued against nutrient application to semi-natural grasslands (Melts et al., 2018). Diversification towards site-adapted management allows for the use of each grassland type at an appropriate intensity and provides the benefits of supporting and regulating services. Grassland diversification often comes along with lower grassland intensity of use, such as fertilisation and cutting frequency. Although reduction of intensity was reported to increase grasslands' quality-adjusted yield in some cases (Schaub et al., 2020), it reduced forage quality in other pastures and meadows (Bruinenberg et al., 2002; Tallowin & Jefferson, 1999; White et al., 2004). This trade-off can be addressed by diversifying livestock type and management, for example by grazing lower yielding animals, such as non-lactating dairy cows, on grasslands managed at lower intensity. Differentiated grassland types under site-adapted management can be harvested at different dates of the vegetation period. This reduces farmer's workload at peak times, and permits the use of agricultural machinery of lower volume and price. Finally, diversification of the grassland mosaic increases landscape aesthetics, which improves the perception of grazing systems by society.

3 | DIVERSIFICATION OF GRAZING LIVESTOCK AND HERD MANAGEMENT

In this section we deal with the diversification of the grazing herd that aims to benefit from inter-specific or inter-breed variability. Due to their nutritional requirements and morphological and digestive capacities, cattle, sheep, horses and goats have contrasting abilities to graze on short swards, digest roughage and detoxify forb secondary compounds. Mixed grazing with different livestock species can therefore increase overall pasture use, due to the complementary of feeding niches and grazing facilitation processes (Dumont et al., 2012; Martin et al., 2020). Mixed grazing can sometimes produce the most species-rich and structurally diverse swards (Gudmundsson & Dyrmundsson, 1994; Loucougaray et al., 2004) and enhance levels of ecosystem services provided by grassland-based systems (Wang et al., 2019). Animal growth usually benefits from mixed grazing. d'Alexis et al. (2014) reported enhanced lamb growth and meat production per hectare in mixed grazing systems of sheep and cattle. Jerrentrup et al. (2020) confirmed this result and reported an additional increase in suckler cow weight gain under mixed grazing. The pattern of animal growth according to sheep-cattle ratio is hump-shaped with a plateau, which offers a wide range of ratios resulting in maximal, or quasi maximal, animal performances. For this reason, fine-tuning the sheep-cattle ratio is not needed to take full advantage of mixed grazing (Joly et al., 2021). Thus, the need for continuous monitoring and corrective adjustments of livestock species ratio is eliminated and leaves the farmer free to focus on other tasks.

Due to dilution effects, mixed grazing is also an efficient strategy to reduce parasitic nematode infection in small ruminants (Marley et al., 2006) and horses (Forteau et al., 2020), which is likely to decrease treatment frequency, associated drug resistance and veterinary costs, and to reduce the negative environmental side effects of drug metabolites on dung beetle assemblages (Sands & Wall, 2018). Thanks to their two sets of incisors, horses graze close to the ground and maintain stable sward patches of high nutritive value (Dumont et al., 2012). Under continuous mixed grazing, cattle are excluded from these short lawns where they cannot meet their daily intake requirements, and switch to tall grass areas where they graze close to horse dungs and reduce sward parasite burden (Figure 1a). However, an alternate stocking of cattle and horses grazing together in a

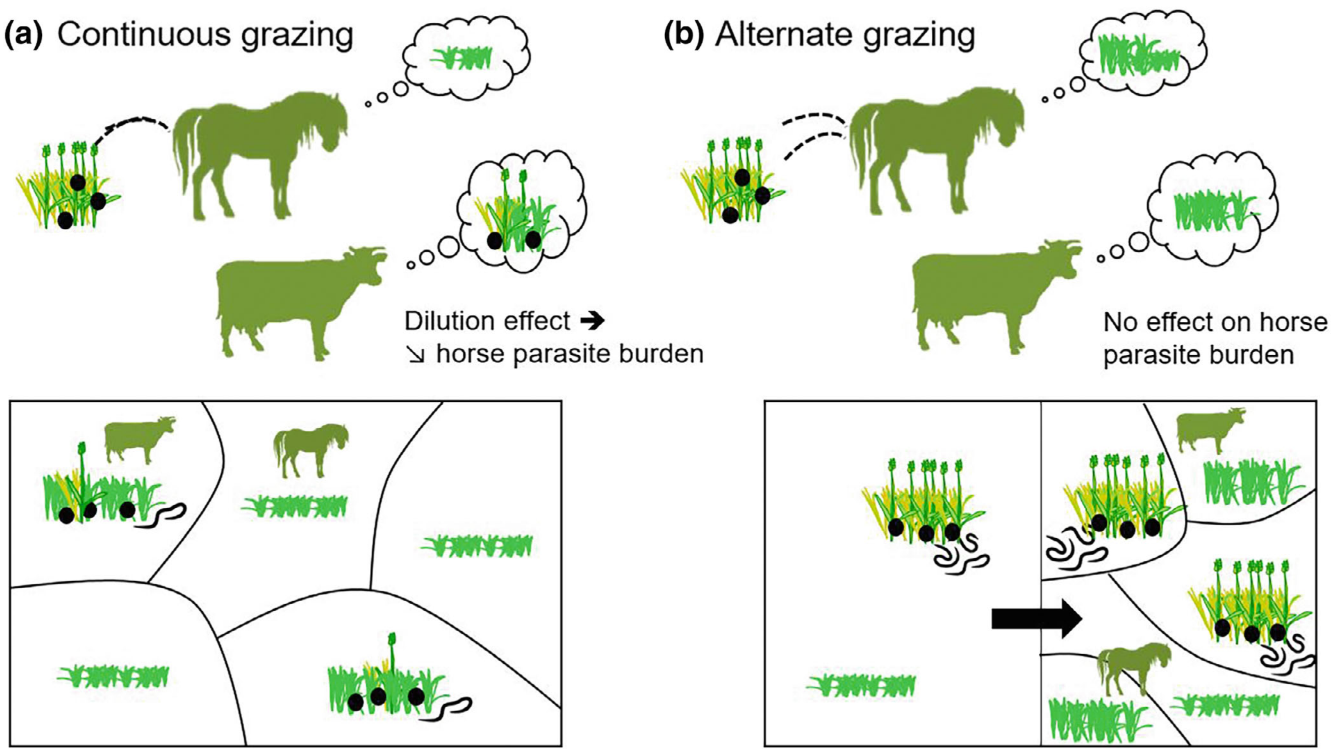

FIGURE 1 Contrasting effects of mixed grazing by cattle and horses on horse parasite burden and plot use according to pasture management: (a) continuous grazing (adapted from Forteau et al., 2020); (b) alternate grazing between two subplots (Fleurance et al., 2022). Under continuous grazing, cattle were excluded from short lawns and switch to tall areas where they graze close to horse dung patches, which was not the case under alternate grazing. Horse dung and nematode larvae are represented in each plot.

mesophile grassland provided animals with high-quality regrowth on the short patches. Consequently, cattle avoided tall areas with reproductive and dead grass, which limited their consumption of strongyle larvae near the horse dungs (Figure 1b). This can explain why no significant benefits of mixed grazing on horse parasitism was measured (Fleurance et al., 2022), and illustrates that co-grazing requires appropriate management to provide its expected benefits.

Mixed farming systems are also gaining interest to reduce inputs and production costs, and as a risk management strategy. Recent surveys in cattle-sheep farms of the French Massif central and across Europe have confirmed that farmers mention the stability of farm economic performance, satisfaction regarding income and an efficient use of grassland resources as the main benefits of mixed grazing systems (Mugnier et al., 2021; Ulukan et al., 2022). Mosnier et al. (2022) simulated that mixed farms have fewer work peaks, lower global warming potential and nitrogen balance, lower production costs and higher and more stable net incomes than specialized farms. In the case of a sheep-cattle mix, sheep production benefits more from the presence of cattle on the farm than cattle benefit from the presence of sheep, which may encourage sheep farmers to diversify more than a beef farmer. However, farm diversification may also reduce the performance of the production process due to an increasing complexity of farming systems (de Roest et al., 2018) and to a limited time that farmers can spend on each activity. Some mixed organic beef-sheep farmers indeed justified the low performance of their sheep flock because the sheep flock was not their priority (Mosnier & Moufid, 2021). Modifying the ewe-cow ratio, usually by adjusting the number of ewes, is the main lever of adaptation used by mixed farmers to cope with market, climatic and workforce-related risks in the short and medium term (Mugnier et al., 2021; Nozières et al., 2011). Although farmers usually consider high workload as a constraint, they also mentioned the pleasure of varied work and the flexibility of work organisation reducing overlaps between calving and lambing periods, among the advantages of mixed farming (Mugnier et al., 2021). In contrast, the benefits of mixed grazing for reducing parasitic nematode infection were not mentioned by these farmers, who instead feared disease transmission among species. Also in mixed cattle-horse systems, two thirds of the mixed farmers surveyed by Forteau et al. (2020) were not aware of the benefits of mixed grazing for parasite nematode management.

Beneficial diversification of livestock type does not necessarily imply grazing of different species in the same farm. Case-adapted management can also include dual-purpose breeds or cross breeding to ideally balance productivity and a sustainable use of available resources (Phocas et al., 2016). Moreover pasture management and resilience can be improved by keeping a 'service herd' of a hardy breed. These low-productive animals still show a number of adaptive traits. Light and big-footed Highland cattle cause less pressure to the ground leading to less erosion and soil compaction (Pauler, Isselstein, Berard, et al., 2020). They thereby allow a site-adapted use of steep slopes (Figure 2a), wet pastures and shallow soils. Moreover, they use pastures more evenly and consequently exploit the available

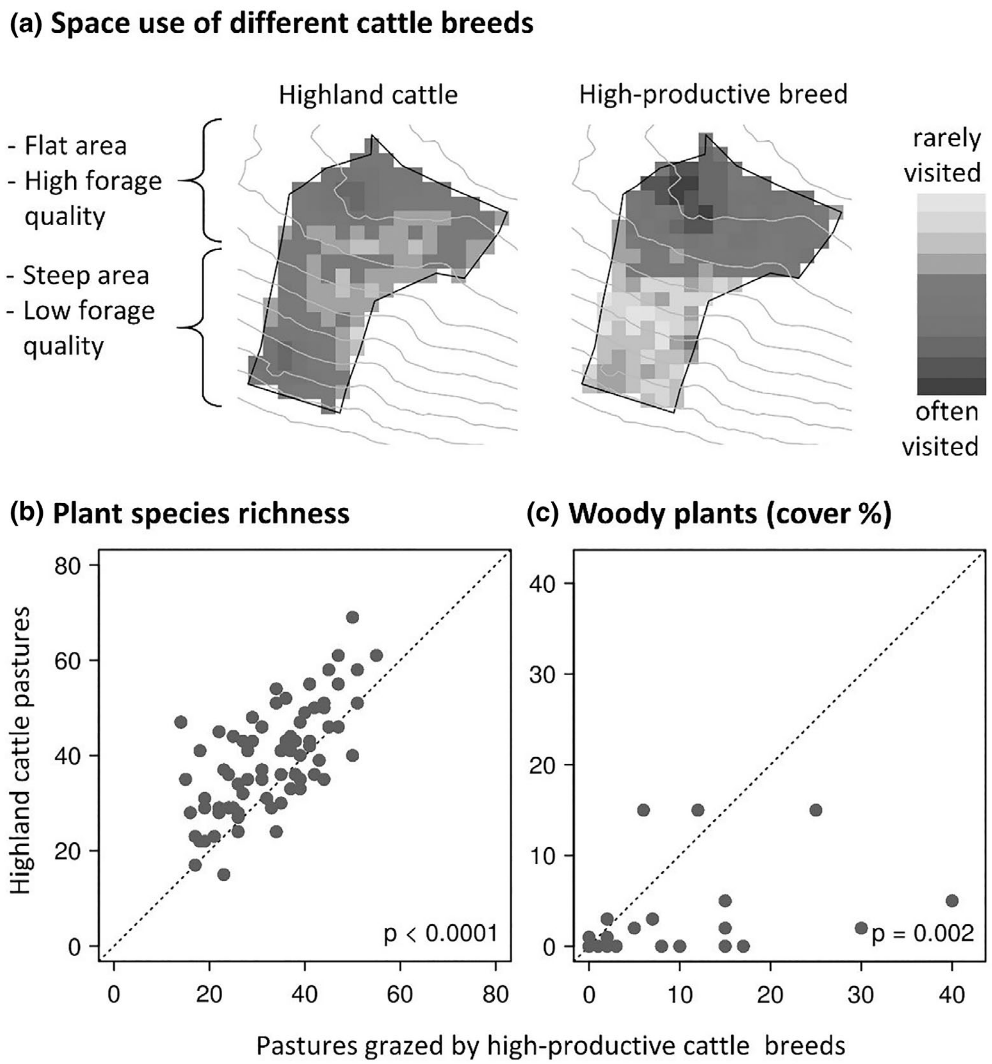

FIGURE 2 Distribution of two cattle breeds in Swiss upland pastures and its consequences on vegetation community: (a) space use of low-productive Highland cattle and high-productive cattle on a steep pasture of heterogeneous vegetation. Highland cattle use the available resources more evenly (Pauler, Isselstein, Berard, et al., 2020). (b) Plant species richness and (c) cover of woody plant species in pastures grazed by Highland cattle for at least 5 years compared to adjacent pastures of more productive breeds. Pastures of each pair were comparable in environmental conditions and management. *p*-values are given for the differences between the paired pastures of different breeds; these are calculated from a generalized mixed-effect model with pair as random factor and with negative binomial (b) and beta (c) likelihoods (Pauler et al., 2019).

resources more efficiently. Pauler, Isselstein, Suter, et al. (2020) showed that low-productive Highland cattle consume more problematic plants like thistles and shrubs than highly productive cattle. These differences in grazing behaviour cause a distinct vegetation in long term with higher plant species richness (Figure 2b), less woody plants (Figure 2c) and less other problematic plants in Highland cattle pastures compared to pastures grazed by more productive breeds under comparable environmental and management conditions (Pauler et al., 2019). Consequently, Highland cattle reduce workload needed for pasture management. Similar findings were presented for low-productive Engadine sheep, consuming green alder shrubs in subalpine-systems most efficiently and thereby hindering shrub encroachment and its numerous negative environmental effects (Pauler et al., 2022). Under low-nutritive value diet, so-called low-productive cattle gain more weight than high-productive cattle (Pauler, Isselstein, Berard, et al., 2020). Consequently, a diversification of livestock increases farm resilience in years of low forage quality. Finally, though the low output and the additional workload of managing a service herd may prevent farmers from diversifying their herd, the products of a service herd can benefit from the system's 'positive image' and be directly sold on-farm.

4 | PRODUCT AND FARM LABOUR DIVERSIFICATION

Transformative changes that enhance the resilience of pasture-based ruminant systems to market price fluctuations can include product diversification (Vagnoni & Franca, 2018) and development of an on-farm processing enterprise and short-distribution channels (Martin et al., 2020), with the aim of creating more added-value. Beyond product diversification, transformative changes can diversify farm activities beyond the food-producing role of agriculture (e.g., agritourism) and the full-time dedication of family members to farming activity (López-i-Gelats et al., 2011).

Product diversification can be achieved by adding pigs or poultry with a short production cycle, to dairy or beef cattle. This diversification allows a more regular cash inflows and more stable incomes as cattle and monogastric meats are sold onto different markets. Moreover, offering a diversified range of product for sale also facilitates the use of short supply channels; in rural areas of central France this was shown to enhance the demand for local beef and pig meat and consumers' willingness to pay (Vollet & Saïd, 2018). Combining monogastric and cattle production can thus be seen as part of the securisation strategy of farmers as it reduces exposure and sensitivity to risks.

On-farm processing and the size of the monogastric production unit are key drivers of farm economic performance. Among 17 organic mixed-species farms from the French Massif central and Occitany, the two economically most efficient farms associated beef cattle to monogastrics and had an on-farm processing enterprise (Steinmetz et al., 2021). Conversely, beef systems with large monogastric production units that sell the animals to cooperatives were highly dependent on external inputs, which led to high excess of nitrogen per hectare (which has a negative impact on grassland biodiversity) without gaining economic efficiency. Due to this high dependence on external inputs, pig production did not reduce income variability compared to specialized cattle farms in this case (Mosnier & Moufid, 2021). Diversification also enhances the need for new technical skills and sometimes for high initial investments for animal housing and waste management, which may act as strong inhibitors of farm diversification (Dumont et al., 2020). In France, data from the organic farm network from the Inosys livestock database reveal that the share of pasture area is the lowest in cattle-monogastric farms (Mischler, 2019). Moreover, there is a risk that farmers become less concerned with grassland management if cereals and pulses are available on the farm and can be used to feed livestock. This could in turn negatively impact grassland nutritive value and biodiversity.

Among 100 European farms operating according to organic farming principles (Ulukan et al., 2021), the five farmers who achieved the best sustainability performance did not seek to maximise the diversity of their system, but rather to make sense of it by creating added value (Ulukan et al., 2022). These five farms combined cattle with pigs or sheep. None of these farmers were engaged in rotational grazing (to avoid the cost of fencing that would be suitable for both cattle and sheep), nor in agritourism. Some of these farmers were involved in processing and some of their products were sold on the farm. In summary, these farmers were using a level of diversity adapted to the resources available and the potential of the environment.

Labour diversification outside agriculture, such as agritourism or off-farm employment may, however, be an attractive option for pastoral households in scenic landscapes. On the one hand, this kind of diversification disconnects farm income from climatic and economic risks related to agriculture (López-i-Gelats et al., 2011). On the other hand, it may increase land abandonment if the additional income is not reinvested into pastoral farming activities. Thus, there is a risk that due to the additional workload outside agriculture, marginal grasslands of high ecological value are poorly managed and finally lost. For instance, in the Catalan Pyrenees, there is a gradual transition from sheep to cattle and even horse production due to the low economic profitability of sheep farming. As shown in Figure 3, sheep grazing preserves the species-rich *Arrhenatherion elatioris* community that is typical of mown (or mown and grazed) meadows. Extensive horse production in only-grazed pastures requires very little in terms of the workforce (López-i-Gelats et al., 2015) and is part of a simplifying management regime, which is triggering a transition away from the typical *Arrhenatherion elatioris* community (Figure 3). Thus, while the

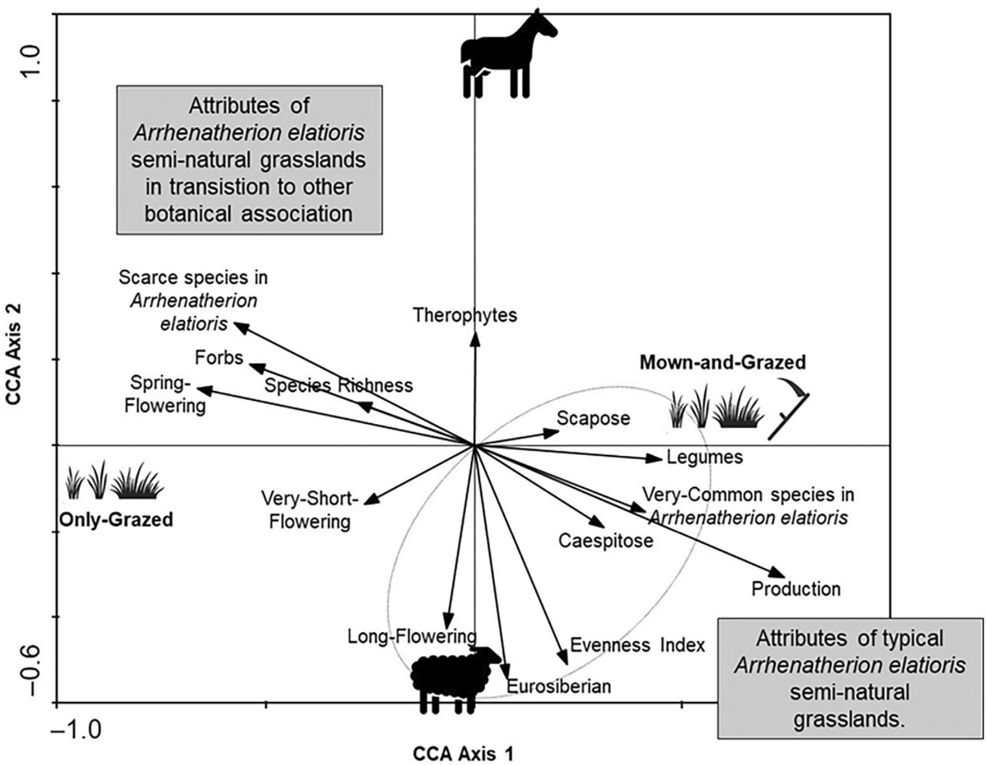

FIGURE 3 Plot scores for the first two axes of a canonical correspondence analysis for species' composition and vegetation community structure of *Arrhenatherion elatioris* semi-natural grasslands of the Catalan Pyrenees under simplification practises resulting from the diversification of pastoral household labour outside agriculture: Horse grazing and abandonment of mowing (adapted from López-i-Gelats et al., 2015). Arrows represent different botanical parameters.

diversification of labour outside agriculture may enhance the resilience of pastoral households, it also removes resources traditionally devoted to the livestock farming activity and thus threatens grasslands of high ecological value.

5 | EXTERNAL SUPPORTS TO FOSTER SYSTEM DIVERSIFICATION

As diversification can reach its limits, external supports must be considered. Public supports and private insurance are important complementary levers to be considered to help farmers achieving sustainable and resilient grassland-based production. Public supports such as environmental payments could reduce farm vulnerability by increasing farm income in all situations. In addition, a public safety net compensates farmers in case of extreme events (climate, market or animal health issues) in several EU countries, which reduces the risk of significant economic loss. However, particular attention must be paid to the conditions of these payments to prevent them to disincentive farmers to manage normal risks themselves (Tangerman, 2011), and to encourage specialized, capital- or input-intensive systems. For instance, the per hectare and per animal head subsidies did not increase diversification but favoured farm enlargement and simplification of practises (Veysset et al., 2014), which may result in poor grassland management.

In the most recent narrative of the Common Agricultural Policy 'CAP for public goods', public subsidies will target more specifically the habitat and cultural services provided by semi-natural grasslands, as they fulfil important functions for biodiversity, recreation opportunities, and scenic and cultural landscapes (e.g., open grassland in Swiss silvopastoral landscapes: Huber et al., 2013). Moreover, European agriculture receives subsidies that encourage livestock farmers to diversify their sources of income to limit further land abandonment in upland areas and retain people in more remote regions (e.g., Pardini & Nori, 2011).

Farmers are also encouraged to take out private insurance. Multi-peril grassland insurance scheme can reduce the variability and the probability of low farm income (Finger & Calanca, 2011). Conversely, many farmers are reluctant to subscribe such insurances they find too costly and prefer to rely on on-farm options and public safety net. As the cost of self-insurance increases for important and rare losses (Mosnier, 2015), insurances could be an interesting option (Clarke & Dercon, 2009), particularly if the public safety net is reduced. However, they should not be considered without assessing beforehand the opportunities provided by the diversification of grassland types, livestock, products and farm labour on each farm.

6 | CONCLUSION

Diversification on different levels allows addressing risks of different natures of risk. Numerous benefits arise from this diversification for economic viability and environmental goals, such as input reduction and habitat conservation. Here, we have demonstrated that the diversification of grassland types, livestock, products and farm labour can secure grassland-based systems in lowlands, mountain and Mediterranean areas, and that farm buffer, adaptive and transformative

TABLE 1 A typology of resilience factors according to Darnhofer (2014) related to on-farm diversity, or diversification of farming practises in grassland-based systems, with examples

Management decisions	Diversification of grassland types and feed resources	Diversification of livestock and herd management	Farm management, and diversification of products and labour
Buffer capability	• Benefit from plant species and plant traits diversity to buffer drought events • Preserve within-farm grassland diversity (e.g., wet areas of poor agronomic value) to buffer drought events	• Use different lines/breeds in mixed herds to benefit from the diversity of their adaptive responses • Keep a 'service herd' of a hardy breed for pasture care • Graze different species together to enhance grass use and decrease parasite burden	• Make fodder stocks to buffer years of low biomass production
Adaptive capability	• Sow a drought-resistant mixture (e.g., sainfoin) to adapt to drought events • Decrease mowing frequency to preserve pasture quality in years of drought events • Temporarily stock biomass for late-season grazing to adapt to fluctuating biomass	• Sell animals to decrease stocking density and adapt to decreased fodder availability • Modify equilibrium between herds in multi-species farms to adapt to fluctuations in market conditions and climatic shocks	• Change type of product (e.g., age at slaughter) to adapt to fluctuations in market conditions • Hire a worker to adapt to labour peaks and increased workload
Transformative capability	• Develop agroforestry (e.g., with *Fraxinus excelsior*) to deal with changes in environmental conditions • Grow some cereals on-farm and graze animals on cover crops to exploit all available resources	• Lengthen lactation duration and animal productive lifespan to limit emissions per unit of product • Add pigs or poultry (that have short production cycles) to cattle farms for more regular cash inflows	• Transform products on-farm to create added value • Diversify outside agriculture (e.g., off-farm employment, agritourism) to disconnect farm income from market conditions

capabilities can be promoted by enhancing within-farm diversity (Table 1). But diversification is not a one-size-fits-all strategy. Supporting diversification aims at site-adapted management to maintain grassland-based systems. Local conditions and farmer requirements must be considered. We showed that there are optimal levels of diversification at different scales that are intertwined and depend on farm characteristics. Interesting levels of joint productivity, quality and stability of grassland production could be achieved by promoting grassland biodiversity through diversified types of grazing animals and adapted mowing and fertilization intensities. Diversity in soil types and grassland exposure can stabilize fodder yield in dry years. The introduction of forage that are less sensitive to dry conditions is a second lever of securization. Nonetheless, attention should be paid to contain the increase in production costs generated by additional mechanized operations and input requirement, and in intensification of herd production. Diversification of products and farm labour are opportunity to add value and to secure the whole farm. However, there are trade-offs and levels of substitution between different levels of diversification. For instance, if the farmer strategy leads to diversified activities, the workforce could be diluted and farmers therefore run the risk of managing each activity less well. This could negatively affect the potential of grassland biodiversity to stabilize and deliver ecosystem services.

Farmers are therefore advised to take a thorough look at the conditions of their farm, to become aware of all opportunities and to realise as much of them as they can manage reliably. Rather than seeking to maximise system diversity, successful farmers aim at using a level of diversity adapted to available resources (including workforce) and the potential of farm environment. Benefiting from local opportunities allows the preservation of grassland biodiversity while also enhancing farm socio-economic resilience, and its mitigation and adaptation potential to climate change and other perturbations. These opportunities are enabled by processes such as experimenting, knowledge sharing, farmer networking and cooperating (Klerkx & Begemann, 2020), which are developing in European grassland-based systems (Dernat et al., 2022) and worldwide (Ruggia et al., 2021).

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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