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Restoring grazing agroecosystems in Mediterranean less favoured areas for resilience and productivity: experts opinion

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Abstract

Mediterranean agroecosystems are under increasing pressures by extreme weather events, which together with poor livestock grazing management bring the already degraded lands closer to desertification. To address these challenges, we develop a decision support manual for sustainable management of degraded lands based on local plant and animal resources. We present a conceptual approach to quantify the quality attributes of current pasture-based livestock and mixed farming systems to increase their added value. Most approaches focus on lowland areas, we propose building a system to assess and quantify the quality and management of grazing lands as well as the small ruminant farming practices in Less Favoured Areas (LFAs) areas of the Mediterranean. The interventions have been proposed by 17 researchers from different disciplines ranging from animal science and animal husbandry, nutrition and genetics, pasture management, plant breeding and soil science to regional development and environmental science and agricultural economics. They are based on technical and socio-economic information, to foster the development of business models towards sustainable management of regenerative grazing. These models are also expected to be used as evidence for motivating farmers and stakeholders in reinforcing grazing as a practice that, when properly used and implemented using local knowledge, reduces land degradation and contributes to the conservation of the local resources. The economic analysis showing the costs and benefits of the applied systems is important to foster the integration and implementation of the recommended schemes and leads to more efficient planning through better decision making. The proposed interventions are designed to stimulate farmers to learn or rediscover grazing techniques, and to stimulate a re-think of priorities on the multi-faceted contribution of grazing agro-ecosystems, among others, on soil health, land degradation, sustainable grazing management and population conservation in LFAs, acknowledging the importance of pastureland regeneration. In the long term the introduction of the decision support manual and the business model will benefit the quality and management of grazing agroecosystems. Furthermore, it is essential to adjust the agricultural policies to implenent the proposed measures.

Keywords Grazing, Agroecosystems, Resilience, Less Favoured Areas, Mediterranean

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Introduction

Livestock farming systems in the Mediterranean areas are under increasing pressure from extreme weather events (droughts, floods), which combined with poor livestock grazing management lead to soil erosion and degradation bringing the agricultural ecosystem closer to desertification [1]. Data concerning arid regions indicate that degradation costs approximately 4–8% of their gross annual domestic product, while covering 40% of the planet's surface area [2]. Although drylands are home to at least 20% of the world's human population [3], it is estimated that approximately 10–20% are suffering severe land degradation. The latter is also observed in mountainous areas [4] where agricultural and management practices, can negatively affect soil condition by up to 90% [5]. These areas based on EU data cover 54% of EU farmland and are characterized as Less Favoured Areas (LFAs), of which 16% are located in high altitudes with challenging climatic conditions (LFA Mountain) and the 38% in areas of poor productivity (LFA—Other than mountain), such as dry lands [6].

The limited rainfall in winter and the high temperatures in summer, causing long periods of drought in LFAs regions, affect agricultural activity. It has been documented that 60–70% of soil ecosystems in these areas are in poor physical, chemical and biological state resulting in low provision of ecosystem services, while the pressure on these lands is expected to increase in the future, with an estimated cost for the EU around 50 billion euro per year [2]. In more detail, according to the European Commission 30 to 50% of the most productive and fertile soils in Europe suffer from soil compaction, while 12.7% are affected by moderate to high erosion resulting in poor soil physical condition. In addition, more than 3.8 million hectares in the EU suffer from salinisation, the majority of which are located in the Mediterranean, while European soils exceed nitrogen and phosphorus limits, which is a major factor in soil degradation and leads to chemical imbalances. These conditions are further exacerbated by the fact that every year the mineral soils under cultivated land lose around 7.4 million tonnes of carbon. This increase greenhouse gas emissions and endanger soil biodiversity (i.e. earthworms and mites species richness has declined), increasing the risk of desertification [7].

Although the pastures located in LFAs, which are characterised by small scale farms, have been important means of subsistence for rural population, their role for a sustainable land restoration and conservation is debated. The low economic competitiveness and the changes in the socio-economic context, have pushed on the intensification of production with little consideration on the potential impacts on ecosystems [8] and their sustainability [9].

New production approaches may help the regeneration of local agroecosystems [10]. Taking all this into account, as well as the latest, widely manifested opinion that livestock production has the highest impact, among agricultural activities, on global warming, farming practices must be assessed and reviewed to build resilience and increase the sustainability of the system. In support of this statement and given that there is a wide debate on production systems, weather intensive or extensive, considering among others their impact on the environment and biodiversity, in this paper, before proposing solutions, we will try to give a framework for their definition. As indicated by ref. [11] intensive production is characterised as largescale, geographically concentrated, commercially oriented, specialized production units, while extensive is defined as small-scale, subsistence, mixed crop and livestock production systems with a limited use of external inputs, such as agrochemicals and machinery, where animal production is based on extensive grazing and hay meadows, and with low stocking densities. However, it has to be noted that production systems, intensities and purposes differ between countries [12] while in the case of the Mediterranean region intensification is notable in the plains of the lowlands which is accompanied by abandonment of the extensive/traditional production systems mostly located in mountainous areas [8]. Furthermore, because the impact of this change has strongly affected small-scale farms that are mainly pasture-based and located in LFAs, this paper fill the research gap discussing a conceptual approach on potential solutions for farmers located in these areas.

In a recent study, assessing the environmental footprint of different mountain farming systems, it was shown that the impact was greater per unit of product and lower per unit of area on extensive than in intensive farms [13]. In terms of production efficiency, the extensive farms had a lower gross energy conversion ratio, but outperformed intensive farming systems in terms of converting nonhuman-edible feed into human food. The large variability detected in terms of the environmental footprint indicates that the farming systems per se are not the main drivers of environmental impacts. Conversion to intensive systems has clearly not reduced the environmental footprint of dairy farming, but clearly increased its dependence on external concentrated feeds and thus resulted in competition between feed and food [14]. Particularly in the case of Mediterranean ecosystems the farming approach of choice may no longer be to maximize the farm level potential, but to adapt production targets to the capacity of the farm.

Besides the provision of safe food and feed and quality livestock products, pasturelands in LFAs contribute to ecosystem services such as the conservation of genetic

plant and animal resources, climate regulation, emissions mitigation [15] and biodiversity conservation [16, 17]. Therefore as their abandonment [16], which is constantly reported, jeopardises the viability of these areas and their continued inhabitation, it is important to find long-term solutions to regenerate and conserve LFAs for agricultural production in the Mediterranean, [18, 19] and for carbon sequestration as well as biodiversity [20, 21]. Although some environmentalists support the idea of the ecosystems being better without any human intervention, even concluding that ruminants are predators that enhance degradation, it has been proven that proper grazing management leads to more resilient ecosystem [22]. Moreover, they tend to ignore that these ecosystems have being developed under livestock grazing practices for many centuries or even millennia [23] and are now part of anthropogenic biodiversity, landscape diversity, and even arable soil fertility management.

The case specific scenarios we propose make best use of local plant and animal resources, insofar they are better adapted to local climatic conditions which consequently reduce environmental stress and increase production performance [24] while serving ecosystem services [25]. As stated by FAO [26] in low input agro-ecosystems the emphasis on improving locally adapted resources leads to more sustainable outputs than high yielding breeds that have been improved to meet the needs of intensive production systems. In addition, the proposed practices enhance land and ecosystems restoration. Intercropping for instance, provides food and animal feed and helps to restore soil fertility, agricultural by-products used as animal feed, while the cultivation of medicinal plants can have beneficial properties for animal health [27].

The use of cutting-edge technological tools (remote sensing, 3D-Geographic Information System (GIS), drone mapping, etc.) can support the modelling and visualisation of scenarios, making them understandable for stakeholders. Furthermore, involving local actors and engaging them in decision making on the management of territories and common goods (pasture, water) can be profitable with the use of new technologies. Good agroecological practices are integrated into a decision support tool for the sustainable management of abandoned and degraded lands which contribute to a more effective implementation of the proposed practices. Country or agroecological region-specific tailored projects can be supported by this tool to re-introduce and/or continue practices on Mediterranean farms in LFAs which improve resource management to restore grazing ecosystems with proven benefits for biodiversity soil carbon and clean water resources.

To mitigate these challenges, we propose building a system to quantify the quality attributes of current pasture-based livestock and mixed farming systems and to assess the management of grazing lands and the small ruminant farming practices in LFAs areas of the Mediterranean. The aim is to promote interventions for the restoration of grazing agroecosystems using a conceptual approach based on local plant and animal resources and a decision support manual for the sustainable management of degraded lands that contribute to the increase of their added value. We introduce conceptual solutions and a business model approach that deliver concrete and feasible plans for the restoration of grazing agroecosystems.

A systematic approach for the regeneration of grazing agroecosystems

Current status and identification of factors affecting the systems

This systematic concept-based approach is based on the restoration of degraded and/or abandoned agroecosystems through the reintegration and upgrading of local knowledge and practices that for millennia have been the main pillar of population support in challenging environments, such as LFAs [28]. The identification, recording and evaluation of the current status of pasture-based production systems, the extent of land degradation problems and the impacts on all aspects of pasture-based ecosystems in the different regions can lead to the need for documentation. This can be achieved by selecting, through a comprehensive evaluation, current farming practices that seem to have potential to contribute to the restoration of Mediterranean agroecosystems and by creating a relevant typology based on common definitions.

Subsequently, identifying factors that have the most decisive impact on the system in terms of pasture-based livestock practices can reveal their potential and identify the main drivers affecting the sustainability of the farming systems and establish the best practises. The initial objective of this assessment is to use the appropriate tools to filter the information collected through the process, in order to focus on the most important issues, while at the same time optimizing the use of locally adapted livestock breeds and forage species. The use of representative indicators scales up the already proven expertise and produces prototypes that in turn provide evidence of their effectiveness in regenerating natural resources and agroecosystem functions. In line with the overall objective, the indicators implemented in specific scenarios in combination with agronomic practices (intercropping, mixed farming etc.) [29] also exploit emerging ecosystem services (Fig. 1). The selection of indicators jointly with local communities, based on plant varieties and livestock breeds adapted to local climatic conditions, strengthens social structures, promotes their implementation and adds value to the outcome.

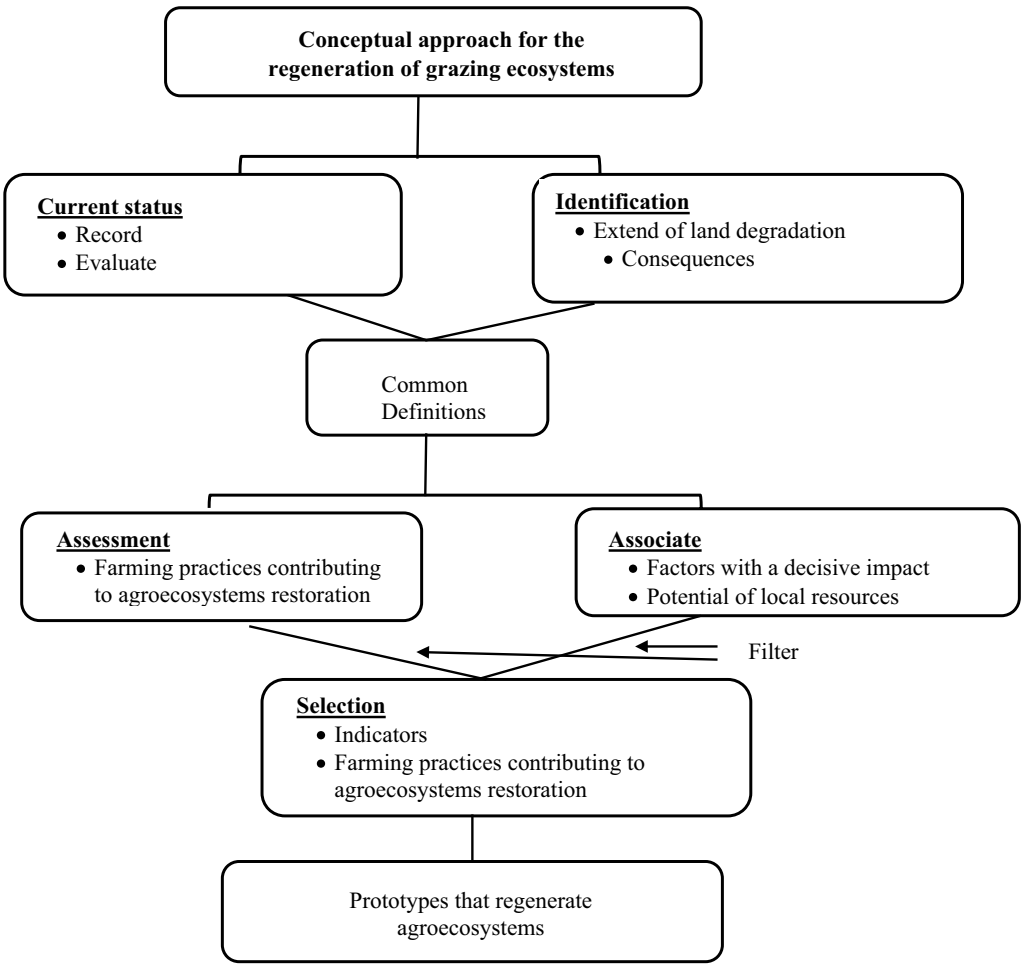

Fig. 1 Conceptual approach for the regeneration of grazing ecosystems

Analysis and assessment of the farming practices in the Mediterranean grazing lands in LFAs

The methodologies applied promote agronomic practices, which restore pasturelands towards feed and food production maintaining and even restoring soil fertility. For example, it has been reported that vegetation restoration in degraded ecosystems prevented further erosion [30], while vegetation cover of protected soils in areas where sustainable grazing was applied resulted in reduced water runoff, reduced sediment loss and lower soil temperature [31]. These practices also enhance biodiversity, promote circular economy through the use of agricultural by-products as animal feed, and improve animal health and product quality using medicinal plant. The effectiveness of the adopted interventions is evaluated based on the agronomic, vegetation and biodiversity data, and through the identification of genetic patterns that contribute to the adaptation of local breeds and varieties [25, 32]. The benefits for biodiversity, livestock and new ecosystem services derived from the practices implemented add value to the assessment of the scheme.

An analysis of the strengths and weaknesses, opportunities and threats (SWOT) records and evaluates the parameters affecting current farming systems and provides an overview of their functions. The assessment is performed on existing systems and farming practices in typical Mediterranean grazing lands and sites on LFAs with (i) low, (ii) moderate, (iii) high, (iv) very high land degradation. The use of cutting-edge technology allows the accurate mapping of the different agro-ecological zones and the assessment of their respective levels of degradation, as a first level of diagnosis necessary to establish focused consultations with the active participation of local stakeholders. In addition, living labs and focus groups are essential to document needs and challenges to integrate social requirements and ensure representation of the different stakeholders. This dual approach aims to create an environment that allows the collection of

diverse and representative information and seeks to foster collaborative innovation involving heterogeneous stakeholders, from citizens to policy makers and researchers. This emphasizes the importance of diverse stakeholder groups that can contribute to a representative approach [33]. With focus groups, smaller groups will engage in more focused discussion on specific topics to create a pool of data collection. These two assessments can provide a complementary approach to documenting pasture-based grazing systems [34].

The implementation in different pasture-based livestock systems applying extensive, moderate, and intensive management practices and the pressure imposed on each system (low to very high) determines and evaluates, together with the system effect on production performance, the health (plant, animal), animal welfare and product quality. To perform such an assessment, the integration and analysis of data on abiotic (soil, climate), biotic factors (flora, fauna) and socioeconomic factors contribute to the selection of pasture-based systems that facilitate the restoration of degraded agroecosystems.

Selection of indicators and development of a business model for the restoration of grazing agroecosystems

Thus, to achieve a smooth transition from the current unsustainable management to the creation of a new system that makes full use of available knowledge, practices and tools, it is necessary to provide business models that rely on a multi-actor approach capable of synthesizing and consolidating shared knowledge, making optimal use of available resources. By covering different scenarios for each of the identified cases that promote land restoration (e.g. extensive, semi-extensive, moderate grazing), synthesising and integrating a diverse range of knowledge, expertise and competences leads to the development of representative business models. It contributes to strengthening the demand for innovation, optimising synergies and aligning the interests and existing innovations of the collaborating stakeholders. This in conjunction with the different probabilities of the outcome (i. low, ii. moderate, high, iv. very high) and the available local plant and animal resources, develop a guide for the proper implementation of case-specific scenarios.

The application of different scenarios on management practices and interventions that enhance the improvement of indicators ensure the sustainability of the system and contribute to the restoration of degraded soils. The development and adaptation to the specific needs of each user (enterprise, cooperative, country/region) among plant and livestock systems that foster the conservation of local resources, the reduction and recycling of external and available inputs respectively, contributes to the further restoration of degraded agroecosystems. To facilitate the management of needs until the successful establishment of the new system, the decision support manual includes a policy-level guide on how to allocate the available subsidies to support stakeholders during the transition period.

Mode of action of the grazing system restoration measures

The application and benefits of FAIR principles to support decision making

The proposed concept-based approach is expected to implement prototypes and decision support tools for pasture-based grazing agroecosystems applying the FAIR (Findable, Accessible, Interoperable and Reusable) Guiding Principles [35]. This will give all stakeholders, from scientists and policy makers to farmers, access to already collected data, enhancing and implementing the ability of automatic data use, for providers and users, while supporting its reuse. This allows actors to better organise and utilise their results, replicate and implement proposed interventions that are optimised to meet their requirements [36]. Furthermore, the application of FAIR principles in the case of Mediterranean agroecosystems in LFAs, provides insights into how data are actually used in scientific communities and promotes the creation of a collaborative consortium that proposes the best practices in the use of the available data [36]. The establishment of the consortium and the cooperation with farmers and local cooperatives in different countries and regions will make it possible not only to widely distribute the decision support tool through the collaborative network, but also to provide information, guidance and support to all stakeholders who need it, maximising accessibility to a wider audience.

In this respect, there is the possibility that the approach may no longer be to maximize the use of farm level potential, but to adapt production targets to the capacity of the farm. Consequently, reinforcing grazing as a practice has the advantage of encouraging farmers to learn or rediscover techniques, mainly through on-the-job training, and to acknowledge that change cannot be immediate. This includes maximising the use of forage associated with traditional extensive production systems, which has also been linked with higher levels of landscape diversity and biodiversity. Particularly in LFAs with steep slopes, traditional extensive production systems have been proven to contribute to the conservation of agricultural areas [37]. At the operational level, implementing the proposed solutions adjusted to case-specific scenarios (e.g. extensive, semi-extensive, moderate grazing) that address farmers' concerns and align social demands serving ecosystem services [25] improve the sustainability of the system. Although, all resources may not be always

used profitably, maintaining an appropriate level of diversity and making efforts to promote a wide range of grazing systems may enhance soil carbon storage and reduce negative impacts of increased grazing pressure in the long term [38]. However, in order to implement the proposed interventions on a larger scale, professional training and advisory services need to be used and the CAP RDPs can play a crucial role in the adoption of new policies that will restore grazing agro-ecosystems [39].

Assessment of agronomic and environmental indicators

The SWOT analysis results provide the basis for the selection of representative indicators that together with pasture-based management practices and interventions are applied in real practice. The evaluation of the obtained results based on the expert interviews, remote sensing & GIS techniques of vegetation mapping, and existing herd movements (daily, seasonal) ensures transparency in risk assessment and eliminates uncertainty. A farming system approach is designed to verify that the implementation of the selected representative satellite-derived environmental indicators provides the resilience of the system and add to the restoration of degraded lands. Satellite remote sensing can provide information on soil erosion, while remote sensing combined with GIS provides basic information on the dynamics and intensity of erosion in time and space [40]. Choosing the appropriate environmental indicator can reduce complexity so that policy options can be clearly formulated, can help identify the need for intervention through analysis of trends or correlations with other indicators and help discover potential sources of innovation through comparison between units [41]. The use of the Normalized Difference Vegetation Index (NDVI), as an indicator of the greenness of the biomass, obtained from satellite data, is currently used together with drone multispectral and lidar monitoring sensors to assess the state of vegetation and its growth before, during and after the application of the proposed interventions was different depending on the management condition, suggesting that grassland management partially filters the climatic drivers of changes in forage production [42]. The results from the agronomic evaluation of flora richness on each test area, soil analysis at different depths together with the estimation of soil GHG fluxes (CO_2, CH_4, N_2O) provide a complete overview of the effect of interventions on soil parameters.

Assessment of zootechnical indicators

The estimation of the herbage mass and the estimation of the forage nutritive value (crude protein, fiber fractions (ADF, NDF), energy, secondary compounds) gives a good insight to maximizing the use of feed nutrients into productive output [43]. The subsequent evaluation of the livestock performance and the assessment of the effect on production (milk and meat samples) by analysing product quality characteristics (e.g. bioactive substances such as fatty acid content, anti-oxidants etc.) contributes to the identification and selection of plants that possess optimal nutritional characteristics [41]. In addition, in vitro gas production technique offers useful insights for the evaluation of feed digestibility as it was recently shown [44]. The use of the in vitro gas production technique to estimate feed digestibility is based on measured relationships between in vivo feed digestibility and in vitro gas production, in conjunction with the feed chemical composition. Recently, it was found that the in vitro gas measurement methods focus on determining the digestion of soluble and insoluble carbohydrates, while the amount of gas produced by a feed during incubation indicates the production of volatile fatty acids (VFA), which are a significant source of energy for ruminants [45]. The resulting gas is produced directly from the microbial degradation of the feed and indirectly from the isolation of acids produced as a result of fermentation.

Assessment of the economic indicators

However, there is a need for widespread application of convincing results, as economic analysis exploring the costs and returns of the applied systems helps to integrate the interventions and make better decisions for more efficient planning. Furthermore, as public and stakeholders' opinion needs to always be considered, it is essential to use focus groups at the local level to analyze the socio-economic and technological constraints and benefits of the recommended changes in the study area. In this way the results of the proposed study highlight how land management practices that are tailored to the needs of all stakeholders can be adopted by countries/regions and provide policy solutions using local resources and open access decision support tools against land degradation.

Development of the concept-based approach

The proposed concept-based approach is developed following an incremental and interdisciplinary framework involving the multiple actors of the pasture-based livestock farming systems. By adopting a lean and cumulative approach, the collected knowledge synthesizes and consolidates commonly accepted grounds, while making optimal use of the complementarities of the different stakeholders and aligning the interests and existing innovations. The overall objective is to support economically and environmentally viable grazing practices, by maximizing the use of forage feed resources and foster benefits of vegetation cover on soil properties. The identified technical, operational, and agroecological measures will contribute to the maintenance of agricultural activity in the LFAs

Table 1 Sustainability challenges and proposed solutions

Challenges	Restoration approach	Result
Soil degradation	Local knowledge and practices already tested at a research scale in the Mediterranean region to restore soil health on degraded lands	Mapping and rating of degraded lands status (i) low, (ii) medium, (iii) high, (iv) very high. Proposition of measures tohat prevent erosion (e.g. establish vegetation that protects soil) and improve soil health
Loss of land productivity and biodiversity	Implementation of regenerative and conservation practices to restore soil fertility and above- and belowground biodiversity	Adoption of good grazing practices associated with desirable changes in biodiversity, plant and community composition of soil microorganisms and grassland productivity
Intensification of agriculture	The use of species, varieties and breeds previously or de novo generated by classic and novel breeding techniques and better adapted to local climatic conditions	Reintroduction of local small ruminant breeds and varieties and implementation of interventions for pasture-based farming systems and mixed farming practices to make full use of available resources
Adopting sustainable land management practices and genetic intervention	Develop soil restoration and land management practices to be adopted in regions already affected by degradation	Implement the use of selected indicators to identify the practices that can restore degraded pasture-based livestock agroecosystems
Promoting durable soil quality restoration to successfully support appropriate grazing practices	Identify the adequate management practices to improve soil quality and enhance grazing potential with less resources use	Implement soil quality improvers to increase grazing potential, biodiversity and durable soil quality parameters. e.g. liming
Socio-economic impact on small-holding farmers	Assess cost and benefits of agricultural practices to restore degraded lands by building business model	Produce a business model using different scenarios (e.g. extensive, semi-extensive, moderate grazing, intercropping, mixed farming) that enhance farmers' income

and the preservation of agroecosystems of high ecological value. The ultimate target is to provide or implement the proposed practices in a consistent way, considering the diversity across the different participating countries and/or regions. Compiling and depositing of the collected data and results in a publicly accessed repository, helps all stakeholders to make realistic decisions as was already seen in the case of other decision-making tools [46].

Discussion

The strategies developed according to the proposed concepts and interventions, once integrated, over a 5-year period, in the Mediterranean region are planned to promote land restoration on pasture-based livestock agroecosystem while ensuring their resilience. The prospectives impacts to be recorded for a further 5-year period contribute to reducing soil erosion, which as it has been recently reported [47] is one of the contributing factors to land degradation, and thus help to improve soil health (Table 1). The later enhances biodiversity which in terms facilitates ecosystems functions [48]. The fact that this concept based-approach identifies, implements, scales up local knowledge and permanently re-introduce and/or promotes the continuation of traditional practices proves that it has an important impact, particularly in the case of pasture-based livestock and mixed crop livestock systems. It not only enhances biodiversity, but has an overall positive effect on livestock production [49, 50].

This has already been reported in Greece where the required inputs were significantly less in nonintensive farming systems with free ranging livestock [51]. This study also showed that these low input systems have a higher level of genetic, species and habitat diversity and that moderate seasonal grazing enhances biodiversity, which cannot be achieved by high-input mechanically upgraded industrial systems [18]. Such systems can maximize interactions, by seeking the highest level of self-sufficiency and reducing inputs; thus, yields may not be the main objective. A second point is that adopting grazing as a practice requires farmers to learn or relearn techniques, mainly through on-the-job training, and to acknowledge the fact that change cannot be immediate. The main challenge is to introduce a system that increases efficiency and practices that restore degraded soils and to create a decision support manual that helps stakeholders, among others, to better adapt to the new conditions.

As it has been previously documented the LFAs which mainly concern the Mediterranean and Alpine regions are characterized by a slow agricultural development, due to lower productivity and labor income, that is about half compared to the highly productive agricultural areas located in the northern European countries. This is partially due to natural limitations and to social and political factors that led to slow development [8]. As this significantly affects the population of farmers, the key elements for the sustainable development of these LFAs are the use of local resources that are adapted and linked to traditional agricultural practices [52]. In a study conducted by ref. [53] to assess the genetic diversity structure of 21 indigenous cattle breeds from across the Mediterranean basin, the authors found that the genetic variants underlying the adaptive response of Mediterranean cattle breeds to local climatic variation. In addition, characterizing their origin may be critical to promote the conservation of genetic resources and associated traditional production systems that are threatened by the increasing use of a small number of commercial breeds.

The effect of reintroducing local animal breeds and plant varieties into agroecosystems and the proposed interventions for pasture-based farming systems, not only aim to make full use of available resources, but also lay the foundations for the long-term implementation and development of practices that restore Mediterranean agroecosystems. In most of the cases local breeds and varieties not only preserve important genetic resources, promoting diversity but also contribute to their resilience and system sustainability [31]. The importance of local adaptation specifically to changing climatic conditions has already been reported, showing promising results leading to increased performance in extreme environments and ultimately contributing useful information to the conservation of these breeds and to sustainable utilization of local resources [18, 25].

When considering the impacts of this concept-based approach and the implementation of the proposed intervention, one of the main tasks that should be taken into consideration is the valorization of the results and the extent to which they can be used as incentives for farms at European level. The initial recording of the tangible parameters that affect the system through the SWOT analysis and the overview of the current situation leads to the identification of the most important parameters affecting the systems. Their classification according to their importance acts as a filter to reduce the information gathered through the process, to an amenable number of the most important issues to be included in the business model and eventually in the decision support manual. The creation of this tool stands in the core of this concept-based approach aiming to enhance the restoration of the degraded lands and pasture-based livestock farming system in a wider extent in different countries/regions and environments.

The resulting decision support manual provides all stakeholders and mainly the farmers the information and reasoning they need to acknowledge the importance of land restoration and the use of local plant and animal resources and apply them on their farms, also helping them to reduce fixed costs. The wide and diverse application of systems tested with this proposed approach, in different environments, the different practices used and their combination with new technologies (automation, precision) cover a wide range of farming practices and alternatives. We aim to highlight the wide potential of pasture and local resource-based livestock systems at an international level. This is further supported by the circularity of resources and the improved economic indicators that underpin these systems and are supported by the results of the proposed interventions. This ranges from the improvement of farm economics to the production of high nutritional value forage that reduces the use of concentrates and/or roughage imports. However, the implementation of such concepts is often associated with potential challenges or obstacles that may arise and need to be addressed to achieve successful implementation.

The solution to such a challenge lies in collaboration between different partners and geographically distributed decision-makers within a single, agreed formulation or well-developed action plans. Moreover, the problems encountered cannot usually be solved by formal models or methodologies. Instead, an argument-based approach of practical reasoning seems to be the appropriate solution. Therefore, what is really happening in the context under consideration is that all stakeholders first identify the main problems and issues to be addressed and then propose possible actions and solutions [54]. An ambitious further objective is to continue the proposed interventions and use a business model that guarantees access to its services to all farmers in all regions of the Union, using the tools offered by automated technologies. This aligns with the recommendation of the European Commission and the European Environment Agency that aims at reversing degradation that has already occurred and bring an ecosystem back towards a good condition. Undoubtfully this requires actions at a policy level and for this reason the UN CBD (Convention on Biological Diversity) target to restore at least 30% of degraded ecosystems by 2030 was adopted [55] while at a European level the objective is to have nature restoration measures in place on at least 20% of EU land and sea by 2030, and have measures in place for all ecosystems in need of restoration by 2050. To this direction, the design and development of the decision support manual for pasture-based livestock farming system is a key contribution not only for the research community but also for farmers and all related stakeholders since it offers multiple approaches for the implementation of similar systems in a wide variety of LFAs and climatic conditions from Mediterranean to Alpine environments.

Conclusion

The urgent need to restore degraded pasturelands underlines the importance of adopting regenerative practices in livestock science as proposed in this paper. This entails the adoption/re-introduction of traditional extensive production systems based primarily on forage feed resources, which have also been associated with higher levels of landscape diversity and biodiversity. While efforts to conceptualize how to improve farming and livestock systems are not missing [51, 56] there is a clear need to further dig into these aspects and focus on LFAs in the Mediterranean region, where customized information is lacking. We provide guidelines and suggest best practices for the adoption of innovative grazing management practices for degraded lands, making full use of local plant and animal resources, that has been proven that are better adapted to local environmental conditions, in LFAs in the Mediterranean basin for pasture-based livestock farming systems. Criteria were identified to set conservation priorities and target economic support in the transition phase of land improvement. In this respect, it is necessary to implement such practices with defined objectives and measurable results upon implementation. Although many efforts have been made in the past that tried to raise awareness of land degradation among stakeholders, the key messages have not reached those who can implement and/or finance restoration and mitigation actions. Farmers are locked into certain patterns of behavior due to environmental, economic, and social conditions that they cannot easily escape.

Therefore, we provide a decision framework to support context-specific policy making and at farm level. We also propose a roadmap for raising awareness of the major issues affecting pasture-based agroecosystems and stress the importance of education to provide relevant information. Focus groups and living labs can be hubs for the exchange of ideas and the establishment of partnerships. Integrating different data sources into decision-making tools provides integrated advice to farmers that can lead to better farm management and increase environmental awareness. Frequently updating practices and feeding the tool with new data will ensure its use over time and propose a framework that can provide diverse and up-to-date information on the upgrading, improvement, and sustainability of pasture-based agroecosystems. This will improve the social value of pastoralism in Mediterranean LFAs and enhance profitability. The integration of different data sources into decision making tools can provide integrated advice to the farmers that can lead to better

farm management and increase environmental awareness. This consequently will not only improve the societal value of livestock farming in LFAs of the Mediterranean but will also contribute to improving their profitability.

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