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A Farmer's Perspective on the Relevance of Grassland-Related Innovations in Mediterranean *Dehesa* Systems

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Abstract: Grasslands are of key importance for the provision of ecosystem services (ES). Suitable management is essential to guarantee their persistence and functionality. There is a growing interest in innovations such as new technologies aimed at facilitating and improving the management of grasslands while increasing their provision of ES. The uptake of innovations by farmers is a complex process, and relevant socio-economic or technological factors that are crucial to farmers are often overlooked. This information can be useful for increasing the adoption of these innovations through the design of public policies to facilitate them. This paper analyses the relevance of the main innovations that can be applied to the management of the grasslands of *Dehesa* farms for the farmers and the factors that might affect this relevance. Through questionaries, we gathered information on the relevance that farmers give to the selected innovations and analysed it by cumulative link models. The results show that innovations aimed at increasing the biomass production of grasslands and resilience such as the use of seed mixtures and the use of forage drought-resistant species are considered highly relevant by *Dehesa* farmers. However, high-tech innovations such as GPS collars were poorly rated which could denote low applicability to the context of *Dehesas* or the existence of barriers hindering the adoption but also a need for further development and better information on their potential. Characteristics of the farmer and farm such as age, education level, and stocking rate seem to be related to the relevance given to some of the innovations. These results provide insightful information for the implementation and research of relevant grassland-related innovations in the context of Mediterranean *Dehesa/Montado* systems, as well as for the design of policies supporting them.

Keywords: policy design; innovation adoption; innovation process; agronomy-related innovations; technological innovations; cumulative link models; farmers' characteristics

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1. Introduction

Grasslands are of key importance for the provision of ecosystem services (ES). Their preservation and sustainable management are essential to guarantee their multifunctionality [1]. Several factors challenge the multifunctionality of grasslands. Among the most important ones are abandonment, land-use change, and climate change [1,2]. In this context, there is a growing interest in innovations aimed at increasing the resilience of grasslands and, the efficiency, and sustainability of their management while maintaining or increasing the provision of ES [2–4]. According to the Food and Agriculture Organisation of the United

Nations (FAO), agricultural innovation "*is the process whereby individuals or organizations bring new or existing products, processes or ways of organization into use for the first time in a specific context in order to increase effectiveness, competitiveness, resilience to shocks or environmental sustainability and thereby contribute to food security and nutrition, economic development or sustainable natural resource management*" [5].

The development and implementation of innovations are especially relevant in High Nature Value (HNV) farming systems [6], where the balance between land use and biodiversity conservation depends on sustainable and active management [7,8]. One of the most representative and important HNV systems is the *Dehesas* system of the Iberian Peninsula, also known as *Montado* in Portugal [9]. *Dehesa* is a savanna-like ecosystem composed of scattered oak trees and pastures [10]. This agrosilvopastoral system covers 3.1 million hectares in the Iberian Peninsula and is recognised as one of the most biodiverse and multifunctional systems in Europe [7,10,11]. This ecosystem is protected by the Habitat Directive, as habitat 6310 "*Dehesas with evergreen Quercus spp.*" [12,13]. *Dehesa* farms are devoted to livestock breeding in extensive systems that rely on rain-fed grasslands to feed the animals [10]. These farming systems also depend on acorn production from holm oaks (*Quercus ilex sub. ballota*) to feed the livestock, especially Iberian pigs [14]. Mediterranean grasslands of *Dehesa* farms are subjected to high inter- and intra-annual variability of rainfall driven by the Mediterranean climate that contributes to their unique and valuable characteristics, but also makes the management of resources challenging [15,16]. Traditional knowledge and adaptation to the resources of farmers have coped with the limiting factors leading to a unique farming system [11]. However, the new socio-economic context, together with threats such as climate change, and diseases put this farming system at risk, which increases the need for innovations to secure the provision of ES in the future. The inter- and intra-annual variability of the rainfall is being exacerbated by climate change [17]. Its effect on Mediterranean grasslands is reduced productivity, higher uncertainty, prolonged regular feed gaps, and more frequent irregular feed gaps [18]. This is reflected in other ecosystem services such as diversity, erosion control, and carbon sequestration [19–22]. Since Mediterranean grasslands are the base of *Dehesas* farming systems, it also affects the profitability of the farms [23], making them more dependent on concentrates and jeopardising the sustainability of the enterprises [20,22]. In addition, the lack of profitability of extensive farming systems is frequently aggravated by inefficient management of the resources.

Research efforts were directed at developing innovations that could increase the resilience of Mediterranean grasslands to face such threats while maintaining their ability to provide multiple ES. Plant breeding and genetic selection led to important agronomic innovations, such as the use of seed mixtures to increase the productivity of grasslands while promoting biodiversity [24,25], or the use of drought-resistant species that could reduce the effects of feed gaps in Mediterranean farming systems [26]. Important technological innovation opportunities have arisen from the development of new technologies in the last few decades, such as remote sensing, GPS collars, and virtual fencing, which were proposed as powerful tools that can contribute to more efficient and sustainable management in the Mediterranean grasslands [27–32]. Recent research projects such as AGROFORWARD (https://www.agforward.eu/index.html) (accessed on 6 May 2022) [33] and Inno4Grass (https://www.inno4grass.eu/en/project) (accessed on 6 May 2022) [34] have significantly contributed to the identification and promotion of grassland-related innovations.

Despite the wide range of potential innovations that were proposed for the management of grasslands, little is known about the preferences and needs of farmers regarding these innovations. The innovation adoption process can be grouped into three general phases; initiation, adoption, and implementation [35]. Having information on the relevance of the innovations for farmers and their attitude towards them is crucial for successful adoption [36] and should be an inherent step in the co-innovation process in any sector. Within the phase of initiation, it can help to recognise the need of farmers (potential adopters) but also in the implementation phase, it can provide useful information on the users' acceptance [37]. This information could provide insights into the compatibility and complexity [37,38] of grassland-related innovations in the context of *Dehesa*. This is essential as it could help to focus and optimise research efforts on the needs of farmers [39] to fulfil the demand for innovations that could solve the challenges that *Dehesa* farms are facing. Additionally, a better knowledge of how the characteristics of the farms and farms might affect their perception of them is essential to inform the innovation adoption process [35,37,40] and to understand which profile of farmers are willing to apply certain innovations [39]. For public policies supporting innovations, such as the Common Agricultural Policy (CAP), having information on the perception of farmers of candidate innovations is of major interest, especially in the light of the new reformed CAP for 2023–2027, which will bring about important changes through eco-schemes [36,41,42].

This study is aimed at investigating the relevance *Dehesa* farmers attribute to several relevant grassland-related innovations and identifying the factors that might be linked to the adoption of these innovations. The results can be useful for prioritising research and for the design of policies targeted at improving the profitability and sustainability of *Dehesas* ecosystems through the innovation process.

2. Materials and Methods

2.1. Selection of Grasslands-Related Innovations

The selection of relevant permanent grassland-related innovations in the context of *Dehesa* farms was based on information collected within the project Sustainable Permanent Grassland Systems and Policies, Super-G (https://www.super-g.eu/) (accessed on 3 May 2022). A list of relevant innovations in the context of grasslands in *Dehesa* farms was produced. This was performed based on expert knowledge. These experts were selected based on their expert criteria as permanent advisors of the Super-G project. The proposed innovations were verified with published research concerning innovations related to the management of grasslands in the context of *Dehesa* farms (Table 1), including both innovations that are already being implemented and those presenting potential to be implemented. Eventually, twelve permanent grassland-related innovations were selected to be evaluated by the farmers (Table 1).

Table 1. Permanent grassland-related innovations selected to be evaluated by the *Dehesa* farmers.

Short Denomination	Description	References
Sow seed mixtures	Sowing of seed mixtures to improve grasslands' productivity, quality, and ecosystem services such as pollination and nitrogen fixation. Mixtures of annuals mainly consist of legumes.	[6,24,25,43,44]
Drought-resistant species	Search for drought-resistant grassland species adapted to the *Dehesa* environment that could develop satisfactorily in a future scenario of reduced rainfall. It can reduce the impacts of regular feed gaps during the summer season by providing out-of-season forage.	[6,18,26,44–49]
Knowledge of grassland performance	Increasing the knowledge of farmers about productivity, quality, and phenology of grasslands species in *Dehesa* farms through Apps, seminars, websites or manuals. The intrinsic complexity of Mediterranean grasslands due to high variability and diversity could difficult their efficient management. Increasing the knowledge in key aspects such as the dynamics of phenology and quality of the different types of grasslands/species could help farmers with more efficient management and inform them in the search for suitable complementary forage crops.	[50–52]
Monitoring soil	Monitoring and assessment of soil health through field indicators Soils of *Dehesa* systems are essential to sustain ecological and economic functions such as pasture production for feeding livestock and regulating water dynamics. Since management has a direct impact on soil health, field indicators can be used to assess the impact of management on soil health status and its effect on farm sustainability.	[53–56]

Table 1. *Cont.*

Short Denomination	Description	References
Grassland fertilisation	Improving fertilisation of *Dehesa* grasslands and development of suitable fertilisation guidelines according to soil and fertiliser type. Application dates of nitrogen fertilisation are determinant to achieving the desired outcomes and avoiding negative effects such as legume depletion. Phosphate fertilisation is essential to maintain and promote the legume content of Mediterranean grasslands and thus improve their quality.	[44]
Manure slurry outputs	Development of tools to make efficient use of manure and slurry generated on the farms. It could minimise the nitrogen loss and the need for external inputs. In *Dehesas* systems the extensive production of ruminants and monogastric livestock (pigs mainly) is sometimes combined with more intensive phases such as fattening of lambs, finishing of beef cattle, or breeding of piglets. The manure and slurry produced in these phases could be integrated into the management of the grasslands of the farm.	[57–59]
GPS collars	GPS collars and associated Apps to obtain information on the localisation and behaviour of livestock. Farmers could use this information to save time in the surveillance and localisation of the animals as well as to derive information on the status of the animals.	[3,6,31,32,43,60]
Virtual fencing	Technology based on collars attached to the animals which emit a tone and an electric pulse when they approach a pre-determined virtual fence. It could substitute the use of physical fences, improve grassland utilisation, and allow easier management of short-duration rotational grazing.	[32,43,61,62]
Remote sensing	Use of drones and satellites to obtain information on biomass production, quality, and composition of grasslands that could be used for the management of the farm. This technology can provide information in nearly real-time on key attributes of the grasslands that can help the farmer in the decision-making.	[27–29,63,64]
Software grass growth	Software and models to forecast the grass growth and biomass production in the short-term based on information on the current stage and weather forecast. It could provide useful information to plan practices such as early sowing at the beginning of autumn and make estimations on forage needs in the short term to feed livestock. It could also allow for more informed grazing management to for example increase stocking rate if higher grass growth is forecasted.	[65–68]
Software GHG emissions	Software and models to assess the GHG emissions of the farm based on the management and provision of recommendations on how to reduce them. There is a growing interest in assessing the GHG emissions of farming activities. This is expected to have an impact on the design of public policies but also on the consumers' preferences. The possibility of quantitatively estimating the GHG emissions at farm level could help extensive farmers to differentiate their products from those with higher GHG emissions.	[69–71]
Dissemination research	Dissemination and divulgation of research on grasslands through websites, seminars, manuals, advising organisations and courses. Establishing communication channels between research and *Dehesa* farmers can increase the effectiveness, competitiveness, resilience, and environmental sustainability of *Dehesa* farms, and thereby could mean a potential innovation in this context.	[34,40,72]

2.2. Data Collection

Information on the relevance of grassland-related innovations for *Dehesa* farmers was gathered by questionaries completed by these farmers from the Andalusia region (Spain). With the aim of targeting farmers performing active management of their farms and showing the intention of implementing innovations, the questionaries were delivered to be filled out by farmers participating in five seminars related to the management of *Dehesa* farms and the answers were collected at the end of the seminars. The topics of the seminars were: (i) Pruning of holm oaks in *Dehesa* farms (20 February 2019), (ii) Management of sheep in extensive farming systems (21 February 2019), (iii) Marketing and commercialisation of *Dehesa* products (13 November 2019), (iv) Techniques for oak regeneration in *Dehesas*, (21 November 2019) and (v) Organic beef cattle production in *Dehesas* (19 February 2020). These seminars cover relevant issues in the context of *Dehesa* systems from which arise the need for innovations and attract farmers concerned about the improvement of the management of their farms. Additionally, the questionary was also passed to the farmers of the Super-G farm network in Spain (https://www.super-g.eu/farm-networks/#table-spain) (accessed on 3 May 2022) that are collaborating in benchmarking and testing innovations in grasslands.

To avoid ambiguity, and to promote a high participation rate, the questionary was designed to prioritise its concision and simplicity. It consisted of a first section aimed at collecting information about the farm and farmer characteristics: Farm size, livestock type, total livestock units by livestock type, age of the farmer, gender, and education level. The second section focused on ranking the relevance that the proposed innovations could potentially play on the management of the farm to respond to their needs. They were asked to answer the central question *What could be the relevance of the following innovations for the management of grasslands in your farms?* by giving a score to each innovation on the Likert scale from 1 (irrelevant) to 5 (very relevant). At the beginning of each seminar, the questionaries were handed out and explained to the participants. In the case of farmers from the Super-G farm network, the questionary was explained in person or by telephone interview before sending/handing the questionary. A total of 55 farmers completed the questionary (average response rate of 45%). After removing incomplete questionaries and those from farming systems different from *Dehesa* farms, the responses of a final set of 42 questionaries were analysed.

2.3. Statistical Analysis

Cumulative link models, also known as ordinal regression models [73–79], were used to analyse the differences in the relevance given to the innovations and their relationship with the farmer and farm characteristics. Cumulative link models allow for the analysis of response variables following an ordered finite set of categories. In this case, the response variable (relevance of innovations) follows an ordinal scale from 1 (irrelevant) to 5 (very relevant). Cumulative link models with logit link [79] were fitted using the "ordinal" package of R [78]. This package also allows fitting cumulative link mixed models, which are cumulative link models with normally distributed random effects [77].

Firstly, the differences in relevance among the different innovations were tested by cumulative link mixed models following Christensen [77] and Mangiafico [80]. To do so, the score given by all the farmers to the twelve innovations (504 scores) was set as the response variable, the innovation as the predictor variable, and the farmer as the random effect. The reason for setting the farmer as a random effect speaks to the fact that each farmer might rank the innovations higher than another one. Significant differences among groups of innovations were tested by a post-hoc test with "*emmeans*" R package [80,81].

To further understand the influence of farm and farmer characteristics on the relevance given to each innovation, a cumulative link model was fitted for each innovation. The score given to the innovation was specified as the response variable. The predictor variables were farm size, livestock type, stocking rate, age of the farmer, and their education level. The stocking rate was calculated as the total livestock units divided by the farm hectares. Total livestock units were calculated based on the reference equivalence tables of the regional government of Andalusia [82]. The stocking rate was calculated with and without pigs. The calculated stocking rate without pigs was used to fit the models since the breeding of Iberian pigs in *Dehesas* is partly dependent on an intensive phase and less reliant on the grassland production grasslands than sheep and cattle [14]. Before fitting the models, the quantitative variables stocking rate and farm size were transformed into categorical variables of three classes, based on their quantiles position: less than 25%, between 25% and 75%, and higher than 75% quantiles position [83–85]. Education level was divided into three categories: (1) From primary to secondary general education, (2) Professional qualification (secondary vocational education), and (3) From university to Ph.D. (tertiary education). Farmer age was divided into three classes: (1) <35 years, (2) 35–55 years, and (3) >55 years. Kendall Tau was used to test multicollinearity among predictor variables. No strong correlation (<0.7) was found (Figure S1) indicating no potential multicollinearity risk, therefore all the variables were used to fit the regressions. To graphically display the relationship between the predictor variables, a categorical principal component analysis was fitted with these variables using the "*princals*" function from "*Gifi*" R package [86].

At first, all the predictor variables were included in a baseline or saturated model. Then, a stepwise model selection based on the Akaike information criterion (AIC) was conducted using the "*step*" function of R to determine the model of the best fit and the most significant variables [74,76,87]. The AIC of the saturated and fitted model as well as the Nagelkerke's pseudo R^2 and p-value of the best-fit model were calculated and reported. This procedure was followed to fit a model for each innovation (Table S1).

Following McKinley et al. [88], coloured tables were used to represent the results of the cumulative link models (Table S1). The results of each model were represented in rows (one by innovation) and the predictor variables in columns. If the predictor variable was dropped from the saturated model, the corresponding cell was coloured in grey. These predictor variables that were kept after the stepwise model selection were coloured in green if the categories of this variable increased the odds of giving a high score to the innovation or in red if they decreased the odds of giving a high score (Table S1). The estimates, odds ratio, and p-value of the levels of each predictor variable included in the best-fit models were also reported. Odds ratio (OR) is the measure of association between an exposure and an outcome [89]. The OR associated with an increase in the exposure of one unit is calculated as the exponential function of the coefficients/estimate (eβ) of the ordinal logistic regression [89]. In this case, the OR is used to compare the effect of the shift from a reference category on the odds of a higher innovation rating (OR > 1) or lower innovation rating (OR < 1). Based on the magnitude of the OR, the effect of the different variables in a model can be compared.

All models were best-fit and validated as recommended by Christensen [74–78]. Assumptions of proportional odds and scale effects were met in all the best-fit models. Hessian number of the best-fit cumulative link models was always <10,000, indicating no sign of non-identifiable models [76]. All statistical analyses were performed using the software R v. 3.6.1 [90].

3. Results

3.1. Information about Farmers and Farms

Table 2 shows the structural variables and the number of observations collected by variable class. Except for "Farmer education level" the observations had an even distribution over the categorical classes created (Table 2). The average farm size is 343 ha, and showed high variability, from 15 ha to 1400 ha. In total, 48% of the farms belonged to the class of farm size (FS) medium (78–432 ha). Concerning the stocking rate, it presented an average value of 0.50 LU/ha, and 0.65 LU/ha when pigs were considered. Farm size correlated negatively (R = −0.65) with stocking rate (with and without pigs). The three main types of livestock in *Dehesa* farms; sheep, cattle, and pigs, were part of the enterprise in 71%, 43% and 43% of the farms, respectively. A total of 55% of the farms had just one species as part of the enterprise. A total of 33% of the farms had two species of livestock, almost all these cases were a combination of pig and a ruminant (sheep or cattle). In 12% of the farms, the three livestock species were present.

The age class of <35 was the least represented, with 10 farmers (24%), while classes 35–55 and >55 had 17 and 15 farmers, respectively. Of the 42 farmers, only six were female. Figure 1 shows the results of the categorical principal component analysis. The first five principal components explained 94% of the total variance. The first and second components were the most contributing components and were therefore selected to generate the loadings plot (Figure 1), which accounted for 27.1% and 24.8% of the variance, respectively, 51.9% in total. The first component indicates discrimination between farms specialised in sheep from those with a combination of cattle and pigs. The second component explained differences in stocking rate, farm size, education level, and age. As commented before, stocking rate and farm size are negatively correlated, and there is an association between education level and farm size (Figure 1). University studies (FE Uni), with 67%, dominated the education level of the *Dehesa* farmers that participated in this study. FE Uni was also the predominant education level across farmer age classes, 50% in <35, 71% in 35–55, and 73% in >55. The same happened concerning the farm size, farmers owning large farms had mostly university studies (91%), being also the predominant education level of farmers owing medium and small farms with 60% and 55% with university qualifications, respectively (data not shown).

Table 2. Structural variables collected from the survey.

Variable	Classes	N
Farm size (FS) (ha) [a]		
Small	<78	11
Medium	78–432	20
Large	>432	11
Stocking rate (LU/ha)		
Low	<0.30	13
Medium	0.30–0.72	18
High	>0.72	11
Stocking rate without pig (LU/ha)		
Low	<0.29	11
Medium	0.29–0.59	20
High	>0.59	11
Sheep	No	30
	Yes	12
Cattle	No	24
	Yes	18
Pig	No	24
	Yes	18
Farmer age (FA)		
	<35	10
	35–55	17
	>55	15
Farmer education level (FE)		
Prim	From primary to secondary general education	8
Prof	Professional qualification (secondary vocational education)	6
Uni	From university to PhD (tertiary education)	28

N: number of observations, [a] Indicates the total land owned/managed.

3.2. Relevance of the Innovations for Dehesa Farmers

There was a contrasting distribution of the scores given to the twelve innovations assessed (Figure 2). For the agronomy-related innovations *Sow seed mixtures*, *Drought-resistant species*, and *Knowledge of grassland performance*, more than 57% of the farmers considered them highly relevant for the management of grasslands on their farms, showing an overall positive rating of these innovations. Conversely, technological innovations, *GPS collars*, *Virtual fencing*, *Remote sensing*, *Software grass growth*, *and Software GHG emissions*, showed a more dispersed distribution of the scores, with just 31% or less of the farmers rating them as highly relevant. The rest of the innovations, *Grassland fertilisation*, *Monitoring soil*, *Manure slurry outputs*, and *Dissemination research* showed an overall trend to a positive rating with 40–48% of the farmers considering them as highly relevant. *Drought-resistant species* was the innovation best rated while *Software GHG emissions* was the worst-rated innovation according to their relevance for the management of grasslands.

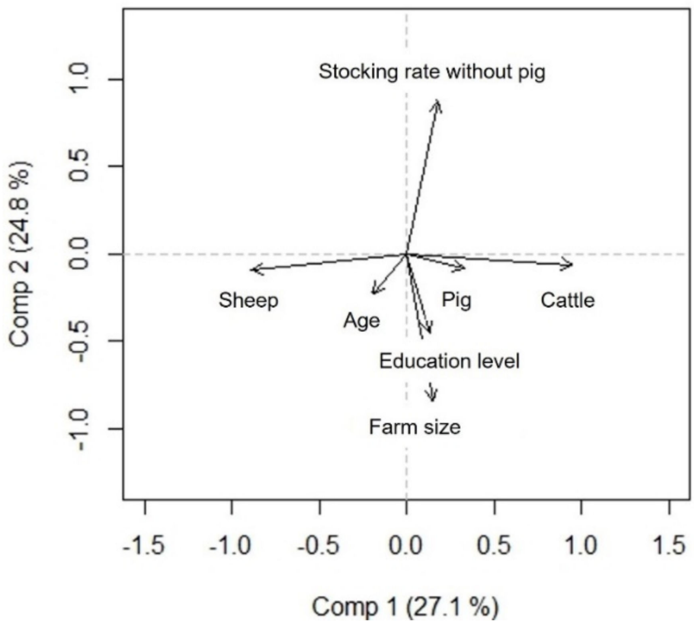

Figure 1. Loadings plot from categorical principal component analysis of structural variables.

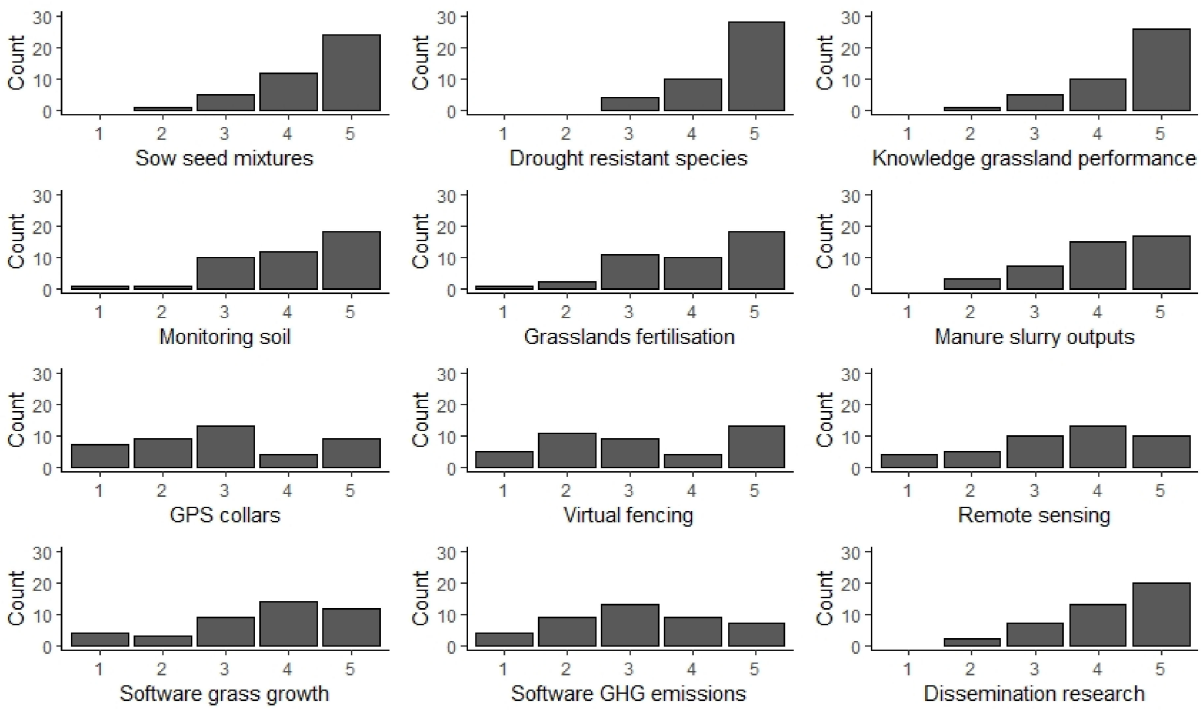

Figure 2. Histograms of relevance scores given to grassland-related innovations on the Likert scale from 1 (irrelevant) to 5 (very relevant) (N = 42).

According to the cumulative link mixed model, there was a statistically significant difference ($p < 0.001$) in the relevance given to the innovations after controlling for the random effect of the farmer. Figure 3 shows the homogeneous groups in which the innovations are grouped by a post-hoc test. As outlined before, there were two main groups of innovations that showed statistical differences ($p < 0.05$) in their relevance. A group of agronomy-related innovations consisting of *Sow seed mixtures*, *Drought-resistant species*, and *Knowledge of grassland performance*, with a median score of 5, had a significantly higher relevance than *GPS collars*, *Virtual fencing*, *Remote sensing*, *Software grass growth* and

Software GHG emissions. Especially, *GPS collars*, *Virtual fencing*, and *Software GHG emissions*, with a median of 3, were significantly rated worse than the rest of the innovations (Figure 3). *Grassland fertilisation*, *Monitoring soil*, *Manure slurry outputs*, and *Dissemination research*, with a median of 4, did not show significant differences with *Sow seed mixtures*, *Drought-resistant species*, and *Knowledge of grassland performance*.

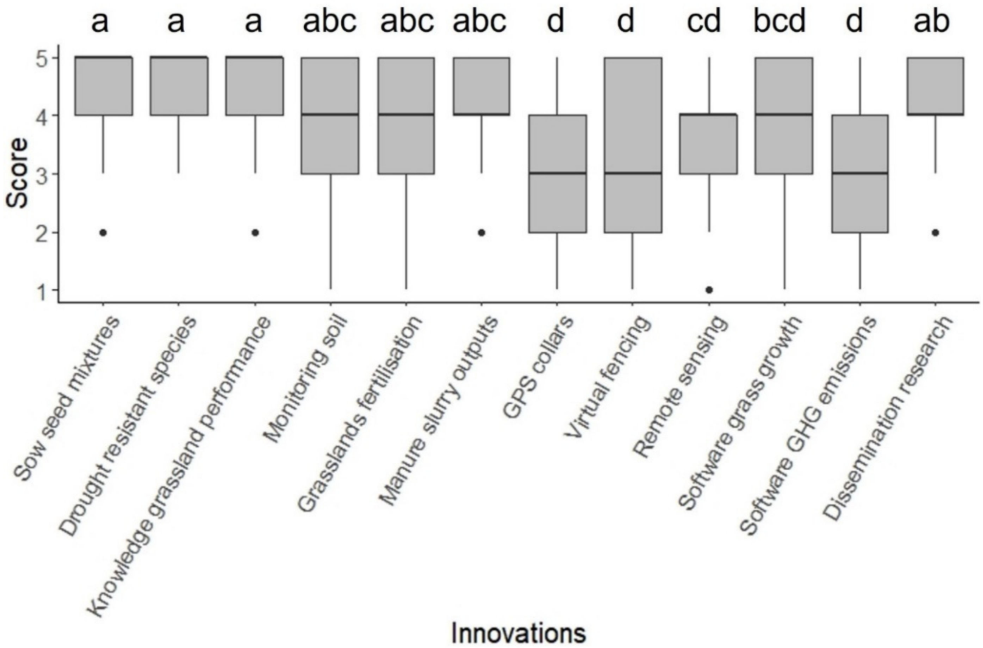

Figure 3. Boxplots of relevance given to grassland-related innovations. Different letters above the boxplots indicate significant differences in the relevance among innovations ($p < 0.05$). Black centre line, median; box, interquartile range; box limits, lower and upper quartiles; whiskers, 1.5× interquartile range; points, outliers.

3.3. Influence of Farmer and Farm Characteristics on the Relevance Given to the Innovations

The random effect of the farmer in the cumulative link mixed model resulted as significant ($p < 0.001$), which justifies studying the effects of farm and farmer characteristics that might influence the relevance given to the different innovations. This was investigated by cumulative link models, whose results are shown in Table S1 and Table 3. For the innovations *Sow seed mixtures*, *Drought-resistant species*, and *GPS collars*, all the predictor variables were dropped by stepwise model selection (Table S1), indicating that none of these variables influenced their relevance. The relevance score of the remaining innovations was influenced by one or more characteristics of the farm/farmer (Table S1). Results of the cumulative link models for these innovations are presented in Table 3.

Contrary to expectations, higher age classes were associated with higher scores for the innovations. For *Knowledge of grassland performance* and *Dissemination research,* the age class 35–55 and >55 increased the odds of higher scores compared to age class <35 (Table 3). *Monitoring soil* also showed increased odds of a higher score for the class 35–55. However, as expected, the education level of farmers was positively associated with high scores of the innovations in which this factor was significant (*Remote sensing* and *Software GHG emissions*) (Table 3). Concerning the characteristics of the farm, the stocking rate significantly affected innovations *Knowledge of grassland performance*, *Software GHG emissions*, and *Dissemination research*. Higher stocking rates increased the odds of higher scores in these innovations. Finally, the livestock type also affected the relevance of some innovations, especially the presence of pigs favoured the positive rating for the innovations *Grasslands fertilisation*, *Manure slurry outputs*, and *Software GHG emissions* (Table 3).

Table 3. Results of the best-fit cumulative link models of the influence of farmer and farm characteristics on the relevance given to the innovations. For the description of variables see Table 1 (response) and Table 2 (predictor). Categories within predictor variables are presented in italics. Missing categories within predictor variables are the reference category for the model. Estimates must be interpreted as the effect of the shift from the reference category on the score of the given innovation. Significance levels: <0.00 ***, <0.01 **, <0.05 *.

Innovation (Response)	Variable (Predictor)	Estimate	Standard Error	OR	*z* Value	*p*-Value
Knowledge of grassland performance	Farmer age *35–55*	3.1	1.1	21.9	2.8	<0.01 **
	Farmer age *>55*	2.7	1.1	14.6	2.5	<0.05 *
	St. rate *medium*	2.4	1.0	10.9	2.4	<0.05 *
	St. rate *high*	2.2	1.1	8.8	2.0	<0.05 *
	Sheep *yes*	1.8	1.0	6.2	1.8	0.07
Monitoring soil	Farmer age *35–55*	2.1	0.8	7.8	2.5	<0.05 *
	Farmer age *>55*	1.0	0.7	2.6	1.3	0.20
Grasslands fertilisation	St. rate *medium*	1.5	0.8	4.4	1.9	0.06
	St. rate *high*	0.6	0.8	1.8	0.7	0.48
	Cattle *yes*	−0.9	0.7	0.4	−1.4	0.15
	Pig *yes*	1.8	0.7	6.1	2.6	<0.01 **
Manure slurry outputs	St. rate *medium*	−1.6	0.8	0.2	−1.9	0.05
	St. rate *high*	0.1	0.9	1.1	0.1	0.88
	Pig *yes*	1.4	0.6	3.9	2.2	<0.05 *
Virtual fencing	Farm size *medium*	0.3	0.7	1.4	0.5	0.62
	Farm size large	1.5	0.8	4.6	1.9	0.06
Remote sensing	FE *prof*	−0.1	0.9	0.9	−0.3	0.74
	FE *uni*	1.5	0.8	4.5	2.0	<0.05 *
	Pig *yes*	1.0	0.6	2.6	1.6	0.11
Software grass growth	Pig *yes*	1.1	0.6	3.1	1.9	0.05
Software GHG emissions	FE *prof*	3.1	1.2	21.4	2.5	<0.05 *
	FE *uni*	2.3	0.9	9.7	2.5	<0.05 *
	St. rate *medium*	−0.9	0.8	0.4	−1.2	0.22
	St. rate *high*	1.8	0.9	6.3	2.1	<0.05 *
	Pig *yes*	3.4	0.8	31.0	4.2	<0.001 ***
Dissemination research	Farmer age *35–55*	2.1	1.0	7.9	2.0	<0.05 *
	Farmer age *>55*	2.7	1.0	14.9	2.7	<0.01 **
	St. rate *medium*	0.1	0.8	1.1	0.1	0.92
	St. rate *high*	2.7	1.1	14.3	2.4	<0.05 *
	Sheep *yes*	2.3	0.9	9.5	2.4	<0.05 *
	Pig *yes*	1.5	0.8	4.6	1.9	0.05

OR: Odds ratio; FE prof: Farmer education level corresponding to secondary vocational education; FE uni: Farmer education level corresponding to tertiary education; St. rate: Stoking rate. Innovations not shown correspond to those in which all the variables were dropped by stepwise model selection resulting in a null model (Table S1). Reference categories: *<25* for Farmer age; *low* for St. rate; *no* for Sheep, Cattle and Pig; *small* for Farm size and *Prim* for FE (Table 2).

4. Discussion

This study intended to put in perspective the research and development of grassland-related innovations in the context of *Dehesa* farms by directly asking *Dehesa* farmers about the relevance that a selection of innovations could play on the management of grasslands in this farming system.

The values of the structural variables (Table 1) show that the questionaries covered the variability of the *Dehesa* farms in terms of, size, stocking rate, and enterprises, in agreement with previous studies that have characterised the typology of *Dehesa* farms [71,83,84,91,92].

4.1. Relevance of the Studied Innovations and Relationship with Farmer and Farm Characteristics

Results showed that there were two main groups of innovations with contrasting scores of relevance. The first group of agronomy-related innovations with high relevance, in which can be found innovations directly related to the performance of the pasture such as *Sow seed mixtures*, *Drought-resistant* species and their fertilisation and quality such as *Grassland fertilisation*, *Manure slurry outputs*, and *Knowledge of grassland performance*. In the second group, with the lowest relevance, high-tech innovations related to the monitoring of livestock and grazing management were included such as *GPS collars*, *Virtual fencing*, and impact assessment tools, for example, *Software GHG emissions*. *Dehesa* farms rely heavily on pasture performance to feed livestock, which justifies the relevance given to innovations directly related to the improvement of the performance of grasslands and increasing their resilience to threats such as climate change. It is worth remarking on the relevance given to the innovation *Drought-resistant species*. It reflects the perception of farmers of the strong dependence on rainfall and its seasonality to feed the livestock in rain-fed farming systems [93,94], highlighting the impacts of feed gaps on the profitability of the farms and how this is being aggravated by climate change [20,22,23]. This innovation together with *Sow seed mixture* was considered of high relevance for the management of grasslands, irrespective of the characteristics of the farm/farmer (Table S1). Given the correspondence between the demand for innovations such as *Sow seed mixture* and *Drought-resistant species* and their demonstrated potential to increase the resilience and performance of grasslands in extensive grazing farming systems [24,25,95], policies such as CAP should promote and facilitate its implementation. In the face of the new reformed CAP for 2023–2027, these innovations were specifically pinpointed in a published list of potential agricultural practices that eco-schemes could support [96]. The recently published IPCC Sixth Assessment Report provides conclusive evidence of the special vulnerability of Mediterranean systems to the already patent climate change effects [17]. Among other solutions, this report has pointed out the use of "*drought-resilient ecologically appropriate plants*" as one of the land-based solutions to combat desertification [17]. In this context, the novel drought-resistant perennial fodder legume, *Bituminaria bituminosa* [26,97], was proposed as a suitable alternative for Mediterranean farming systems. An improved cultivar of this species [98] is being tested within the Super-G project to be included in *Dehesas* systems to increase their resilience to climate change effects [97].

Innovations that can be labelled as high-tech (*GPS collars*, *Virtual fencing, Remote sensing, Software grass growth,* and *Software GHG emissions*) seem to be of low relevance for *Dehesa* farmers. The poor score given to them points to two main reasons (i) low applicability and/or interest in these innovations in the context of *Dehesas* and (ii) the initial stage of development in the S-shaped innovation curve [37,38]. In the case of *GPS collars*, with the current functionalities offered by this technology, it may result in low interest for *Dehesa* farmers. *Dehesa* farms are delimited and subdivided by physical fences where the typical grazing method is rotational grazing with long grazing and resting periods (low frequency of rotation). Therefore, farmers have control of the movement of the animals and do not need to spend too much time and resources on the localisation of the herd. Conversely, localisation of livestock in non-fenced high-mountain grasslands can be a resource- and time-consuming task, in which GPS collars could make a difference in management optimisation [60]. For GPS collars to be implemented and widespread technology in *Dehesas*, further functionalities should be developed. Some of them could be calving/lambing detection based on animal behaviour analysis through machine learning algorithms or information on the energy demands based on activity monitoring [60,99–101]. Similarly, virtual fencing could not be suitable or necessary for the grazing method of *Dehesas* and could adapt better to strip or ration grazing methods typical of dairy farming systems of temperate grasslands [102,103]. Innovations such as *Remote sensing* and *Software grass growth* can be an example of innovation at an initial stage of development S-shaped innovation curve. These technologies were implemented in the management of grasslands in other latitudes, for example, GrassCheck [65,66]; in Northern Ireland and Pastures from Space [104] in Australia. However, in Mediterranean grasslands, this technology is still to be developed. Although recent studies have shown potential for its use in *Dehesa* farms [27–29,105,106] there is a need for further optimisation of the models and, especially, platforms and applications that could make this technology accessible and usable by farmers. This need aligns with the lack of dissemination and information transference of the research being developed in this and similar high-tech innovations which could indicate the fact that *Dissemination research* was highly rated (Figures 2 and 3). Therefore, the poor relevance score given to these innovations may result from the combination of a deficient development of the innovations (and associated platforms and Apps facilitating their use) and the lack of information on their potential. To facilitate the implementation and user acceptance, the proposed innovations have to be perceived as profitable [39] reliable, and predictable by farmers, otherwise, their willingness to adopt them could mean a barrier difficult to overcome [107]. This is especially important in the case of technological applications, for which it seems to lack transference of research results to practical use in the context of *Dehesa* systems. The low productivity and high dependency on the rainfall of Mediterranean grasslands could contribute to the low interest in high-tech innovations.

It is worth highlighting also the relevance of *Dissemination research* which points to the need for a direct and closer relationship between advisers and researchers [34]. For example, Porqueddu et al. [72], showed that farmers from Sardinia (Italy) considered direct relationships with advisers and researchers as the most reliable sources to adopt innovations. They also found that seminars, field days, or visiting innovative farms are inspirational events that encourage them to adopt innovations [72].

The association between higher age classes and better rating of some innovations contrasts with previous studies reporting a negative correlation between age and willingness to innovate [108,109]. However, other studies have found a positive relationship between farmer age and adoption [40,110]. In this case, the positive relationships might be associated with the higher education level of farmers in the superior age classes (see Section 3.1. Information about farmers and farms). According to the farm and farmer characteristics, it seems that larger farms, are owned by older farmers with university studies [111,112], and this profile could show a higher interest and demand for certain innovations. This aligns with previous research reporting a positive association between older farmers with higher education levels and the adoption of agricultural technologies [39]. This is confirmed by the relationship found between the education level and the higher relevance score given to some high-tech innovations such as *Software GHG emissions* and *Remote sensing* (Table 3) [39]. However, these results must be carefully interpreted and confirmed by future research since they might be also affected by the unbalanced observations in the three classes of farmer education level, with 66.6% having tertiary education (Table 2). Plieninger et al. [112], in a study on *Dehesa* managers' attitudes toward management, regeneration, and conservation of *Dehesas*, also reported that most of the responders (57.5%) had attended college.

The fact that farmers managing higher stocking rates tended to provide higher scores of relevance for *Knowledge of grassland performance*, *Software GHG emissions*, and *Dissemination research* could be related to the specialisation of these farmers and therefore a higher need for innovations to optimise and facilitate the management. Finally, the presence of pigs as part of the enterprise was related to a higher relevance of innovations concerning the management of manure, GHG emissions, and fertilisation. This might show the need for better management and integration of the residues and the impact of this type of livestock on *Dehesa* farms.

4.2. Study Limitations and Future Research

This study focused on grassland-related innovations in *Dehesa* systems. However, oak trees play a central role in this agroforestry system, being described as ecosystem engineers [10,113–115]. Therefore, to fully cover the innovations of interest for *Dehesa* farmers, those affecting the management of oak trees should be considered. One of the main threats to *Dehesa* systems is the lack of tree regeneration due to intensification and livestock/wild ungulates browsing [116,117] and oak mortality due to the root-rot disease caused by *Phytophthora cinnamomi* [118]. Previous studies have highlighted the demand for tree-related innovations in agroforestry systems across Europe [6]. Future research should complement the results presented in this study with information on the preference and relevance of tree-related innovations to contribute to the integrative view of innovations and policies that should be applied in agroforestry systems [11]. Apart from management-related innovations, there is also a need for socio-economic innovations in the marketing and commercialisation of products from *Dehesa* farms [6,43,119]. The value-added of these products and ecosystem services associated with their production, is frequently, not fully reflected in the final prices, which is essential to improve the profitability and economic sustainability of these farms [6,120,121]. Higher revenues and profitability of *Dehesa* farms could provide a suitable environment for the adoption of innovations. According to the stakeholders' perspective of HNV agroforestry systems, the low profitability of these systems is putting at stake their sustainability and persistence [6,36], and therefore hindering the adoption of innovations. Governance strategies and public policies should respond to this challenge, and the way through seems to be the compensation for the public ecosystem services provided by these systems [120,122,123]. Since the objective of this study was not to produce a complete list of innovations, we are aware that several relevant innovations such as those related to water harvesting and minimum tillage are missing from this analysis and must be addressed in future research.

Results from this study have shown that characteristics of farm/farmers affect the relevance of the innovations for farmers. This information can be useful to target farms and farmers that will have a higher willingness to implement certain innovations, thus facilitating the innovation adoption process [37,39]. Future research should also investigate the opportunity cost and risk associated with the adoption of the proposed innovations since these are certainly factors driving the willingness to implement innovations. This paper also highlights the importance of co-creating innovations [124,125] for an efficient co-innovation process that avoids the risk of investing resources in the development of innovations that are not useful or demanded by farmers.

Some farm and farmer characteristics not included in this study might also be affecting the preference and relevance of innovations for *Dehesa* farmers. For example, belonging to social groups or producer organisations was found to promote information sharing and technology adoption [40]. Farms association and cooperative membership are key features that might influence both relevance and adoption of innovations [126] in *Dehesa* farms, and should, therefore, be taken into account in future research. Additionally, farm characteristics such as tree density could mean a technical limitation for the implementation of innovations such as remote sensing for grasslands due to high canopy cover impeding grass cover monitoring. Finally, it is worth remarking that the results and conclusions derived from this study apply to grassland-related innovations in the specific case of *Dehesas*. These results should not be extrapolated to different farming systems, in which the relevance of the studied innovations could differ considerably.

The aforementioned limitations indicate that more detailed studies with a higher sample are necessary to confirm the findings of this study and go deeper into the factors affecting the relevance given to the innovations. However, the presented results emphasise the importance of consulting farmers in order to develop useful, applicable, and meaningful innovations for *Dehesa* farming systems and to inform the policies supporting them.

5. Conclusions

Concerning the objectives of this study the conclusions are:

- Innovations aimed at increasing the performance and resilience of grasslands such as the use of new seed mixtures to improve the performance and diversity of grasslands and the adoption of new forage drought-resistant species are considered highly relevant by *Dehesa* farmers. Considering the potential of these measures to improve: (i) the profitability of the farms, (ii) their resilience to face current and future threats such as increasing droughts and (iii) their ability to provide ES; these types of innovations should be targeted by policies.

- High-tech innovations were, overall, poorly rated by *Dehesa* farmers. This might denote low applicability to the context of *Dehesas* or the need for further development of the innovations and better information on their potential.
- Dissemination of research results is demanded by *Dehesa* farmers and could be essential to promote the innovation process.
- Famer and farm characteristics such as age, education level, and stocking rate seem to be related to the relevance given to some of the innovations and could play an important role in the willingness to adopt them.

This study provides insightful results that can inform the implementation and research of relevant innovations in the context of Mediterranean grasslands and *Dehesa*-like systems, as well as contribute to the relevance of policies aimed at developing and implementing these innovations. Future research should confirm and complement these findings to contribute to integrated approaches for the innovation process and policy design in *Dehesas* and similar agroforestry systems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13081182/s1, Figure S1: Kendal Tau correlation coefficients among innovations; Table S1: Influence of farmers and farm attributes on the relevance of permanent grasslands-related innovations.

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