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Quality Production of Sainfoin Swards Challenged by Global Change in Mountain Areas in the Western Mediterranean

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Abstract: Legume-based livestock forage systems are widespread and socially relevant agroecosystems that are essential for delivering high-quality forage. Therefore, it is critical to determine how climate change and management might affect the functioning of forage agroecosystems. The objective of this study was to explore the potential of sainfoin swards under different management regimes by combining results from an experiment on species diversity effects on yield developed under extreme climatic conditions and a survey of sainfoin (*Onobrychis viciifolia* Scop.) swards and nutritive value in mountain regions in Catalonia, Western Mediterranean. Our results show that 12–59% of the variability in forage nutritive value parameters was accounted for by management. Young cattle-grazed swards showed higher nutrition quality that decreased faster than sheep-grazed or only mown swards. Mixing sainfoin with orchardgrass increased fiber content (e.g., +22% neutral detergent fiber) and decreased protein (−26%) and lignin (−11%) compared to sainfoin monocultures. However, under the extreme climatic conditions of the last three years, the only diversity effect found on yield was the identity of the species present. We propose that a combination of different sainfoin management regimes might be beneficial regionally for both quality forage production and overall biodiversity conservation, whereas traditional systems may be vulnerable to changing climatic conditions.

Keywords: agroecosystem management; cattle grazing; extreme climatic events; nutrition value; quality forage yield; sheep grazing

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1. Introduction

Legume-based forage livestock systems are widespread agroecosystems of critical ecological and social importance [1,2]. These systems are essential for delivering quality forage to maintain animal quality production [3,4]. However, forage systems are currently experiencing the impacts of global change, including both climate change and modifications in management.

Climate change is particularly acute in the Mediterranean region, where temperatures are rising above [5] and precipitations decreasing below [5] the long-term mean. In Catalonia, Western Mediterranean, a temperature anomaly up to +2 °C was recorded in 2022 (https://web.gencat.cat/en/actualitat/detall/2022-lany-mes-calid-mai-registrat-a-Catalunya, accessed on 4 November 2023). In addition, current precipitation patterns are complex and disparaging, threatening productivity in the region. (a) Precipitation is strongly heterogeneously distributed, spatially and temporally; (b) precipitation is decreasing, including the sowing and growing seasons; (c) rainfall unpredictability has increased; and (d) short-lived rainstorms have increased [6] (https://www.meteoblue.com/en/climate-change/catalonia_spain_3336901, accessed on 4 November 2023). Yet, feed production is very important in Catalonia [7], where forages are among the top seven agricultural produces, representing more than half the total tones of those seven (https://www.idescat.cat/indicadors/?id=aec&n=15425, accessed on 4 November 2023). Extreme climatic events are threatening productivity [8] and the forage industry in the region.

Traditionally, in mountain areas in the Catalan Pyrenees, combining cutting and grazing in forage systems, particularly in sainfoin forage swards [9], but not only in them [10], was very common. There was a main harvest of forage herbage in spring, sometimes a secondary harvest in fall, and the regrowth was grazed by either cattle or sheep [10]. However, in the last decades, management has been shifting toward cattle-grazed or only-cut systems [9]. Due to a trend among farmers to simplify management, they frequently integrate agricultural activities with the services sector, including agrotourism [11]. Significant modifications in agricultural practices have been reported in less favored areas in the Mediterranean region [12]. Furthermore, a potential for a greater use of alternative legume species, at least for sheep-grazing systems, has been reported in Europe, including the Mediterranean [13]. Re et al. (2014) [14] have emphasized sainfoin potential for sustainable farming in Mediterranean environments.

Among forage species, sainfoin presents many advantages in terms of high forage quality and good adaptability [15–17] and has been recognized as a profitable option in certain environments [18,19]. It is also suitable for grazing [13,20,21]. Nowadays, there is an increasing interest in sainfoin as a forage species [22], even as a pulse [23]. Agronomically, sainfoin has been reported equal in yield, crude protein content, and persistence to alfalfa, and is equally or more palatable than alfalfa to ruminants, with comparable levels of animal productivity per unit forage consumed [24,25].

In an experimental set-up in the context of an agrodiversity experiment, Kirwan et al. [26] and Ribas et al. [27] found that sainfoin performed well in four-species mixtures, two grasses and two legumes, particularly in combination with *Medicago sativa* L. (alfalfa). The combination of those two species frequently used in Mediterranean forage swards was advantageous and showed beneficial production effects over monocultures and other forage species and mixtures under extreme climatic conditions [27]. Other authors have also reported enhanced yield in sainfoin mixtures [28]. Nonetheless, other papers have reported a low competitive ability of sainfoin in mixtures with grasses [9,24,29]. They found that the inclusion of orchardgrass (*Dactylis glomerata* L.) in a mixture with sainfoin reduced weed species biomass and proportion, which was consistent with other authors, such as Kirwan et al. [30], Connolly et al. [31], Franco et al. [17], and Sebastià et al. [9], who also found that the main driver of sward and sainfoin biomass decline was sward age and interaction with management factors.

Sainfoin is a widely cultivated legume in temperate regions with calcareous soils around the globe [32]. Farmers and researchers highly appreciate this legume because sainfoin contains condensed tannins that reduce protein degradation in the rumen and methane emissions [13,33–35]. However, sainfoin has limited resprouting capacity [36–38]. This might cause a fast decrease in forage quantity and quality with sward age and an increase in open sites for weed species [9]. Forage swards of sainfoin, alone and sometimes in mixtures with orchardgrass, used to be very common in the calcareous, mid-mountain areas in the Pyrenees [9,19].

Positive effects of sainfoin have been reported on sward chemical composition and sheep performance in sheep-grazed pastures in both Mediterranean and cold temperate grasslands in Europe, with no clear effects on Central European cattle-grazed swards [13]. However, to our knowledge, no study has analyzed the effects on nutritive value comparing only mown, sheep-, and cattle-grazed swards of different ages within the same region in on-farm studies under similar climatic and soil conditions. This information builds on previous results on yield [9] and shows the potential of combining different managements for quality forage in a vanishing world where farmers' livelihoods are increasingly difficult and there is a need for simplification and third-party and part-time farming [39], as climate conditions are increasingly challenging for forage production [8].

In this paper, we combine information from two studies carried out in different years in the same mountain region in the Eastern Pyrenees to explore the potential of sainfoin as a forage species under global change conditions, including yield resistance to extreme climatic events and nutrition value responses to changes in sward management. First, we use the results of an experiment where four-species mixtures and monocultures of two grasses and two legumes were sown at different proportions to investigate yield responses during two (extremely dry and hot) years after establishment. Second, we use the results of a survey of commercial sainfoin swards of diverse ages after sowing and management according to different options determined by the farmers to investigate how management affects forage nutritive value throughout time and how the resulting changes are related to changes in productivity and composition.

2. Materials and Methods

2.1. Experimental Set-Up to Investigate Sainfoin Yield under Extreme Climate

An experiment on forage mixtures was established in the fall of 2021 at the Agricultural School of the Solsonès (latitude: 41.98081, longitude: 1.55701, altitude: 565 m a.s.l.) in Olius (Solsonès county). Bedrock primarily consists of marl, limestone, and sandstone. The experimental site has a loamy soil texture with a pH of 8.2. The area used to have a mean annual temperature of approximately 12 °C and a mean annual precipitation of 854 mm. During the experiment, the weather proved to be extremely warm and dry, with a mean annual temperature of 13.4 °C. In June 2022, we experienced a maximum temperature of 40.1 degrees Celsius. Additionally, 2022 was an incredibly dry year; precipitation was only 576.6 mm and was distributed into 81.7 mm in winter, 118.5 mm in spring, 231.5 mm in summer, and 144.9 mm in fall. The sowing year, 2021, was even drier, with an annual precipitation of 486.1 mm. These climatic nuances during the experimental period underscore the challenges posed by extreme climate events, notably the substantial increase in temperatures and decreased precipitation, which significantly influenced the experimental outcomes and led to the early conclusion of the experiment due to a lack of sufficient soil moisture. We address the behavior of sainfoin under extraordinarily stressful conditions compared to other forage species in the experiment, both in mixtures and monocultures.

The experiment investigated the effects of sown diversity on forage yield and included monocultures and mixtures of four forage species: two grasses and two legumes. The grasses were *Lolium perenne* L. (common name: ryegrass; variety: Nui) and *Dactylis glomerata* (common name: orchardgrass; variety: Amba), and the legumes were *Medicago sativa* (common name: alfalfa; variety: Capitana) and *Onobrychis viciifolia* (common name: sainfoin; variety: Común). All four species were sown in a monoculture and in mixtures at different proportions, including dominance by each species in turn (0.7 of the dominant in turn compared to 0.1 of the others), the codominance of two species (either the two grasses or the two legumes dominating), and the centroid, where all species were sown at equal proportions (0.25:0.25:0.25:0.25). Treatments were randomly assigned to plots before sowing. Thus, our experimental design followed the simplex design [30,40], where there are no replicates, but forage species are sown at a variety of proportions, including the four monocultures. In this way, the experimental design benefits from the power of regression for data analysis. Check Moral et al. [30] for a recent review and more details about this method.

The experimental plots were sown on 28 October 2021, and we performed three harvests between spring 2022 and spring 2023, scheduled as follows: First Harvest: 7 June 2022, Second Harvest: 7 November 2022, and Third Harvest: 8 June 2023. Afterward, the experiment was finished by a lack of rain. The size of the cut area for each harvest was

5.40 m^2 based on machine width. To determine herbage yield, the following procedures were followed. Herbage fresh weight in each plot was determined using a dynamometer in the field. Subsamples weighing at least 1 kg were collected immediately after cutting each strip, sealed in plastic bags to remove air, and stored refrigerated. In the laboratory, the fresh weight of the subsamples, including the water content in the bags, was recorded. Subsequently, subsamples were oven-dried at 60 °C until constant weight, and dry weight was recorded. The ratio of fresh weight to dry weight was used to calculate the dry weight of the yield based on the fresh weight of the strip.

2.2. Survey to Investigate Sainfoin Quality under Different Management

A field survey on sainfoin swards of different ages after sowing was conducted in mountain areas in the Solsonès and Alt Urgell counties, between 42°01′ and 42°09′ N latitude and 1°22′ and 1°33′ E longitude (Eastern Pyrenees, Catalonia, Spain). Sampling was carried out in mountain areas with a Sub-Mediterranean climate, from 600 to 1300 m altitude.

Farmers in the area use a variety of management practices. In particular, the swards had one of three management regimes: only mown twice a year; mown once a year and grazed by sheep; and mown once a year and grazed by cattle. In all three cases, the forage is cut and removed as hay at least once a year. The survey included fields with those three management regimes, as found non-experimentally depending on each farmer's choice. The survey was thus stratified within management, and the cases unbalanced within the stratum: 24 sheep-grazed, 9 cattle-grazed, and 6 only mown swards, according to sward availability. Only mown swards tended to appear at lower altitudes and sheep-grazed ones at higher altitudes, but the altitude was never a significant factor in our study. Other management variations were recorded for each commercial farming sward. Because this is an on-farm, experimental study, not all possible management combinations were present, and data were treated accordingly.

Grazing intensity was moderate according to local standards, 0.2–0.4 Livestock Units (LUs) ha^{-1} or equivalent, and occurred late in the season. Sheep grazing was the most common management regime, but an increase in cattle farming compared to sheep farming has been reported in the Eastern Pyrenees [41]. Most swards were sown as monocultures of the legume sainfoin, but some were mixtures with orchardgrass. Most swards were sown in spring, but a few were sown in fall. The survey was older than the experiment, and the climatic conditions at that point were not as extreme. In total, 39 sainfoin swards were sampled. Sward age ranged from 1 to 6 years after sowing. All swards were sampled at peak biomass, right before the spring harvest.

Interviews with the farmers were carried out to investigate sward age (year after sowing, 1 to 6), previous crop (cereal or potatoes), management regime (only mown, sheep-grazed or cattle-grazed), mixture (sainfoin in monoculture or with *Dactylis glomerata*), sainfoin variety (local or French), sowing season (spring or fall), sowing density (75 to 200 kg ha^{-1}), and sward extension (surface in ha, 0.1 to 4). Sainfoin varieties in the Pyrenees are not well cataloged, and thus it was impossible to identify those varieties used by farmers in the region beyond the local terminology, which we provide. Furthermore, the mixture/monoculture comparison in this study, although providing interesting information, is handled cautiously because mixtures in the study region are infrequent and not well distributed within management regimes. We rely on the experiment described above for more in-depth information about mixtures, although the survey provided interesting information about the forage quality properties.

We assessed shifts in nutritive value in sainfoin swards grown in monocultures or mixtures and managed according to one of three regimes: only mown; mown and grazed by cattle; and mown and grazed by sheep. Mowing (forage cut and removed as hay) is performed in spring while grazing takes place by the end of the growing season. Because this is a survey and not an experimental set-up, results represent farmers' choices.

A 10 × 10 m plot was established in the middle of each sampled sward, and the number of plant species was recorded in this 100 m^2 plot (SR100). A 2 × 2 m quadrat was set in the middle of each 100 m^2 plot. In the corners of each 2 × 2 m quadrat, four 0.5 × 0.5 m sub-quadrats were established, and herbage was harvested separately. Herbage from three of the sub-quadrats was separated into species to determine vegetation composition, including sainfoin and weed species biomass. Standing dead biomass was also separated. Herbage from the other sub-quadrat was sealed in polyethylene bags, dried at 60 °C, and then used for chemical analysis and forage quality evaluation. Herbage from all sub-quadrats was used to determine total biomass after oven-drying at 60 °C.

2.3. Determination of Herbage Quality

Dried samples were ground to pass a 1 mm stainless steel screen (Cyclotec 1093 Sample mill, Tecator, Hoeganaes, Sweden) and stored at 4 °C until they were needed for use. The samples were analyzed in duplicate. Procedures described by AOAC [42] were used to determine dry matter (DM), ash content or mineral matter (MM), and organic matter (OM). Crude protein (CP) was determined by the Kjeldhal procedure (N_t × 6.25) using a Kjeltec Auto 1030 Analyser (Tecator, Hoeganaes, Sweden). Samples were analyzed sequentially for neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) in accordance with the method described by Goering and Van Soest [43] on an Ankom^{220Ò} fiber analyzer incubator (Ankom, Macedon, NY, USA). The fiber analysis was determined on an ash-free basis without alpha-amylase. Digestible organic matter (DOM) and forage units' milk (FU_{milk}) were predicted following standard regressions provided by Andrieu et al. [44]. Quality parameters were expressed on a concentration basis as a percentage of dry matter (DM).

2.4. Data Analysis

We assessed the effects of sown diversity on yield under extreme climates using the DI and GDI modeling framework [40,45]. To this effect, we used the DImodels package. We used the autoDI and the DI commands to determine the best model both automatically and manually, as well as the coefficients of the models.

We assessed the effect of sward age on herbage nutritive value in the survey following a synchronic approach of succession, according to which swards of different ages are sampled simultaneously to reconstruct time effects in space by time substitution [46].

To investigate the effect of sward management factors on herbage, quality variables we used. First, regression techniques. For each quality variable, the initial model included explanatory variables such as sward age, management regime (only mown, grazed by cattle, grazed by sheep; included as dummy variables), and the first-order interaction as the main variables of interest; other management factors included were mixtures (sainfoin with *Dactylis glomerata* or in monoculture), the sainfoin variety (local or French), and sowing date (fall or spring). The variable seeding density and the previous crops could not be determined for all swards and, therefore, were tested in preliminary modeling and were non-significant in all analyses. Categorical variables were introduced in the models as dummy variables (value 1 or 0). Mean estimates were calculated for the variables showing significant regime or regime × sward age variation. Tukey post hoc tests were applied for comparisons of means among managements, where a mixture of sainfoin with orchardgrass was tested against sainfoin monocultures; a French sainfoin variety was tested against a local variety; spring sowing was tested against fall; and management regime (and interaction with time), where cattle grazing was tested against other management regimes.

We calculated the Pearson correlation between the nutritive value parameters and between those and several sward vegetation variables (structural and compositional) to find the total aboveground and sainfoin biomass, weed biomass, and proportion. In all cases, we applied the Bonferroni correction for multiple comparisons.

In addition, we used a multivariate analysis in order to assess the relative importance of environmental factors on herbage's nutritive value. Those multivariate techniques are highly suited for our study because this study is a survey including swards commercially run by farmers, and thus the studied treatments are unbalanced, depending on what is available in the region. We performed direct ordination of swards' nutritive value by Redundancy Analysis (RDA) using two groups of environmental factors as explanatory variables: (a) management variables and (b) sward composition and structure variables. Management variables included sainfoin monoculture vs. mixture with orchardgrass; sainfoin variety (local vs. French); sowing period (fall vs. spring); sward age; management regime (only mown/sheep-grazed/cattle-grazed); and the management regime × sward age interaction. Sward structural variables included total yield (aboveground biomass, kg ha^{-1}); sainfoin biomass (kg ha^{-1}); weed biomass (kg ha^{-1}); weed proportion (%); SR100, the number of species in 100 m^2; and aboveground dead biomass (kg ha^{-1}). Categorical variables were included as dummy variables. Initially, RDA was performed with covariates, including altitude and other topographic variables. The inclusion of those covariates did not improve the explanatory power of the analysis, and thus the simpler version without covariates was selected. We performed a forward selection of environmental variables and tested the discriminatory power of the variables by the non-parametric Monte Carlo permutation test with 9999 permutations. Finally, we performed a Variation Partitioning Analysis (VPA) of nutritive value variation and tested the conditional effects of the two groups of environmental variables used in the RDA: management and sward structure.

Sward nutritive value data were centered and standardized before the multivariate analyses were performed. All multivariate analyses were performed using CANOCO [47]. Other statistical analyses were performed in R [48].

3. Results

3.1. Sainfoin Yield Response to Extreme Climate

Sward production was low during the two experimental study years and the three performed harvests (Figure 1A). As expected, the harvest in fall was the lowest (Figure 1). There was a diversity effect on yield, but this effect was based on the sown species identity, also known as the portfolio effect (Figure 1B). The species that performed better under the highly stressful climatic conditions was sainfoin, followed by alfalfa (Table 1). The two grasses had lower yields than the two dicots. The estimated yield of the two legumes outperformed the two grasses by 43 and 59% for alfalfa and 75 and 89% for sainfoin, and raygrass was the forage that performed the worst in all cases (Table 1). There was no clear advantage in yield in mixtures compared to monocultures (Figure 2).

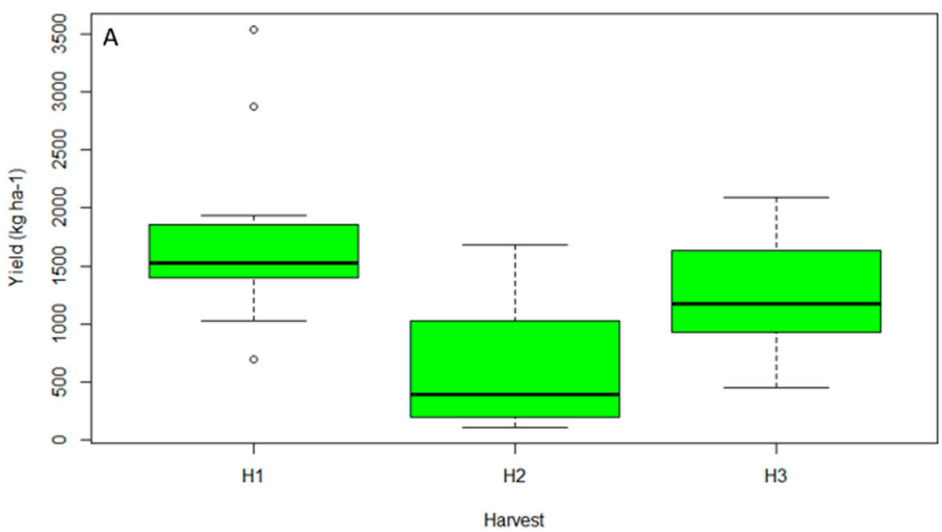

Figure 1. *Cont.*

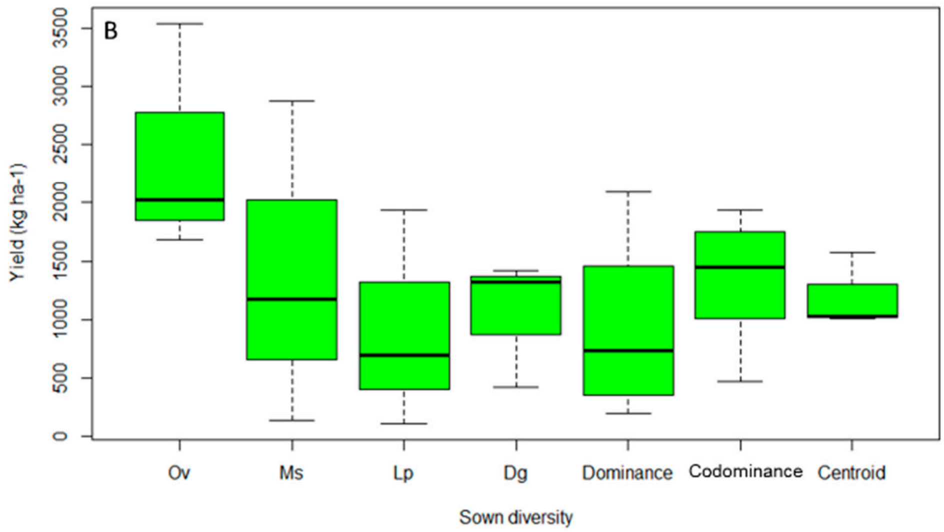

Figure 1. (**A**) Mean ± 1 SE yield per harvest across treatments during the two experimental years after sowing, where H1 and H2 were harvests performed in spring and summer 2022, and H3 is the harvest in spring 2023. (**B**) Mean ±1 SE yield per sown diversity treatment across harvests and years. Ov, Onobruchis viciifolia; Ms, Medicago sativa; Lp, Lolium perenne; Dg, Dactylis glomerata; dominance, sward dominated in turn by one of the four species.

Table 1. Species identity effects on sward yield from the DI models. * $p < 0.05$, *** $p < 0.001$.

Species	Main Effects (β)
Lolium perenne	733.3 *
Dactylis glomerata	871.3 *
Medicago sativa	1348.1 ***
Onobrychis viciifolia	1915.7 ***

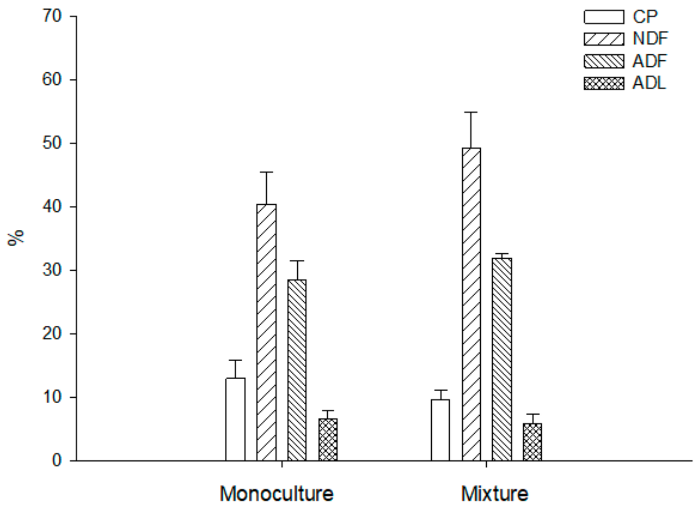

Figure 2. Differences in crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) in mixtures of sainfoin with orchardgrass compared to sainfoin monocultures.

3.2. Sainfoin Quality Response to Management

Management factors explained 12 to 59% of the variability of individual nutritive value parameters (Table 2). ADF was the nutritive parameter that was least responsive to management factors (Table 2). Both ADF and NDF were higher in mixtures with orchardgrass than sainfoin monocultures (Table 2; Figure 2), while protein (CP) and lignin

(ADL) were higher in sainfoin monocultures than mixtures (Table 2, Figure 2). NDF was highest in sheep-grazed and lowest in cattle-grazed sainfoin swards, independent of sward age, and increased with sward age independent of management regime (Table 2). That is, there was no management regime per sward age interaction.

Table 2. Regression analysis of forage chemical composition and nutritive value parameters against management variables. *p*-values are indicated for each factor included in the final model of each nutritive value parameter. For each model, the *p*-value and adjusted R^2 are indicated.

	MM	CP	NDF	ADF	ADL	FU_{milk}	DOM
Mixture vs. monoculture	-	0.0005	0.0002	0.0172	0.0237	-	-
Variety	-	-	-	-	0.0018	-	-
Sowing period	-	-	-	-	<0.0001	-	-
Regime	0.1724	<0.0001	0.0363	-	0.0109	0.0572	0.0389
Sward age	0.9767	0.1714	0.0165	-	0.2499	0.7873	0.8392
Sward age x regime	0.0003	<0.0001	-	-	0.0225	0.0087	0.0014
p-value	<0.0001	<0.0001	0.0001	0.0172	0.0002	0.0148	0.0011
R^2_{adj}	0.50	0.59	0.39	0.12	0.45	0.19	0.31

All nutritive value parameters, other than NDF and ADF, responded to sward age according to management regime (significant management regime × sward age interaction; Table 2). MM and ADL were lowest and CP, DOM, and FU_{milk} were the highest (Figure 3) in young cattle-grazed swards, but nutritive value deteriorated faster with sward age in cattle-grazed swards than under other management regimes (Table 2; Figure 3). That is, in cattle-grazed sainfoin swards, the proportion of MM and ADL in forage increased distinctly with sward age, and CP, FU_{milk}, and DOM decreased (Table 2; Figure 3). Conversely, sheep-grazed and only mown sainfoin swards were more stable throughout time, with only slight changes in nutritive value with sward age (Figure 3). ADL was highly responsive to most management factors (Table 2). In addition to the responses to management factors described above, ADL content in herbage was higher in the French (6.56 ± 0.06) than in the local sainfoin variety (6.38 ± 0.07) and was higher in swards sown in fall than in those sown in spring.

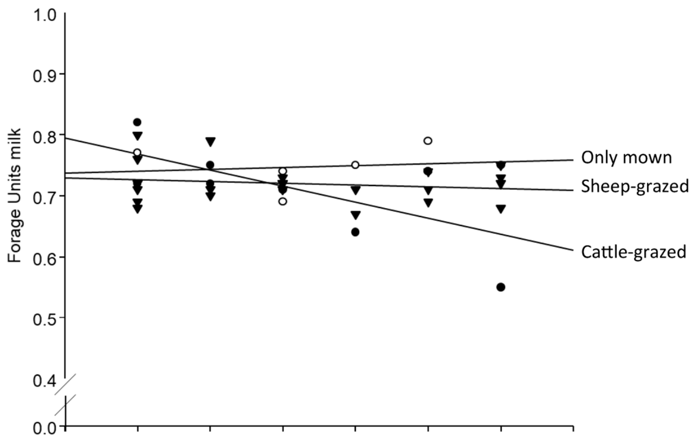

Figure 3. *Cont.*

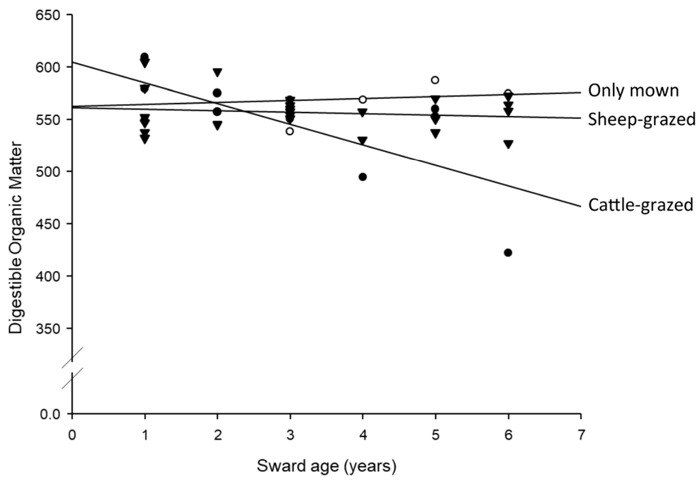

Figure 3. Relationship between the two calculated nutritive value indices and sward age. Above: forage units milk (FU_{milk}) Mcal/kg DM; below: digestible organic matter (DOM) g/kgDM. Curves estimated from models are shown for each management regime by different symbols. Closed circles, cattle grazing; closed inverted triangles, sheep grazing; open circles, only mown.

Direct ordination through RDA and randomization techniques for the forward selection of explanatory variables (Figure 4) confirmed the trends anticipated through regression analysis (Table 2) and allowed an in-depth analysis of the relationship between overall quality value with management factors and with sward compositional and structural variables (Figure 4). RDA showed how direct and indirect effects (through sward structural changes) of management explained an important part of the variation of forage nutritive value in sainfoin swards (Figure 4). RDA axis 1 separated cattle-grazed and time (on the positive side) from sheep-grazed and only mown swards (on the negative side), and also separated mineral matter, toward the positive side, from crude protein, DOM, and FUs (Figure 4), confirming the decrease in nutritive value with time, in particular in cattle-grazed swards. RDA axis 2 separated NDF and ADF from CP and MM, the first parameters linked to sheep grazing over time, compared to other managements. Regarding the structural sward parameters, those were mostly responsive to RDA axis 1, sainfoin biomass, and total yield on the negative axis, and were related to high nutritive value (Figure 4), and weed biomass and proportion were related to dead biomass on the positive side of RDA 1 (Figure 4).

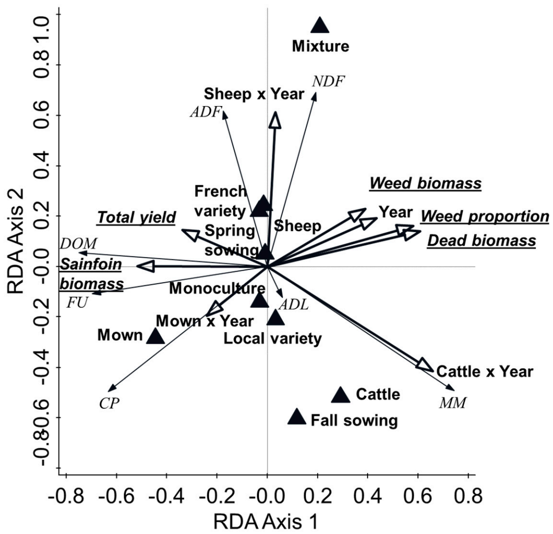

Figure 4. Representation on the first two axes of a Redundancy Analysis (RDA) of nutritive value parameters and the two sets of explanatory variables: management variables (in bold) and sward structural variables (in bold and italics).

Forward selection related to RDA included first the cattle grazing × sward age interaction (27.8%) and, second, cattle grazing (16.6%). Mixing added 14.8% and was the third selected factor. Other management factors included in the forward selection process were sowing period (6.1%) and sainfoin variety (5.9%). Thus, overall, the management regime added an almost 50% explanatory power of nutrition value, mostly in interaction with sward age (33.4%). Dead biomass (11.5%) and forage yield (4.9%) were the main sward structural factors explaining forage quality variability. Weed biomass and proportion combined added less than 4%.

In summary, cattle-grazed sward dynamics throughout time was the main factor explaining forage nutritive value (positive side of the first RDA axis, RD1), with MM increasing in the same direction (Figure 4), suggesting a gradient of forage quality decline. Sainfoin biomass increased toward the negative side of this RD1, which is associated with an increase in forage quality (FU_{milk}, DOM). Sainfoin biomass (and CP) also increased toward the positive side of the second RDA axis, while weed biomass and proportion and dead biomass increased toward the negative side, together with fiber content (RD2; Figure 4). Therefore, RD2 could be interpreted as a fiber–protein gradient (Figure 4).

The VPA confirmed the important role of management on nutritive value, with management single effects accounting for 61.7% of the variation explained by the environmental variables considered, sward vegetation structure single effects explaining 8%, and the shared management and structural effects explaining 30.3%. Overall, 41.8% of the total variation in nutritive value was explained by both sets of environmental variables according to the VPA.

4. Discussion

Sainfoin performed better in terms of yield compared to other forage species under very harsh climatic conditions in mountain regions in Catalonia, Western Mediterranean (Figure 1). In addition, management was important in terms of quality herbage, and the combination of cutting with grazing involved some advantages in nutritive value, which changed throughout time depending on the livestock species (Table 2).

Contrary to the work by Ribas et al. [27], sainfoin outperformed alfalfa under those extremely stressful conditions in our experiment and in our drier experimental field of Olius compared to Gósol (the location used by Ribas et al. [27]). In addition, in our experiment, the only diversity effect was the portfolio effect; that is, the effect of having at least one productive, or in this case, drought-tolerant species, in the mixture (Table 1). The two studies point out that combining species in mixtures can be beneficial because it can guarantee forage yield under different climatic conditions in different years by at least one tolerant species and perhaps obtain an added effect of forage species interactions (sown diversity benefits) in climatically milder years. Our study also points out that sainfoin has potential under the new climatic rules, although more research on this forage, including the development of drought-tolerant varieties, must be undertaken. Acknowledging the potential of sainfoin for animal feed under current environmental conditions, important efforts for testing varieties have been undertaken recently (Gardhouse 2020, Ignatiev 2020, Biligetu et al., 2021) [49–51].

Sainfoin has been recognized as an important forage species in terms of livestock growth and health [20,24,33,52]. However, several authors point out the difficulties of sainfoin management because of the reduced competitive ability of this species [24,29]. Our survey results show a dependence of forage nutritive value on sainfoin sward management (Table 2, Figures 1 and 2). Furthermore, sward structural and compositional variables affected nutrition value mostly through management effects (Figure 4; according to a VPA of around 13% of shared variation vs. over 3% of unique sward structural effects).

Although we did not have enough management combinations to fully test all options because of the survey nature of this part of our study, as opposed to a purely experimental study (see [25] for a discussion on the difficulties of sward evaluation under grazing), our results comparing the nutritional value of sainfoin monocultures and mixtures with orchardgrass support the benefits of grass–legume forage mixtures reported in the literature (Figure 2; [4,24,53]). Indeed, mixed sainfoin swards had higher fiber and lower lignin content than sainfoin monocultures, although protein content was also lower in mixtures (Table 2, Figure 2). Those results correspond to studies in previous, less climatically challenging years. Thus, we still need to learn how and if extreme climate interacts with the different management types, and if so, how the different performance parameters of the sward react.

It has been shown that sainfoin sowing date and management can affect forage yield and weed infestation [9,29]. We found that sowing in fall increased the proportion of lignin in herbage, which was most likely related to extended sward age (Table 2). Furthermore, cattle have been found to prefer sainfoin mixed with grasses [54].

Some nutritive properties were more responsive than others to the management factors, but most of the nutritive parameters were significantly related to variation in the sward management regime (Table 2). Indeed, the management regime was the main factor affecting nutritive value (Table 2, Figure 3). Nonetheless, management regime effects on forage quality interacted with time for most nutrition parameters (Table 2; Figures 2 and 3). Cattle-grazed swards attained high nutritive value shortly after establishment but experienced a decrease in forage nutritive value after the third year (Table 2; Figures 2 and 3). Cattle-grazed swards highly increased levels of ashes (MM) in herbage with time (Figure 4), which is in accordance with the results of previous researchers [55]. They also increased lignin content and decreased crude protein proportion (Figure 4), resulting in an overall decrease in herbage quality with sward age (Figure 3). The hypothesis that sheep grazing decreases herbage quality compared to cattle grazing in grasslands [41] held for young sainfoin swards but could not be supported for old swards because forage quality decreased in cattle-grazed swards over time compared with other management regimes (Figures 2 and 3). A rapid increase in weeds and a decrease in sainfoin biomass with time with cattle grazing could be part of the explanation and display higher stability under other management regimes (Figure 4).

Our results have important implications for management and sward duration after establishment. To preserve herbage nutritive value, cattle-grazed swards should have a relatively short duration after sowing compared to other management regimes, as they lose nutritive value with time (Figures 2 and 3). However, those trends were only slightly related to shifts in vegetation structure and composition through decreases in sainfoin biomass and increases in weeds (Figure 4), suggesting that there could be a direct effect of cattle grazing on sainfoin nutritive properties, perhaps through ecophysiological changes [33,56]. Furthermore, previous authors [9] found that cattle-grazed swards showed strong shifts in vegetation composition with sward age compared to other management regimes. Therefore, ecophysiological responses and changes in companion plant species could be additional factors explaining the residual variation in nutritive value that are unexplained by the management and vegetation factors considered in this study (Figure 4). The combination of the three management regimes was found to increase plant diversity at the regional scale [9] and was particularly favored in old cattle-grazed swards. Therefore, the maintenance of the three management regimes, combined with an increased use of sainfoin mixtures, could provide benefits in terms of quality forage yield and biodiversity conservation and guarantee that at least some of the species in the mixtures will perform well under the current extremely uncertain conditions. For cattle-grazed swards, the trade-off would be maintaining young swards for increased forage quality versus maintaining old sainfoin swards for biological conservation purposes. Supporting legume-based mixtures in the region could contribute to sward persistence, as shown by Fin et al. [57], but more information is needed about the stability and performance of sainfoin-based mixed swards under grazing conditions and an increasingly warmer and drier environment. Results by Küchenmeister et al. [58] suggest that temporary drought can be less important than management (monocultures vs. mixtures) on nutritive value. Furthermore, Poudel et al. [59] pointed out that the performance of orchardgrass in mixtures with sainfoin performs better compared to monocultures in both irrigated and unirrigated environments. Ribas et al. [27] and Poudel et al. [59] pointed out the advantages of sainfoin and alfalfa mixtures. However, we still need more information on how nutritional parameters react in front of extreme climatic events and if there is an interaction between management and climatic extremes in terms of yield and nutrition value. The inventory of sainfoin varieties worldwide, and further research on sainfoin varieties and management, such as by Kölliker et al. [60] and Delgado et al. [61], could contribute to an increased interest in forage under climate change conditions.

5. Conclusions

The decision to manage legume-based forage swards through grazing by sheep or cattle, or through mowing only, has consequences for forage nutritive value and sward duration. Generally, cattle-grazed swards showed forage with higher nutritive value than swards with other management regimes. However, cattle-grazed sainfoin swards lose herbage nutritive value rapidly. The duration of only mown and sheep-grazed sainfoin swards can be extended, as they decrease in nutritive value slowly. However, other considerations, including biodiversity conservation or soil carbon protection, could recommend combining all three management regimes and long sward duration within the same region. Furthermore, our results suggest that sainfoin can be an option under global change conditions, and a conservative management approach, combining management types, including grazing by different livestock, as well as mixtures with other forage species, could contribute to confronting the high uncertainty under current environmental and socio-economic conditions. Our results open a new line of investigation that is useful for farmers and managers using not only sainfoin but other legume-based forage systems. However, the question remains, after the last climatically challenging years, if there is a future for traditional forage systems in the Western Mediterranean mountains.

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