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The conversion of rockrose (*Cistus ladanifer* L.) shrubland into biodiverse pastures

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KEY CONTRIBUTION
The manuscript highlights key contributions of sustainable pasture management, including improving soil health and water retention, sequestering carbon for climate change mitigation, conserving biodiversity, reducing wildfire risks, and promoting sustainable agricultural practices that balance ecological, economic, and social factors.

ABSTRACT

Pastures in the Mediterranean region are vital for sustaining local agriculture and preserving biodiversity. When well-managed, these pastures enhance soil structure and fertility, reduce erosion, and improve water retention. These functions are especially critical in a climate marked by hot, dry summers and mild, wet winters. Moreover, these systems play a key role in carbon sequestration, contributing significantly to climate change mitigation. Mediterranean pastures also support the conservation of endemic plant species and provide essential habitats for a variety of wildlife. Quinta do Freixo (Algarve, Portugal) with an area around 800 hectares, is dedicated to sustainable agriculture and promotes ecological, economic and social sustainability. In addition to organic agriculture production, the farm also produces value-added food products and offers rural tourism experiences. On this farm, a dense shrubland of rockrose (*Cistus ladanifer* L.) is converted into pastures using a holistic method that includes mechanical cutting of the shrubs, spreading hay and grazing with Campaniça sheep under a regenerative rotational grazing (RRG) system. As a part of the project named "Revitalgarve: Revitalization of rural areas" (PRR-C05-i03-I-000237), these restored pastures are regularly monitored. Assessments included measurements of dry matter production and floristic composition. In addition, both the pastures and *Cistus ladanifer* shrublands were evaluated for the nutritional value and mineral composition of their foliage material. This approach has contributed to the development of species-rich pastures, rich in legumes and grasses and characterized by high protein content, excellent digestibility, and a well-balanced mineral composition. Although *Cistus ladanifer* had a relatively lower nutritional value due to its lower protein content and digestibility, the analysis showed that its aerial parts can serve as a supplementary feed resource, especially in periods of forage scarcity, contributing to overall feed availability in extensive grazing systems.The control of shrublands through this practice maintains biodiversity and reduces the risk of wildfires by effectively managing fuel loads.

Introduction

The rising affluence in developing nations is projected to drive an increase of over 70% in the demand for animal protein products over the coming decades (Henchion et al., 2017; Tilman and Clark, 2014; Furnitto et al., 2025). This surge in demand could result in up to an 80% rise in greenhouse gas emissions from agriculture, which could severely damage ecosystems if agricultural practices remain unchanged (Tilman and Clark, 2014). In this context, grassland-based agriculture presents a promising and sustainable approach to enhancing food production capacity (Huyghe et al., 2019; Barthram et al., 2005; Nakagami, 2016).

Silvopastoral systems occupy several million hectares of agricultural land in the European Union, with a strong presence in southern member states. These areas are characterized by environmental constraints including shallow soils with low nutrient content, steep slopes, and low water availability, conditions commonly found in Mediterranean rangelands (Pinto-Correia et al. 2018; Rigueiro-Rodríguez et al., 2009; Bergmeier et al., 2010; Plieninger et al., 2015; Bruno-Soares et al., 2011). Animal farming is particularly important for Portugal, where permanent pastures used for grazing occupy around 2.1 million hectares, representing approximately 52% of its Utilisable Agricultural Area (UAA) (INE, 2019).Permanent pastures, especially those with rich botanical diversity composition and their proper management, are essential for sustainable agricultural production and environmental conservation. They offer multiple benefits, from maintaining soil health to mitigating climate change (Moreira and Coelho, 2008). Well-managed pastures can prevent soil erosion by improving its structure and increasing water infiltration (Teague et al., 2011), which can, in many cases, contribute to aquifer recharge. Continuous ground cover protects the soil from direct impacts of rain and wind, conserving nutrients and organic matter. Additionally, pastures ensure biodiversity and landscape preservation, providing habitats for various plant and animal species and playing a vital role in ecosystem services such as pollination and biological pest control (Sanderson et al., 2013; Moreira and Coelho, 2008). They also act as carbon sinks, sequestering carbon-dioxide (CO_2) from the atmosphere and storing it in the soil and plant biomass, helping to reduce greenhouse gases (Conant et al., 2001). Moreover, they are crucial for reducing combustible materials, a critical element in preventing wildfires (Davies et al., 2010). Economically, pastures are essential for the livelihoods of millions of farmers, promoting resilient agricultural practices, ensuring food security, and fostering the stability of rural communities (Hopkins, 2000).

Cistus ladanifer is a resinous, perennial sclerophyllous shrub associated with labdanum production. It commonly grows in the understory of oak and pine forests and often becomes dominant in degraded or low-diversity scrublands. These shrubs are early successional species, well suited to the disturbance patterns of Mediterranean ecosystems, especially recurrent wildfires. The native area occupies 2 million hectares in the south and southwest of the Iberian Peninsula, mostly in poor and acidic soils and, infrequently, in ultramafic and calcareous soils (Almeida et al., 2023). This species is well adapted to hot and dry landscapes and is expected to be highly resilient to climate change, which is starting to increase the aridity of the Mediterranean Basin (Guiot and Cramer, 2016; Ferreira et al., 2021). Being a highly flammable species, it poses a significant risk for the spread of wildfires, making its control or regular and complete exploitation essential for fire prevention (Alves-Ferreira et al., 2023).

In this context, the seasonal use of these areas for sheep grazing, could offer a viable and sustainable solution. The palatability of the leaves of these plants makes them very attractive for animal consumption. Browse species supply green material for grazing animals and can be the only source of nutrients during some periods of the year (Bruno-Soares et al., 2011). However, there are a number of constraints in using browse plants as animal feeds, such as their high fibre fraction and also high levels of phenol compounds in their foliage (Lefroy et al., 1992). Although its nutritional value is limited by low protein and digestibility, it contains high levels of condensed tannins, which can modulate rumen fermentation and improve the oxidative stability and fatty acid profile of animal products (Pereira and Gregorini, 2022). Seasonal variation in the chemical composition and digestibility of its morphological fractions, particularly the leaves, has also been reported, with higher nutritive value observed in winter and spring (Guerreiro et al., 2022).

These *Cistus ladanifer* areas could also be cut and converted into biodiverse pastures using the practice of regenerative rotational grazing (RRG), where pastures are divided into smaller paddocks and livestock are rotated frequently at high stocking densities. This approach allows for extended rest periods, enabling grass recovery and regeneration, which ultimately enhances livestock productivity while promoting ecosystem health, biodiversity, and long-term resilience (de Otálora et al., 2021; Jacobo et al., 2006).

The aim of this study was to evaluate the effects of converting *Cistus ladanifer* shrublands into biodiverse pastures in Algarve region through integrated management practices, including mechanical shrub cutting, spreading biodiverse hay, and grazing with 'Campaniça' sheep using regenerative rotational grazing (RRG). With this aim, we structured the study around three research questions. First, how does the biomass and floristic composition, particularly the presence of legumes and grasses, change after restoration? Second, does the transformation of *Cistus ladanifer* shrublands produce high-quality pastures? Third, can *Cistus ladanifer* be used as feed for sheep during certain periods?

Materials and methods

Study area

Quinta do Freixo is located in the municipality of Loulé (Portugal), within the "Barrocal" region, an intermediate zone between the mountains and the coastal plain (Figure 1). This area, in the southern Portugal's Algarve region, is characterized by limestone-rich soils, high groundwater availability, and notable agricultural fertility. Its calcareous geology and karstic features support productive land use and a diverse range of Mediterranean vegetation (Cabral and Galego, 2024). Covering an area of approximately 800 hectares, Quinta do Freixo is dedicated to activities ranging from agriculture and livestock farming to processing and rural tourism. The entire area is certified for organic production.

Experimental design

The experiment was conducted from January to July 2024. The original vegetation cover of a north-facing slope (37°16'08.0"N, 8°07'31.3"W) was dominated by rockrose (*Cistus ladanifer*), with some cork oaks (*Quercus suber*), holm oaks (*Quercus ilex*), and stone pines (*Pinus pinea*). In May, the rockrose shrubland was mechanically cleared using a brush cutter (CML-1300, 1.30 m, Galucho, Portugal) attached to a tractor (5075E, 70 hp, John Deere, USA), covering an area of approximately 6.3 hectares, as shown in Figure 1. Subsequently, a flock of 1000 Campaniça sheep was introduced into one-hectare electric fence enclosures, which were rotated every five days, following a regenerative rotational grazing (RRG) system. Each day, 56 bales of hay produced on the farm, each weighing 20 kg, were supplied per hectare. As a result of these interventions, natural pastures emerged in the area, which had previously been dominated by dense shrubland.

Regarding grazing, the study involved two pastures, focusing on biomass production, floristic composition, mineral content, and nutritional value: Pasture A (PA), established in 2022, where the supplied hay was primarily composed of oats (*Avena sativa*) and vetch (*Vicia villosa*); and Pasture B (PB), established in 2023, where the hay originated from a meadow containing a biodiverse mix of annual legumes and grasses *(Avena strigosa*, × *Triticosecale*, *Lolium multiflorum*, *Vicia villosa*, *Vicia sativa*, *Melilotus officinalis*, *Medicago truncatula*, *Medicago polymorpha*, *Medicago rugosa*, *Medicago littoralis*, *Trifolium subterraneum*). During the study period, the pastures were not grazed. Additionally, we also considered the areas surrounding the established pastures, dominated by *Cistus ladanifer* (Clad) (plants with between 2 and 6 growth seasons), to analyze the mineral composition and nutritional value of the leaves (Figure 1).

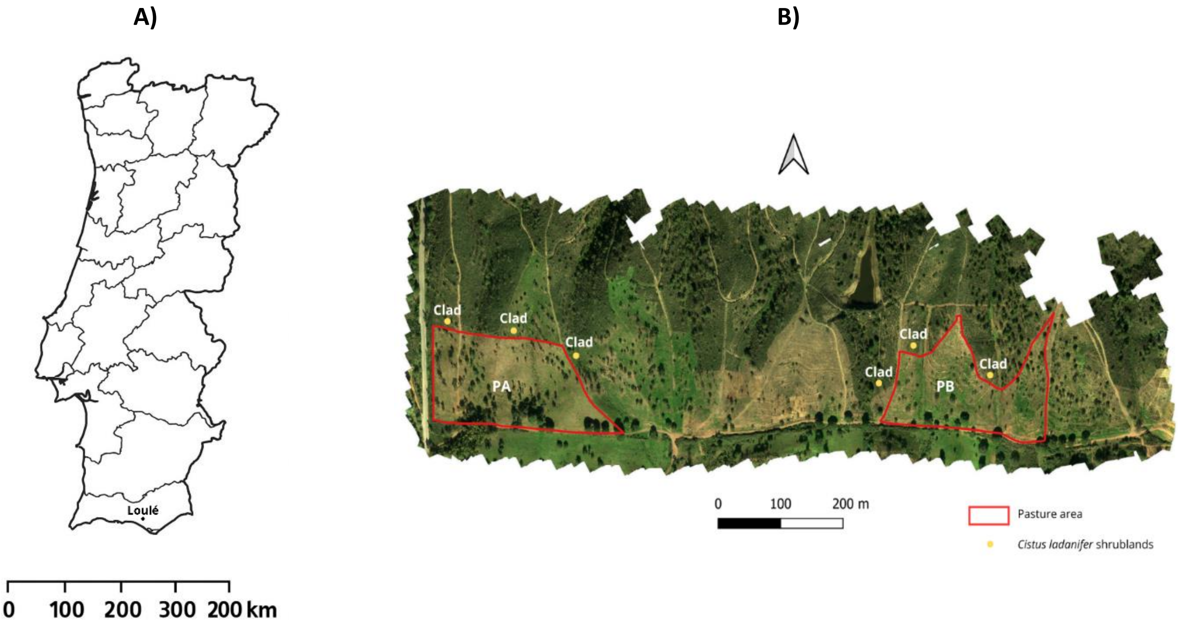

Figure 1 Map of A) location of study site Loulé within Portugal, and B) experimental design in Quinta do Freixo. **PA** - Pasture A (3.4 hectares); **PB** - Pasture B (2.9 hectares); **Clad** - sampling points correspond to areas with natural occurrence of Cistus ladanifer, from which leaf samples were collected for analysis

Climatic and soil characterization

The Algarve region is characterized by a mild Mediterranean climate, with an annual average of 3300 hours of sunshine and 571 mm of precipitation as described by Cabral and Galego (2024). These climatic conditions, marked by hot, arid summers and mild, wetter winters, have significant implications for ecosystem functioning, water resource management, and agricultural practices in the region.

Temperature data for 2024 were collected at Quinta do Freixo using a sensor (SD-TEMP-01, Onset Computer Corporation, USA) installed at a height of 2 meters, connected to a corresponding channel analog data logger (HOBO MX1105, Onset Computer Corporation, USA). Precipitation data were obtained from the Loulé meteorological station of the Portuguese Institute for Sea and Atmosphere (IPMA).

Mean temperatures increased progressively from a minimum of 11.8 °C in January, reaching a maximum of 24.3 °C in August, followed by a decline towards the end of the year, with December averaging 12.8 °C. Monthly precipitation ranged from 1 mm in July to a peak of 77 mm in December. The wettest months were December (77 mm), October (68 mm), and November (65 mm), while the summer months

(July and August) had minimal rainfall (1 mm and 3 mm, respectively), reflecting a pronounced dry season. (Figure 2).

Geologically, the substrates consist of schists and greywackes, which give rise to Mediterranean Brown Soils (Px) (Kopp et al., 1989). Soil pH is acidic (around 5.7), and soil organic carbon content is generally below 2%.

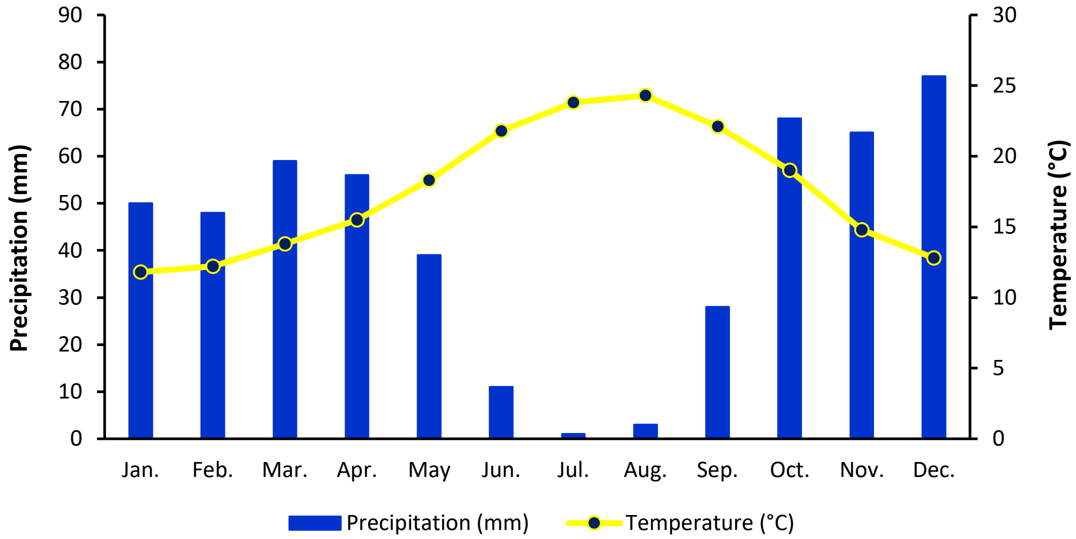

Figure 2 Average monthly precipitation and temperature in 2024 at the Loulé meteorological station and Quinta do Freixo, respectively

Biomass and floristic composition

The biomass production of pastures was estimated using a rising plate meter (RPM) (Klootwijk et al., 2019; Liu et al. 2011). This common, nondestructive, and easy-to-use tool consisted of a graduated iron shaft (in cm) and a PVC circular plate measuring 35 cm in diameter and weighing 145 grams. The RPM was placed on the sward and measures the resistance of the sward toward the plate, which depends not only on grass length, but also on sward structure (Sanderson et al., 2001). Grass height was translated into biomass in kilograms of dry matter (DM) per hectare using a calibration equation that includes a factor to represent quadratic relationship between grass height and biomass based on cutting and weighing. A calibration equation was developed for each type of pasture (Figure 3).

The floristic composition was determined. A total of 18 vegetation samples were collected for each pasture type during spring (April). For each sample, plants were clipped within a randomly selected circular area of 0.101 m² within the pasture. The collected plants were categorized by the botanical family into legumes, grasses, and other (e.g., *Plantago lanceolata*, *Raphanus raphanistrum*, *Sanguisorba verrucosa*, *Glebionis coronaria*). Additionally, samples of *Cistus ladanifer* leaves were randomly collectted for future nutritional and mineral detemination. Plant material was transported to the laboratory and all collected samples were initially washed with tap water, followed by a second wash with deionized water containing a non-ionic detergent (0.1%) to remove surface contamination. The samples were then washed with 0.01 M HCl, and rinsed three times with distilled water. The dry matter (DM) of the shoots was determined by drying the samples at 60 °C until a constant weight was achieved.

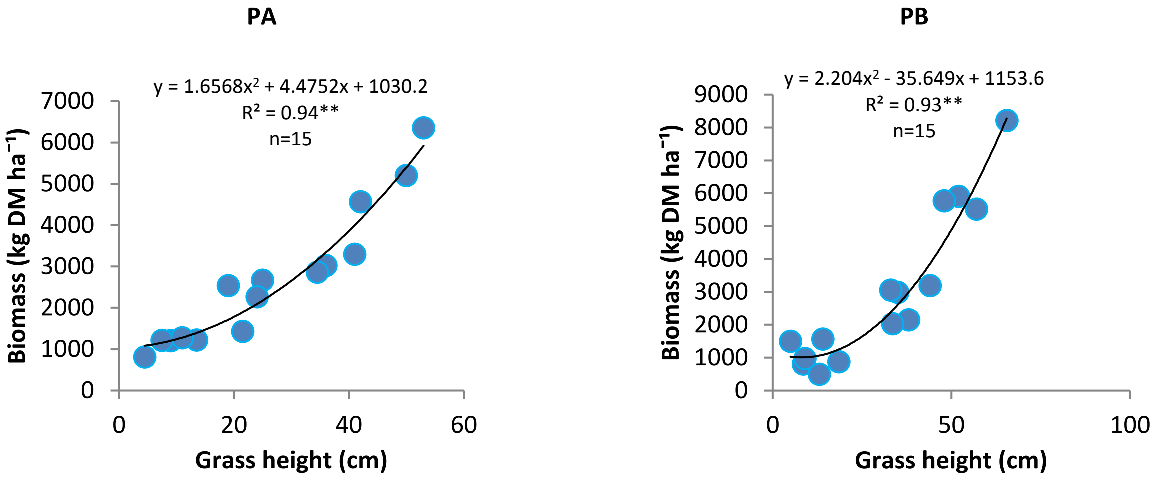

Figure 3 Relationship between biomass (kg DM ha^{-1}) and grass height (cm) readings
** significant at $P<0.001$

Nutritional value analysis

Ground samples (1 mm) of dry matter (DM) from PA, PB and Clad were analysed for nutricional value. The analysis included the determination of humidity, ash, crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and in vitro digestibility. Crude protein content was determined using the Kjeldahl method (NP EN ISO 5983-2:2009). Nitrogen content was estimated through digestion, distillation, and titration with 0.1N hydrochloric acid. Crude protein was then calculated by multiplying the nitrogen content by the conversion factor of 6.25. The ash content was determined by incinerating the sample at 550 °C, following the NP ISO 5984:2014 standard. The crude fat content was estimated according to the NP ISO 6492:2014 method, with slight modifications. The method of Robertson and Van Soest (1981) was preformed to separate fibre fractions into NDF (NP EN ISO 16472:2013), ADF, and ADL)(EN ISO 13906:2008). The moisture content was determined at 103 °C in accordance with the NP ISO 6496:2018 standard. In vitro digestibility wasassessed following the method of Tilley and Terry (1963), with slight modifications as described by Iowerth et al. (1975).

Mineral composition

Dried plant samples were ground to powder and digested with an acidic solution consisting of nitric acid and peroxide oxygen according to standard laboratory procedures. The total nitrogen (N) content of the plant material was determined by the Kjeldahl method (Selecta, micro-Kjeldahl-6014206, Spain). The concentration of P, K, Ca, Mg, S, Fe, Cu, Zn and Mn was determined by inductively coupled plasma optical emission spectroscopy ICP-OES (7000 series, Agilent Technology, U.S.A.). Macronutrients were expressed in grams per kilogram of DM while micronutrients were expressed in milligrams per kilogram of DM.

Statistical analysis

The statistical analyses were conducted using IBM SPSS® software version 29. To compare the means, a one-way analysis of variance (ANOVA) and a Duncan multiple range test at a significance level of $P \leq 0.05$ were employed. The establishment between Grass height (X) and biomass (Y) production was achieved through nonlinear regression models ($Y = aX^2 + bX + c$).

Results

The conversion of Cistus ladanifer shrubland into pastures significantly transformed the landscape, resulting in well-established, species-rich swards (Figure 4). The biomass revealed significant differences between pastures. At the beginning of the experiment, PA showed 512.8 ± 51.0 kg DM ha^{-1} of biomass in January with a tendency to increase over time, reaching a value of 2410.5 ± 118.6 kg DM ha^{-1} in June. The accumulated biomass in PB ranged from 1249.0 ± 339.2 kg DM ha^{-1} in January to 6272.5 ± 356.0 kg DM ha^{-1} in June (Figure 5).

Figura 4 A) Dense shrubland of **Clad** - Cistus ladanifer; B) **PA** - Pasture A: area intervened in 2022 (3.4 hectares) and whose hay composition was based on oats and vetch and C) **PB** – Pasture B: area intervened in 2023 (2.9 hectares) and whose hay composition came from a meadow with a biodiverse mixture of legumes and grasses. (April, 2024)

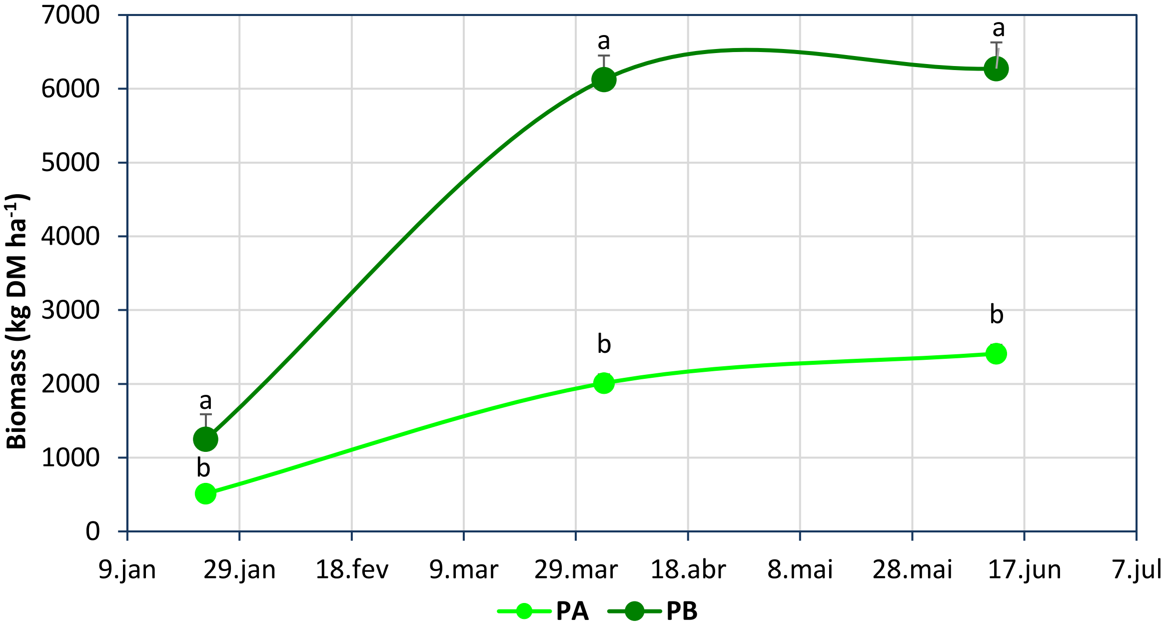

Figure 5 Evolution of average dry matter (DM) production in 2024. Different letters indicate significant differences between treatments (*P*≤ 0.05). Error bars represent 95% confidence intervals

In PA, the biomass of each botanical family ranged from 990.0 kg DM ha^{-1} to 1922.6 kg DM ha^{-1}. Grasses were the group with the highest biomass, amounting to 1922.6 kg DM ha^{-1}, representing approximately 46.9% of the total pasture biomass. The biomass of legumes was 1055.3 kg DM ha^{-1}, while other families accounted for 990.0 kg DM ha^{-1}, corresponding to 27.3% and 25.8% of the total bio-mass, respectively (Figure 6A).

In PB, the biomass of each botanical family ranged from 650.2 kg DM ha^{-1} to 3093.5 kg DM ha^{-1}. Grasses were also the dominant group, with a biomass of 3093.5 kg DM ha^{-1}, representing approximately 57.6% of the total pasture biomass. The biomass of legumes was 1170.2 kg DM ha^{-1}, while other families contributed 650.2 kg DM ha^{-1}, accounting for 26.1% and 16.3% of the total biomass, respectively (Figure 6B).

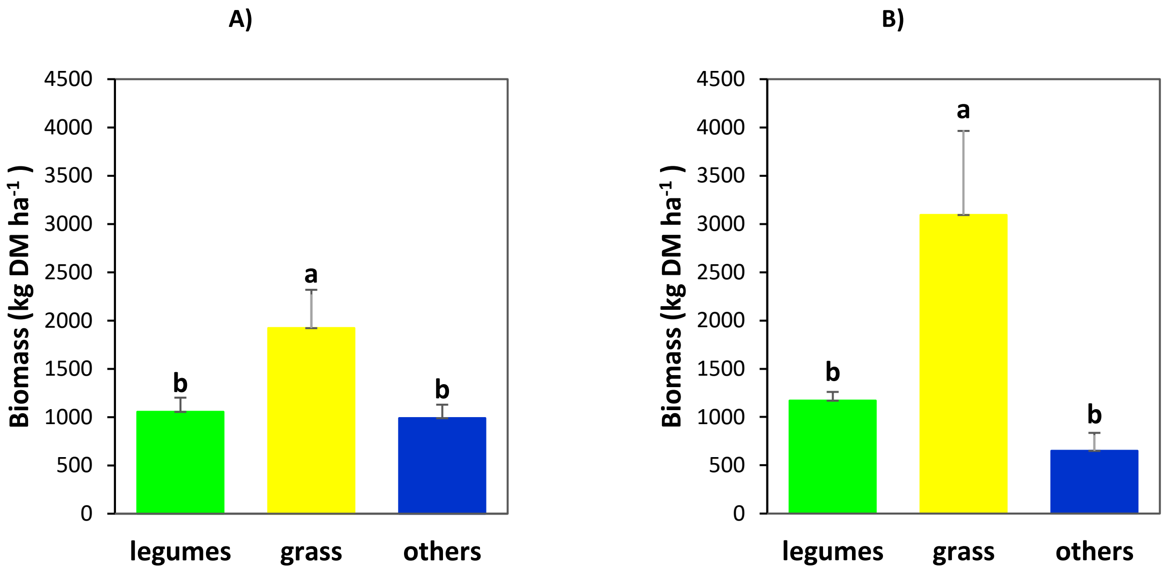

Figure 6 Average biomass production (Kg DM ha^{-1}): A) Pasture A and B) Pasture B. Different letters indicate significant differences between treatments (*P*≤ 0.05). Error bars represent 95% confidence intervals

PA has higher moisture content (5.7%), showing significant difference from PB (4.7%) and Clad (3.5%). PA also shows the highest ash content (6.6%), followed by PB (5.7%) and rockrose (3.9%). Crude protein is the highest in PA (9.8%), decreasing in PB (8.4%) and Clad (5.9%). PB has the highest NDF (58.8%), indicating more structural carbohydrates, while PA and Clad are lower (48.7% and 29.8%, respectively). ADF is the highest in PB (36.1%) compared to PA (32.3%) and Clad (20.7%). A comparison of the ADL in biomass did not reveal significant differences. PA is the most digestible (57.6%), significantly more than PB (46.5%) and Clad (42.9%) (Figure 7).

The macronutrient composition of the treatments is presented in Table 1. Nitrogen (N) concentration ranged from 7.5 to 13.9 g kg^{-1} DM, with PA showing the highest concentration—a 46% increase compared to Clad. Phosphorus (P) concentration varied between 1.4 and 1.8 g kg^{-1} DM, with PA showing the highest value, significantly higher than Clad, and similar to PB. Potassium (K) levels were the highest in PA (17.7 g kg^{-1} DM), more than 2.6 times greater than the value observed in Clad (6.7 g kg^{-1} DM). Both PA and PB had similarly high K content, with no significant difference between them. Sodium (Na) followed the same trend, with PA and PB showing higher concentrations (2.5 and 2.3 g kg^{-1} DM, respectively) compared to Clad (0.6 g kg^{-1} DM). Although Calcium (Ca) concentrations were similar in PA and Clad, both were higher than PB. Magnesium (Mg) levels did not differ between PA and Clad

(1.8 g kg^{-1} DM), but were significantly higher than in PB (1.3 g kg^{-1} DM). Sulfur (S) concentration was relatively stable across treatments, with slightly higher values in PA and PB compared to Clad. For Chlorine (Cl), PA and PB had higher concentrations (7.7 and 8.6 g kg^{-1} DM) than Clad (1.0 g kg^{-1} DM), reinforcing the higher concentrations of macronutrients of the improved pastures.

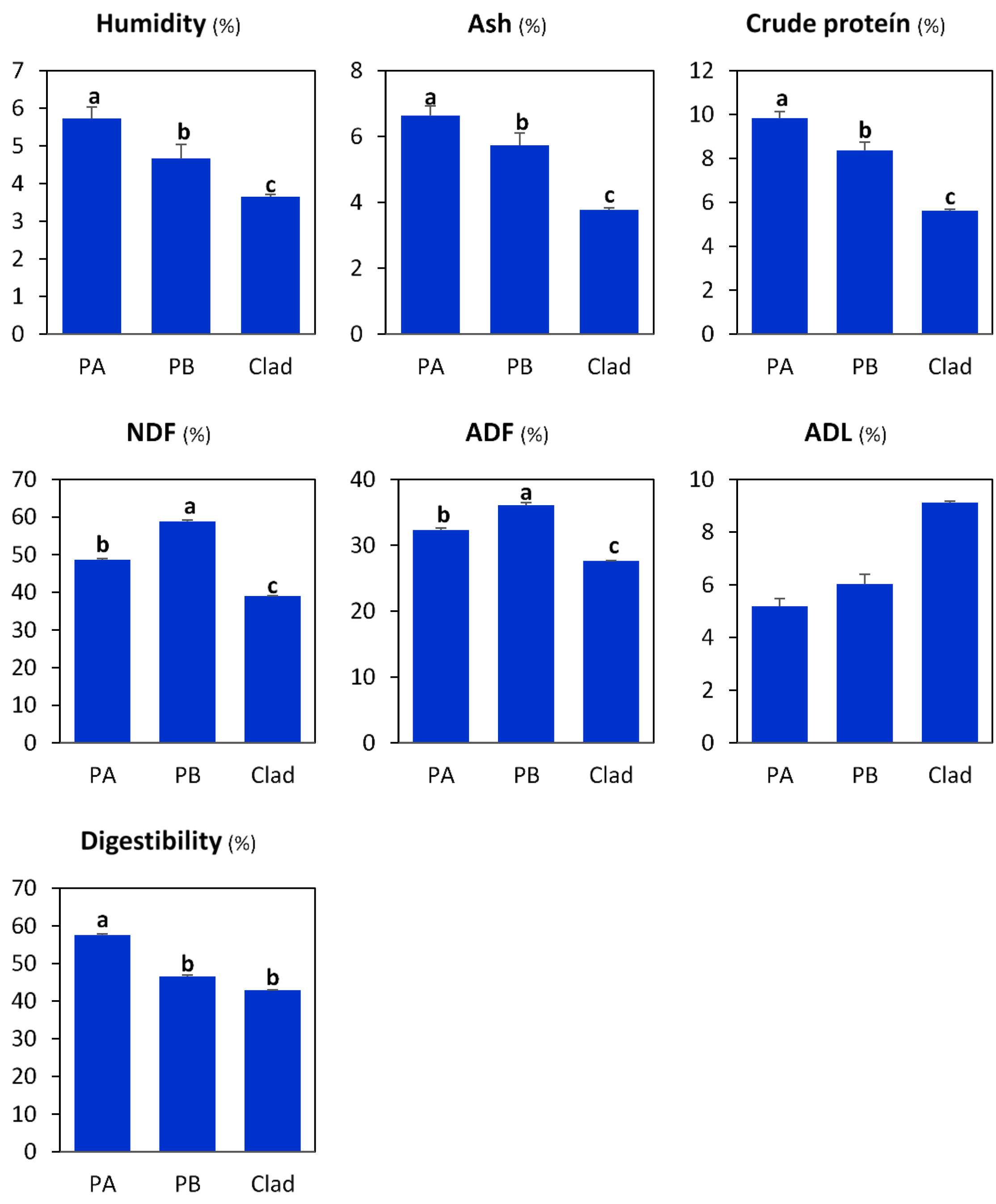

Figure 7 Average nutritional value of PA, PB and Clad. Values for humidity, ash, crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and in vitro digestibility in % of DM. For each parameter analysed, different letters represent significant differences between samples ($P \leq 0.05$). Error bars represent 95% confidence intervals

Table 1 Mean of macronutrients (g kg^{-1} DM). For each parameter analysed, different letters represent significant differences between samples ($P \leq 0.05$)

Treatment	N	P	K	Na	Ca	Mg	S	Cl
PA	13.9 ± 0.7 a	1.8 ± 0.1 a	17.7 ± 0.9 a	2.5 ± 0.2 a	5.2 ± 1.0 a	1.8 ± 0.1 a	1.7 ± 0.0 a	7.7 ± 1.1 a
PB	9.1 ± 0.6 b	1.5 ± 0.2 ab	14.7 ± 1.2 a	2.3 ± 0.1 a	1.2 ± 0.7 b	1.3 ± 0.1 b	1.6 ± 0.1 a	8.6 ± 0.8 a
Clad	7.5 ± 0.4 b	1.4 ± 0.0 b	6.7 ± 0.1 b	0.6 ± 0.0 b	4.4 ± 0.3 a	1.8 ± 0.0 a	1.4 ± 0.0 b	1.0 ± 0.1 b

The micronutrient concentrations of the treatments are presented in Table 2. Iron (Fe) ranged from 77.0 to 120.7 mg kg^{-1} DM. However, no statistically significant differences were observed among treatments. Manganese (Mn) levels were significantly higher in Clad (160.0 mg kg^{-1} DM) compared to PA and PB, which had lower and statistically similar values (113.0 and 107.3 mg kg^{-1} DM, respectively). Zinc (Zn) concentrations were significantly higher in PA and Clad (both 33.0 mg kg^{-1} DM) compared to PB (19.0 mg kg^{-1} DM), indicating higher Zn availability in those treatments. Copper (Cu) remained relatively stable across all treatments (13.7–14.3 mg kg^{-1} DM), with no significant differences observed. Boron (B) was significantly higher in PA (23.0 mg kg^{-1} DM) and Clad (22.0 mg kg^{-1} DM) than in PB (13.0 mg kg^{-1} DM), highlighting a greater micronutrient richness in the former treatments.

Table 2 Micronutrient concentrations (mg kg^{-1} DM). For each parameter analysed, different letters represent significant differences between samples ($P \leq 0.05$)

Treatment	Fe	Mn	Z	Cu	B
PA	120.7 ± 24.6	113.0 ± 18.6 b	33.0 ± 4.0 a	13.7 ± 0.3	23.0 ± 3.1 a
PB	106.0 ± 10.4	107.3 ± 13.0 b	19.0 ± 2.6 b	14.3 ± 0.3	13.0 ± 0.0 b
Clad	77.0 ± 2.5	160.0 ± 2.5 a	33.0 ± 1.0 a	13.7 ± 0.3	22.0 ± 1.2 a

Discussion

Animal performance on pasture results from the interaction between forage quantity and nutritive value. Quantity determines how much of the potential can be achieved, while nutritive value sets that potential. Efficient management should balance both to optimize productivity (Sollenberger and Vanzant, 2011). The results demonstrated that the PB, whose hay composition came from biodiverse mixture of legumes and grasses, had more accumulated biomass than PA, whose hay composition was based on oats and vetch. These findings indicate that biodiverse pastures had a greater accumulation of biomass over time, likely due to differences in plant composition, as supported by studies on pasture dynamics in similar regions (Jongen et al., 2024; Hidalgo-Galvez et al., 2023).

Annual pastures provide most of the feed and are essential to sustain high livestock productivity at a time of year when energy demand is greatest for lactation and growing young animals (Thomas et al., 2021). Kliem (2024) reported beneficial effects on nutritional quality of meat from lambs grazing biodiverse vs perennial ryegrass pasture. As such, biodiverse pastures should be considered for incorporation into grazing systems. In our study, PA appears to be the most nutritionally favourable for digestibility and protein content, while PB has the highest fiber content. Clad exhibits a lower nutritional profile compared to other treatments.

Some studies have reported low crude protein content and digestibility in *Cistus ladanifer* (Guerreiro et al., 2015; Guerreiro et al., 2022). In our study, protein content was similar to previous reports, but digestibility was higher, possibly due to environmental factors, plant phenological stage, or site-specific conditions. Although Cistus ladanifer is considered a feed with poor nutritional value due to its low protein content and digestibility, its aerial parts, rich in phenolic compounds and condensed tannins, can serve as a supplementary forage for small ruminants and as a source of bioactive compounds to modulate rumen metabolism and improve the oxidative stability of animal products (Guerreiro et al., 2015; Jerónimo et al., 2020).

The abundance of minerals available to livestock is governed by a range of factors including the quantum of that mineral in the pasture and mineral interactions that may impact its absorption by the animal (Li et al., 2025). PA, which contains a higher proportion of other botanical family species (25.8%) compared to PB (16.3%), demonstrated superior macronutrient levels, particularly of nitrogen, phosphorus, and potassium. This aligns with the findings of Li et al. (2025), who reported that the inclusion of herbs and legumes in pasture mixtures enhances the mineral composition of forage. Both PA and PB showed higher concentrations of K, Na, S, Cl compared to Clad, reinforcing their greater mineral availability and nutritional value for livestock. Although Clad was lower in several macroelements, it showed comparatively higher levels of Ca and Mg, suggesting a potential complementary role in mixed grazing systems. Similar benefits have been observed in other shrubs and non-conventional forages, which can contribute essential minerals otherwise limited in typical grass–legume systems (Darch et al., 2020; Masters et al., 2019). The complementary use of shrubs and herbaceous species, as highlighted by Papachristou et al. (1999), also contributes to ecological resilience and system sustainability.

Conclusion

These integrated management practices contributed to the development of species-rich pastures, combining legumes and grasses with high protein content and excellent digestibility. Additionally, the control of shrublands through this practices maintains biodiversity and reduces wildfire risk through effective fuel load management. Finally, further long-term studies are required to confirm the consistency and applicability of these findings across diverse soil types, climatic conditions, and pasture compositions.

Author Contributions: The concept was initially proposed by J.V. and A.N., who subsequently devised the experimental design. The experiment was conducted by J.V., I.F., A.R., I.M., A.R.T. and A.N., who also collected the data. All authors were engaged in the analysis and the discussion of the data. The authors responsible for the preparation of the manuscript were J.V. and A.N.. All authors have read and approved the final manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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