Universidade de Évora - Instituto de Investigação e Formação Avançada
Universidade do Algarve - Faculdade de Ciências e Tecnologia

Programa de Doutoramento em Ciências Agrárias e Ambientais

Tese de Doutoramento

Intensificação sustentável da produção de ovinos no montado: estudo da interação entre a produtividade de pastagens naturais e a gestão dinâmica do pastoreio

Emanuel Ruben dos Santos Carreira

Orientador(es) | A. M. F. Pereira
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A tese de doutoramento foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor do Instituto de Investigação e Formação Avançada:

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Évora 2024

Para os meus pais, irmã e avó Maria.

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com um beijinho especial,

estejam onde estiverem.

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Resumo

O objetivo desta tese foi melhorar a compreensão das inter-relações entre os componentes do ecossistema Montado: solo, pastagem, árvores e animais. Os ensaios decorreram, ao longo de quatro anos, na Herdade da Mitra, numa parcela (Eco-SPAA) com área de 4,2 ha dividida em quatro parcelas com áreas semelhantes. Foram constituídos quatro tratamentos: com e sem aplicação de calcário dolomítico e, pastoreio contínuo (PC) *versus* pastoreio diferido (PD).

Os ensaios desenvolveram-se em duas fases: entre julho de 2018 e junho de 2020; e, entre setembro de 2019 e outubro de 2021. A primeira fase visou avaliar o efeito da aplicação de calcário dolomítico e da copa das árvores na produtividade, qualidade e composição florística da pastagem. Em cada parcela foram georreferenciadas 3 árvores, identificando-se dois pontos de amostragem para cada uma delas, um na projeção da copa e outro fora, perfazendo um total de 24 pontos. Na segunda fase, avaliaram-se os efeitos da aplicação de calcário dolomítico e de pastoreio (PC *versus* PD), com diferentes encabeçamentos, na produção, qualidade e composição florística da pastagem, nas preferências de pastoreio e na compactação do solo. Identificaram-se 12 pontos de amostragem por parcela, representativos das comunidades vegetais.

Os resultados mostram que: i) a aplicação de calcário dolomítico contribuiu para a redução da acidez do solo e da toxicidade de manganês, favorecendo a produção de pastagem; ii) o PD deu indicações para a melhoria da composição florística da pastagem; iii) os ovinos exploraram as áreas disponíveis de forma semelhante embora com padrões temporais específicos para cada parcela; iv) os dois sistemas de pastoreio, não determinaram diferenças significativas na compactação do solo.

Estes resultados são bons indicadores para uma possível intensificação sustentável da produção de ovinos no Montado sem que esta acarrete prejuízos aparentes no solo e na pastagem.

Palavras-chave: Montado; pastagens; tecnologias; pastoreio; ovinos.

Title: Sustainable intensification of sheep production in the montado: study of the interaction between natural pastures productivity and the dynamic management of grazing

Abstract

The aim of this thesis was to improve understanding of the interrelationships between the components of the Montado ecosystem: soil, pasture, trees and animals. The trials took place over four years at Herdade da Mitra, on a plot (Eco-SPAA) with an area of 4.2 ha divided into four plots with similar areas. There were four treatments: with and without the application of dolomitic limestone and continuous grazing (CG) versus deferred grazing (DG).

The trials took place in two phases: between July 2018 and June 2020; and between September 2019 and October 2021. The first phase aimed to assess the effect of applying dolomitic limestone and the tree canopy on the productivity, quality and floristic composition of the pasture. Three trees were georeferenced in each plot and two sampling points were identified for each of them, one in the projection of the crown and the other outside, making a total of 24 points. In the second phase, the effects of applying dolomitic limestone and grazing (CG versus DG), with different headings, on the production, quality and floristic composition of the pasture, grazing preferences and soil compaction were assessed. Twelve sampling points were identified per plot, representative of the plant communities.

The results show that: i) the application of dolomitic limestone helped to reduce soil acidity and manganese toxicity, favouring pasture production; ii) the PD gave indications for improving the floristic composition of the pasture; iii) the sheep exploited the available areas in a similar way, although with specific temporal patterns for each plot; iv) the two grazing systems did not determine significant differences in soil compaction.

These results are good indicators for a possible sustainable intensification of sheep production in the Montado without causing apparent damage to the soil and pasture.

KEYWORDS: Montado; pastures; technologies; grazing; sheep.

Índice

CAPÍTULO 1

Introdução

As alterações climáticas tendem a condicionar cada vez mais a sustentabilidade dos ecossistemas, em geral, e dos sistemas de produção agropecuários, em particular. Em Portugal, sobretudo a Sul do rio Tejo, estas alterações tendem a manifestar-se de forma mais acentuada, assistindo-se, a uma tendência para o aumento das temperaturas médias, a diminuição da precipitação anual e para uma distribuição desta, cada vez mais irregular ao longo do ano, de acordo com dados do Instituto Português do Mar e da Atmosfera (2023). Paralelamente, tem-se verificado por parte da população, um crescente interesse e preocupação acerca dos efeitos das alterações climáticas, na degradação dos ecossistemas e na consequente perda da biodiversidade. Por outro lado, a sociedade, está mais atenta e é mais exigente quanto ao modo de produção dos alimentos, nomeadamente os de origem animal. O consumidor tende a preocupar-se, cada vez mais, com a cadeia de produção, com a origem e o bem-estar dos animais, com os sistemas de produção, com o tipo de alimentação e sua origem, tendendo a valorizar os produtos oriundos de sistemas de produção baseados em pastagens. O consumidor tende também a valorizar produtos provenientes de sistemas de produção eficientes, com menor recurso a combustíveis fósseis, água, fertilizantes e aditivos. Neste contexto, poderá perspetivar-se o conceito de intensificação sustentável, procurando, simultaneamente, incrementar a produtividade por unidade de área e minimizar os *inputs*, contribuindo assim para a maior resiliência dos sistemas.

Os sistemas agro-silvo-pastoris, pelas suas caraterísticas intrínsecas, desempenham um papel muito importante, na conservação da natureza, na manutenção da biodiversidade e na promoção do bem-estar animal. A produção animal no Montado, caraterístico da região Mediterrânica e, em particular do sul de Portugal, inclui-se nesta tipologia de sistemas de produção. Este ecossistema é considerado complexo devido às inter-relações entre o clima e os seus quatro componentes fundamentais: solo, pastagem, árvores e animais. A estratégia da União Europeia "do prado, ao prato" enquadra, valoriza e enfatiza a produção animal possível de realizar no Montado. No entanto, este ecossistema tem evidenciado alguma decadência nas últimas décadas, sobretudo pela excessiva mortalidade de árvores e pela reduzida regeneração natural.

Os solos predominantes no Montado, apresentam, em geral, baixa fertilidade, baixo teor de matéria orgânica (MO), problemas de acidez e frequente toxicidade pelo manganês (Mn). As práticas agrícolas associadas à intensificação da produção cerealífera em meados do século passado, com sucessivas mobilizações do solo, ou outras que ainda hoje ocorrem, contribuíram substancialmente para a diminuição do número de árvores, para a degradação da qualidade do solo, com efeitos negativos na produção, qualidade e composição florística da pastagem e, consequentemente, na produção animal.

O Montado, como comunidade não clímax, requer a intervenção humana, na gestão das suas componentes e estratos, a fim de evitar a evolução para a floresta Mediterrânica. Se tal acontecer, a produção agropecuária poderá ficar comprometida, originando problemas de sustentabilidade económica, alimentar e social. As funções recentes e associadas ao Montado passam, além de produção pecuária sustentável, pela manutenção da biodiversidade, pelo sequestro de carbono, a fixação de azoto e a regulação do ciclo da água.

Os factos anteriormente abordados, permitem identificar as problemáticas subjacentes aos estudos relativos à tese que se apresenta: avaliar como é que se concretizam as relações entre os vários componentes do Montado e sugerir abordagens alternativas que possibilitem melhorar a eficiência dos sistemas de produção, em consonância com a preservação da biodiversidade.

A bibliografia consultada refere que a correção do pH do solo, a adubação fosfatada e a correta gestão dos sistemas de pastoreio são fatores suscetíveis de beneficiarem a pastagem. A aplicação de calcário dolomítico é apontada como uma solução para o aumento do pH do solo e para a redução da toxicidade pelo Mn. A adubação fosfatada complementa o efeito da correção do pH na fertilidade do solo. Por outro lado, a forma como os animais interagem com a pastagem, pode ter efeitos diferentes no solo, na pastagem, na produtividade dos sistemas de pastoreio e na sustentabilidade global do ecossistema.

O melhor conhecimento sobre as interações entre solo, árvores, pastagem e animais, constituem a base para a intervenção integrada nas várias componentes do ecossistema. As tecnologias de monitorização, a partir de deteção remota (nomeadamente via imagens de satélite) ou através de sensores próximos, podem ser ferramentas fundamentais para apoio à tomada de decisão.

O trabalho que suporta esta tese procurou, através de diferentes ensaios e delineamentos experimentais, avaliar as inter-relações entre o clima e os componentes fundamentais do Montado. Foram colocadas as seguintes hipóteses que originaram os diferentes objetivos:

1- A correção do pH do solo poderá aumentar a quantidade de biomassa produzida e sua qualidade e assim proporcionar a redução da suplementação animal no Outono?
2- De que forma a produtividade e composição florística da pastagem se relaciona com a aplicação de calcário dolomítico, com a presença de árvores e o com o tipo de pastoreio?

3- Como é que as tecnologias de monitorização expedita do solo e da pastagem podem melhorar a qualidade da tomada de decisão?
4- De que forma o tipo de pastoreio e a carga biótica instantânea, juntamente com a correção do solo, são suscetíveis de interferir na seletividade e na manutenção do valor nutritivo da pastagem?
5- Que impacto ocorre na compactação do solo, por efeito do pisoteio, em sistema de pastoreio contínuo *versus* diferido, com diferentes cargas bióticas por hectare?

A tese está organizada de acordo com a seguinte sequência dos ensaios:

Ensaio 1: Calibração e validação de um espetrómetro de infravermelho próximo (NIR – Near-infrared) portátil, para estimativa da qualidade de pastagens de sequeiro.

Ensaio 2: Avaliação do efeito da copa das árvores e da aplicação de calcário dolomítico, na produção, qualidade e composição florística em pastagens de sequeiro.

Ensaio 3: Avaliação do efeito da aplicação de calcário dolomítico, de dois tipos de pastoreio (contínuo versus diferido) e diferentes cargas bióticas, na composição florística em pastagens de sequeiro.

Ensaio 4: Avaliação do efeito da aplicação de calcário dolomítico, do tipo de pastoreio (contínuo versus diferido) e de diferentes cargas bióticas nas preferências alimentares de ovinos, quando a taxa de crescimento da pastagem é máxima.

Ensaio 5: Avaliação do efeito do tipo de pastoreio (contínuo versus diferido) e de diferentes cargas bióticas na compactação do solo.

Face ao conjunto de artigos produzidos, a tese é composta por onze capítulos, iniciando com uma introdução geral, a apresentação dos materiais e métodos, a revisão bibliográfica em artigo de revisão, cinco capítulos que correspondem a outros tantos artigos de investigação (quatro publicados e um em pré-impressão), uma discussão geral, com a integração dos resultados obtidos, uma conclusão geral e perspetivas e por fim, referências bibliográficas (apenas da introdução e discussão geral; as referências bibliográficas de cada capítulo encontram-se no final do respetivo artigo).

CAPÍTULO 2

Materiais e metodologias

Os estudos que compõem esta tese foram conduzidos ao longo de 4 anos, numa área de pastagem natural com um coberto arbóreo constituído por azinheiras (*Quercus rotundifolia* Lam.). A área experimental é constituída por 4 parcelas contíguas com dimensão de cerca de 1ha cada, perfazendo um total de 4,2ha. Nas parcelas 3 e 4 foi aplicado calcário dolomítico (2 ton/ha) em novembro de 2017 e junho de 2019. Nas parcelas 1 e 2 não foi aplicado qualquer corretivo. Em dezembro de 2018 foram aplicados 100 Kg/ha de adubo binário (18-46-0) nas quatro parcelas.

Os ensaios decorreram em dois períodos: (i) de julho de 2018 a junho de 2020; (ii) de setembro de 2019 a outubro de 2021. No primeiro período de ensaios, em cada parcela foram selecionadas três árvores, associando a cada uma delas dois pontos de amostragem: um na área de projeção da copa e outro fora da copa, perfazendo um total de 24 pontos georreferenciados. Nesses pontos, foram colocadas caixas de exclusão de pastoreio. Em cada ponto foram efetuadas medições na pastagem, ao longo do ciclo, com o sensor ótico próximo "OptRx". Concomitantemente, procedeu-se ao corte da pastagem (em área próxima e representativa) para posteriores determinações laboratoriais de matéria verde (MV), matéria seca (MS), proteína bruta (PB) e fibra em detergente neutro (NDF). Entre 2018 e 2020, durante a Primavera, procedeu-se ao levantamento da composição florística da pastagem. Em cada ponto de amostragem foram igualmente efetuadas colheitas de amostras de solo, em outubro de 2018 e março de 2020.

Ao longo do ensaio, as parcelas experimentais foram pastoreadas por ovinos de raça Merino Branco e Merino Preto, adultos, não gestantes e não lactantes. Até junho de 2019, as 4 parcelas foram pastoreadas de forma semelhante em pastoreio contínuo, com um encabeçamento de 6-7 ovelhas por hectare.

No segundo período de ensaios (entre setembro de 2019 e outubro de 2021) foram constituídos grupos de pastoreio, que foram distribuídos pelas quatro parcelas, sujeitas aos seguintes tratamentos: P1NC – sem aplicação de calcário dolomítico e pastoreio contínuo (1 CN/ha); P2ND - sem aplicação de calcário dolomítico e pastoreio diferido (2,3 CN/ha); P3TD - com aplicação de calcário dolomítico e pastoreio diferido (2,3 CN/ha); P4TC – com aplicação de calcário dolomítico e pastoreio contínuo (1 CN/ha).

Os animais em pastoreio contínuo (PC) permaneceram nas parcelas durante todo o ciclo vegetativo da pastagem. Os animais em pastoreio diferido (PD) permaneceram nas parcelas em períodos variáveis, em função de critérios de exclusão relacionados com a altura média da pastagem. Assim, a saída dos animais nas parcelas de PD ocorreu sempre que a altura média das pastagens fosse igual ou inferior a 50 mm e, nestes casos, os animais só retornaram à pastagem quando esta apresentou altura média igual ou superior a 100 mm. Nos períodos em que os animais permaneceram fora das parcelas de PD, estes foram colocados em cercas com pastagem semelhante no mesmo regime de alimentação, por forma a manter a respetiva condição corporal.

Neste segundo período de ensaio, em cada parcela foram georreferenciadas 12 áreas de amostragem, de acordo com as diferentes comunidades de espécies botânicas constituintes da pastagem. O ponto central de cada uma destas áreas de amostragem foi identificado com bandeiras em varetas de plástico, numerados de 1 a 48. Nestas áreas, foram efetuadas, ao longo do ciclo vegetativo, medições da altura da pastagem seguidas de recolha de amostras para determinação laboratorial da PB e de NDF. Para avaliação da compactação do solo, pelo efeito do pisoteio dos animais, foram igualmente efetuadas medições com o cone penetrómetro eletrónico nas 48 áreas de amostragem.

Ao longo dos ensaios recorreu-se também a imagens de satélite (Sentinel-2) para obtenção de índices relacionados com o vigor vegetativo da pastagem: o NDVI (Normalized Difference Vegetation Index) e o NDWI (Normalized Difference Water Index).

Em 2021, entre 13 de março e 7 de junho realizaram-se observações diurnas (do nascer ao pôr do Sol; aproximadamente 12 h), sistemáticas (de 10 em 10 minutos), do comportamento dos ovinos para identificação das suas preferências de pastoreio ao longo da primavera. Estas observações foram efetuadas por observadores treinados, em dois dias consecutivos e em seis datas, entre março (dias 13 e 14) e junho (dias 6 e 7). No dia anterior a cada uma destas datas de observações, em cada um dos 48 pontos de amostragem, foram efetuadas medições da altura da pastagem e recolhidas amostras para determinação da PB e de NDF.

Todos os dados foram organizados cronologicamente e estruturados por forma a cumprir os objetivos particulares da tese, os quais se concretizaram através da publicação de cinco artigos de investigação.

CAPÍTULO 3

Revisão sobre o ecossistema Montado nas relações com os sistemas de produção

applied sciences

Review

Montado Mediterranean Ecosystem (Soil–Pasture–Tree and Animals): A Review of Monitoring Technologies and Grazing Systems

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Featured Application: Montado is an agro-silvo-pastoral ecosystem characteristic of the south of Portugal, which is called Dehesa in Spain. Due to the interactions between its fundamental components—soil, pasture, trees, and animals—it is considered a highly complex ecosystem. Therefore, there are no scientific works published in which these interactions are evaluated simultaneously. This review paves the way for carrying out work that integrates the four fundamental components, with the greatest need to study the effects of grazing animals on soil, pasture, and trees.

Abstract: Montado is an agro-silvo-pastoral ecosystem characteristic of the south of Portugal and called Dehesa in Spain. Its four fundamental components—soil, pasture, trees, and animals—as well as the climate make Montado a highly complex ecosystem. This review article provides an overview of the state of the art of Montado from the point of view of the agro-silvo-pastoral ecosystem and the scientific work carried out in this context. Thus, the aim is: (i) to describe and characterize the Montado ecosystem, as an agro-silvo-pastoral system; (ii) to reveal experimental tests carried out, technologies used or with the potential to be used in the monitoring of Montado; (iii) to address other technologies, carried out in similar and different agro-silvo-pastoral ecosystems from south Portugal. This review consists of three chapters: (a) components of Montado and their interactions; (b) advanced technologies for monitoring Montado; (c) grazing systems. No review article is known to provide an overview of Montado. Thus, it is essential to carry out research on grazing and its effects on the soil and pasture in the Montado ecosystem.

Keywords: Montado ecosystem; continuous grazing; deferred grazing; Alentejo; precision agriculture; sensors; Dehesa; complexity; climate

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1. Introduction

Montado is a multifunctional agro-silvo-pastoral ecosystem, characteristic of the Mediterranean region [1]. This ecosystem is made up of four fundamental components—soil, pasture, trees, and animals—which are interconnected, influencing each other [2]. Montado is also influenced by the Mediterranean climate, characterized by a great variability in precipitation and temperature in each year and between years [3]. For these reasons, Montado is considered an ecosystem of great complexity and variability, both spatial and temporal [4].

Although at times the intervention of humans has proven to be harmful to the Montado ecosystem, their role is fundamental for preserving the attributes that characterize Montado (non-climax community) so that it does not degenerate again into a Mediterranean forest.

This review takes a journey through time, from the beginnings of Montado to the present day. Our intention is to show research work carried out in Montado or in similar ecosystems and production systems, with the aim of improving production efficiency, contributing to the conservation of natural resources, and ensuring animal welfare. The focus emphasizes the last 20 to 30 years, aiming at characterizing and describing the Montado ecosystem. Its conservation/improvement is essential for environmental, productive, social, and economic reasons. To make this happen, it is crucial to monitor this ecosystem. Understanding its genesis, as well as the technological tools and technical options for agriculture, can lead to the greater profitability of production systems without compromising environmental issues and animal welfare.

One of modern agriculture's significant challenges is the creation of production systems that combine low input levels with high food production efficiency and minimal environmental impacts [5]. These authors' statements imply the concept of sustainable intensification, which is very important nowadays in agricultural systems. Therefore, sustainable intensification involves improving the efficiency of production systems and increasing productivity per hectare, with a minimum use of production factors.

The first steps consist usually of the characterization and evaluation of the soil and pasture. Traditional methods include collecting samples in a limited area and subsequent laboratory procedures [6]. These processes imply great investment in terms of time and human resources, making them quite expensive [7]. However, several expeditious technologies currently allow for characterization and evaluation without resorting to traditional methods, allowing for fast, large-scale measurements while correlating well with laboratory results [8].

In recent years, two or three research groups have carried out research work in Montado and Dehesa (Portugal and Spain, respectively). In Portugal, the research group's works are authored by Serrano et al., and in Spain, the teams are authored by Marcos et al. and Moreno et al.

We are still determining the existence of other published review works on Montado, which simultaneously integrate its general characterization and the expeditious technologies available for Montado monitoring and grazing issues. This seeks to pioneer concerning the description and integration of the Montado ecosystem as a whole.

This article aims to: (i) describe and characterize the Montado ecosystem, as an agro-silvo-pastoral system; (ii) reveal experimental tests carried out and technologies used or with the potential to be used in the monitoring of Montado; (iii) acknowledge other works carried out in similar and different conditions from ours, for eventual replication or not, in the Montado; (iv) provide a structure for future research work.

2. The Montado Ecosystem

Montado is characterized by an arboreal stratum formed by trees with open canopies, dominated by holm oaks, cork oaks or other quercines (Quercus genus), and by herbaceous annual species and shrubs [9]. So, it is an agro-silvo-pastoral ecosystem, multifunctional, and characteristic of the Alentejo region in Portugal, where agricultural, livestock and forestry, beekeeping, forestry, hunting, and tourism activities are combined [1,9–11]. This agro-silvo-pastoral system, typical of semi-arid Mediterranean conditions, is called "Dehesa" in Spain. In the Iberian Peninsula, Montado occupies 73,000 Km^2 (7,300,000 ha), where cork oaks (*Quercus suber* L.), holm oaks (*Quercus rotundifolia* Lam.), and black oaks (*Quercus pyrenaica* Willd.) are found [12,13]. In Portugal, the Montado represents 33% of the forest area [14,15]. A recent work mentions that the Portuguese territory is occupied by 1 million hectares of Montado [16]. Figure 1 shows the distribution of Montado/Dehesa in the Iberian Peninsula.

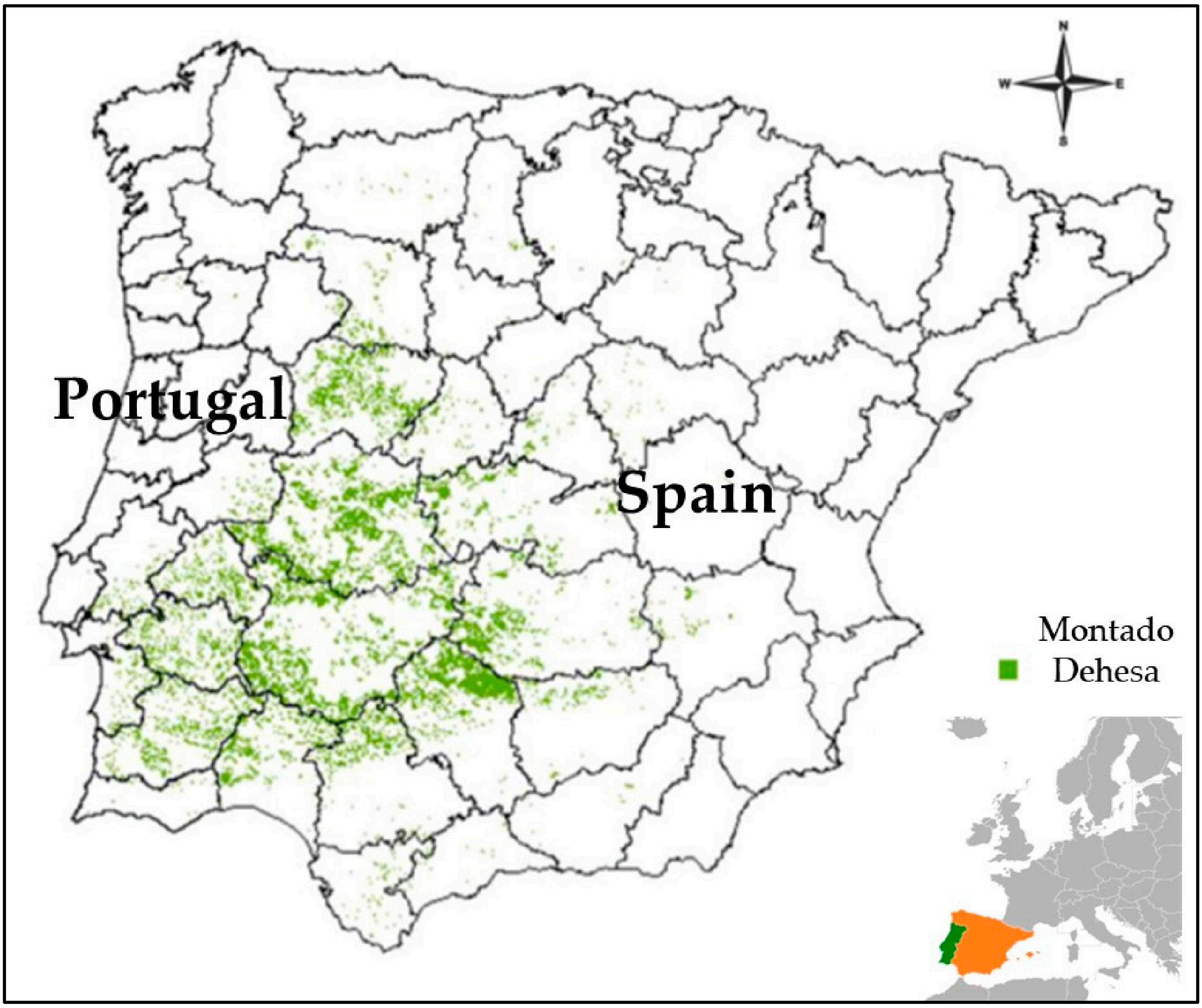

Figure 1. Distribution of Montado and Dehesa in Portugal and Spain. Adapted from [13].

Montado, as found nowadays, is the result of an evolution of the Mediterranean forest, shaped by different agrarian policies and, consequently, by the human presence [17]. The opening of the Mediterranean woodland and the maintenance of grazing and agricultural practices in its understory led to the Montado ecosystem [18].

This ecosystem originated by interactions between humans, who lived in this region, and nature, shaping it over time to meet their survival needs [19]. Over the centuries, the original Mediterranean ecosystem was changed into an agro-silvo-pastoral ecosystem associated with extensive land holdings [17]. Until 1880, the use of Montado was more similar to the current use in modern times, with livestock (mainly sheep and Iberian pigs, but also some goats and cows) being the animal's fundamental element of this ecosystem. After 1880, the development of new cultural techniques, especially for cereals, and the progress of roads and railways led to the creation of a cultivated Montado, decreasing the area of the traditional Montado [17]. Natividade [20] states that, until 1850, Montado was dense scrubland governed only by natural laws, without direct human intervention and with very fertile soils, where sporadic ground clearance by fire facilitated spontaneous regeneration. With the national policies that promoted the intensification of cereal production (in the early twentieth century until 1918; the wheat campaign between 1929 and 1935, lasting until the end of World War II; and the agrarian reform between 1975 and 1979), the trees of Montado were eliminated, and the landscape became clean and treeless (Figure 2a), distinct from the traditional Montado (Figure 2b) [11,17].

Figure 2. Montado Ecosystem devoid of trees for cereal production (**a**) and traditional Montado with greater tree cover (**b**).

All these stages of cereal production, namely, wheat, led to significant soil degradation due to deforestation by burning, cutting down trees, successive tillage with heavier farm implements, and, consequently, erosion [17,19]. Until the mid-twentieth century, the agricultural activity in Montado was based on rotations, starting with wheat, followed by barley or oats, with variable duration, based on soil fertility [20,21]. These cultural practices led to the degradation of this ecosystem, mainly by the tillage technique, which damaged the soil structure and the tree roots. Natividade [20] also mentions that the cultivation of Montado led to higher crop yields and acorns and lower risks of fires, highlighting that Montado provided cork, cereals, firewood, and meat as a result of the greatly intensified production in this ecosystem. The disturbance of the soil structure influences seed germination factors, such as water content, temperature, light, oxygen, and nitrates (Wicks et al., 1995; Botto et al., 1998) cited by [22]. In addition to this action, soil disturbances also influence the location of seeds in the soil profile and thus can promote or inhibit the germination status [23,24]. However, a crop rotation of 1 or 2 years, which includes a pasture, leads to an improved soil structure and increased organic matter (OM) content, interrupting the life cycles of pests and weeds and also contributing to the natural fertilization of the soil [25].

The disappearance of trees and livestock on these plots, associated with soil mobilization, contributed to the reduction in OM, leading to the import and application of chemical fertilizers to make up for the loss of wheat production [17]. On the other hand, the intense emigration in the 1960s from Portugal to some countries in northern and central Europe and the incipient mechanization of agriculture at this time led to the abandonment of land and agricultural activities, allowing for the appearance of bushes, both in the traditional Montado and in areas transformed into plots of arable land for cereal production [17]. It should be noted that, throughout the 20th century, many management options for Montado, its soils, animals, and vegetation, were selected based on policies that were not very appropriate for the reality of Montado and the region where it is located [19]. Often, these policies, emanating from the European Economic Community, did not consider the specificities of the region, nor its resources or ecological and cultural values [19]. As a result, the decisions taken could have been more assertive for promoting the sustainability and productivity of Montado in a balanced way.

On the other hand, the appearance of the African swine fever in the second half of the 20th century contributed to the decrease in the production of the Montanheira pig, resulting in more emphasis on the production of ruminants, namely, beef cattle. Grazing in Montado plays a crucial role in its maintenance, as it prevents the proliferation and development of shrub species, such as cistus (*Cistus ladinifer* L.) and the Montado sargassum (*Cistus salvifolius* L.) [10].

The stability and sustainability of Montado result from human intervention in the original Mediterranean woodland that, although in some periods has been profound and continued, has respected the limits of the ecosystem [19]. If the action of humans ceases, the Montado tends to return to Mediterranean woodland. However, we must reinforce that humans have also contributed to the destruction of many hectares of Montado, through the intensification of crops, leading to a decrease in biodiversity and the stability of the landscape created [17]. The Montado landscape that we recognize today has been affected by human actions which resulted from a combination of socioeconomic and ecological factors, which created an ecosystem of high biological and cultural value [11,19,26,27]. Montado is thus a non-climax community, maintained in equilibrium by human action. Although with some negative actions by humans, Montado is considered a valuable habitat due to the tremendous biological diversity it supports [28]. Associated with the production systems in Montado are the rural settlements in the villages and agricultural holdings [17]. Montado is also considered a High Nature Value (HNV) production system, according to the classification proposed by the European Environmental Agency for agricultural and silvo-pastoral systems [11]. Recently, Montado has been defined as a mixed ecosystem, agro-silvo-pastoral, consisting of a herbaceous stratum where permanent pastures predominate and an arboreal stratum with a special incidence of cork oaks and holm oaks, grazed by animals (sheep, cattle, goats, and pigs) in an extensive regime [4]. However, due to the decreasing economic importance of agricultural crops under Montado, namely, cereals, Montado tends to be considered, currently, as a silvo-pastoral system, where the production of beef cattle became very accentuated, right at the end of the last century, due to the incentives associated with this type of production.

Currently, in order to preserve and improve the Montado ecosystem, farmers are subsidized through various mechanisms linked to packages of ecosystem services (such as the improvement of soil fertility), through the Common Agricultural Policy [16].

It was in 1320 that the first reference to cork harvesting was recorded. In the 15th century, Portugal was exporting cork to northern Europe, originating from Montados, which also provided grazing for livestock—the primary resource of the population [20]. Currently, the Montados and Portuguese Cork oak forests produce over 50% of the world's cork [9]. The economic value of cork as a product of Montado is unquestionable, as well as the importance of Portugal in the world framework of cork production and processing [11,19].

Furthermore, Montado has a high animal and plant biodiversity [10]. In terms of terrestrial vertebrates alone, it supports more than 130 species, something that in Portugal is only surpassed by riparian habitats [10]. It is no mere coincidence that one of the habitats with the greatest number of faunal species is precisely one where man has his presence [10]; additionally, as paradoxical as it may seem, human activity in the Montado has been the ultimate cause of this biodiversity.

2.1. Climate Characteristics

Montado is located in a geographical region influenced by the Mediterranean climate. The designation of Mediterranean climate comes from the fact that its extensive area of influence is located in the Mediterranean Sea basin. However, it is also present in California, Chile, South Africa, and Australia [27]. According to Feio [3], the Mediterranean climate is the only climate on earth with the particularity of presenting a hot summer lasting more than four months, associated with a high irregularity in precipitation, both inter- and intra-annually.

Fonseca [19] states that the values of accumulated annual precipitation in the Mediterranean region vary between 300 and 800 mm. It is, therefore, a climate characterized by a remarkable seasonality and by a marked interannual irregularity, with the occurrence of rainy years and dry years, in a bimodal frequency distribution (Nahal, 1981), cited by [15,17,29]. Between 1865 and 1990, in Seville, Spain, the values of accumulated annual precipitation varied between 400 and 1000 mm, with a mean value of 572 mm [26]. Marcos et al. [30] report annual precipitation values of 500 to 600 mm for the Extremadura region in Spain. In a time series between 1871 and 2007, for the Évora meteorological station, the average accumulated annual precipitation was 627 mm, with a minimum value of 203 mm in 1991 and a maximum value of 1186 mm in 1895 [31]. From data available at [31], we can see that, over time, the average annual rainfall has been decreasing: between 1900 and 2007, the average annual rainfall was 624 mm; between 1950 and 2007 it was 608 mm; between 1970 and 2007 it was 588 mm; between 1990 and 2007 it was 551 mm; and between 2000 and 2007 it was 538 mm. These values may highlight climate change and the decrease in the amount of annual precipitation in the Mediterranean region.

More recent data for the agricultural years 2015/2016, 2016/2017, and 2017/2018 report values for cumulative precipitation for the Évora region (Alentejo) of 547 mm, 421 mm, and 612 mm, respectively [2]. However, in the same region, in the 2018/2019 crop year, there was only 315 mm of precipitation, while in the following year, this value already reached 627 mm [32]. The annual cumulative precipitation in this region ranges from 300 to 650 mm, distributed mainly between October and March [15,32]. However, other regions of the world, where the Mediterranean climate is also felt, have different average precipitation values. Something similar occurred in the Perth region in southern Australia, where the average annual cumulative precipitation, for the period 1992 to 1994, was only 327 mm [33].

In this climate, natural droughts are recurrent. The severity of drought is increasing and may be even greater due to climate change and human action [34]. In a region called l'Abruzzo, in central Italy, an increase in the mean annual temperature of 1.7 °C was recorded between 1950 and 2014, which translates into a 0.26 °C increase, for each decade [35]. It is common in the Alentejo region to have several days with temperatures above 40 °C in summer and with minimum temperatures below 0 °C in winter [19,32]. In the Estremadura region, the average minimum temperature recorded was 3.4 °C, and the average maximum temperature was 35.6 °C [30].

The irregularity of rainfall, combined with hot and dry summers and winters, although rainy, with temperatures often below vegetative zero, means that grass production in the Montado is also very irregular. In a comparison of the average monthly temperature between 1981 and 2010 and between September 2015 and August 2018 for this region, the average temperature tends to fall between 3 and 5 °C in the months of September, October, and November. It tends to increase 2 to 3 °C in the months of April, May, and June [2]. In the same time series mentioned above for Évora, between 1871 and 2007, the average maximum temperature is 19.6 °C, with a maximum of 24.7 °C in 1995 and a minimum of 16.6 °C in the year 1989. Between 1900 and 2007, the average annual maximum temperature was 19. 5°C and showed a tendency to increase; between 1950 and 2007, it was 19.7 °C; between 1970 and 2007, it was 19.8 °C; between 1990 and 2007, it was 20.4 °C; and between 2000 and 2007, it was 20.6 °C [31]. Again, these increments may show the effects of climate change, which are being felt in this region. Mediterranean regions, with some semi-arid characteristics, tend to be particularly affected by climate change in the form of increasing temperature and decreasing precipitation [36].

2.2. The Components of the Montado

2.2.1. The Soil

Soil fertility depends on the OM content, which results from the decomposition of organic residues such as leaves, branches, and dry grassland biomass and roots [9]. The predominant soils of the region where Montado occurs are soils with structural and fertility limitations, classified as Cambisoils, derived from granite [37]. They are thin, stony, acidic, and poor in phosphorus (P) and nitrogen (N), have imbalances at the micronutrient level (namely, the magnesium (Mg)/manganese (Mn) ratio), and are degraded as a result of erosion and nutrient loss, mainly due to their typical undulating topography, associated with intensive forms of land use [4,38,39]. Cambisoils are classified as Pg and Pgm (non-humic litholic soils of semi-humid and semi-arid climates) in the Portuguese soil classification. They are characterized by having a low cation exchange capacity, coarse texture, percentage of OM < 1%, pH < 5.5, and low water holding capacity [40,41].

Marcos et al. [30] experimented with the "Dehesas" of Extremadura, Spain, subdivided into three phases: (i) evaluate the effect of trees (holm oak) on soil, light, microclimate, soil moisture, roots, and the crop in 16 cultivated plots of hazel (*Avena sativa* L.); (ii) evaluate the effects of different soil uses (forest, grazing, and abandonment) on trees; (iii) evaluate the response of trees to fertilization in four plots (oat only, oat and fertilization, grazing only, and grazing and fertilization). Regarding the radiation transmission through the canopy, for the herbaceous plants, the distance between these and the tree trunk (0.5; 1.0; 2.5; 5.0; 10.0; 20.0; and 30.0 m) and their orientation was taken in account, considering the four cardinal points (N, S, E, W). This study concluded that the radiation transmitted during the growth of herbaceous plants (pasture and oat) increased rapidly and significantly with the distance to the trunk. At 10.0 m from the trunk, the available radiation was greater than 95%, with non-significant differences between 10.0, 20.0, and 30.0 m, except in the north orientation, where the differences were significant between 10.0 and 20.0 m but not between 20.0 and 30.0 m. According to Marcos et al. [30], trees have a positive effect on most soil chemical parameters, mainly on OM, total N, nitrate (NO^{3-}), P availability, cation exchange capacity, exchangeable potassium (K), and calcium (Ca). All these parameters were significantly higher under the canopy projection than outside the canopy. Values tended to decrease with an increasing distance to trees, with non-significant differences between 10.0, 20.0, and 30.0 m. Additionally, Moreno et al. [42] obtained an OM content under the canopy of Holm oak trees about twice as high as that found beyond the projection of those trees. A study carried out in Montado, in the region of Évora (Alentejo), reports that the soil under the canopy showed significantly higher levels of OM, N, P, K, and Mg, with mean values of 3.1% vs. 1.7%, 0.2% vs. 0.3%, 117.7 vs. 68.2 mg/kg, 359.3 vs. 180.5 mg/kg, and 115 mg/kg vs. 76. 3 mg/kg, for each parameter, under and outside the canopy, respectively. No significant differences were found for texture, pH (values of 5.4 vs. 5.3, under and outside the canopy, respectively), and Mn (values of 16.2 mg/kg vs. 11.8 mg/kg, under and outside the canopy, respectively) [43]. The canopy is essential for protecting the soil from direct rainfall that can cause landslides and soil erosion, particularly on steep slopes. The soil under the canopy is often more permeable and has a higher water-holding capacity than bare soil [9]. On very acid soils (pH below 5.0), grazing can lead to higher acidification rates [44] compared to agricultural crops where no grazing occurs.

2.2.2. Trees

In Montado, as already mentioned, the main tree species present are Holm oak and Cork oak, managed mainly to produce acorns (for animal feed) and cork, respectively [15]. Extensive areas south of the Tejo River, which once had densities of around 120 trees/ha, today have densities of less than 40 trees/ha [11]. The scarcity or even absence of natural regeneration in the Montados, which has been observed over recent decades, makes the renewal and perpetuity of ecologically stable stands unviable, contributing to the emergence of clearings that gradually increase until they become plots of cleared land, distinct from the traditional Montado [11]. Montado is seriously threatened by the low prevalence of the natural regeneration of Cork oaks and Holm oaks [27,45]. However, in addition to the advanced age, the stands denote a lower density due to the poor management of agricultural practices and the incidence of pests and diseases [11,27,45].

During the second half of the 20th century, millions of trees were eliminated in Mediterranean areas, mainly from the most productive lands [30], in order to promote cereal production. The mechanization that accompanied the intensification of cereal production in the 20th century also led to a progressive elimination of the tree layer [9]. The Holm oak and the Cork oak are well adapted to the high temperatures and dry periods characteristic of the Mediterranean summer, as well as the relatively poor soils that are typical of the region [10,20]. The Holm oak Montados predominate in the Alentejo interior, while the Cork oak Montados occur preferentially in the Tejo and Sado basins [10]. According to these authors, this distribution results from the abiotic preferences of the trees themselves. The Holm oak tends to occur in a Mediterranean climate with continental influence, with annual rainfall between 300 and 550 mm [46]. However, it can develop in soils of diverse origins, avoiding those that are very sandy. The Cork oak occurs in a Mediterranean climate with Atlantic influence, higher rainfall (between 600 and 800 mm per year), the preference of light and deep soils, and more water availability [46].

Trees can modify the soil and microclimate much more than crops. They have strong enabling effects, produce important ecosystem services, and compete for resources with grazing [30,32,43]. In the Dehesas, several authors have reported positive effects of trees on soil nutrients, soil water storage capacity, and pasture production in terms of quality and diversity [47–49]. Additionally, the accumulation of tree leaves on the soil increases the OM content [10]. According to Benavides et al. [50], the positive effect of tree shade in reducing evapotranspiration leads to a higher moisture content of the soil under the canopy when compared to the soil outside the canopy. Still, the tree canopy prevents sunlight penetration into the pasture, affecting its production [51]. Peri et al. [52] conducted a study in New Zealand, in which they compared the growth and dry matter (DM) production of the grass *Dactylis glomerata* L. on four types of pasture (unshaded, slatted, tree-shaded, and tree-shaded and slatted), where the trees present were *Pinus radiata* species, with a density of 200 trees/ha. These authors obtained DM/ha/year yields of 8200 kg, 7300 kg, 6300 kg, and 3800 kg for each treatment, respectively. The reduction in the quantity and quality of light directly affects the physiological processes of plants, decreasing the production of carbohydrates in pastures and the production of DM [52]. Hussain et al. [51] compared the total biomass production in pastures, composed mostly of *Lolium perenne* L., *Holcus lanatus* L., and *Trifolium repens* L., covered by willow and poplar and outside the canopy, concluding that this production is significantly higher outside the canopy than under it. These authors obtained average values of 13.4, 12.2, and 10.3 ton/ha/year of DM outside the canopy, poplar understory, and under willow, respectively. Serrano et al. [53], in a study carried out in Montado, in the Évora region, in which they compared soil fertility and the production and quality of pasture under and outside the canopy of Holm oak trees, reported that soil fertility under the canopy is superior compared to that of the soil outside the canopy. These authors found OM values of 2.3% under the canopy and only 1.8% outside the canopy; for P_2O_5, the values found under and outside the canopy were 39.8 mg/kg and 28 mg/kg, respectively; for K_2O, the values found were 146 mg/kg and 72 mg/kg under and outside the canopy, respectively. In another study of Montado, Serrano et al. [32] report that, in terms of productivity (green matter (GM) and DM), the canopy had a positive effect in autumn, while in winter and spring, the highest productivity was seen outside the canopy.

These authors obtained average values of GM in autumn of 7250 kg/ha and 6850 kg/ha, under and outside the canopy, respectively; in winter, they obtained average values of GM of 1085 kg/ha and 1530 kg/ha, under and outside the canopy, respectively; in spring, they obtained average values of GM of 6250 kg/ha and 1235 kg/ha, under and outside the canopy, respectively. Regarding productivity in terms of kg/ha DM, Serrano et al. [53] obtained average values in autumn of 1050 and 1000 kg/ha, under and outside the canopy, respectively; in winter, these values were 1750 and 2050 kg/ha, under and outside the canopy, respectively; in spring, these values were 1700 and 4300 kg/ha, under and outside the canopy, respectively. These authors also mention that grazing under the canopy is of higher quality (higher crude protein—CP) than grazing outside the canopy. Thus, for the % CP in the pasture DM, Serrano et al. [53], in autumn, found values of 23.6% and 18.5% under and outside the canopy, respectively; in winter, these values were 17.9% and 16.5%, under and outside the canopy, respectively; in spring, CP was 14.8% and 8.25%, under and outside the canopy, respectively. The canopy structure is a relevant factor in the competition for light [50], varying with tree age and species [54]. In the Mediterranean region, competition for water is usually another limiting factor for pasture growth [51,55], particularly in locations with dry summers when high temperatures are recorded [50]. The canopy also modifies the soil and air temperature [30]. According to these authors, on warm days, the air temperature was significantly lower under the canopy when compared with that obtained outside the canopy, finding values of 14.2 °C, 16.1 °C, 16.5 °C, and 16.6 °C at 1, 10, 20, and 30 m away from the trunk of the tree, respectively. On cold days, the opposite happened, i.e., air temperature was higher under the canopy than outside. The same was verified for soil temperature, which was higher under the canopy on cold days and lower on hot days. On hot days, the maximum soil temperature under the canopy was 29.6 °C, while outside, it was 46 °C [30].

The type of management chosen for grazing may be necessary for containing the harmful effects on trees in their juvenile phase. Factors such as the stocking rate, the rotation of livestock species by plot, the length of stay in each one, and the composition and amount of supplements provided to animals should be evaluated properly [45]. According to Belo et al. [45], the agricultural practices and the conduct of grazing animals that have occurred in Montado are not the most appropriate for the processes of the dispersal and establishment of young plants and their development into adult trees; however, the same authors also infer that grazing has a positive effect in denser Montados, since the animals remove the herbaceous stratum, reduce the shrub stratum, and, consequently, decrease the susceptibility to fire of this ecosystem.

2.2.3. Pastures, Characteristics, and Management

Pastures are communities mainly composed of herbaceous plants and sometimes associated with shrubs consumed by grazing animals (mainly ruminants) in the production site itself. They are systems of high heterogeneity due to variations in the number of species present and differences in the length of phenological cycles of the constituent plants, as well as continuous changes caused by different environmental and grazing factors [7,56,57].

The floristic composition of the pasture is a good indicator of pasture quality [1]. It depends on each region's soil and climate conditions and the grazing system adopted. According to Voisin and Lecomte [58], in a pasture sown with *Poa pratensis* L. and *Trifolium repens* L. (50/50), the percentage of *Trifolium repens* L. can vary from 1 to 80% after a few years, depending on the interval between each grazing period: weekly grazing provides 80% *Trifolium repens* L.; grazing every 4 weeks provides only 50%; if grazing is only every 12 weeks, the percentage of *Trifolium repens* L. will be only 1%. However, pasture rest periods are fundamental for plant development and seed production [1]. According to Voisin and Lecomte [58], we can conclude that: (i) a sown pasture is quickly transformed into a poor-quality pasture, with an undesirable floristic composition, as a result of an inadequate grazing system; (ii) an adequate grazing system can transform an old and degraded pasture into a pasture of excellent quality. The floristic composition of the pasture is affected by grazing selectivity, stocking rate density, and grazing season [59]. In addition to this, Voisin & Lecomte [58] identified three causes for the degradation of pasture floristic composition: (i) poor soil drainage; (ii) poor soil fertilization/corrections; (iii) poor grazing management, abusing continuous grazing. However, according to Zhu et al. [60], in a study conducted in

China, grazing with cattle, sheep, and goats does not affect the species richness of pasture plants, although it significantly reduces plant biomass and increases heterogeneity in plant heights. Carreira et al. [1] carried out a study in Montado pastures to evaluate the effects of the type of grazing (continuous vs. deferred) and the application of dolomitic limestone on the floristic composition of the pasture. The authors identified 103 different species belonging to 25 botanical families. This work infers that deferred grazing may contribute to the increase in the number of legume species in the pasture and improve the floristic composition of the pasture. From this same study, the authors also conclude that grazing with high biotic loads eliminates undesirable plants with low nutritional value, such as *Diplotaxis catholica* L.

The pasture structure directly influences intake by grazing animals (Gordon and Benvenutti, 2006) cited by [61]. Consequently, the pasture height is a significant factor influencing the intake and production of grazing animals [62].

Animal production is affected by the feed value of the pasture, which is a function of voluntary feed intake (quantity) and nutritive value [7]. The nutritive value of pasture, or the quality, is described in terms of crude CP, acid detergent fiber (ADF), neutral detergent fiber (NDF), ash, lignin (ADL), lipids, metabolizable energy (ME), and digestible OM (Holmes et al., 2007) cited by [7]. The nutritive value of the pasture thus determines the productive response per unit of pasture consumed [7]. The constituent plants of the pasture generally have a high proportion of water, varying between 10 and 50% DM, and pastures with high nutritive value usually have low DM values [63].

According to Miao et al. [64], the inter-annual precipitation variability can explain the differences in the quantity and chemical composition of the various pasture species. Biomass production and its nutritive value increase with the annual increase in rainfall if it occurs in favorable periods for pasture growth (autumn and spring). Temperatures of 5.5 °C generally stop plant growth, and temperatures lower than 8–10 °C reduce the growth of temperate grasses [29]. The evapotranspiration rate in pastures, at the beginning of spring (April), decreases until the end of spring and ends at the beginning of July. During summer (July to September), when the soil surface is dry, there is no transpiration of the pasture, resuming after the beginning of autumn rains (October) [43]. Furthermore, in summer, the pasture is dry, so it has no transpiration. Soil moisture increases N availability and the rate of N assimilation by plants, leading to an increase in pasture productivity [64]. Most permanent pastures in the Montado have a deficient production of DM [21] and are also considered poor [41]. What is referred to by Belo et al. [21] is based on studies cited by them: (a) Lourenço et al. (1999) found DM production values in pastures in Montado of 800 kg/ha/year; (b) Crespo (1997) notes that the production of DM does not usually exceed 1500 kg/ha/year; (c) Simões (2004) refers to a DM production in autumn/winter of 695 kg/ha and in spring of 2014 Kg/ha. However, Efe Serrano [65] refers to around 3000 kg/ha/year. In a more recent study, comparing pasture DM production under the canopy and outside the canopy, Serrano et al. [43] found the following average values: (i) under the canopy—437, 1232, 1804, 2751, and 2363 kg/ha for the months of December, March, April, May, and June, respectively; (ii) outside the canopy—425, 1868, 2987, 3582, and 6191 kg/ha for the months of December, March, April, May, and June, respectively. In another study carried out by Serrano et al. [53], in which the DM production of the pasture in Montado was compared under and outside the tree canopy, the authors state average values under the canopy of 980, 916, 2469, 3852, and 3180 kg/ha for the months December, February, March, May, and June, respectively; outside the canopy, the values are 964, 1698, 1757, 3414, and 2936 kg/ha for the months of December, February, March, May, and June, respectively. In the same study by Serrano et al. [53], the authors obtained mean CP values under the canopy of trees of 22.9, 22.4, 15.9, 11.2, and 8% for the months of December, February, March, May, and June, respectively; outside the canopy, the values were 21.3, 19.8, 13.5, 9.8, and 6.3% for the months of December, February, March, May, and June, respectively. In a study where pasture samples were collected and CP was determined in Montado, at the peak of spring (30 March to 13 April), average CP values of 13.5%, 12.1%, and 10% were found for the region of Évora, for the Portalegre region, and for the Beja region [66]. In another study carried out on rainfed pastures in Montado, Serrano et al. [67] obtained CP values for autumn, winter, and spring, under and outside the tree canopy, and in soils with the application of dolomitic limestone and without this application in the agricultural years 2018/2019 and 2019/2020. For the year 2018/2019, they obtained average values of CP in autumn, winter, and spring of 24.7 and 21%, 19.6 and 19.1%, and 10.5 and 8.9% in soils with the application and non-application of dolomitic limestone, respectively. For the year 2019/2020, average CP values were obtained in autumn, winter, and spring of 19.3 and 18.8%, 14.4 and 15.7%, and 13.7 and 13% in soils with and without the application of dolomitic limestone, respectively. For the year 2018/2019, they obtained average CP values in autumn, winter, and spring of 21.1 and 20.5%, 20.3 and 18.4%, and 12.2 and 7.2% under and outside the canopy of trees, respectively. For the year 2019/2020, they obtained average values of CP in the autumn, winter, and spring of 22.1 and 16%, 15.5 and 14.6%, and 17.4 and 9.3% under and outside the canopy of trees, respectively.

The recommended process for reclaiming pastures in the Mediterranean region and increasing their productivity consists of increasing soil fertility by applying phosphate fertilizers and correcting Mn toxicity and soil acidity [41,68,69]. The excessive application of nitrogen fertilizers to pastures, or the application of N at less favorable times of the year, increases nitrate leaching and phosphate (PO_4) adsorption on soil particles, which eventually leads to surface and groundwater pollution and the eutrophication of surface water bodies [70]. According to Miao et al. [64], pasture degradation affects the resilience of ecosystems. In a study carried out in Montado by Simões et al. (2006), cited by [21], in which the productivity of natural pastures was compared with biodiverse pastures rich in legumes. It was demonstrated that the DM production, in some cases, doubled, and the proportion of species with greater nutritional value in biodiverse pastures increased. This allowed stocking rates to triple in number.

Correction for the acidity and associated toxicities of aluminum (Al) and Mn and P can allow for five-fold increases in pasture productivity [69]. Sometimes, the focus is on the needs of the animal without considering the needs of the plants and the importance of of root reserves so that they can quickly regrow after a period of grazing [58]. Plant growth will be slow if the plants have few reserves accumulated in their roots, even if there are adequate conditions for growth.

On the other hand, if there are sufficient reserves and green leaves in high numbers, the plants use sunlight efficiently and can produce three to four times more GM/ha/day [58]. Voisin and Lecomte [58] state that triple the pasture's resting time will increase the pasture production by up to ten times. Proper management can result in a significant improvement in the quality of natural pasture. However, cyclical periods of food shortage cannot be avoided, and in some of these periods of scarcity, acorns can contribute to better animal nutrition naturally [9]. From an economic standpoint, pasture is essential, since a forage unit (UF) obtained from pastured grass costs only 15 to 20% of the same UF obtained from commercial concentrate feed [71]. Carvalho [69] also states that the importance of improved permanent pasture results from the fact that it is arguably the cheapest food for ruminant animals.

According to Tang et al. [72], the effects of grazing on ecosystems depend greatly on grazing intensity. According to Voisin and Lecomte [58] and Matthew et al. [73], animal production systems in pastures can have an important influence on pasture composition, quality, and production., When ingesting plant biomass, grazing animals return between 70 and 95% of plant nutrients to the soil, through urine and feces, modifying and accelerating the flow of nutrients [44]. The stocking rate also greatly influences pasture productivity and may contribute to its improvement or degradation. Traditionally, the stocking rate in Montado was 0.35 normal heads (NH) [27], which is equivalent to about 2 sheep/ha.

2.3. Services Provided by the Montado Ecosystem

The spatial and temporal heterogeneity of Montado leads to an increase in the richness of ecological niches—herbaceous, shrubby, and tree plants—with some of the species being very rare or threatened with extinction [9,11]. In addition to providing multiple products, such as cork, firewood, meat (beef, sheep, pig, and goat), mushrooms, aromatic herbs, and honey, Montado also provides a vast array of ecosystem services, such as the regulation of the water cycle, carbon fixation, erosion prevention, high biodiversity, recreation and leisure activities and the support of local identity [11]. Production systems involving agricultural crops and animal production are characterized by the exploiting synergies, resulting from new interactions between soil, plants, animals, and the atmosphere, allowing for greater productivity and lower vulnerabilities [74].

Montado is associated with vital environmental services, such as soil protection, water regulation, and carbon sequestration [75]. Carbon sequestration in the Montado is of great importance, mainly due to the long-lived trees that constitute it, which promote carbon storage for very long periods [9,11]. In addition, pasture and soil are significant carbon sinks in the Montado, and healthy cork oak forests with reasonable tree cover can annually sequester around 1–3 tons of carbon/ha [11]. Wang et al. [76] and Wang et al. [77] infer that those soils where pastures are installed play a crucial role in mitigating greenhouse gas emissions. In trials in different regions of China, higher metane (CH_4) sequestration values were obtained in grazed soils than in non-pastured soils. The values increased with an increasing stocking rate: 2.73, 2.83, 5.49, and 8.23 kg/ha/year, respectively, for non-grazing, light, moderate, and heavy use in Sichuan province; 2.82, 2.75, 5.41, and 7.59 kg/ha/year in Xinjiang Autonomous Region; and, 2.89, 2.81, 5.31, and 8.38 kg/ha/year in the Inner Mongolia Autonomous Region [77].

Table A1 (Appendix A) summarizes the works mentioned in Section 2, where one can verify the component to which each refers, the production system, and the region/country where they were carried out.

Figure 3 shows, in terms of percentages, the country of origin of the works cited in Section 2. As we can see in Figure 3, more than half of the works cited in this chapter were carried out in the Iberian Peninsula, followed by New Zealand and China.

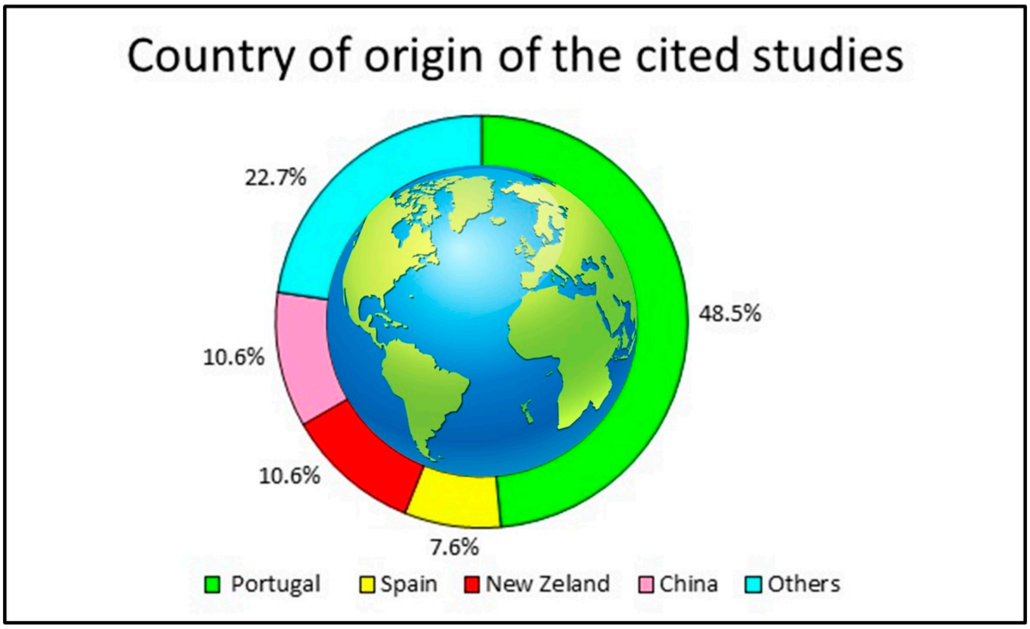

Figure 3. Country of origin of the studies mentioned in Section 2.

3. Technologies of Monitoring in Montado

3.1. Laboratory Analysis for Soil and Pasture Characterization

The characterization of soils in agricultural fields is traditionally carried out by collecting several soil samples per hectare (always a limited number), followed by physicochemical laboratory analyses [6,78]. However, this method is limited and very expensive since it is impossible to sample the field, in addition to the great need for labor [6,79]. The spatial variability of soil nutrients can be affected by the type of soil, topography, vegetation, climate, and anthropogenic activities [79], making the traditional sampling method fallible due to the heterogeneity that may exist on the same plot of land. Traditional soil sampling and the consequent laboratory analyses are also time-consuming, expensive, and impractical from a practical perspective, leading to a growing interest in automatic monitoring methods [78]. The same authors refer to the NIR (near infrared) sensor as an excellent option for quantifying the spatial variability of the leading chemical parameters and soil fertility. Serrano et al. [80] conducted a study using a benchtop NIR sensor to estimate soil moisture and P in pastures in Montado. These authors obtained high correlations for the calibration (r^2 = 0.85 and r^2 = 0.777 for OM and P, respectively) of the sensor and for its validation (r^2 = 0.847 and r^2 = 0.761 for soil moisture and P, respectively). Although with benchtop NIR, no physical-chemical analysis of the soil is necessary, colleting samples in the field is still necessary, with all the inherent disadvantages already listed.

Regarding the methods for assessing pasture biomass, they are grouped into direct and indirect [81]. Direct methods require cutting and laboratory determinations (Figure 4), while indirect methods use sensors to assess the pasture. Laboratory methods for quantifying pasture nutritive value are expensive and time-consuming, and due to the high cost of determinations, sampling is limited to specific locations, which limits the possibility of managing or exploring variability within and between pastures [7].

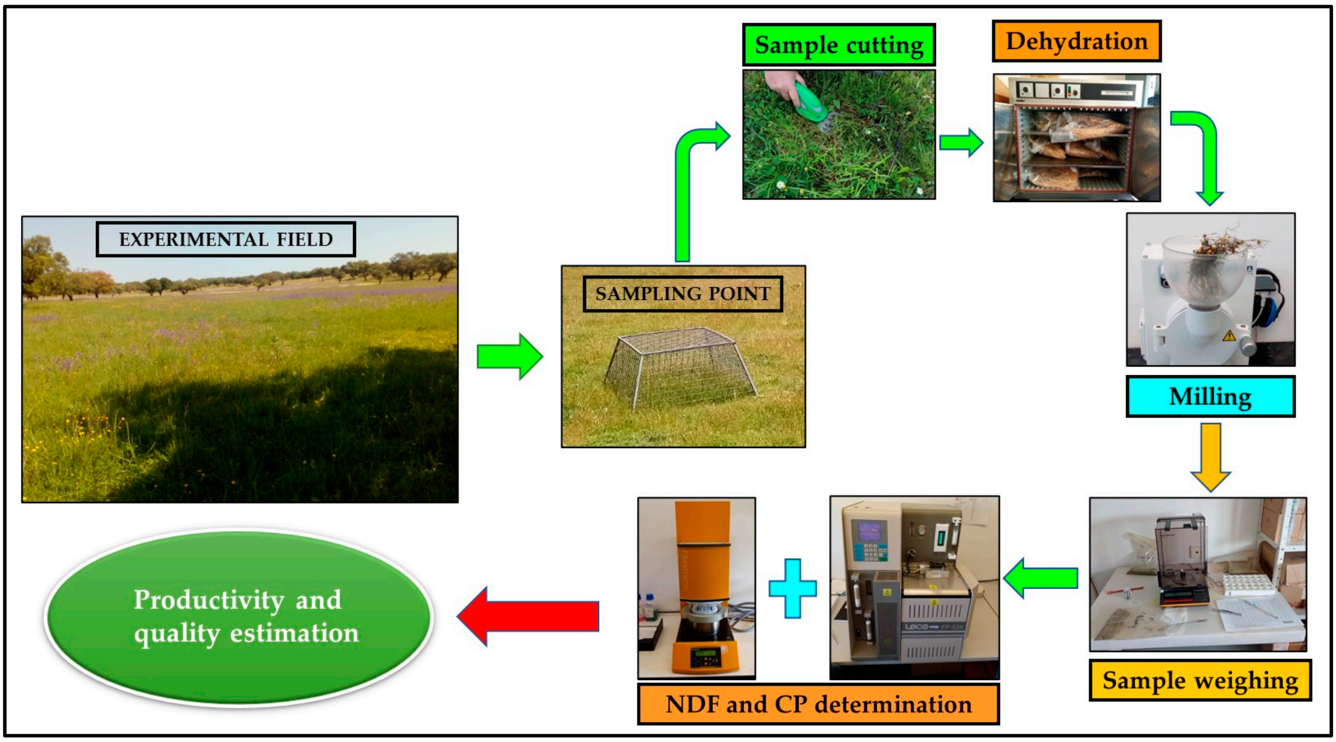

Figure 4. Explanatory diagram of the traditional pasture sampling and laboratory processing process.

According to Pullanagari et al. [56], to assess pasture quality, conventional laboratory methods have been used, such as wet chemistry, according to the "Association of Official Analytical Chemists" [82]. However, that methodology falls short of what is necessary and required from the point of view of monitoring pasture quality, considering the spatial and temporal variability of these systems. Using the NIR technique to assess pasture quality is considered reliable, especially in terms of CP and NDF [83]. However, using benchtop NIR equipment has the drawbacks already mentioned, which are inherent in the cutting and processing of pasture samples [66], although wet chemistry analyses are avoided. Therefore, the survey of the spatial and temporal variability of productivity, based on the cutting and collection of samples of pasture for bromatological analysis, is a demanding method in terms of labor [84], destructive [85], time-consuming and expensive [56,57,86], and unfeasible from a practical perspective, which has led to growing interest in expedited methods [7]. According to Gebremedhin et al. [8], recent developments in the technological field of portable electronic sensors are an adequate response, allowing for fast, reliable, and large-scale measurements. Indirect pasture sampling methods minimized the physical removal of vegetation and were developed mainly to obtain quick results and be able to be used in large areas [87]. Therefore, it becomes imperative to use new non-destructive technologies, which allow us to better understand the variability of production in large areas and implement new production strategies, such as precision agriculture (PA), or zones of differentiated management [81].

3.2. Precision Agriculture

Precision agriculture (PA) is not an end in itself; rather, it constitutes an integrated and internationally standardized approach to sustainable agriculture, which increases the efficiency of resource use, reducing the risks and uncertainty of the management decision [88,89]. For Fountas et al. [90] and Nawar et al. [6], PA's final objective is managing crop and soil variability to increase profitability and reduce environmental impacts. PA allows for varying the application of inputs, such as fertilizers, depending on the needs of the soil/crops [6,91]. According to Serrano et al. [92], easy access to new technological tools, namely, access to spatial georeferencing systems, such as the Global Positioning System (GPS), allows for a knowledge of the variability of soil and crop parameters. According to Pierce and Nowak (1999), cited by [93], PA gives the possibility to do the right thing in the right place, at the right time, and in the right way. Therefore, PA bases its applicability on using technologies to detect and decide what is "right" [88]. Seelan et al. [91] state that PA is a method that involves crop management according to soil variability and site-specific conditions. It is very promising in economic and ecological terms. According to Campo (2000b), cited by [94], PA brings the following benefits: (a) reduction in the quantities of production factors; (b) reduction in production costs; (c) reduction in environmental contamination; (d) increase in crop yields.

The detection and measurement of properties of soils and the crops through sensors provides large amounts of exploration data (big data), which, if properly collected, stored, and interpreted, can provide excellent means to improve knowledge about the factors that determine the production process [89]. In the specific case of animal production, the success of PA comes from integrating all the information collected by various sensors to monitor plants, soil, and grazing dynamics together [43].

3.2.1. Global Navigation Satellite Systems (GNSS)

Knowledge of the characteristics of the plots is essential for developing any engineering project involving agro-silvo-pastoral activities [95]. In this sense, the positioning based on GNSS has become an essential tool for surveying areas, mapping, PA, engineering and construction, aerial images, and sensors and management of public services, presenting greater precision and positioning reliability, if compared to the GPS [96]. The GNSS technology allows for terrestrial mapping, by collecting georeferenced data, which provides the area and perimeter of the plots [97]. Altimetric surveys aim to obtain unevenness of selected points [95]. The variation of altimetric values can be correlated with several soil characteristics, such as texture, water retention capacity and nutrient content [98]. Thus, using GNSS RTK (Real Time Kinematic) technologies has become an alternative for obtaining altimetry data for agriculture, combining high accuracy and good operational performance [99]. Alba et al. (2010), cited by [99], compared the data obtained by GPS RTK, in static mode, obtaining correlations of 99%, with topographic surveys carried out conventionally. These data show the potential of GPS RTK for surveying the altimetry of plots. Additionally, according to Hauglin et al. [100], the accuracy and precision of the altimetry data obtained through the GNSS RTK technologies are visible, even on board vehicles that travel through the plots. However, according to Rabelo et al. [99], when using all-terrain vehicles, the collection of altimetric data should only be carried out in parallel lines to the crop lines, with a speed of ± 2.2 m/s. The use of these new technologies, combined with the use of specific computer programs, facilitating field and office work, also significantly improves the accuracy of measurements since they are less subject to interference from errors caused by environmental conditions and also from errors caused by human interference [95]. In PA, GNSS-based positioning includes topographic mapping, crop production maps, and machine driving [101]. However, the altimetric survey carried out with GNSS receivers in the open field is more accurate than that in plots with trees, since the tree canopy leads to signal loss, which affects the accuracy and precision of the results [95].

3.2.2. Soil Monitoring

As previously mentioned, soil laboratory analysis is time-consuming and expensive in determining its physicochemical characteristics. Thus, there is a growing need to use expeditious and fast methods for this characterization through sensors, intending to complement and/or replace traditional sampling methods [102]. The soils have significant spatial and temporal variability, conditioning the productivity of the established crops. This variability can be monitored through several sensors, not having one that can, by itself, completely characterize the complexity of the soil [6]. However, if the sensor incorporates a GPS, field maps can be obtained, identifying low- and high-productivity areas [56].

Proximal sensors for measuring soil characteristics provide data quickly, with low associated costs, and also allow for the understanding of the spatial and temporal variability of the soil in a given plot (Kuang et al., 2012) cited by [6]. However, it should be noted that the acquisition cost of these sensors is high. Soil Apparent Electrical Conductivity (ECa) has been described as the primary variable for characterizing the soil and defining differentiated Management Zones (MZ) [103]. Since the soil is not uniform, the term is ECa, the electrical conductivity of uniform soil that gives the same reading [104]. The ECa expresses the concentration of soluble salts in the soil [105]. The ECa of the soil is a function of the humidity, salinity, temperature, apparent density, and percentage of clay [6,104]. ECa can be used as an estimate of these characteristics if the contributions of other soil properties that affect electrical conductivity are known or can be estimated (Dafonte, 2004). Soil ECa, according to Peralta and Costa [79], is negatively correlated with altitude ($r^2 = -0.91$), where the values of salt content, pH, sodium, and cation exchange capacity are high. According to this study, ECa is also negatively correlated with soil OM ($r^2 = -0.72$).

The ECa measurement can be performed by electromagnetic sensors, which measure the variations in soil moisture, clay percentage, texture, depth, and ion content [79]. The soil sensors most used in pasture monitoring are electromagnetic induction sensors, which are used in agriculture to monitor salinity and identify soils affected by sodium [106]. Interest in this technology has grown in response to the high spatial resolution, possibly with GPS being used to determine the spatial variability of soil properties [106]. Electromagnetic sensors are a non-invasive, non-contact method for characterizing soil spatial variability based on Faraday's law and have been used for about 20 years to characterize agricultural soils [106]. These mobile sensors are a fast and inexpensive method that allow you to assess soil variability over large areas more quickly [6]. However, according to Kuang et al. (2012), cited by [6], electromagnetic sensors are limited to quantifying the soil parameters mentioned above, although they are a fast method. Direct ground contact sensors are generally only used on arable land. However, the Veris conductivity meters are capable of physically penetrating pasture soil [107], being widely used in Montado plots in Alentejo. In a study, Serrano et al. [108] aimed to show interest in measuring ECa with Veris to define different MZs in undercover Montado pastures in the Évora region and found significant and positive correlations between ECa and soil moisture (r^2 = 0.7088). In another study on pastures in Alentejo, Serrano et al. [109] obtained significant correlations between ECa, measured with the Veris sensor in 2012 and 2013, and soil moisture, clay, silt, sand, OM, pH, and P. In this study, with an electromagnetic sensor, the authors only mentioned significant correlations in 2013 for the following parameters: soil moisture, silt, pH, P, and N.

3.2.3. Pasture Monitoring

Solar radiation interacting with plant tissues, or their canopies is reflected, absorbed, or transmitted. The spectral characteristics of these components are determined by the properties of tissues or plant canopies, and the reflected light can be used to assess the plant's biophysical and biochemical properties [110]. Furthermore, according to Rascher and Pieruschka [110], a low reflectance intensity from plant leaves is in the visible wavelength (400 to 700 nm), which implies a high absorbance. On the contrary, a high reflectance in the near infrared region (700 to 1100 nm) is due to the plant's low absorption of light.

The use of remote and proximal sensors to evaluate cultures involves the relationship between the measurement of multispectral reflectance, plant temperature, photosynthesis, and evapotranspiration [91]. However, the application of the sensor becomes difficult in permanent pastures where there are trees, irregular plant spacing, morphology, and color compared to crops where there is only a single pattern [89].

The application of remote sensing techniques to monitor production systems where, in addition to crops, there is grazing is difficult due to the great complexity of these systems [43]. Pullanagari et al. [7] state that multispectral images, which come from remote sensors, have the potential to quickly estimate the quality of the pasture in the field without the need for cutting, collection, and laboratory analysis. According to Handcock et al. [78], the most consistent correlations between data obtained by multispectral sensors and field observations, concern the rainy season. Remote sensing, particularly hyperspectral imaging, has been described as an auspicious non-destructive tool for determining the nutrient concentration in vegetation [43]. According to Albayrak [111] using hyperspectral sensors to estimate pasture quality has produced satisfactory results.

According to Serrano et al. [43], applying technologies with sensors in pasture and grazing systems is challenging since these systems have significant spatial and temporal variability. However, according to those authors, nearby sensors with higher spatial and temporal resolution can overcome some of these challenges. On the other hand, pasture products have a low economic value that limits the use of new technologies [81], sometimes requiring a very high initial investment. Although proximal sensors monitor only a point or a reduced area, they differ from satellite images' scope. If they are mounted on a mobile platform, they have the potential to provide continuous data and capture rapid changes in the proportions of photosynthetically active radiation [78]. In this way, they constitute an essential database for making better decisions [78]. Optical sensors that can be mounted on vehicles are included in the category of proximity sensors [107]. Optical sensors are divided into passive (use natural light) and active (have their own light source), the latter being able to work in any light condition, including at night [81]. Generally, the information collected by the optical sensors is transformed into vegetation indices [112].

Currently, the agricultural producer has easy access to satellite images, at a low cost and with much important information regarding the crops and soil of their farms [6]. Thus, it becomes possible to continuously monitor pasture biomass based on multispectral satellite images with a high spatial resolution, which is very useful in decision making by agricultural managers [57]. According to Pullanagari et al. [56], the accurate and real-time estimation of pasture quality is crucial for the more informed adoption of management practices, such as applying fertilizers based on pasture needs. According to Serrano et al. [43], satellite remote sensing constitutes an interesting perspective due to the response scale, process speed, and low cost. Those authors also mention that satellite images with different geometric and spectral characteristics (Landsat 8 and Sentinel-2) have been used in monitoring the Montado ecosystem. However, one of the main limitations in the use of satellite images is the presence of clouds [78,113] and, in the case of Montado, the existence of trees, which limits the capture of satellite images, under the canopies [43]. To overcome this limitation, using proximal sensors under the canopy of trees is crucial [78]. The information collected through hyperspectral sensors can help agricultural producers to improve productivity, performance, and farm resilience, allowing for more accurate and timely decision making [56]. According to this study, the regular monitoring of the pasture with nearby hyperspectral sensors allows for efficient rotations to be programmed and the supply of supplementary food to be planned only when there is an inadequate level of nutrients in the pasture. On the other hand, this study also mentions that having real-time information about the nutrients in each plot allows for easy adjustment in the number of animals (stocking rate).

To support grazing management decisions and to better understand spatial and temporal changes and variability in rangelands, obtaining an accurate estimate of the biomass in these ecosystems is crucial [114]. As mentioned, the traditional methods of cutting and collecting samples of pasture for later bromatological analysis and weighing to obtain the productivity and/or quality of the pasture, despite being quite accurate, become unfeasible because they are expensive in terms of time, human resources, and money. In this regard, and according to Fricke and Wachendorf [115], remote sensing techniques can be fundamental since they allow for quantifying and mapping the spatial and temporal variability of the constituent plants of the pastures, being an expeditious and non-destructive method. A vegetation index widely used to estimate pasture productivity and quality is the NDVI (Normalized Difference Vegetation Index), which can be obtained through a proximal sensor or multispectral satellite images. NDVI is related to the amount of chlorophyll in plants [85] and, consequently, to their vegetative vigor (Kawamura, 2007), cited by [81]. It can be calculated from satellite images through the reflectance, by plants, of the emitted radiation [116] or from nearby sensors, such as “OptRx” [117]. The NDVI is derived from the reflectance ratio of red to near infrared [85]. Serrano et al. [118], in a study where they correlated the NDVI values through the proximal OptRx sensor with the production of the Montado pasture, obtained a relatively low correlation (r^2 = 0.47). Additionally, with the OptRex sensor, Serrano et al. [117] obtained high and significant correlations between pasture quality parameters and the NDVI (r^2 = 0.7537 for CP and r^2 = 0.8375 for NDF). The “OptRx” sensor measures high NDVI values in places with high DM and GM production, which is directly related to a higher density of photosynthetically active vegetation and is also correlated with the CP content [43]. Serrano et al. [81] infer that productivity and NDVI values are higher in places where pasture moisture is high, corresponding to northwest and southwest orientations.

On the other hand, according to the same authors, the NDVI values were higher in younger plants and in places with a high percentage of legumes. Still, according to Serrano et al. [81], the active proximal sensor “OptRx” can identify different botanical species, different development stages, and different productivity zones. On the other hand, Godinho et al. [119] used NDVI data from the Sentinel-2 satellite, verifying that the values of that index showed a solid and positive high correlation (r^2 = 82.8) with the values of the percentage of canopy cover in Montado. In addition, remote optical sensors can potentially detect physiological and biochemical changes in plants, in addition to the non-invasive detection of changes in photosynthetic energy conversion, which can help in decision making in an agricultural context [110].

Since both NDVI and capacitance present very similar and acceptable results for the characterization of pasture productivity, it is understandable that the active optical sensor "OptRx" will gradually replace the Grassmaster II (technology that allows for the estimation of pasture production). This eventual replacement is based on the advantages of this sensor concerning the capacitance probe, namely, regarding the possible speed of continuous monitoring of the pasture (on a mobile platform) without the operator's manual intervention at various points of the pasture [81]. However, in a study by Serrano et al. [118], a strong correlation was obtained between Grassmaster II readings and pasture biomass production (r^2 = 0.75). Thus, the total pasture biomass can be estimated directly through cutting and weighing or indirectly through capacitance meters (Gonzalez et al., 1990), cited by [85]. During the 1970s, many methods were evaluated. Some methods, such as the electronic capacitance probe (Grassmaster II), have been adapted commercially. Capacitance instruments generally consist of an electrical circuit that generates a signal at a specific frequency and then performs a capacitance measurement of the air–plant mixture [84]. This equipment makes it possible to automatically record and store the values of all the readings taken in each plot to be later downloaded to the computer and processed [38,84]. This is a recognized advantage, since the operator does not need to interfere in recording the information, being able to sample a large area.

According to Virkajarvi [120], the measurements made by the capacitance probe vary depending on the type of plants that make up the pasture and changes in its structure. The Grassmaster II features 2 calibration equations developed on New Zealand pastures to estimate pasture DM production (kg/ha). these pastures consisted of a mixture of rye and clover, in a ratio of 80/20, respectively, with a DM content of 14–16% [38]. In a study carried out by Serrano et al. [121], in three Montado plots in Alentejo, to calibrate a capacitance probe (Grassmaster II) and to estimate pasture productivity in this ecosystem, robust correlations were obtained (r^2 = 0.94 and r^2 = 0.81 for DM in February and March, respectively). According to Zanine et al. [122] and Carvalho et al. [123], biomass quantification is based on the fact that the capacitance of the air is low, while that of the vegetation is high, being necessary to calibrate the probe before being used. Therefore, it is necessary to carry out several readings quickly and effectively before taking readings in the intended locations.

Capacitance probes have become a fast, accurate, and non-destructive technology for estimating vegetation production [124]. However, significant restrictions on using the capacitance probe include its inability to estimate the production of individual species (Pieper, 1978), cited by [84]. When vegetation is more homogeneous and has fewer moisture content variations, estimates based on capacitance probe readings are more reliable [125]. However, this probe has great potential for estimating the production of GM and DM in cultures consisting of a single plant species [84]. Serrano et al. [38] found very high correlations in pastures composed of grasses (r = 0.90) and in heterogeneous pastures (r = 0.87) between pasture DM and Grassmaster II readings. As for pastures composed essentially of legumes, Serrano et al. [38] obtained a moderate correlation (r^2 = 0.48). In this context, Serrano et al. [43] obtained very consistent correlations (r^2 = 0.606 and 0.818) between the values obtained with the capacitance probe and pasture productivity (DM and GM), at all evaluation times (months of December 2015 and June 2016). These facts reveal the practical interest of using the Grassmaster II as a quick method for estimating the productivity of pastures in the south of Portugal. According to Serrano et al. [81], in places where pasture humidity is high, productivity is also higher, as well as capacitance values. This same study also found that the less advanced the phenological state of the plants and the greater the percentage of legumes, the greater the capacitance values.

Carreira et al. [66] carried out a study in pastures under Montado to calibrate and validate the use of a portable NIR sensor in the evaluation of pasture quality. From this study, the authors obtained values of r^2 = 0.73 and 0.69 for calibration and validation, respectively, for the NDF of the pasture samples; for CP, values of r^2 = 0.51 and 0.36 were obtained for calibration and validation, respectively [66]. Several authors state that the main advantages of the portable NIR are its low weight, ease of use, direct measurements in the pasture, non-destructive nature, time-saving in cutting and sample processing, more frequent evaluations, and more timely decision making at the moment of evaluation, thus overcoming the spatial and temporal variability of the pasture [56,126–129].

Moeckel et al. [57] consider that using sensors in pastures is sometimes tricky, with some limitations relating to each specific sensor. Thus, according to Nawar et al. [6], sensor fusion is an attractive option for incorporating several variations in scales (vertical and horizontal) and unequal properties. There are three main types of sensor fusion: (1) nearby sensor fusion; (2) fusion of remote and near sensor(s); (3) fusion of remote sensors. The fusion of sensors can lead to more precise and accurate monitoring of the soil and/or pasture since it allows for the acquisition of more than one type of information simultaneously, which can contribute to improving decision making by the farmers and agricultural managers [130]. However, according to Gobbett et al. [86], sensor fusion can lead to challenges and problems related to the configuration, image capture, validation and data management, and analysis of these data to derive calibrated scientific information.

3.2.4. From the Establishment of Management Zones (MZ) to Variable Rate Technologies (VRT)

Generally, agricultural producers apply identical numbers of production factors, such as fertilizers or correctives, throughout the plot; in a plot, the needs of the soil/crop can be very different depending on the physical-chemical characteristics of the soil, topography, and specific weather conditions [6]. According to Moral et al. [131], although the soil ECa can be used to help define soil MZ, it must be considered that its correlations with soil fertility are variable and sometimes low. Peralta and Costa [79] also state that the definition of MZ (by measuring the ECa of the soil) is only sometimes correct, especially for excessively and moderately drained soils. Furthermore, topography plays a significant role in influencing the spatial variation of ECa [132].

Agricultural producers prefer this approach of treating the plots homogeneously, as it is quicker and easier to implement. However, uniform application leads to the economic inefficiency of these production systems and high environmental costs [6], since it does not consider the spatial variability of the soil [79]. In this regard, the concept of Management Zones (MZ) arises, which consists of managing areas of agricultural fields in a differentiated way, depending on the needs and physical-chemical characteristics of the soil. MZ are a form of PA, whose main objective is to decide on the quantities of production factors to be applied in a given situation, depending on the soil and the crop [79]. This concept is different than the traditional production method since it manages the variability of the plots to increase productivity and efficiency by using production factors, not forgetting environmental protection [133]. According to Koch et al. (2004), cited by [6], the MZ brings economic efficiency and a reduction in production factors to the producer. These production factors are only applied where and when needed in each zone [6]. Therefore, according to those authors, when comparing the cost-effectiveness between variable rate technology (VRT) and uniform application, there is a clear advantage for the former, in different situations and with different fertilizers. Each MZ, according to Seelan et al. [91], becomes a differentiated management unit in which profitability can be increased, reducing production factors, through VRT.

Figure 5 is a summary of the use of different expedient technologies for soil and pasture monitoring.

Table A2 (Appendix A) summarizes the works mentioned in Section 3, where one can observe which technology or sensor was used, the general and specific application, the type of sensor used, and the geographic location where each experimental study occurred.

Figure 6 shows the percentage of studies that were cited in Section 3 that looked at proximal sensors, remote sensors, and both. In these studies, the potential of using different technological tools to monitor and characterize the different components of Montado was tested.

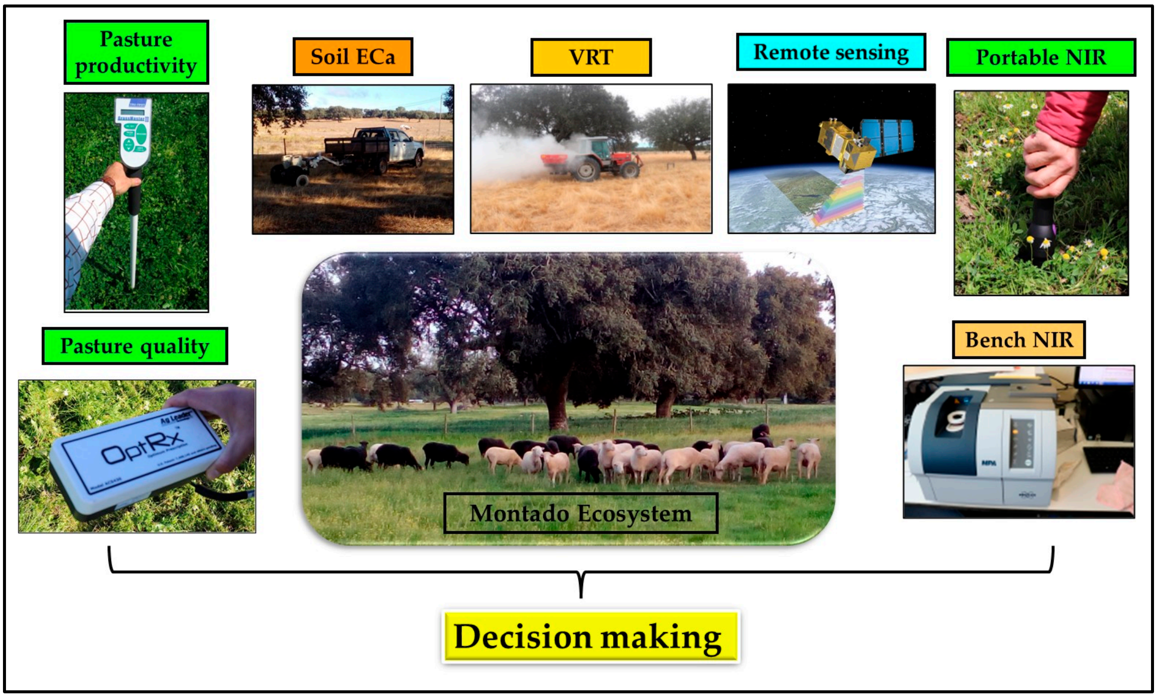

Figure 5. Summary diagram of technologies referred to in this review for soil and rangeland monitoring.

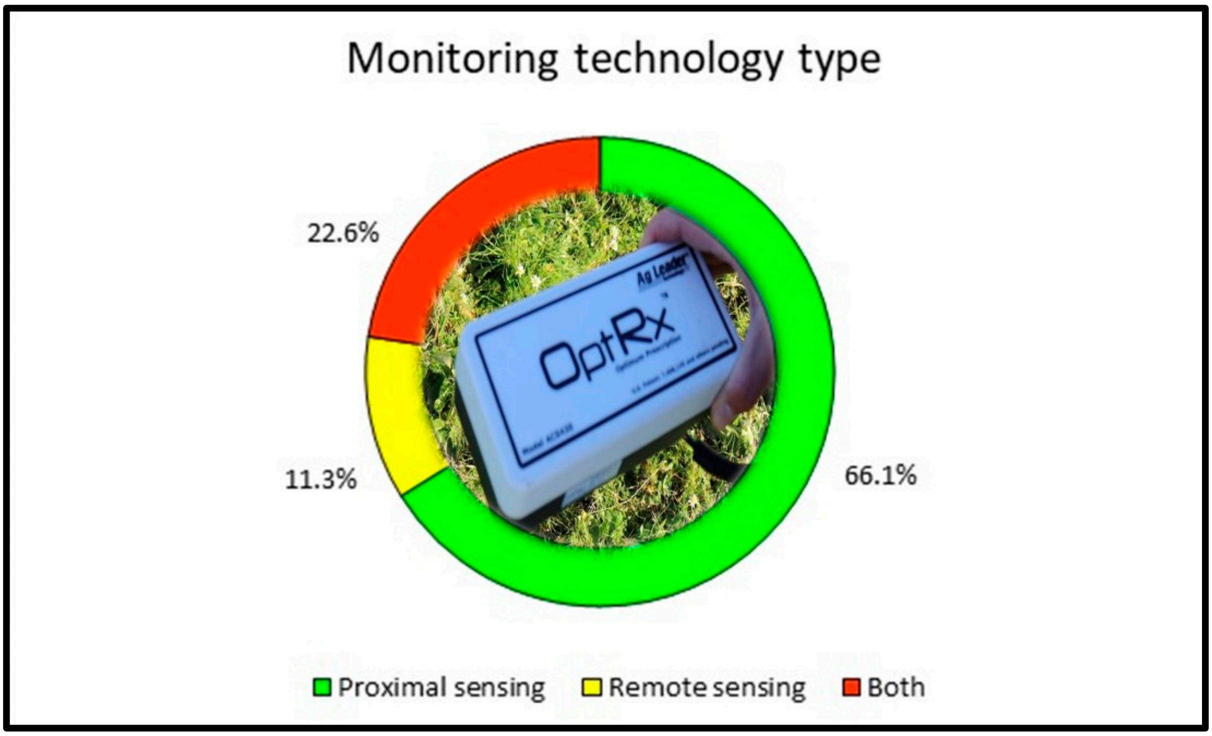

Figure 6. Monitoring technology type.

Figure 7 shows the percentages of studies cited in Section 3, referring to different components of Montado (pasture, soil, grazing, and trees, among others), monitored and characterized with different proximal and/or remote sensors.

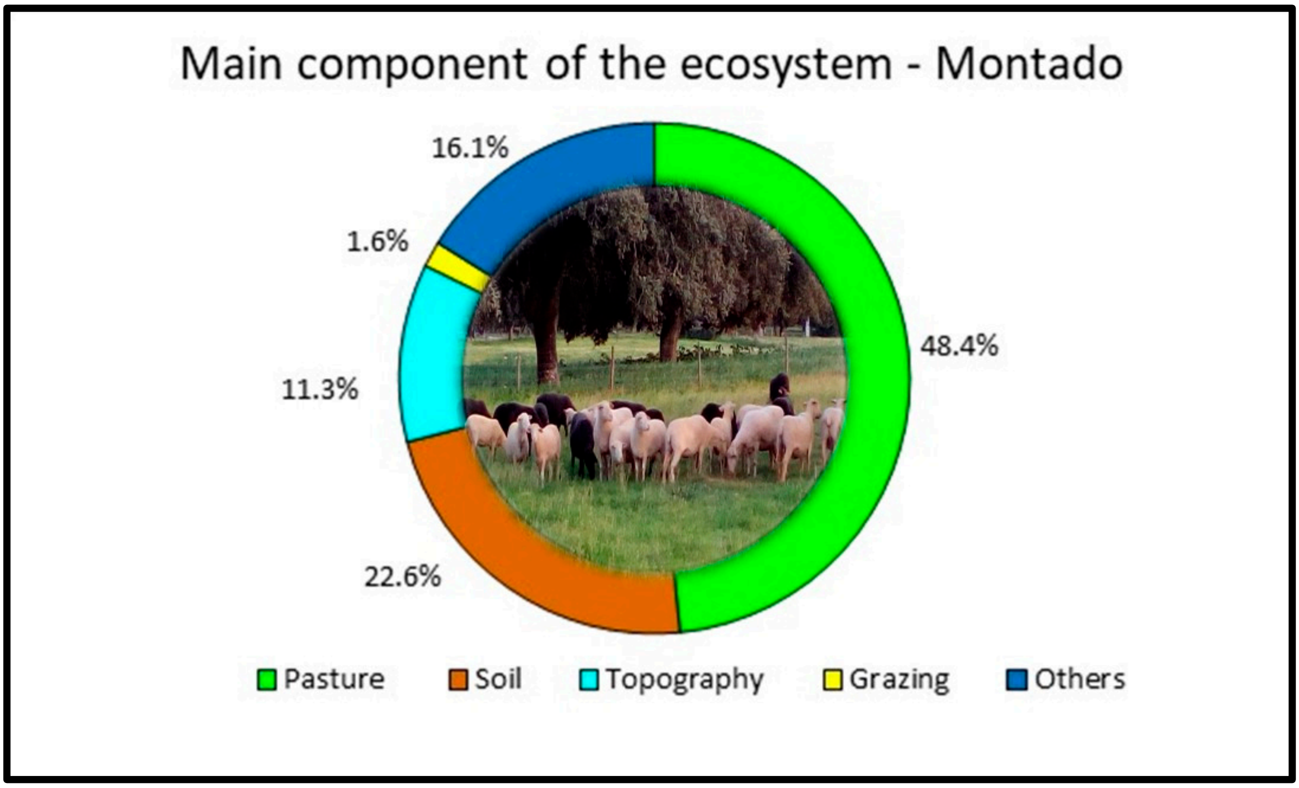

Figure 7. Main component of the ecosystem—Montado.

4. Grazing

Grazing is a vital issue for the management of agricultural areas and for nature conservation [134,135]. Grazing is a biological activity in which plants, animals, and the environment interact with each other [136]. Voisin and Lecomte [58] defined grazing as the animal meeting with the pasture. For Beetz and Rinehart [25], it is a cheap and relatively simple way to generate income for the producer, since the animals move and consume the food in the place where it is produced. In this way, cutting, transporting, storing, and distributing to animals are avoided. According to Zhu et al. [60], pasture biodiversity is influenced by its type (temporary vs. permanent), the type of grazing, and the animal species that graze it (cattle, sheep, pigs). Intermittent grazing is the grazing management system that most frequently supports extensive livestock production in Montado. In this system, the animals rotate through the various pasture plots, individualized by fences, without any order and/or pre-defined periods. However, continuous grazing may occur in larger areas. In Montado, the length of stay in grazing areas varies from year to year, not following a predefined plan but based on the assessment of the pasture, subjectively assessed by the head of exploration [11]. This empirical method comes from practical experience accumulated over time and cannot be expressed using any equation Voisin and Lecomte [58]. When making informed decisions, in this context, the producer must consider the amount of pasture available, the area of the plots and the estimated growth rates, the number of animals, and their nutritional needs [25].

4.1. Effects of Grazing on Soil and Pasture

Guevara-Escobar et al. [54] report that soils used as pasture tend to acidify due to NO_{3-} leaching, nutrient extraction, and OM accumulation in the soil. As with crops, the presence of animals can also lead to soil acidification due to the extraction of nutrients [5].

However, this acidification process is only relevant in the long term, in addition to the fact that the soils that support pastures are more protected against erosion [25]. The main contribution of animal production to soil acidification is the flow of urine, which passes through soil macropores, surpassing the surface layers. Acidification can become even more significant if, in addition to the leaching of nitrates, there is also leaching of basic cations [5]. The Stocking rate is the main factor that defines soil acidification rates, since more animals can also increase acidification due to urine dynamics [137] and the export of basic cations [5], such as Ca^{2+} and Mg^{+}. However, the acidification process is temporary since the decomposition of organic residues from plants improves soil acidity [138].

In this sense, there is a clear advantage for silvopastoral systems, such as Montado, in which residues from pastures and trees contribute to this attenuation of soil acidity. On the other hand, according to Martins et al. [5], grazing over several years during the winter, regardless of the stocking rate, contributes to a higher soil pH when compared to plots where only crops are produced without any grazing. According to this study, the availability of Ca^{2+} and Mg^{+} at the end of 11 years of trials was also greater where there was grazing during the winter, regardless of stocking, than it was in plots where this was not verified, with the final balance also being less harmful.

This study demonstrates that neither the introduction of grazing animals on cropland nor the stocking rate led to more significant soil acidification. According to Buterlly et al. [138], crop residues, which remain in the soil, are very important for the redistribution of its alkalinity. However, these authors also note that it is difficult to evaluate the direct biochemical effects of residues on the pH of the soil from agronomic processes since the alteration of the pH of the soil by residues will depend on the relative contribution of the processes of the production or consumption of alkalinity and the depth at which they occur. According to Wang et al. [77], there is clear evidence that grazing affects the activity and composition of communities of microorganisms in the soil and vegetation, thus affecting the sequestration of methane in the soil, which, according to Tang et al. [72], may contribute to global warming. However, there are contradictory positions regarding methane sequestration in soils where grazing occurs. Liu et al. [139] reported that grazing with 4 to 5 ewes/ha during the day, between November and April, led to a decrease in CH_4 sequestration in the soil by 47% in the temperate semi-arid steppes of China during the growing season pasture. Qi et al. (2005), cited by [72], inferred that continuous grazing during the pasture growing season led to increased CH_4 sequestration in the soil. Therefore, according to Tang et al. [72], CH_4 sequestration in soils where there is grazing may depend on the intensity of grazing, its duration, or the physicochemical conditions of the soil.

Soil CH_4 sequestration decreases with an increasing stocking rate. In the study by Tang et al. [72], this significant effect was only verified with a high stocking rate since, with moderate and low stocking rates, there were no significant differences in grazing. A higher stocking rate, according to this study, also leads to a decrease in soil organic carbon (5%), soil moisture (16%), and pasture biomass (114%). Additionally, regarding the duration of grazing, Tang et al. [72] found significant differences, and the sequestration of CH_4 in the soil decreased with the increase in the number of days of grazing. This trend is even more remarkable when there is continuous grazing over months or years, with significant decreases being verified if grazing is continuous over ten years.

4.2. Grazing Systems

The choice of grazing system is the key to the success or failure of an agricultural operation, both economically [25] and environmentally. Continuous grazing entails grazing the same plot, during the grazing season, year after year [140], generally with a relatively low stocking rate. According to Tang et al. [72] long grazing periods negatively affect methane uptake in the soil and, consequently, decrease carbon sequestration in pastures and soil. In addition, continuous grazing is one of the factors responsible for the degradation of ecosystems where overgrazing occurs [64]. In continuous grazing systems, excessive trampling harms the pasture and the soil [58].

On the other hand, according to Barriga [62], in continuous grazing systems, nutrients are returned to the soil through feces and urine. In the Patagonian steppe, in South America, grazing with domestic herbivores is still recent. However, it has caused severe degradation, mainly due to continuous intensive grazing, albeit in very large and very heterogeneous enclosures [140]. The diversity of plant species leads to selective grazing and excess dry residues on the soil surface, which translates into the replacement of preferred species by non-preferred species [25,140], not necessarily being those intended in the pasture, in terms of nutritional value. However, we must remember that there are no good or lousy grazing systems. Some grazing systems are designed to achieve particular objectives according to the soil and climate conditions, the relief, the soil, the animal genotypes, and the production system. In this context, Pereira et al. [141] state that, considering the diversity of plant species, soil types, and climatic conditions of rangeland ecosystems around the world, agronomic practices and pasture improvements for achieving "intensification" targets differ widely across countries and regions. This statement is corroborated by Holechek [140] when he states that, for a grazing system to be beneficial and function properly, the needs of vegetation, soil, and animals, which are part of these production systems, must be taken into account. Continuous grazing has some limitations, as it allows for selectivity and causes heterogeneity in the pasture. In this way, overgrazed and undergrazed areas occur simultaneously [140,142], reducing the possibility of the recovery of the more grazed areas [143]. However, in a study carried out in plots dominated by weedy shrubs (*Cistus Ladanifer* L.), the authors concluded that continuous grazing with 2 to 3 AU/ha led to a decrease in the number of shrubs and an increase in desirable herbaceous plants with good nutritional value, especially from the *Poaceae* and *Fabaceae* botanical families [143].

On the other hand, using pasture intermittently, through deferred grazing in several plots (multi-paddock), leads to satisfactory productive, ecological, and economic results [144]. Deferred grazing involves grazing the plot in longer or shorter grazing periods depending on the amount of pasture, generally with a high stocking rate [1]. Thus, it is crucial to define the number of plots to reduce the occupation time of each one; not all need to have the same area, but they do need to have the same production capacity [58]. In this sense, Holechek [140] infers that deferred grazing makes it possible that areas preferred by animals are not as harmed as in continuous grazing, regarding the vigor and production of plants in these areas.

Miao et al. [64] carried out a study of Yak grazing in China in which they compared three levels of deferred grazing—low stocking rate—0.75 yak/ha; average stocking rate—1 yak/ha; and high stocking rate—1.25 yak/ha—with a plot where there was no grazing. The authors state that, in the plot without grazing, there was a more outstanding production of pasture biomass (1272 kg/ha), followed by the plot with a low stocking rate (1250 kg/ha), the plot with a medium stocking rate (1076 kg/ha), and, finally, the plot with a high stocking rate (925 kg/ha). Concerning the nitrogen content (related to crude protein) of the pasture, the highest value found was for the plot with a high stocking rate (16.3%), followed by the one with a medium stocking rate (15.3%), the one with a low stocking rate (14.8%), and the plot where there was no grazing (14.2%). However, a more significant daily weight gain by the animals in this study occurred in the plot with a low stocking rate (489 g/yak/day), followed by the plot with a medium stocking rate (439 g/yak/day), and, finally, the plot with a high header (394 g/yak/day).

Regardless of the type of grazing, its management may be necessary, containing the harmful effects on the trees in the pasture in their juvenile phase. For this reason, the stocking rate, the rotation of livestock species among the plots, the length of stay in each plot, and the composition and amount of supplements supplied to the animals should be conveniently evaluated [45]. Thus, deferred grazing can minimize the detrimental effects of selective overgrazing in areas preferred by animals [144]. According to Barcella et al. [145], overgrazing can lead to soil degradation and the loss of biodiversity. On the other hand, undergrazing can lead to a greater preponderance of less palatable species with lower food value and to replacing pastures with forests, with a loss of habitat. According to Voisin and Lecomte [58], deferred grazing is recommended, with short grazing periods and long resting periods, in semi-arid regions. This recommendation could be applied to the case of Alentejo. According to Voisin and Lecomte [58], deferred grazing is the most correct technique for improving the floristic composition of a degraded pasture. Deferred grazing, although it may allow the animal a relative selection of the pasture, allows the total DM ingested to satisfy the nutritional needs of the animals without compromising an abundant production of good-quality grass [58], provided that the necessary conditions for this production (appropriate precipitation and temperature) exist.

On the other hand, continuous grazing has some advantages, especially concerning lower investments in physical fences to separate grazing plots and animal watering, further simplifying pasture and grazing management [25]. Additionally, Holechek [140] and Santos et al. [146] state that continuous grazing presents better productive results for the animals since they can select their diet. In practical terms, converting from a continuous grazing system to a deferred grazing system implies more significant management needs and major changes in livestock farming, such as the plot sizing stocking rate calculation, watering, and grazing time in each plot [25].

4.3. Biotic Loads per Unit Time and Area

Whenever there is grazing in a specific area, there is a rest period for the pasture so that the plants can recover and replenish their root reserves [58]. According to these authors, the periods between each grazing event should be variable, avoiding, as much as possible, that the same plants are not bit off more than once, in the same grazing event, without resting the plot. In this segment, deferred grazing systems are the most recommended, with advantages for the animal and for the pasture. Beetz and Rinehart [25] also state that, after each grazing period, a leaf area should be left, which allows for the rapid regrowth of the pasture without harming the root reserves of the plants. In grazing systems with a high stocking rate, in a short period and with a subsequent rest period of 7 weeks (short-term grazing), more significant infiltration of water into the soil is promoted, the selectivity is reduced, and the leaf area index is improved [140]. After a grazing period, rest periods for pastures are essential for maintaining pasture productivity [147] and for planning the following grazing periods [25].

On the other hand, the stocking rate influences the performance and productivity of grazing animals in an ecosystem [64]. The stocking rate and grazing period can influence the feed quality, pasture intake, and animal performance [148]. Grazing management affects the growth and development of rangelands [149]. Animal behavior changes depending on the stocking rate and the season of the year [59]. Increasing the stocking rate increases the grazing time [150]. In a study carried out in China by Xiao et al. [59] to evaluate the effects of grazing on the pasture, comparing two levels of stocking rates (8 ewes/ha and 16 ewes/ha) revealed that the height, herbage mass, and density of the pasture, as well as the CP concentration, were significantly higher, with a lower stocking rate, while the NDF and ADF concentrations were significantly lower.

On the contrary, Miao et al. [64] report that more significant stocking rates confer more excellent nutritional value to the pasture. However, they negatively affect the quantity produced since the plants are more grazed, preventing the advancement to other phenological states. According to Fonseca et al. [61], height is a very important variable for the managing pastures and grazing, whether with fixed or variable stocking. Barriga [62] states that an ideal average height should be found. Moraes et al. [74] report that the pasture height correlates with the pasture mass. In a study carried out in the United Kingdom on permanent pasture composed of perennial grasses, Bell et al. [126] found robust correlations between height and GM (r^2 = 0.87) and height and DM (r^2 = 0.84). The same study states that pastures with average heights of less than 7 cm lead to lower nutritional values. In a study carried out by Fonseca et al. [61], intending to define the ideal height of sorghum for direct grazing by beef heifers, the authors state that the ideal height is 50 cm since it allows for a maximum ingestion rate, also increasing the weight gain of the animals. In addition, heights below 50 cm can seriously compromise the regrowth of the plants after being grazed.

On the other hand, according to Miao et al. [64], concerning the dead biomass that remains on the soil in the summer and can prevent plant germination in the following autumn, higher stocking rates lead to lower mantle death, and vice versa. The stocking rate has a negative linear relationship with the amount of dead biomass. It should be noted that wet years allow for grazing with greater stocking rates than dry years. According to Bell et al. [126], with a moderate stocking rate, the pasture has superior forage digestibility, since there is constant growth with a more significant presence of more nutritious vegetative material (leaves and young stems). Grazing with a moderate stocking rate reduces the effects of animals trampling the soil, preventing compaction. It should be taken into account that, with moderate biotic loads, there is an adequate production of plant residues aboveground, contributing to the protection of its structure [62] and increasing fertility. Overgrazing can lead to soil degradation and the loss of biodiversity.

In contrast, under-grazing can lead to a greater preponderance of less palatable species with lower food value and the loss of habitat, overlapping a shrub layer [145]. Both should be avoided [58]. In extensive systems, the marginal bioclimatic nature of grazing in arid, semi-arid, and humid tropical soils plays a fundamental role in establishing different "patterns of regional degradation", such as desertification, the invasion of woody species, and deforestation [141]. According to Asner et al. [151], these processes generally lead to a situation in which the negative impacts of drought and low soil fertility are exacerbated by intensive grazing. Consequences include an increasing proportion of bare soil and increased soil compaction in affected rangeland areas. Both changes reduce water infiltration and increase runoff, erosion rates [151], and soil degradation [152], and an invasion of weeds may occur [141].

Pastures are usually managed by establishing the stocking rate, with relatively low grazing pressures, allowing animals to choose their diet [33]. According to Holechek [140] and Sales-Baptista et al. [153], animals tend to spend more time in preferred pasture areas, where the essential resources are found, such as food, water, shade, and protection. The structure and composition of plant communities constituting pastures are affected by grazing in general [58,64] and, above all, by selective grazing [154]. Selective grazing occurs when the stocking rate is low concerning the green mass produced [155]. Furthermore, when the floristic composition of the pasture is heterogeneous, there is a greater tendency for selective grazing to occur, although it depends on the phenological states of the different species throughout the year [1]. According to Faria [156], replacing sheep with cattle on farms in the Iberian Peninsula led to changes in grazing management (number of grazing days and animal rotation), the grass structure, and the floristic composition of the pasture. However, the latter was affected to a lesser degree. A low stocking rate leads to a greater availability of the pasture per animal, allowing for the choice of preferred plants and parts of plants [25], which have the highest nutritional value, with animals spending less energy in the search and capture of food. Thus, according to Barriga [62], animal efficiency is maximized due to the higher feed conversion, requiring less pasture. However, Heady [157] states that animals select different plants and parts of plants depending on the time of year and the phenological state. Grazing cattle tend to choose plants and plant parts that provide nutrients according to their needs [58]. However, it must be taken into account that selective grazing tends to promote the degradation of pastures since animals ingest plants with greater nutritional value and are more palatable, not allowing them to produce seeds or keep them alive to ensure the continuity of the species. In this case, the plants that are perpetuated in the pasture are those with lower nutritional value and those that are less palatable, thus leading to the gradual degradation of the pastures [25].

On the other hand, overgrazing can lead to low soil coverage by perennial plants (Nie et al., 2005), cited by [158], which leads to several productive and environmental problems, such as the low growth of the plants that make up the pastures, erosion and the loss of soil fertility, and the loss of biodiversity [158]. According to these authors, studying and developing pasture and grazing management strategies for restoring soil cover by perennial plants is crucial. A severe problem with our production systems is not so much overgrazing as a lack of management and balance. Animals are often placed on pasture without any kind of control, either from the point of view of the animal (species, breed, stocking rate, body condition) or the pasture (height, density, species, phenological state). Overgrazing can occur both in continuous and deferred grazing systems.

Regarding the shape of the plots, we must bear in mind that there are zones of access to water, or the exit/entrance, which have the shape of a funnel (angle below 45°) [58]. The soil and pasture of these zones will be negatively affected by trampling [58]. Troughs must be in such a way as to avoid excessive trampling in certain areas, contributing to the degradation of the soil and pasture in these places, reducing the useful area of the plots.

4.4. Importance of Grazing in the Equilibrium of Ecosystems

The animal is the fundamental component for grazing systems, with a soil–plant–animal relationship. This interaction allows for the recycling of nutrients through urine and feces, leading to lower production costs and environmental impacts, maximizing the use of nutrients in the system [136]. According to a survey carried out by Garrido et al. [159], with stakeholders of the Dehesa agro-silvo-pastoral system, grazing is a management practice considered fundamental to maintaining an open landscape structure that supports biodiversity.

According to Garrido et al. [159], many marginal soils were abandoned in the last decades in the Dehesa, resulting in the invasion of bushes and, therefore, increasing the probability of the occurrence of forest fires. If used as pasture, these soils can be used and managed in a beneficial way for animals, the environment, and the rural population. Watkinson and Ormerod [135] stated that plant and animal biodiversity depend on grazing intensity. According to Belo et al. [45], in denser Montados, grazing may benefit the strength of the recovery of the trees by removing herbaceous vegetation and some brushwood, which are fire enhancers. Added here are the beneficial effects of maintaining soil fertility and reducing production costs [160]. On the other hand, we must consider that producers are interested in obtaining the best productive results and profitability, maintaining the sustainability of production systems and biodiversity, and requiring the integration of knowledge of the biology of the species and the correct adjustment of management actions [144].

Table A3 (Appendix A) summarizes the works mentioned in Section 4, where one can verify the animal species used in grazing, the evaluated parameters, the grazing, the stocking rate, and the region/country where the study occurred.

Figure 8 shows the percentages of studies cited in Section 4, referring to the animal species that was used in grazing in each experimental work.

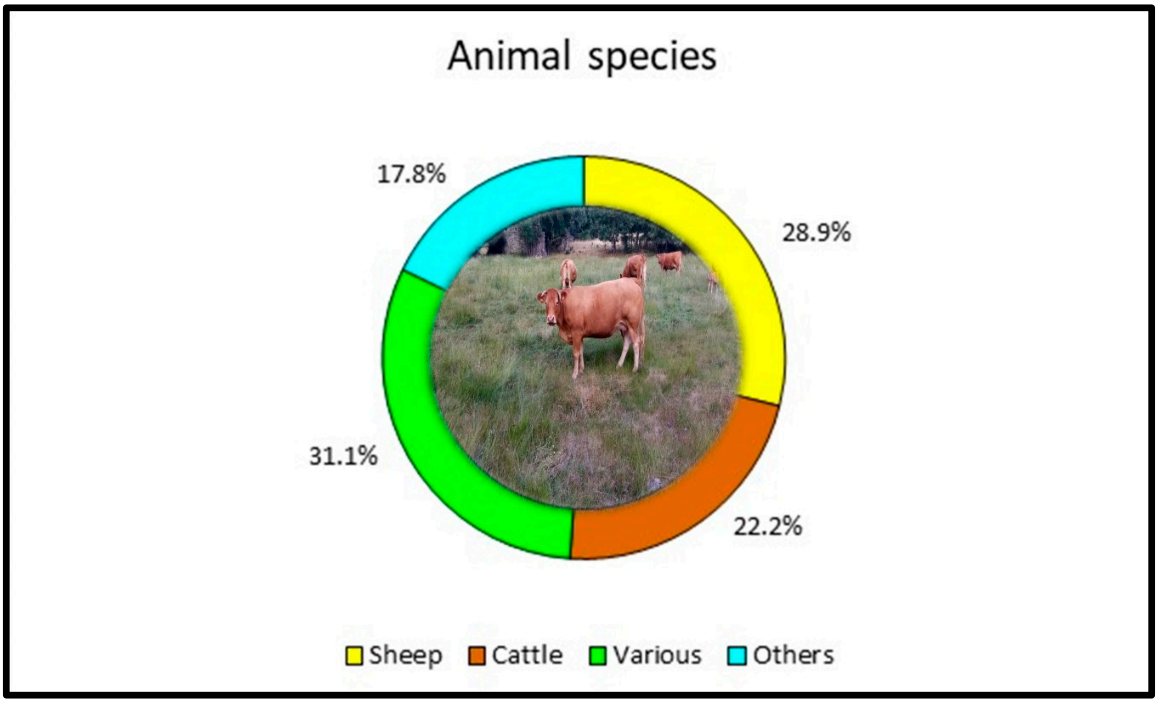

Figure 8. Animal species in studies cited in Section 4.

Figure 9 shows the percentage of studies cited in Section 4, referring to each grazing system. Most experimental work has tested various types of grazing.

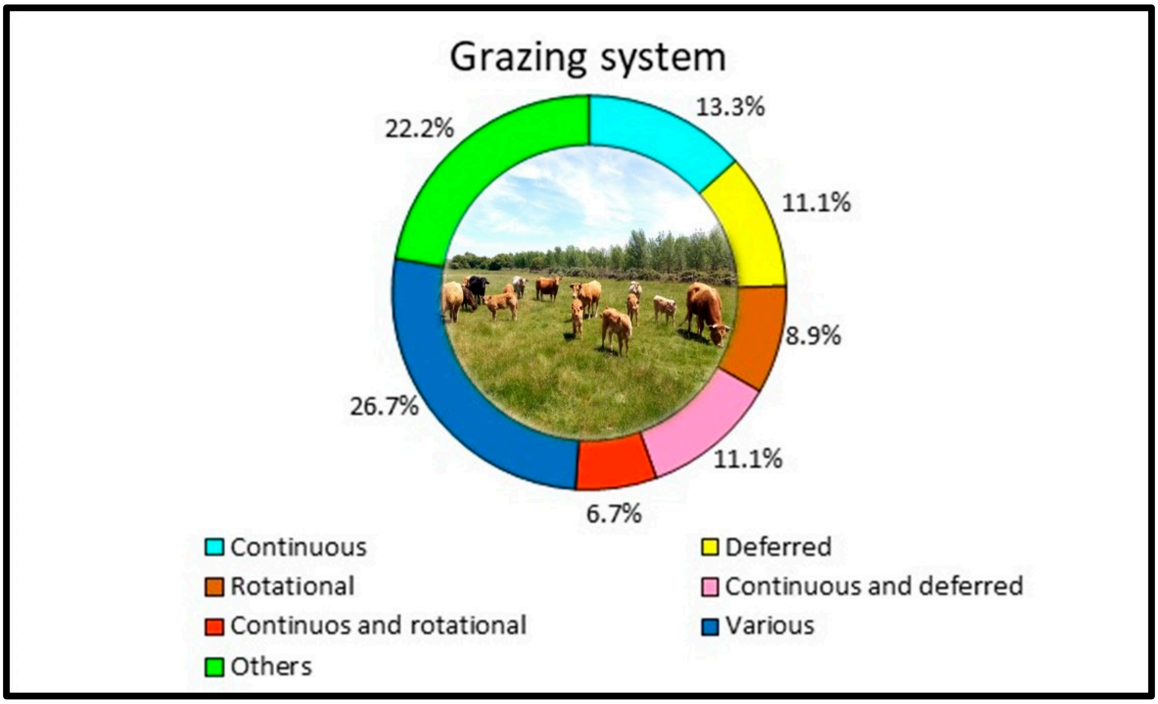

Figure 9. Grazing systems referred to in Section 4.

5. Concluding Remarks

Montado is a very complex agro-silvo-pastoral ecosystem characteristic of the south of Portugal. Its complexity comes from the interrelations between its fundamental components—soil, pasture, trees, and animals—associated with the Mediterranean climate. It is characterized by significant irregularities in precipitation and temperature between years and within the year itself, and this high complexity makes it difficult to understand it as a whole.

In this review, given its length and the many themes underlying and interconnecting, it becomes clear how complex the Montado ecosystem is, as the literature reveals.

The scientific works published in indexed journals about Montado only deal with some of its components, not knowing published works that are integrators, as provided in this review. There are some books and book chapters that focus on the history of Montado and describe each of its components, with some scientific data. Some of these data come from research projects, mainly in the 1980s and 1990s of the last century. Furthermore, some of the agricultural practices described in these books result from the empirical knowledge of agricultural producers and managers who work in production systems based on Montado.

As for technologies with the potential to monitor the Montado ecosystem, there are several published scientific papers, some of which are cited here. Based on the results of these studies, several expeditious technological tools allow for monitoring and estimating physical-chemical properties of the soil, as well as the nutritional value and productivity of pastures, with good correlations with traditional methods.

According to studies cited in this review article, using expedited technologies to estimate the productivity and/or quality of pastures and for soil characterization, several tools already exist. These tools allow for more accurate decisions in the Montado ecosystem, without resorting to traditional sampling techniques and laboratory procedures.

To estimate pasture productivity, the Grassmaster II capacitance probe proved to be a good tool to be used in Montado. In turn, to estimate pasture quality in this ecosystem, we can use the optical sensor OptRex (NDVI), with which very strong correlations were obtained with CP and NDF. The portable micro NIR also has the potential to estimate CP and NDF in the Montado ecosystem pastures.

The ECa, measured with the Veris sensor, proved to be very effective in characterizing soil as well as estimating the nutrient concentrations and percentage of OM.

The least studied component is grazing, which we consider crucial in agro-silvo-pastoral systems. Therefore, it is considered essential and extremely important to carry out experimental tests that allow us to understand how the animals, the animal species, the stocking rate, and the grazing system can influence the soil, pasture, and trees in Montado. It will also be necessary to associate these experimental works, with a greater focus on agricultural and animal production, with an environmental component.

Due to the high complexity of Montado, experimental work involving all components will also be complex. However, it is essential to perform it to understand its complexity better and to be able to contribute to its conservation, improve the efficiency of the production systems based on it, and improve the sustainability and resilience of the ecosystem without forgetting animal welfare.

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Appendix A

Table A1. Works cited in Section 2.

Reference	Production System	Component	Country/Region
[18]	Montado	Animals—Alentejano Pigs	Portugal (Alentejo)
[36]	Crops and irrigated	Climate	Portugal (south)
[26]	Dehesa	Climate	Spain
[34]	General	Climate	Portugal
[3]	General	Climate and agriculture	Portugal
[20]	Montado/cork oak	Description of cork oak/Montado	Portugal
[28]	Dehesa	Ecosystem functions and services	Spain
[9]	Montado	Ecosystem functions and services	Portugal (Alentejo)
[1]	Montado	Floristic composition	Portugal (Alentejo)
[53]	Montado	Floristic composition	Portugal (Alentejo)
[60]	Meadow steppe	Floristic composition	China
[45]	Montado	General	Portugal (Alentejo)
[19]	Montado	General characterization	Portugal (Alentejo)
[11]	Montado	General characterization	Portugal (Alentejo)
[10]	Montado	General characterization	Portugal (Alentejo)
[27]	Montado	General characterization	Portugal (Alentejo)
[17]	Montado	General framework	Portugal (Alentejo)
[25]	Pasture	Grazing	Review
[4]	Montado	Monitoring technologies	Portugal (Alentejo)
[2]	Montado	Monitoring technologies	Portugal (Alentejo)
[35]	High-mountain pastures	Pasture	Itália
[54]	Hill pastures	Pasture	New Zealand
[63]	Pastures ecosystem	Pasture	New Zealand
[71]	Pastures ecosystem	Pasture	Portugal
[39]	Permanent pastures	Pasture	Portugal (Alentejo)
[51]	Silvopastoral system	Pasture	New Zealand
[29]	General	Pasture and forage	Portugal
[59]	Hill pastures	Pasture and grazing	China
[64]	Hill pastures	Pasture and grazing	China
[60]	Meadow steppe	Pasture and grazing	China
[76]	Pastures ecosystem	Pasture and grazing	China
[61]	Pastures ecosystem	Pasture and grazing	Brazil
[52]	Silvopastoral system	Pasture and trees	New Zealand
[72]	Eurasian steppe	Pasture, soil, grazing	China
[65]	Pastures ecosystem	Pasture, soil, grazing and climate	Portugal (south)
[33]	Pastures	Pastures and grazing	Australia
[58]	Pastures ecosystem	Pastures and grazing	France
[41]	Annual crops	Soil	Portugal (south)
[22]	Crop and soil	Soil	Mediterranean region
[23]	Crop and soil	Soil	Review
[24]	Crop and soil	Soil	Review
[48]	Dehesa	Soil	Spain (Andalucia)
[40]	Soil general	Soil	Portugal (Alentejo)
[70]	Agroecosystems	Soil and pasture	New Zealand
[44]	Grazed pasture	Soil and pasture	New Zealand
[68]	Pastures ecosystem	Soil and pasture	USA
[38]	Permanent pastures	Soil and pasture	Portugal (Alentejo)
[49]	Dehesa	Soil and trees	Western Spain
[73]	Pastures ecosystem	Soil, pasture, and floristic composition	Island
[74]	Crop Silvopastoral system	Soil, pasture, and grazing	Brazil

Table A1. *Cont.*

Reference	Production System	Component	Country/Region
[62]	Crop Silvopastoral system	Soil, pasture, and grazing	Brazil
[77]	Pastures ecosystem	Soil, pasture, and grazing	China
[69]	Crop-livestock systems	Soil, pasture, and irrigation	South–Portugal
[43]	Montado	Soil, pasture, and trees	Portugal (Alentejo)
[21]	Montado	Soil, ruminants, and pigs	Portugal (Alentejo)
[32]	Montado	Technologies and pastures	Portugal (Alentejo)
[118]	Montado	Technologies, pastures, and soil	Portugal (Alentejo)
[15]	Montado	Trees	Portugal–Ribatejo
[75]	Montado	Trees	Portugal (Alentejo)
[14]	Montado	Trees and pasture	Portugal (Alentejo)
[50]	Silvopastoralism	Trees, pasture, and grazing	New Zealand
[30]	Dehesa	Trees, pasture, and soil	Spain (Extremadura)
[67]	Montado	Trees, pasture, and soil	Portugal (Alentejo)
[12]	Wood pastures of Europe	Trees/forests	Europe

Table A2. Synthesis of the works cited in Section 3.

Reference	Technology/Sensor	General Application	Specific Application	Sensor Type	Country/Region
[96]	GNSS	Animal monitoring	Not applicable	Satellite	Australia
[91]	Remote sensing	Crops	Fertilizer and fungicide application	Portable and Satellite	USA
[94]	PA general	Crops	Not applicable	Not applicable	Review
[99]	RTK in GNSS	Crops	Altimetry	Portable	Brazil
[116]	Remote sensing	Crops	Management zones	Satellite	Argentina
[97]	RTK in GNSS	Crops	Operation crop weed control	Satellite and mobile	Italy
[8]	General sensors	Forage crops	Biomass production	Not applicable	Review
[95]	Total FOIF® modelo OTS685(L)	Forests	Altimetry	Satellite	Brazil
[100]	GNSS	Forests	Altimetry	Portable	Norway
[128]	Portable NIRS and benchtop NIRS	Meat	Meat Quality	Fixed and portable	Italy
[101]	NRTK	Olive grove	Altimetry	Portable	Spain
[56]	Spectroradiometer	Pasture	CP, ADF, NDF, ash, DCAD, lignin, lipd, ME, OMD	Portable	New Zealand
[7]	Multispectral radiometry	Pasture	CP, ADF, NDF, ash, DCAD, lignin, lipids, ME, OMD	Portable	New Zealand
[57]	Ultrasonic and Spectral Sensor	Pasture	Biomass production	Portable	Germany
[89]	PA general	Pasture	Productivity and quality	Portable and satellite	Review
[92]	Grassmaster II	Pasture	Biomass production	Portable	Portugal (Alentejo)
[43]	OptRx	Pasture	Ash, CP and NDF	Portable	Portugal (Alentejo)
[121]	Grassmaster II	Pasture	Biomass production	Portable	Portugal (Alentejo)
[108]	Infrared camera (ThermaCAM™)	Pasture	Temperature	Portable	Portugal (Alentejo)
[78]	Multispectral proximal sensors and digital cameras	Pasture	Productivity and quality	Fixed	Australia

Table A2. *Cont.*

Reference	Technology/Sensor	General Application	Specific Application	Sensor Type	Country/Region
[81]	OptRx and Grassmaster II	Pasture	Productivity and quality	Portable	Portugal
[84]	Capacitance Meter Probe	Pasture	Biomass production	Portable	USA
[85]	Not applicable	Pasture	Biomass production	Portable	USA
[86]	Sensor Fusion for PA	Pasture	Quality	Portable	Australia
[87]	Indirect methods—rising plate	Pasture	Biomass production	Portable	Brazil
[112]	Proximal Sensing	Pasture	Quality pasture	Portable	USA
[114]	Hyperspectral Remote Sensing	Pasture	Biomass production	Portable	China
[115]	Proximal Sensing	Pasture	Biomass production	Portable	Germany
[117]	Proximal and Remote Sensing	Pasture	DM, CP, and NDF	Satellite and portable	Portugal (Alentejo)
[122]	General evaluation methods	Pasture	Biomass production	Not applicable	Brazil
[123]	General evaluation methods	Pasture	Biomass production	Not applicable	Review
[124]	Capacitance Meter Probe	Pasture	Biomass production	Portable	USA
[125]	Capacitance Meter Probe	Pasture	Biomass production	Portable	USA
[83]	Benchtop NIRS	Pasture	CP, CF, NDF, ADF, ADL and Ash	Fixed	Italy
[66]	Portable NIRS	Pasture	CP and NDF	Portable	Portugal
[126]	Portable NIRS	Pasture	Prodution and quality	Portable	England
[127]	Benchtop NIRS	Pasture	DM, CP, NDF, Ash, EE, ADF, and ADL	Fixed	Italy
[111]	ASD ViewSpect®	Pasture	N, P, K, ADF, and NDF	Portable	Turkey
[120]	Pasture Probe™ V 4.3	Pasture	Biomass production	Portable	Finland
[110]	Proximal Sensing	Plants	Variations of photosynthesis	Portable	USA
[129]	Portable NIRS	Semolina	Quality	Portable	Italy
[6]	PA general	Soil	Variable-Rate Fertilization	Not applicable	Review
[79]	Veris 3100	Soil	Apparent electrical conductivity	Towable	Argentina
[98]	GPS	Soil	Altimetry	Portable	Brazil
[102]	Visible–Near-Infrared (vis–NIR)	Soil	Soil fertility	Fixed	Brazil
[104]	Veris	Soil	Apparent electrical conductivity	Towable	Spain
[105]	Not applicable	Soil	Apparent electrical conductivity	Not applicable	Brazil
[106]	RTK in GNSS and "Dualem 1S"	Soil	Apparent electrical conductivity	Towable and portable	Portugal (Alentejo)
[80]	Benchtop NIRS	Soil	OM and P	Fixed	Portugal (Alentejo)
[38]	RTK (GPS)	Soil	Altimetry and P	Portable	Portugal (Alentejo)
[109]	Veris 2000 XA and DUALEM 1S	Soil	Apparent electrical conductivity	Towable	Portugal (Alentejo)
[130]	Sensor Fusion for PA	Soil	Not applicable	Satellite, towable, and portable	USA
[103]	Electromagnetic induction sensor	Soil	Apparent electrical conductivity	Towable	Northern Europe

Table A2. *Cont.*

Reference	Technology/Sensor	General Application	Specific Application	Sensor Type	Country/Region
[131]	Veris 3100	Soil	Apparent electrical conductivity	Towable	Spain
[132]	Veris 3101	Soil	Apparent electrical conductivity	Towable	USA
[88]	PA general	Soil and pasture	Variability soil; Productivity and quality of pasture	Portable, fixed, and satellite	Review
[108]	VRT, Veris 2000 XA, and Trimble RTK/PP-4700 GPS	Soil and pasture	Apparent electrical conductivity, NDVI, and NDWI	Satellite, towable, and portable	Portugal (Alentejo)
[90]	PA general	Soil, crops, and pasture	Prodution and soil fertility	Not applicable	USA and Denmark
[107]	PA general	Soil, pastures, and animals	Not applicable	Not applicable	Review
[119]	Remote Sensing	Trees	Estimating tree canopy cover	Satellite	Portugal (Alentejo)
[93]	PA general	Not applicable	Not applicable	Not applicable	Review
[133]	PA general	Not applicable	Not applicable	Not applicable	Review

PA—Precision Agriculture; CP—crude protein; ADF—acid detergent fiber; NDF—neutral detergent fiber; DCAD—dietary cation–anion difference; ME—metabolizable energy; OMD—organic matter digestibility; OM—organic matter; P—phosphorus; DM—dry matter; CF—crude fiber; ADL—acid detergent lignin; EE—ether extract; N—nitrogen; K—potassium; GNSS—global navigation satellite systems; GPS—global position system; NIRS—near infrared spectroscopy; RTK—real-time kinematic; NRTK—network-based real-time kinematic.

Table A3. Synthesis of the works cited in Section 4.

Reference	Grazing Species	Evaluated Parameters	Grazing Type	Stocking Rates	Country/Region
[134]	Cattle	Floristic composition	Continuous vs. Seasonal	Moderate, heavy, and very heavy	Israel
[135]	Not applicable	Not applicable	Not applicable	Not applicable	Review
[58]	Not applicable	Not applicable	Continuous vs. Deferred	Not applicable	France
[25]	Not applicable	Not applicable	Rotational	Not applicable	
[60]	Cattle, Goat, Sheep	Floristic composition	Deferred only with diurnal grazing	Moderate (7 sheep/ha)	China
[11]	Cattle, Goat, Sheep, and Pig	Not applicable	Continuous and intermittent	Equivalent to 1 to 7 sheep/ha	Portugal
[54]	Cattle and Sheep	CP, ADF, NDF, Ash, ME, and DM	Rotational	Not applicable	New Zealand
[54]	Cattle and Sheep	Floristic composition	Rotational	Not applicable	New Zealand
[5]	Cattle	Soil chemical properties	Deferred	Intensive, moderate, and no-grazing	Brazil
[138]	Not applicable	pH soil	Not applicable	Not applicable	Australia
[77]	Cattle, Goat, Sheep	Metane emission and sequester	Deferred	Light, moderate, and heavy	China
[72]	Sheep	Metane emission and sequester	Not applicable	Light, moderate, and heavy	China
[139]	Sheep	Methane uptake	Deferred only with diurnal grazing	4 to 5 sheep/ha	China
[136]	Not applicable	Behavior of grazing	Not applicable	Not applicable	Review
[62]	Cattle	Pasture height	Deferred	Not applicable	Brazil
[159]	Cattle, Goat, Sheep, and Pig	Stakeholder survey	Not applicable	Not applicable	Spain (Extremadura)

Table A3. *Cont.*

Reference	Grazing Species	Evaluated Parameters	Grazing Type	Stocking Rates	Country/Region
[160]	Sheep	DM, CP, EE, Ash, NDF, ADF, and ADL	Continuous and Rotational	Not applicable	Italy
[144]	Not applicable	Not applicable	Deferred, Continuous, and Rotational	Not applicable	Review
[140]	Not applicable	Not applicable	General grazing systems	Not applicable	Not applicable
[64]	Yak	N, ADF, CF, ME, and DM; LWG	Continuous only with diurnal grazing	0.75, 1, and 1.25 yak/ha	Tibetan Plateau
[141]	Not applicable	Not applicable	Sustainable grazing systems	Not applicable	Review
[142]	Cattle	Floristic composition	Continuous and Rotational	Moderately heavily	USA
[143]	Sheep	Floristic composition	Continuous	14 to 21 sheep/ha	Portugal (central region)
[1]	Sheep	Floristic composition	Continuous and Deferred	7 sheep/ha vs. 16 sheep/ha	Portugal (Alentejo)
[145]	Cattle	Floristic composition and Behavior	Continuous	0.8 cattle/ha	Italy
[146]	Sheep	Pasture selectivity and height	Continuous and Deferred	28 sheep/ha	Brazil
[147]	Sheep	DM, CP, NDF, ADF, ADL, LWG, and Digestibility	Continuous and Deferred	0, 6.7, and 9.3 sheep/ha	China
[148]	Sheep	LWG	Continuous and Deferred	1.5, 3, 4.5, 6, 7.5, and 9 sheep/ha	China
[149]	Cattle	DMD, CP, height, and Intake	Not applicable	Not applicable	Japan
[152]	Not applicable	Not applicable	Not applicable	Not applicable	Review
[59]	Sheep	CP, CPI, DM, DMI, ADF, NDF, EE, and Behavior	Continuous	8 sheep/ha and 16 sheep/ha	China
[61]	Cattle	DM, Height, Short-term intake rate	Short-term intake	Not applicable	Brazil
[74]	Not applicable	Not applicable	Not applicable	Not applicable	Brazil (Review)
[141]	Not applicable	Not applicable	Not applicable	Not applicable	Review
[33]	Sheep	LWG and wool prodution	Rotational	7 sheep/ha	Australia
[153]	Not applicable	Not applicable	Not applicable	Not applicable	Review (Montado)
[151]	Not applicable	Not applicable	Not applicable	Not applicable	Review
[155]	Not applicable	Not applicable	Not applicable	Not applicable	Review
[156]	Cattle and Sheep	Height and floristic composition	Not applicable	Not applicable	Portugal (Alentejo)
[157]	Cattle and Sheep	Not applicable	Continuous vs. Specialized	Not applicable	Review
[158]	Sheep	Soil moisture and floristic composition	No-grazing, Continuous, and Deferred	Not applicable	Australia
[137]	Cattle	LWG, Digestibility, and Excretions	Continuous	Moderate and Low	England
[150]	Sheep	Behavior of Grazing and OMI	Continuous	2, 3, 4, 6, 8, and 11 sheep/ha	China

CP—crude protein; ADF—acid detergent fiber; NDF—neutral detergent fiber; ME—metabolizable energy; OMI—organic matter intake; DM—dry matter; CF—crude fiber; ADL—acid detergent lignin; EE—ether extract; N—nitrogen; LWG—live weight gain; DMD—dry matter digestibility; CPI—crude protein intake; DMI—dry matter intake.

References

1. Carreira, E.; Serrano, J.; Gomes, C.J.P.; Shahidian, S.; Paniagua, L.L.; Pilirito, A.; Lopes Castro, J.; Carvalho, M.; Pereira, A.F. Effect of Sheep Grazing, Stocking Rates and Dolomitic Limestone Application on the Floristic Composition of a Permanent Dryland Pasture, in the Montado Agroforestry System of Southern Portugal. *Animals* **2022**, *12*, 2506. [CrossRef] [PubMed]
2. Serrano, J.; Shahidian, S.; Da Silva, J.M.; Paixão, L.; Carreira, E.; Pereira, A.; Carvalho, M. Climate changes challenges to the management of Mediterranean Montado ecosystem: Perspectives for use of precision agriculture technologies. *Agronomy* **2020**, *10*, 218. [CrossRef]
3. Feio, M. *Clima e Agricultura: Exigências Climáticas das Principais Culturas e Potencialidade Agrícolas do Nosso Clima*; Ministério da Agricultura, Pescas e Alimentação: Lisboa, Portugal, 1991; ISBN 972-9175-25-X.
4. Serrano, J. Utilização eficiente dos recursos no Montado: Sensores próximos e detecção remota no apoio à tomada de decisão. *Perspetiva* **2019**, *2020*, 18–25.
5. Martins, A.P.; Cecagno, D.; Borin, J.B.M.; Arnuti, F.; Lochmann, S.H.; Anghinoni, I.; Bissani, C.A.; Bayer, C.; Carvalho, P.C.F. Long-, medium- and short-term dynamics of soil acidity in an integrated crop–livestock system under different grazing intensities. *Nutr. Cycl. Agroecosyst.* **2016**, *104*, 67–77. [CrossRef]
6. Nawar, S.; Corstanje, R.; Halcro, G.; Mulla, D.; Mouazen, A.M. Delineation of Soil Management Zones for Variable-Rate Fertilization: A Review. In *Advances in Agronomy*, 1st ed.; Elsevier Inc.: Amsterdam, The Netherlands, 2017; Volume 143. [CrossRef]
7. Pullanagari, R.R.; Yule, I.J.; Tuohy, M.P.; Hedley, M.J.; Dynes, R.A.; King, W.M. Proximal sensing of the seasonal variability of pasture nutritive value using multispectral radiometry. *Grass Forage Sci.* **2013**, *68*, 110–119. [CrossRef]
8. Gebremedhin, A.; Badenhorst, P.E.; Wang, J.; Spangenberg, G.C.; Smith, K.F. Prospects for measurement of dry matter yield in forage breeding programs using sensor technologies. *Agronomy* **2019**, *9*, 65. [CrossRef]
9. Batista, T.; Mascarenhas, J.M.; Mendes, P. Montado's ecosystem functions and services: The case study of Alentejo Central-Portugal. *Probl. Landsc. Ecol.* **2017**, *XLIV*, 15–27.
10. Reis, D.G.; Calafate, L.C. Os montados—Conciliação entre Homem e Natureza. *Captar* **2013**, *4*, 13–26.
11. Pinto-Correia, T.; Ribeiro, N.; Potes, J. *Livro Verde dos Montados*; Instituto de Ciências Agrárias e Ambientais Mediterrânicas—Universidade de Évora: Nossa Senhora da Tourega, Portugal, 2013; Available online: http://www.icaam.uevora.pt/Noticias-e-Informacoes/Temas-e-Eventos-Arquivo/Livro-Verde-dos-Montados (accessed on 12 May 2023).
12. Plieninger, T.; Hartel, T.; Martín-López, B.; Beaufoy, G.; Bergmeier, E.; Kirby, K.; Montero, M.J.; Moreno, G.; Oteros-Rozas, E.; Van Uytvanck, J. Wood-pastures of Europe: Geographic coverage, social-ecological values, conservation management, and policy implications. *Biol. Conserv.* **2015**, *190*, 70–79. [CrossRef]
13. Horrillo, A.; Escribano, M.; Mesias, F.J.; Elghannam, A.; Gaspar, P. Is there a future for organic production in high ecological value ecosystems? *Agric. Syst.* **2016**, *143*, 114–125. [CrossRef]
14. Paço, T.A.; David, T.S.; Henriques, M.O.; Pereira, J.S.; Valente, F.; Banza, J.; Pereira, F.L.; Pinto, C.; David, J.S. Evapotranspiration from a Mediterranean evergreen oak savannah: The role of trees and pasture. *J. Hydrol.* **2009**, *369*, 98–106. [CrossRef]
15. David, T.S.; Pinto, C.A.; Nadezhdina, N.; Kurz-Besson, C.; Henriques, M.O.; Quilhó, T.; Cermak, J.; Chaves, M.M.; Pereira, J.S.; David, J.S. Root functioning, tree water use and hydraulic redistribution in Quercus suber trees: A modeling approach based on root sap flow. *For. Ecol. Manag.* **2013**, *307*, 136–146. [CrossRef]
16. Guimarães, M.; Pinto-Correia, T.; de Belém Costa Freitas, M.; Ferraz-de-Oliveira, I.; Sales-Baptista, E.; da Veiga, J.F.F.; Tiago Marques, J.; Pinto-Cruz, C.; Godinho, C.; Belo, A.D.F. Farming for nature in the Montado: The application of ecosystem services in a results-based model. *Ecosyst. Serv.* **2023**, 61. [CrossRef]
17. Ferreira, D.B. Evolução da paisagem de montado no Alentejo interior ao longo do século XX: Dinâmica e incidências ambientais. *Finisterra* **2001**, *36*, 179–193. [CrossRef]
18. Oliveira, A.R.; Durão, A.; Carvalho, F. Biodiversidade da raça suína autóctone portuguesa porco alentejano (Sus ibericus). *Rev. Int. Em Língua Port.* **2019**, *35*, 151–166. [CrossRef]
19. Fonseca, A. *O Montado no Alentejo: (Séculos XV a XVIII)*; Edições Colibri: Lisboa, Portugal, 2004; ISBN 972-772-505-8.
20. Natividade, J.V. *Subericultura*; Direção Geral dos Serviços Florestais e Aquícolas: Lisboa, Portugal, 1950.
21. Belo, C.C.; Coelho, I.; Rolo, J.; Reis, P. Sistemas agroflorestais em Portugal continental. *Parte II: Montados, condições de uso do solo e evolução. Rev. de Ciências Agrárias* **2014**, *37*, 122–130.
22. Calado, J.; Basch, G.; de Carvalho, M. Appearance of spontaneous plants from disturbed and undisturbed soil under mediterranean conditions. *Rev. de Ciências Agrárias* **2008**, *31*, 68–78. Available online: http://www.scielo.oces.mctes.pt/scielo.php?pid=S0871-018X2008000200008&script=sci_arttext (accessed on 12 May 2023).
23. Dyer, W.E. Exploiting Weed Seed Dormancy and Germination Requirements through Agronomic Practices. *Weed Sci.* **1995**, *43*, 498–503. [CrossRef]
24. Locke, M.A.; Reddy, K.N.; Zablotowicz, R.M. Weed management in conservation crop production systems. *Weed Biol. Manag.* **2002**, *2*, 123–132. [CrossRef]
25. Beetz, A.E.; Rinehart, L. Rotational grazing. In *Encyclopedic Dictionary of Landscape and Urban Planning*; Springer: Berlin/Heidelberg, Germany, 2010; p. 857. [CrossRef]

26. Joffre, R.; Rambal, S.; Ratte, J.P. The dehesa system of southern Spain and Portugal as a natural ecosystem mimic. *Agrofor. Syst.* **1999**, *45*, 57–79. [CrossRef]
27. Potes, J.M. *O Montado no Portugal Mediterrânico*; Edições Colibri: Lisboa, Portugal, 2011; 193p.
28. Plieninger, T.; Wilbrand, C. Land use, biodiversity conservation, and rural development in the dehesas of Cuatro Lugares, Spain. *Agrofor. Syst.* **2001**, *51*, 23–34. [CrossRef]
29. Moreira, N. *Agronomia das Forragens e Pastagens*; Sector Editorial; Universidade de Trás-os-Montes e Alto Douro: Vila Real, Portugal, 2002; 183p.
30. Marcos, G.; Obrador, J.; García, E.; Cubera, E.; Montero, M.; Pulido, F.; Dupraz, C. Driving competitive and facilitative interactions in oak dehesas through management practices. *Agrofor. Syst.* **2007**, *70*, 25–40. [CrossRef]
31. IPMA. Instituto Português do Mar e da Atmosfera. 2023. Available online: https://www.ipma.pt/ (accessed on 27 February 2023).
32. Serrano, J.; Shahidian, S.; Machado, E.; Paniagua, L.L.; Carreira, E.; Moral, F.; Pereira, A.; de Carvalho, M. Floristic composition: Dynamic biodiversity indicator of tree canopy effect on dryland and improved mediterranean pastures. *Agriculture* **2021**, *11*, 1128. [CrossRef]
33. Norman, H.C.; Wilmot, M.G.; Thomas, D.T.; Barrett-Lennard, E.G.; Masters, D.G. Sheep production, plant growth and nutritive value of a saltbush-based pasture system subject to rotational grazing or set stocking. *Small Rumin. Res.* **2010**, *91*, 103–109. [CrossRef]
34. Miranda, P.M.A.; Valente, M.A.; Tomé, A.R.; Trigo, R.; Coelho, M.F.E.S.; Aguiar, A.; Azevedo, E.B. O Clima de Portugal nos Séculos XX e XXI The Portuguese Climate in the 20th and 21st Centuries. Alterações Climáticas Em Portugal. Cenários, Impactos e Medidas de Adaptação. Projecto SIAM II. Ph.D. Thesis, Universidade dos Açores, Ponta Delgada, Portugal, January 2006; pp. 1–89.
35. Evangelista, A.; Frate, L.; Carranza, M.L.; Attorre, F.; Pelino, G.; Stanisci, A. Changes in composition, ecology and structure of high-mountain vegetation: A re-visitation study over 42 years. *AoB Plants* **2016**, *8*, 1–11. [CrossRef]
36. Valverde, P.; Serralheiro, R.; De Carvalho, M.; Shahidian, S.; Rodrigues, C. Efeitos das alterações climáticas nas necessidades úteis de rega na bacia do Guadiana. *Rev. Recur. Hídricos* **2014**, *35*, 53–67. [CrossRef]
37. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014, International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; Update 2015; World Soil Resources Report 106; Food and Agriculture Organization (FAO): Rome, Italy, 2015; 188p.
38. Serrano, J.M.; Peça, J.O.; da Silva, J.R.M.; Shahidian, S.; Carvalho, M. Phosphorus dynamics in permanent pastures: Differential fertilizing and the animal effect. *Nutr. Cycl. Agroecosyst.* **2011**, *90*, 63–74. [CrossRef]
39. Serrano, J.M.; Shahidian, S.; Marques da Silva, J.R. Small scale soil variation and its effect on pasture yield in southern Portugal. *Geoderma* **2013**, *195–196*, 173–183. [CrossRef]
40. Cardoso, J.C. Os solos de Portugal. Sua classificação, caracterização e génese. In *1—A Sul do Tejo. Secretaria de Estado da Agricultura*; Direcção Geral dos Serviços Agrícolas: Lisboa, Portugal, 1965.
41. Carvalho, M.; Goss, M.J.; Teixeira, D. Manganese toxicity in Portuguese Cambisols derived from granitic rocks: Causes, limitations of soil analyses and possible solutions Toxicidade de manganês nos Cambissolos derivados de rochas graníticas em Portugal: Causas, limitações das análises de solo. *Rev. de Ciências Agrárias* **2015**, *38*, 518–527. Available online: https://revistas.rcaap.pt/rca/article/download/16339/13306/53722 (accessed on 12 May 2023). [CrossRef]
42. Moreno, G.; Obrador, J.J.; García, A. Impact of evergreen oaks on soil fertility and crop production in intercropped dehesas. *Agric. Ecosyst. Environ.* **2007**, *119*, 270–280. [CrossRef]
43. Serrano, J.; Shahidian, S.; Da Silva, J.M.; Sales-Baptista, E.; De Oliveira, I.F.; De Castro, J.L.; Pereira, A.; De Abreu, M.C.; Machado, E.; de Carvalho, M. Tree influence on soil and pasture: Contribution of proximal sensing to pasture productivity and quality estimation in montado ecosystems. *Int. J. Remote Sens.* **2017**, *39*, 4801–4829. [CrossRef]
44. Haynes, R.J.; Williams, P.H. Nutrient Cycling and soil fertility in grazed pature ecosystem. *Adv. Agron.* **1993**, *49*, 119–199.
45. Belo, C.C.; Pereira, M.S.; Moreira, A.C.; Coelho, I.S.; Onofre, N.; Paulo, A. Montado—Ecossistemas e Bem-Estar Humano em Portugal. *Montado* **2009**, 251–293. Available online: http://repositorio.ipsantarem.pt/handle/10400.15/604 (accessed on 12 May 2023).
46. Capelo, J.; Catry, F.; Silva, J.S. Biologia, ecologia e distribuição da azinheira. In *Árvores e Florestas de Portugal. Os Montados—Muito Para Além das Árvores*; Silva, J.S., Ed.; Público/FLAD/LPN: Lisboa, Portugal, 2007; pp. 119–129.
47. Corona ME, P.; Ciudade, G.A.; Criado, B.G.; Aldana, B.V. Patterns of aboveground herbage prodution and nutritional quality structure on semiarid grasslands. *Commun. Soil Sci. Plant Anal.* **1995**, *26*, 1323–1341. [CrossRef]
48. Gallardo, A.; Rodríguez-Saucedo, J.J.; Covelo, F.; Fernández-Alés, R. Soil nitrogen heterogeneity in a Dehesa ecosystem. *Plant Soil* **2000**, *222*, 71–82. [CrossRef]
49. Cubera, E.; Morena, G. Effect of single Quercus ilex trees upon spatial and seasonal changes in soil water content in dehesas of central western Spain. *Ann. For. Sci.* **2007**, *64*, 355–364. [CrossRef]
50. Benavides, R.; Douglas, G.B.; Osoro, K. Silvopastoralism in New Zealand: Review of effects of evergreen and deciduous trees on pasture dynamics. *Agrofor. Syst.* **2009**, *76*, 327–350. [CrossRef]
51. Hussain, Z.; Kemp, P.D.; Horne, D.J.; Jaya, I.K.D. Pasture production under densely planted young willow and poplar in a silvopastoral system. *Agrofor. Syst.* **2009**, *76*, 351–362. [CrossRef]

52. Peri, P.L.; Lucas, R.J.; Moot, D.J. Dry matter production, morphology and nutritive value of Dactylis glomerata growing under different light regimes. *Agrofor. Syst.* **2007**, *70*, 63–79. [CrossRef]
53. Serrano, J.; Roma, L.; Shahidian, S.; Belo, A.D.F.; Carreira, E.; Paniagua, L.L.; Moral, F.; Paixão, L.; Marques da Silva, J. A Technological Approach to Support Extensive Livestock Management in the Portuguese Montado Ecosystem. *Agronomy* **2022**, *12*, 1212. [CrossRef]
54. Guevara-Escobar, A.; Kemp, P.D.; Mackay, A.D.; Hodgson, J. Pasture production and composition under poplar in a hill environment in New Zealand. *Agrofor. Syst.* **2007**, *69*, 199–213. [CrossRef]
55. Peri, P.L.; Varella, A.C.; Lucas, R.J.; Moot, D.J. Cocksfoot and lucerne productivity in a Pinus radiata silvopastoral system: A grazed comparison. *Proc. N. Z. Grassl. Assoc.* **2001**, 139–147. [CrossRef]
56. Pullanagari, R.R.; Yule, I.J.; Tuohy, M.P.; Hedley, M.J.; Dynes, R.A.; King, W.M. In-field hyperspectral proximal sensing for estimating quality parameters of mixed pasture. *Precis. Agric.* **2012**, *13*, 351–369. [CrossRef]
57. Moeckel, T.; Safari, H.; Reddersen, B.; Fricke, T.; Wachendorf, M. Fusion of ultrasonic and spectral sensor data for improving the estimation of biomass in grasslands with heterogeneous sward structure. *Remote Sens.* **2017**, *9*, 98. [CrossRef]
58. Voisin, A.; Lecomte, A. *La Vaca y la Hierba: Cómo Obtener Buenos Rendimientos del Ganado Vacuno*; Editorial Tecnos: Madrid, Spain, 1968.
59. Xiao, X.; Zhang, T.; Angerer, J.P.; Hou, F. Grazing seasons and stocking rates affects the relationship between herbage traits of alpine meadow and grazing behaviors of tibetan sheep in the Qinghai–Tibetan plateau. *Animals* **2020**, *10*, 488. [CrossRef] [PubMed]
60. Zhu, H.; Wang, D.; Wang, L.; Bai, Y.; Fang, J.; Liu, J. The effects of large herbivore grazing on meadow steppe plant and insect diversity. *J. Appl. Ecol.* **2012**, *49*, 1075–1083. [CrossRef]
61. Fonseca, L.; Mezzalira, J.; Bremm, C.; Filho, R.; Gonda, H.; Carvalho, P.C.F. Management targets for maximising the short-term herbage intake rate of cattle grazing in Sorghum bicolor. *Livest. Sci.* **2012**, *145*, 205–211. [CrossRef]
62. Barriga, P.A.B. Produção de Novilhos em Pastagem de Inverno Com Diferentes Intensidades de Pastejo e Adubação Nitrogenada em Integração Lavoura-Pecuária. Tese de Doutoramento. Ph.D. Thesis, Universidade Tecnológica Federal do Paraná, Câmpus Pato Branco, Pato Branco, Brazil, 2019.
63. Lambert, M.G.; Litherland, A.J. A practitioner's guide to pasture quality. *Proc. N. Z. Grassl. Assoc.* **2000**, *115*, 111–115. [CrossRef]
64. Miao, F.; Guo, Z.; Xue, R.; Wang, X.; Shen, Y. Effects of grazing and precipitation on herbage biomass, herbage nutritive value, and yak performance in an alpine meadow on the Qinghai-Tibetan Plateau. *PLoS ONE* **2015**, *10*, e0127275. [CrossRef]
65. Efe Serrano, J. *Pastures in Alentejo: Technical Basis for Characterization, Grazing and Improvement*; Universidade de Évora—ICAM, Ed.; Gráfica Eborense: Évora, Portugal, 2006; pp. 165–178.
66. Carreira, E.; Serrano, J.; Shahidian, S.; Nogales-Bueno, J.; Rato, A.E. Real-time quantification of crude protein and neutral detergent fibre in pastures under montado ecosystem using the portable nir spectrometer. *Appl. Sci.* **2021**, *11*, 10638. [CrossRef]
67. Serrano, J.; Shahidian, S.; Costa, F.; Carreira, E.; Pereira, A.; Carvalho, M. Can soil ph correction reduce the animal supplementation needs in the critical autumn period in mediterranean montado ecosystem? *Agronomy* **2021**, *11*, 514. [CrossRef]
68. Daniels, M.B.; Delaune, P.; Moore, P.A.; Mauromoustakos, A.; Chapman, S.L.; Langston, J.M. Soil Phosphorus Variability in Pastures: Implications for Sampling and Environmental Management Strategies. *J. Environ. Qual.* **2001**, *30*, 2157–2165. [CrossRef] [PubMed]
69. Carvalho, M. A Seca e a Intensificação Sustentável dos Sistemas Agro-Pecuários: Desafios e Soluções. Dossier Secas e Cheias: Como gerir? *Indústria e Ambiente 110 Maio/Junho.* 2018. Available online: https://rdpc.uevora.pt/bitstream/10174/23541/1/M%C3%A1rio%20Carvalho%202018.pdf (accessed on 12 May 2023).
70. Di, H.J.; Cameron, K.C. Nitrate leaching in temperate agroecosystems: Sources, factors and mitigating strategies. *Nutr. Cycl. Agroecosyst.* **2002**, *64*, 237–256. [CrossRef]
71. Crespo, D. Em tempos de crise qual o papel das pastagens e forragens no desenvolvimento da agricultura. *Agrotec Rev. Técnico—Científica* **2011**, *1*, 30–32.
72. Tang, S.; Zhang, Y.; Zhai, X.; Wilkes, A.; Wang, C.; Wang, K. Efect of grazing on methane up take from Eurasian steppe of China. *BMC Ecol.* **2018**, *18*, 11. [CrossRef] [PubMed]
73. Matthew, C.; Tillman, R.W.; Hedley, M.J.; Thompson, M.C. Observations on the Relationship Between Soil Fertility, Pasture Botanical Composition, and Pasture Growth Rate; for a North Island Lowland Pasture. *Proc. N. Z. Grassl. Assoc.* **1988**, *144*, 141–144. [CrossRef]
74. Moraes, A.; de Faccio Carvalho, P.C.; Anghinoni, I.; Lustosa, S.B.C.; de Andrade Costa, S.E.V.G.; Kunrath, T.R. Integrated crop-livestock systems in the Brazilian subtropics. *Eur. J. Agron.* **2014**, *57*, 4–9. [CrossRef]
75. Rêgo, F.C.; Vasco, I.; Carvalho, J.; Bugalho, M.; Morgado, Â.; Silva, L.N. *Sobreiro—Uma barreira contra a desertificação*; Report in partnership by the Center for Applied Ecology Baeta Neves of the Higher Institute of Agronomy, Lisbon, Portugal and the WWF Mediterranean Program Via Po, 25c Rome, Italy; WWF: Gland, Switzerland, 2008; 20p.
76. Wang, Z.P.; Song, Y.; Gulledge, J.; Yu, Q.; Liu, H.S.; Han, X.G. China's grazed temperate grasslands are a net source of atmospheric methane. *Atmos. Environ.* **2009**, *43*, 2148–2153. [CrossRef]

77. Wang, C.; Han, G.; Wang, S.; Zhai, X.; Brown, J.; Havstad, K.M.; Ma, X.; Wilkes, A.; Zhao, M.; Tang, S.; et al. Sound management may sequester methane in grazed rangeland ecosystems. *Sci. Rep.* **2014**, *4*, 4444. [CrossRef]
78. Handcock, R.N.; Gobbett, D.L.; González, L.A.; Bishop-Hurley, G.J.; McGavin, S.L. A pilot project combining multispectral proximal sensors and digital cameras for monitoring tropical pastures. *Biogeosciences* **2016**, *13*, 4673–4695. [CrossRef]
79. Peralta, N.R.; Costa, J.L. Delineation of management zones with soil apparent electrical conductivity to improve nutrient management. *Comput. Electron. Agric.* **2013**, *99*, 218–226. [CrossRef]
80. Serrano, J.; Shahidian, S.; Marques da Silva, J.; Paixão, L.; de Carvalho, M.; Moral, F.; Nogales-Bueno, J.; Teixeira, R.F.M.; Jongen, M.; Domingos, T.; et al. Evaluation of Near Infrared Spectroscopy (NIRS) for Estimating Soil Organic Matter and Phosphorus in Mediterranean Montado Ecosystem. *Sustainability* **2021**, *13*, 2734. [CrossRef]
81. Serrano, J.M.; Shahidian, S.; Marques da Silva, J.R. Monitoring pasture variability: Optical OptRx® crop sensor versus Grassmaster II capacitance probe. *Environ. Monit. Assess.* **2016**, *188*, 1–17. [CrossRef] [PubMed]
82. AOAC Official Method. *Official Methods of Analysis of AOAC International*, 18th ed.; AOAC International: Arlington, VA, USA, 2005.
83. Danieli, P.P.; Carlini, P.; Bernabucci, U.; Ronchi, B. Quality evaluation of regional forage resources by means of near infrared reflectance spectroscopy. *Ital. J. Anim. Sci.* **2004**, *3*, 363–376. [CrossRef]
84. Currie, P.O.; Hilken, T.O.; White, R.S. Evaluation of a Single Probe Capacitance Meter for Estimating Herbage Yield. *J. Range Manag.* **1987**, *40*, 537. [CrossRef]
85. Higgins, K.F.; Jenkins, K.J.; Clambey, G.K.; Uresk, D.W.; Naugle, D.E.; Klaver, R.W.; Norland, J.E.; Jensen, K.C.; Barker, W.T. *Vegetation Sampling and Measurement*; Iowa State University: Ames, IA, USA, 2012.
86. Gobbett, D.L.; Handcock, R.N.; Zerger, A.; Crossman, C.; Valencia, P.; Wark, T.; Davies, M. Prototyping an operational system with multiple sensors for pasture monitoring. *J. Sens. Actuator Netw.* **2013**, *2*, 388–408. [CrossRef]
87. Cunha, W.F. Métodos Indiretos para Estimativas de Massa de Forragem em Pastagens de *Cynodon* spp. Master's Thesis, Universidade de São Paulo, São Paulo, Brazil, 2002.
88. Zhang, N.; Wang, M.; Wang, N. Precision agriculture—A worldwide overview. *Comput. Electron. Agric.* **2002**, *36*, 113–132. [CrossRef]
89. Schellberg, J.; Hill, M.J.; Gerhards, R.; Rothmund, M.; Braun, M. Precision agriculture on grassland: Applications, perspectives and constraints. *Eur. J. Agron.* **2008**, *29*, 59–71. [CrossRef]
90. Fountas, S.; Blackmore, S.; Ess, D.; Hawkins, S.; Blumhoff, G.; Lowenberg-Deboer, J.; Sorensen, C.G. Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt. *Precis. Agric.* **2005**, *6*, 121–141. [CrossRef]
91. Seelan, S.K.; Laguette, S.; Casady, G.M.; Seielstad, G.A. Remote sensing applications for precision agriculture: A learning community approach. *Remote Sens. Environ.* **2003**, *88*, 157–169. [CrossRef]
92. Serrano, J.M.; Peça, J.; Palma, P.; Silva, J.R.; Carvalho, M. Calibração e validação de um medidor de capacitância num projecto de agricultura de precisão em pastagens. *Rev. de Ciências Agrárias* **2009**, *32*, 85–96.
93. Pierpaoli, E.; Carli, G.; Pignatti, E.; Canavari, M. Drivers of Precision Agriculture Technologies Adoption: A Literature Review. *Procedia Technol.* **2013**, *8*, 61–69. [CrossRef]
94. Tschiedel, M.; Ferreira, M.F. Introdução À Agricultura De Precisão: Conceitos E Vantagens. *Ciência Rural* **2002**, *32*, 159–163. [CrossRef]
95. Novachaelley, A.J. Avaliação de Coordenadas Planimétricas e Altimétricas Com Uso de Estação Total e Receptores Gnss No Interior de Florestas. Bachelor's Thesis, Universidade Tecnológica Federal do Paraná—UTFPR—Dois Vizinhos, Curitiba, Brazil, 2013.
96. Janssen, V. GNSS-Based Animal Tracking: An Indirect Approach. In Proceedings of the 18th Association of Public Authority Surveyors Conference (APAS2013), Canberra, Australia, 12–14 March 2013.
97. Marucci, A.; Colantoni, A.; Zambon, I.; Egidi, G. Precision farming in hilly areas: The use of network RTK in GNSS technology. *Agriculture* **2017**, *7*, 60. [CrossRef]
98. Cremonini, L.C.M. DGPS na Colheita de Cereiais no Estado de São Paulo. Master's Thesis, Agronomy, Area of Concentration: Agricultural Machines, São Paulo, Brazil, 2002.
99. Rabelo, M.W.O.; Griebeler, N.P.; Nazareno, N.R.X. Quality of altimetric surveys in sugarcane agricultural lands performed with GNSS RTK receiver mounted on an all-terrain vehicle. *Appl. Geomat.* **2019**, *11*, 111–119. [CrossRef]
100. Hauglin, M.; Hansen, E.H.; Næsset, E.; Busterud, B.E.; Gjevestad, J.G.O.; Gobakken, T. Accurate single-tree positions from a harvester: A test of two global satellite-based positioning systems. *Scand. J. For. Res.* **2017**, *32*, 774–781. [CrossRef]
101. Garrido, M.S.; de Lacy, M.C.; Ramos, M.I.; Borque, M.J.; Susi, M. Assessing the accuracy of NRTK altimetric positioning for precision agriculture: Test results in an olive grove environment in Southeast Spain. *Precis. Agric.* **2019**, *20*, 461–476. [CrossRef]
102. Rossel, R.A.V.; Rizzo, R.; Demattê, J.A.M.; Behrens, T. Spatial Modeling of a Soil Fertility Index using Visible-Near-Infrared Spectra and Terrain Attributes. *Soil Sci. Soc. Am. J.* **2010**, *74*, 1293–1300. [CrossRef]
103. Meirvenne, M.; Islam, M.M.; De Smedt, P.; Meerschman, E.; Van De Vijver, E.; Saey, T. Key variables for the identification of soil management classes in the aeolian landscapes of north-west Europe. *Geoderma* **2013**, *199*, 99–105. [CrossRef]

104. Dafonte, J.D. Sensores basados en la medida de la conductividad eléctrica para evaluar las propriedades del suelo y su aplicación en agricultura de precisión. In Proceedings of the II Jornadas sobre Agricultura de Precisión, A Coruna, Spain, 15–17 July 2004; pp. 56–63. (In Spanish).
105. Netto, A.D.O.A.; Gomes, C.C.S.; Lins, C.C.V.; Barros, A.C.; Campeche, L.F.D.S.M.; Blanco, F.F. Características químicas e salino-sodicidade dos solos do Perímetro Irrigado Califórnia, SE, Brasil. *Cienc. Rural* **2007**, *37*, 1640–1645. [CrossRef]
106. Serrano, J.M.; Peça, J.O.; Marques da Silva, J.R.; Shaidian, S. Mapping soil and pasture variability with an electromagnetic induction sensor. *Comput. Electron. Agric.* **2010**, *73*, 7–16. [CrossRef]
107. Trotter, M. Precision agriculture for pasture, rangeland and livestock systems. In Proceedings of the 15th Australian Gronomy Conference Food Security from Sustainable Agriculture, Lincoln, New Zealand, 15–18 November 2010; pp. 248–253.
108. Serrano, J.; Shahidian, S.; da Silva, J.M.; Paixão, L.; Calado, J.; de Carvalho, M. Integration of Soil Electrical Conductivity and Indices Obtained through Satellite Imagery for Differential Management of Pasture Fertilization. *AgriEngineering* **2019**, *1*, 567–585. [CrossRef]
109. Serrano, J.; Shahidian, S.; da Silva, J.M. Spatial and temporal patterns of apparent electrical conductivity: DUALEM vs. Veris sensors for monitoring soil properties. *Sensors* **2014**, *14*, 10024–10041. [CrossRef] [PubMed]
110. Rascher, U.; Pieruschka, R. Spatio-temporal variations of photosynthesis: The potential of optical remote sensing to better understand and scale light use efficiency and stresses of plant ecosystems. *Precis. Agric.* **2008**, *9*, 355–366. [CrossRef]
111. Albayrak, S. Use of reflectance measurements for the detection of N, P, K, ADF and NDF contents in sainfoin pasture. *Sensors* **2008**, *8*, 7275–7286. [CrossRef]
112. Qi, J.; Chehbouni, A.; Huete, A.R.; Kerr, Y.H.; Sorooshian, S. A modified soil adjusted vegetation index. *Remote Sens. Environ.* **1994**, *48*, 119–126. [CrossRef]
113. Batista, A.C. Detecção de incêndios florestais por satélites. *Floresta* **2004**, *34*, 237–241. [CrossRef]
114. Wang, X.; Guo, N.; Zhang, K.; Wang, J. Hyperspectral remote sensing estimation models of aboveground biomass in Gannan rangelands. *Procedia Environ. Sci.* **2011**, *10 Pt A*, 697–702. [CrossRef]
115. Fricke, T.; Wachendorf, M. Combining ultrasonic sward height and spectral signatures to assess the biomass of legume-grass swards. *Comput. Electron. Agric.* **2013**, *99*, 236–247. [CrossRef]
116. Cicore, P.; Serrano, J.; Shahidian, S.; Sousa, A.; Costa, J.L.; da Silva, J.R.M. Assessment of the spatial variability in tall wheatgrass forage using LANDSAT 8 satellite imagery to delineate potential management zones. *Environ. Monit. Assess.* **2016**, *188*, 513. [CrossRef]
117. Serrano, J.; Shahidian, S.; Marques da Silva, J. Monitoring Seasonal Pasture Quality Degradation in the Mediterranean Montado Ecosystem: Proximal versus Remote Sensing. *Water* **2018**, *10*, 1422. [CrossRef]
118. Serrano, J.; Shahidian, S.; da Silva, J.M.; Paixão, L.; Carreira, E.; Carmona-Cabezas, R.; Nogales-Bueno, J.; Rato, A.E. Evaluation of near infrared spectroscopy (NIRS) and remote sensing (RS) for estimating pasture quality in Mediterranean montado ecosystem. *Appl. Sci.* **2020**, *10*, 4463. [CrossRef]
119. Godinho, S.; Guiomar, N.; Gil, A. Estimating tree canopy cover percentage in a mediterranean silvopastoral systems using Sentinel-2A imagery and the stochastic gradient boosting algorithm. *Int. J. Remote Sens.* **2017**, *39*, 4640–4662. [CrossRef]
120. Virkajärvi, P. Comparison of Three Indirect Methods for Prediction of Herbage Mass on Timothy-Meadow Fescue Pastures. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **1999**, *49*, 75–81. [CrossRef]
121. Serrano, J.; Carreira, E.; Fonseca, A.; Shahidian, S. Avaliação da sonda Grassmaster II como ferramenta para estimativa da produtividade de pastagens de sequeiro no Alentejo. *Rev. de Ciências Agrárias* **2018**, *41*, 781–880.
122. Zanine, A.D.M.; Santos, E.M.; Ferreira, J.D. Principais métodos de avaliação de pastagens. *Rev. Electrónica de Vet. REDVET* **2006**, *VII*, 1–13. Available online: http://www.veterinaria.org/revistas/redvet/n111106/110634.pdf (accessed on 12 May 2023).
123. Carvalho, R.C.R.; Athayde, A.A.R.; Valeriano, A.R.; Medeiros, L.T.; Pinto, J.C. Método de determinação da disponibilidade de forragem. *Ciência et Praxis* **2008**, *1*, 7–10.
124. Morris, M.J.; Johnson, K.L.; Neal, D.L. Sampling Electronic Shrub Ranges Capacitance with an Instrument. *J. Range Manag.* **1976**, *29*, 78–81. [CrossRef]
125. Terry, W.S.; Hunter, D.H.; Swindel, B.F. Herbage Capacitance Meter: An Evaluation of Its Accuracy in Florida Rangelands. *J. Range Manag.* **1981**, *34*, 240. [CrossRef]
126. Bell, M.J.; Mereu, L.; Davis, J. The Use of Mobile Near-Infrared Spectroscopy for Real-Time Pasture Management. *Front. Sustain. Food Syst.* **2018**, *2*, 76. [CrossRef]
127. Parrini, S.; Acciaioli, A.; Franci, O.; Pugliese, C.; Bozzi, R. Near Infrared Spectroscopy technology for prediction of chemical composition of natural fresh pastures. *J. Appl. Anim. Res.* **2019**, *47*, 514–520. [CrossRef]
128. Lanza, I.; Conficoni, D.; Balzan, S.; Cullere, M.; Fasolato, L.; Serva, L.; Contiero, B.; Trocino, A.; Marchesini, G.; Xiccato, G.; et al. Assessment of chicken breast shelf life based on bench-top and portable near-infrared spectroscopy tools coupled with chemometrics. *Food Qual. Saf.* **2021**, *5*, 1–11. [CrossRef]
129. Cecchini, C.; Antonucci, F.; Costa, C.; Marti, A.; Menesatti, P. Application of near-infrared handheld spectrometers to predict semolina quality. *J. Sci. Food Agric.* **2021**, *101*, 151–157. [CrossRef] [PubMed]
130. Adamchuk, V.I.; Rossel, R.A.V.; Sudduth, K.A.; Lammers, P.S. *Sensor Fusion for Precision Agriculture*; In-Tech: Rijeka, Croatia, 2011. [CrossRef]

131. Moral, F.; Terrón, J.; da Silva, J.M. Delineation of management zones using mobile measurements of soil apparent electrical conductivity and multivariate geostatistical techniques. *Soil Tillage Res.* **2010**, *106*, 335–343. [CrossRef]
132. Kravchenko, A.N.; Bollero, G.A.; Omonode, R.A.; Bullock, D.G. Quantitative Mapping of Soil Drainage Classes Using Topographical Data and Soil Electrical Conductivity. *Soil Sci. Soc. Am. J.* **2002**, *66*, 235–243. [CrossRef]
133. Adhikari, K.; Carre, F.; Toth, G.; Montanarella, L. *Site Specific Land Management General Concepts and Applications*; Institute for Environment and Sustainability: Ispra, Italy, 2009. [CrossRef]
134. Sternberg, M.; Gutman, M.; Perevolotsky, A.; Ungar, E.D.; Kigel, J. Vegetation response to grazing management in a Mediterranean herbaceous community: A functional group approach. *J. Appl. Ecol.* **2000**, *37*, 224–237. [CrossRef]
135. Watkinson, A.R.; Ormerod, S.J. Grasslands, grazing and biodiversity: Editors' introduction. *J. Appl. Ecol.* **2001**, *38*, 233–237. [CrossRef]
136. Santos, B. Comportamento de Pastoreio—Behavior of grazing. *REDVET Rev. Electrónica de Vet.* **2010**, *11*, 1–33.
137. Orr, R.J.; Griffith, B.A.; Cook, J.E.; Champion, R.A. Ingestion and excretion of nitrogen and phosphorus by beef cattle under contrasting grazing intensities. *Grass Forage Sci.* **2012**, *67*, 111–118. [CrossRef]
138. Butterly, C.R.; Baldock, J.A.; Tang, C. The contribution of crop residues to changes in soil pH under field conditions. *Plant Soil* **2013**, *366*, 185–198. [CrossRef]
139. Liu, C.; Holst, J.; Brüggemann, N.; Butterbach-Bahl, K.; Yao, Z.; Yue, J.; Han, S.; Han, X.; Krümmelbein, J.; Horn, R.; et al. Winter-grazing reduces methane uptake by soils of a typical semi-arid steppe in Inner Mongolia, China. *Atmos. Environ.* **2007**, *41*, 5948–5958. [CrossRef]
140. Holechek, J.L. Considerations concerning grazing systems. *Rangelands* **1983**, *5*, 208–211.
141. Pereira, L.E.T.; Silva, S.C.; Matthew, C.; López, I.F.; Fischer Sbrissia, A. *Grazing Management for Sustainable Grazing Systems*; Burleigh Dodds Science Publishing: Cambridge, UK, 2018; Volume 2019, pp. 79–122. [CrossRef]
142. Teague, W.R.; Dowhower, S.L. Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. *J. Arid Environ.* **2003**, *53*, 211–229. [CrossRef]
143. Mendes, P.; Meireles, C.; Vila-Viçosa, C.; Musarella, C.; Pinto-Gomes, C. Best management practices to face degraded territories occupied by Cistus ladanifer shrublands—Portugal case study. *Plant Biosyst.* **2015**, *149*, 494–502. [CrossRef]
144. Teague, R.; Provenza, F.; Norton, B.; Steffens, T.; Barnes, M.; Kothmann, M.; Roath, R. Benefits of multi-paddock grazing management on rangelands: Limitations of experimental grazing research and knowledge gaps. In *Grass Lands: Ecology, Management and Restoration*; Schroder, H.G., Ed.; Nova Science Publishers, Inc.: Hauppauge, NY, USA, 2008; pp. 41–80. ISBN 978-1-60692-023-7.
145. Barcella, M.; Filipponi, F.; Assini, S. A simple model to support grazing management by direct field observation. *Agric. Ecosyst. Environ.* **2016**, *234*, 107–117. [CrossRef]
146. Santos, M.; Afonso, L.; Carvalho, B.; Rêgo, A.; Queiroz, G.; Medica, J.; Moraes, L.; Carmo, L. Apparent selectivity of sheep in deferred marandu palisadegrass pastures with variable initial heights. *Arq. Bras. de Med. Vet. e Zootec.* **2019**, *71*, 1727–1734. [CrossRef]
147. Ma, L.; Yuan, F.; Liang, H.; Rong, Y. The effects of grazing management strategies on the vegetation, diet quality, intake and performance of free grazing sheep. *Livest. Sci.* **2014**, *161*, 185–192. [CrossRef]
148. Lin, L.; Dickhoefer, U.; Müller, K.; Wang, C.; Glindemann, T.; Hao, J.; Wan, H.; Schönbach, P.; Gierus, M.; Taube, F.; et al. Growth of sheep as affected by grazing system and grazing intensity in the steppe of Inner Mongolia, China. *Livest. Sci.* **2012**, *144*, 140–147. [CrossRef]
149. Hirata, M.; Kunieda, E.; Tobisa, M. Short-term ingestive behaviour of cattle grazing tropical stoloniferous grasses with contrasting growth forms. *J. Agric. Sci.* **2010**, *148*, 615–624. [CrossRef]
150. Lin, L.; Dickhoefer, U.; Müller, K.; Wurina; Susenbeth, A. Grazing behavior of sheep at different stocking rates in the Inner Mongolian steppe, China. *Appl. Anim. Behav. Sci.* **2011**, *129*, 36–42. [CrossRef]
151. Asner, G.P.; Elmore, A.J.; Olander, L.P.; Martin, R.E.; Harris, T. Grazing systems, ecosystem responses, and global change. *Annu. Rev. Environ. Resour.* **2004**, *29*, 261–299. [CrossRef]
152. O'Mara, F.P. The role of grasslands in food security and climate change. *Ann. Bot.* **2012**, *110*, 1263–1270. [CrossRef]
153. Sales-Baptista, E.; d'Abreu, M.C.; Ferraz-de-Oliveira, M.I. Overgrazing in the Montado? The need for monitoring grazing pressure at paddock scale. *Agrofor. Syst.* **2016**, *90*, 57–68. [CrossRef]
154. Fabian, Y.; Sandau, N.; Bruggisser, O.T.; Kehrli, P.; Aebi, A.; Rohr, R.P.; Naisbit, R.E.; Bersier, L.F. Diversity protects plant communities against generalist molluscan herbivores. *Ecol. Evol.* **2012**, *2*, 2460–2473. [CrossRef] [PubMed]
155. Ribatski, E.O.; dos Santos, F.S.; Neto, F.N. Revisão sobre utilizações de RPAs no cenário agrícola. *Braz. J. Technol.* **2018**, *1*, 313–333. Available online: http://www.brjd.com.br/index.php/BJT/article/view/1146/1003 (accessed on 12 May 2023).
156. Faria, N. Predicting agronomical and ecological effects of shifting from sheep to cattle grazing in highly dynamic Mediterranean dry grasslands. *Land Degrad. Dev.* **2019**, *30*, 300–314. [CrossRef]
157. Heady, H.F. Continuous vs. Specialized Grazing Systems: A Review and Application to the California Annual Type. *J. Range Manag.* **1961**, *14*, 182. [CrossRef]

158. Nie, Z.N.; Zollinger, R.P. Impact of deferred grazing and fertilizer on plant population density, ground cover and soil moisture of native pastures in steep hill country of southern Australia. *Grass Forage Sci.* **2012**, *67*, 231–242. [CrossRef]
159. Garrido, P.; Elbakidze, M.; Angelstam, P.; Plieninger, T.; Pulido, F.; Moreno, G. Stakeholder perspectives of wood-pasture ecosystem services: A case study from Iberian dehesas. *Land Use Policy* **2017**, *60*, 324–333. [CrossRef]
160. Grigoli, A.; Todaro, M.; Di Miceli, G.; Genna, V.; Tornambè, G.; Alicata, M.L.; Giambalvo, D.; Bonanno, A. Effects of continuous and rotational grazing of different forage species on ewe milk production. *Small Rumin. Res.* **2012**, *106*, S29–S36. [CrossRef]

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CAPÍTULO 4

Monitorização da qualidade da pastagem com espetrómetro NIR portátil

applied sciences

MDPI

Article

Real-Time Quantification of Crude Protein and Neutral Detergent Fibre in Pastures Under Montado Ecosystem Using the Portable NIR Spectrometer

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Featured Application: The knowledge of pastures' nutritional value in the Montado ecosystem is critical for farm managers' decision-making regarding soil fertilization, animal supplementation and grazing management. Laboratory determinations of the parameters related to pastures' nutritional value (crude protein, fibre and others) are very expensive, destructive and costly, in terms of time and labour. This study shows the potential of a portable near-infrared spectrometer as a fast and non-destructive technique for estimating, in situ, pasture quality parameters.

Abstract: The Montado is a Mediterranean agro–forestry–pastoral ecosystem. Knowledge of pastures' nutritional value is critical for farm managers' decision-making. Laboratory determinations are very expensive, destructive and costly, in terms of time and labour. The objective of this experimental work was to calibrate and validate a portable near-infrared spectrometer (micro-NIR) to predict the nutritive value (neutral detergent fibre, NDF and crude protein, CP) of pastures in the peak of spring 2021. Thus, a total of 87 pasture samples were collected at eight experimental fields located in the Alentejo, Southern region of Portugal. The results show good correlations between in-situ micro-NIR measurements and pasture NDF reference values (R^2 of 0.73 and 0.69 for calibration and validation models, respectively), and a moderate correlation between micro-NIR measurements and pasture CP reference values (R^2 of 0.51 and 0.36 for calibration and validation models, respectively). These results show the potential of this tool for the quick evaluation of pasture quality and constitute a starting point for future work, which should include the monitoring of temporal variability (throughout the entire vegetative cycle of the pasture) and spatial (with geo-referenced information) diversity of pastures characteristic of the Montado ecosystem in the Mediterranean region.

Keywords: micro NIR; portable NIR spectrometry; pastures; crude protein; fibre; real-time; decision making

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1. Introduction

Montado is a multifunctional agro–forestry–pastoral ecosystem [1] of "High Natural Value" [2], where agricultural, forestry and animal production come together [3]. It usually occupies soils with structural and fertility limitations: shallow, stony, acidic, nutrient-poor, with micronutrient imbalances (namely the magnesium/manganese ratio) [3] and degraded due to erosion and loss of nutrients [4]. Montado is a highly complex system, and this complexity results from the interaction between climate, relief and the various elements that make up this ecosystem: soil, pasture, trees and animals [3,5]. This ecosystem is located in a geographical region called Alentejo, in Southern Portugal, which is affected by the Mediterranean climate. This climate is characterized by hot, dry summers and mild winters, with large rainfall irregularities [6] great seasonality and variability [5]. This variability in rainfall in each year and between years, means that pasture production (quantity and quality) is also irregular. According to Miao et al. [7] the inter-annual variability of precipitation may explain the differences in the quantity and quality of pasture, with biomass production and its nutritional value increasing with the annual increase in precipitation. On the other hand, the fertility of the soils, the diversity in the floristic composition, the trees and grazing animals, also contribute to great variability in productivity and quality of the pasture [8]. In this sense, also, Biewer et al. [9] report that the nutritional value of pasture can be very variable within the same field, during the growing period, due to nutritional deficiencies, frost, and drought or grazing.

Knowledge of the nutritional value of pasture and its availability over time can lead to improvements in production systems and grazing management of ruminants [9–11]. According to Serrano et al. [12] grazing management decisions are made as a function of pasture quality and availability. Therefore, monitoring pasture quality leads to increased farm efficiency [13]. Real-time information about the nutritional value of the pasture will allow the farmer to make more informed decisions regarding animal supplementation [11]. The survey of the spatial and temporal variability of biomass, based on the cutting and collection of pasture samples, is a destructive, time-consuming, expensive [13,14], and labour-demanding method, impracticable from a practical perspective [15], which has led to a growing interest in expeditious methods [16]. The time required to sample processing [11] and to obtain the results of the determinations of the nutritional value of the pasture [10], carried out in the laboratory, is also another indirect cost, often preventing the use of these determinations by the farmer for decision-making [12,13,17]. Indirect pasture sampling methods minimize the physical removal of vegetation and were mainly developed with the aim of obtaining rapid methods that can be used over large areas [18]. In this sense, new non-destructive technologies are increasingly used, in order to better understand the variability of production in large areas and implement new production strategies [19]. Recent developments in the technological field, in terms of electronic sensors, are already an effective response today, allowing fast, reliable and large-scale measurements [20]. As an alternative to traditional methods, a method emerged that uses near-infrared (NIR) equipment, which through reflected infrared radiation estimate the chemical constituents of pastures [10].

NIR spectroscopy (NIRS) is based on the absorptions of C–H, N–H, O–H, C–N and C–C groups present in organic constituents [13], as well as S–H groups [21]. This technique measures the spectrum of infrared energy reflected from a sample illuminated by white light [11]. NIR radiation has an amplitude from about 780 to 2500 nm in the electromagnetic spectrum [17,21–23]. According to Murphy et al. [24] this radiation amplitude varies between 700 and 2500 nm. Givens and Deaville [25] refer that this spectral region varies between 730 and 2500 nm. NIR measurements can occur by transmittance, reflectance or transflection; transmittance allows information to be obtained from the entire volume of the sample that is traversed by light, while reflectance only allows information to be obtained from the surface of the sample [17]. With NIRS it is possible to determine the chemical composition of animal feed quickly, non-destructively [10,17], with less sample pre-processing and with high precision [14,25]. According to these authors, this technique contrasts with traditional chemical analyses, as it does not require reagents and does not produce residues. In addition, this method allows for faster and cheaper determinations [10,26–28]. Alomar et al. [29] report that NIRS has been widely used because it is a fast, reliable and capable method of evaluating the quality of pastures. The technique is rapid, non-destructive [21,25,26,30,31], precise, and cost-effective, compared with other laboratory techniques [32]. However, for it to be used in different conditions and different pastures, it requires calibration, using reference data [10]. The variability associated with natural pastures compromises the use of NIRS somewhat, since calibration and validation are more challenging when environmental variation is high [33]. On the other hand, Danieli et al. [27] report that this technique allows a reliable evaluation of pasture quality, especially in terms of CP (crude protein) and NDF (neutral detergent fibre). The use of near-infrared spectroscopy (NIRS) for green pasture analysis has been available for several years in many European laboratories, which determine the components of animal feed [12]. However, the use of this laboratory equipment requires the cutting of pasture samples, which, as already mentioned, is a costly method in terms of time, money and labour, as well as being inaccurate, as it is not possible to sample the entire field. According to Serrano et al. [12] it also requires pre-processing the sample to be homogeneous, before performing the spectroscopic analysis. This pre-processing involves the dehydration of pasture samples and their grinding. When the pre-processing of the samples is not carried out, the precision decreases, due to the heterogeneity of the samples, especially with regard to the size of the particles [33]. The use of the NIRS technique for the evaluation of fresh samples has several obstacles, including irregular particle size and sample heterogeneity [34]. With the advancement of technology, smaller and lighter equipment emerged, which gave rise to portable equipment [17]. These sensors have several advantages over laboratory models, especially in terms of size, weight and manufacturing process, as well as less initial investment [35]. According to Lanza et al. [23], in recent times, more attention has been paid to portable NIR than to laboratory models, due to reduced weight and ease of use, allowing direct, non-destructive and in-situ sample measurement. Portable sensors have the advantage that the sensor itself is taken to samples and not the other way around, which allows for a win-time in the process of obtaining results and reducing costs and labour in collection, transport, processing and laboratory analysis [31]. Pullanagari et al. [28] refer that real-time analysis with the micro NIR overcomes the spatial and temporal variability of the pasture. According to Alomar et al. [29], in samples with large amounts of water, strong absorption signals are generated, which overlap and darken other spectral characteristics, which can lead to non-linear responses, which has led to this technique being used mainly with dry samples. Also, according to Kademi et al. [36], spectra are often disturbed by different interferences in the signal acquisition, which is a practical problem of this technique. Another problem associated with these portable sensors is their narrow wave-length range [35]. According to Bell et al. [11] the main advantage of portable NIRS is that it allows a more frequent analysis of the pasture, reducing the time interval between sequential nutritive value readings, thus contributing to more timely decision making. Parrini et al. [33] report that in field pasture analysis allows a reduction in costs and time, compared to laboratory analyses. Portable NIRS makes it possible to analyse and provide the farmer with real-time data relating to pasture and soil nutrients in a soil–pasture–animal system [11].

The aim of this study was to calibrate and validate the use of a portable near-infrared spectrometer to predict pasture quality (crude protein and neutral detergent fibre) in the Montado ecosystem during spring peak.

2. Materials and Methods

2.1. Study Area

This work was carried out between 30 March and 13 April 2021, at six farms located in the Alentejo region of Portugal. Figure 1 shows the geographical location of these farms, “Grous” (Gro) and “Azinhal” (AZI) farms are located in the district of Beja (Lower Alentejo region); “Padres” (PAD), “Murteiras” (MUR) and “Mitra” (MIT) farms are located in the district of Évora (Central Alentejo region); and “Tapada dos Números” (TAP) farm is located in the district de Portalegre (Upper Alentejo region). Dryland pastures under scattered Holm oak and Cork oak are grazing by sheep or cows in continuous or rotational systems. The characteristics of each farm were described by [37,38].

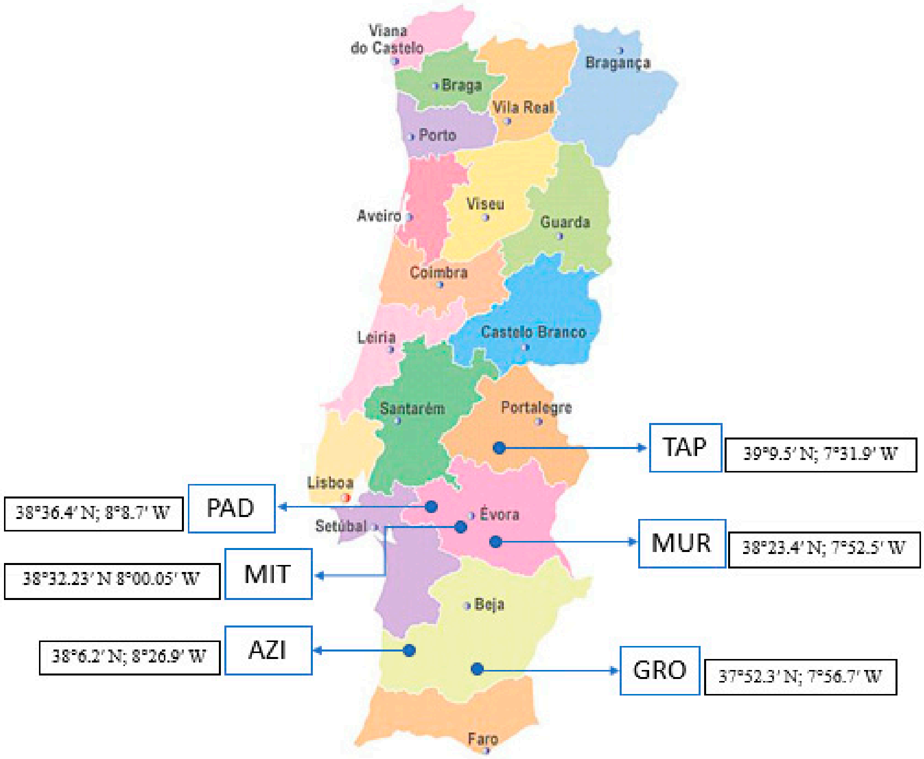

Figure 1. Map of Portugal with the location of each farm.

2.2. Samples Mensurements and Colletion

For this study, 87 pasture samples were used, each consisting of a composite of three random locations, for each monitored and georeferenced sampling point. At each of these locations, measurements were taken with an infrared spectrometer, then the pasture was cut (Figure 2) and placed in a plastic bag, properly identified with the sample code. At each location, a metal quadrat with 0.1 m^2 of area was placed to define the area for the above-mentioned procedures. Note that on the Mitra farm, there were three different plots (Mitra A, Mitra B and Mitra C).

Figure 2. Portable near-infrared (NIR) sensor measurement (**a**) and pasture sample cut (**b**).

2.2.1. Reference Chemical Processing

The samples were then transported to the Animal Nutrition and Metabolism Laboratory—MED Mediterranean Institute for Agriculture, Environment and Development, weighed on arrival and their fresh weight recorded. Later, they were placed in an oven at 65 °C, for 72 h, to be dehydrated, having been weighed at the end and their dry weight recorded. Drying temperatures between 65 °C and 70 °C are acceptable for the dehydration of pasture samples [34]. With fresh weight and dry weight, the pasture dry matter (DM, in kg·ha^{-1}) and pasture moisture content (PMC, in % of DM) were calculated. According to Alomar et al. [34] the dehydration of pasture samples is carried out with the main objective of preserving the pasture that cannot be immediately analysed in the laboratory, in addition to facilitating grinding, reducing water variations between samples and homogenizing each sample, and thus reducing sampling errors. Next, the dehydrated samples were ground in a Perten instrument mill equipped with a 1-mm sieve, for subsequent determination of reference values of CP and NDF, expressed in percentage on a dry weight basis, using conventional wet chemistry methods according to the Association of Official Analytical Chemists [39]: (i) the nitrogen content was determined according to the Kjeldhal method, i.e., a colorimetric determination on an automatic analyser (Bran + Luebbe) with a conversion factor for CP of 6.25 (method no. G-188-97 Rev 2, Bran + Luebbe, Analyzer Division, Norderstedt, Germany); (ii) NDF content was determined according to the Goering and Van Soest method (1970) in a Fiberted digester (Foss Tecator AB, Hoganas, Sweden).

2.3. Sprectra Collection

Spectra were obtained in situ with a Micro-NIR OnSiteW (VIAVI, Santa Rosa, CA, USA), a portable device which collects diffuse reflectance spectra in the spectral range between 950–1650 nm, with a spectral resolution of 6.2 nm and equipped with an InGas photodiode array detector, equipped with a sapphire window of 18 mm with an aluminium enclosure for use in the field. Spectra were collected with 10 ms as the integration time and 100 as the scan count. Prior to spectra acquisition and to verify the spectrometer performance, a series of tests were undertaken. A white reference was built using Spectralon to register the total reflectance value and a dark reference (total absorbance) was recorded leaving the tungsten lamps on, with the empty support, also known as dark current scan.

From each area of 0.1 m^2 five spectra were collected. Using the instrument software (MicroNIR™ Pro software, Version 3.1), the mean spectrum was calculated and exported as Log (1/R). During the development of the CP and NDF models, the important spectral regions were selected according to the weighted regression coefficients plot and the spectral range was limited to these wavelengths.

2.4. Statistical Analysis

To evaluate the accuracy of the models we preformed a multivariate data analysis using the Unscrambler software (version 10.4, CAMO, ASA, Oslo, Norway), and, for the descriptive analysis, the means and standard deviations (SD) of CP and NDF reference values were calculated.

A PLSR algorithm was used to obtain the calibration model to predict pasture CP and NDF. PLSR is a calibration technique widely used in studies involving absorbance, as it avoids the problem of very high intercorrelation between different absorbance bands [40]. The entire spectra were used, ranging from 1093 nm to 1670 nm. First derivative and SNV pre-processing transformations were used prior to calibration modelling but they did not improve the model performance in comparison to raw spectra. So, the raw spectra data was used to build the calibration models. For the model development, an internal calibration (cross-validation) was preformed using Kernel algorithm with 20 segments. Outliers were excluded by PLSR. Warning limits were predefined for the detection of potential outliers. The criteria used to detect outliers was based on the F-Residuals and Hotelling's T2 statistics, calculated with an error of 0.05 and with 95% of confidence, respectively. Model performance was evaluated through coefficient of determination (R^2), the root–mean–square error (RMSE), residual predictive deviation (RPD) and average difference between predicted and actual values (Bias). The R^2 is an excellent indicator of robustness and model accuracy [37]. Although R^2 is often the main statistical indicator used to assess the accuracy of the calibration model, according to Davies and Fearn [41] it is not the best indicator for this purpose, as it depends on the range. The RPD value is directly related to the quality of the calibration model, and the higher its value, the better the model [42]. This index corresponds to the ratio between the standard deviation (SD) of the reference values of laboratory determinations and the RMSE [28,37]. Finally, the bias indicator is related to the difference between the calibration and validation predicted and measured values [28,31]. The smaller the bias, the more accurate the model.

The RMSE (Equation (1)), as the designation indicates, is an error, which should have its absolute value as low as possible. The RPD (Equation (2)) is an index of model quality, which should be as high as possible.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(E_{\mathrm{i}} - M_{\mathrm{i}})^2}{n}} \quad (1)$$

$$RPD = \frac{SD}{RMSE} \quad (2)$$

where n is the number of observations, E_i are the estimated values and M_i are the observed values.

The software for multivariate data analysis was "UnscramblerX" (version 10.5.1), with a confidence level of 95% ($p < 0.05$).

3. Results

3.1. Meteorological Conditions

Figure 3 illustrates the thermopluviometric graph for the districts of Beja, Évora and Portalegre. The total precipitation (b) in this cycle of pasture production (July 2020 to June 2021) was 500 mm for the district of Beja, 628 mm for the district of Évora and 840 mm for the district of Portalegre. Just based on this climatic data, the climatic variability between districts where the farms of this study are located, is already evident. The differences in the amount of total rainfall were 128 mm, between Beja and Évora, and 240 mm, between Évora and Portalegre, which influences pasture production and quality. The average temperature (a) between July 2020 and June 2021 was 17.2 °C for the district of Beja, 16.9 °C for the district of Évora and 16.4 °C for Portalegre. These data also show that average temperature during the vegetative cycle of the pasture is higher at the farms located further south. As can be seen in Figure 3a,b, the distribution of both precipitation and temperature are irregular throughout the year: some months show large amounts of precipitation and others only residual values. The spring of 2021 was particularly dry, which may have influenced pasture quality and production. In March 2021 the precipitation values were 24.4 mm, 19.6 mm and 14.3 mm for the districts of Beja, Évora and Portalegre, respectively, and in April they were 40.6 mm, 64.2 mm and 92.5 mm for Beja, Évora and Portalegre, respectively. However, we should note the high values of precipitation in February, when temperatures are already beginning to increase.

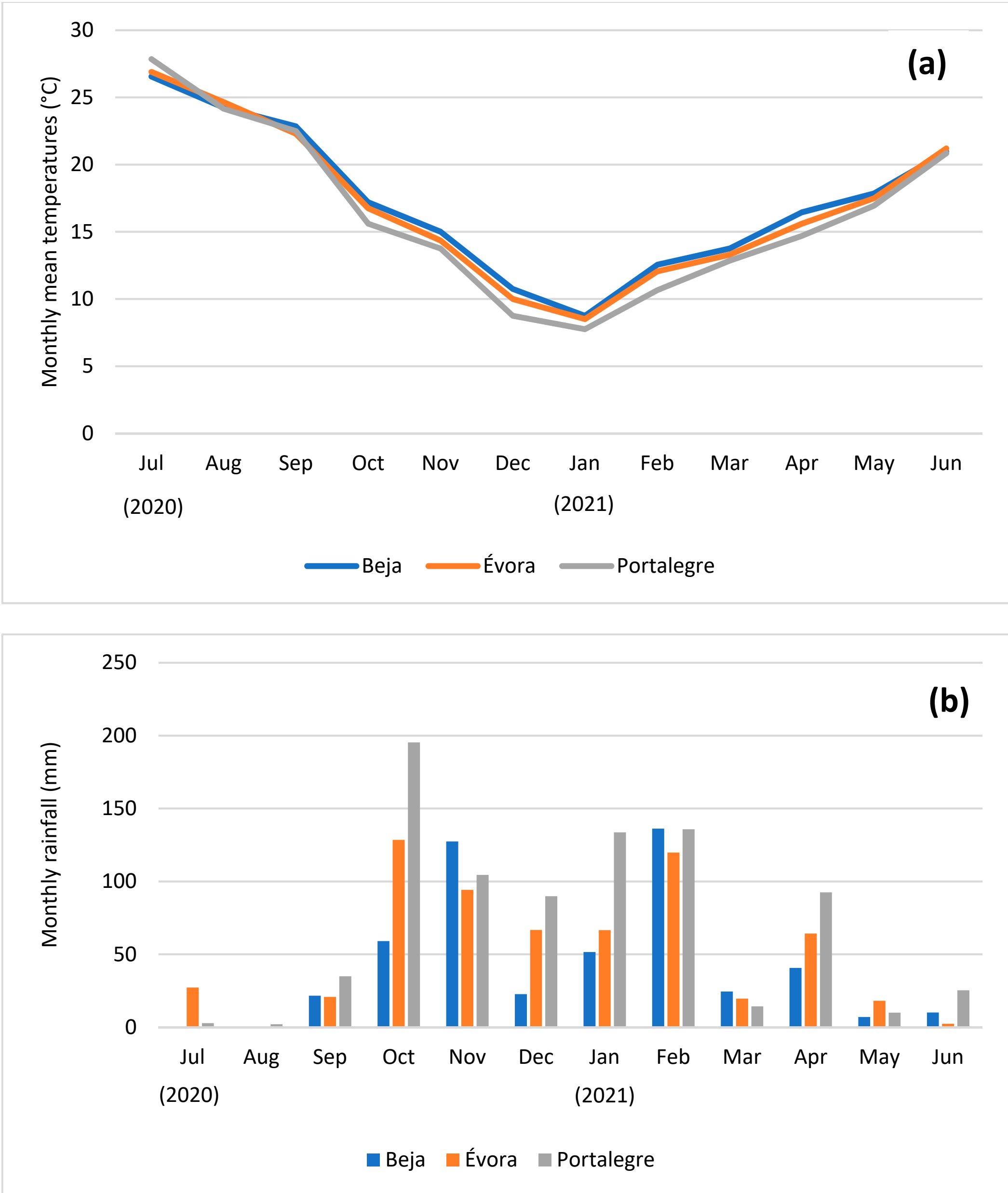

Figure 3. Thermopluviometric graphic for the districts of Beja, Évora and Portalegre between July 2020 and June 2021 (source: Portuguese Institute of Sea and Atmosphere). (**a**) Monthly mean temperatures (**b**) monthly rainfall.

The Alentejo region, where the study fields are located, is affected by the Mediterranean climate, with characteristic hot and dry summers and mild and humid winters, although there is a very pronounced irregularity of precipitation. Peak production and pasture quality occurs in spring, when the soil moisture content (SMC) is above 10% [8] and temperatures rise, but not excessively. In the Alentejo region, in dryland pastures, as temperatures increase throughout the spring and, consequently, the available SMC decreases, the pasture begins to dry out and its nutritional value gradually decreases. Therefore, this study took place only in late March and early April, as the pasture was at its peak production.

3.2. Evaluation of CP and NDF Reference Data

Table 1 shows the dates of micro NIR sensor measurements and pasture sample collection, number of samples, the mean and SD of pasture quality parameters (NDF and CP, in % of dry matter, DM). Mean reference value of NDF was 45.7% (range between 33.0 and 58.6%), which indicates the great variability between fields in the Mediterranean region, although all the pasture fields are in the phase of peak production (between the end of March and beginning of April). In regards to CP, the mean was 12.9% DM (range between 8.2% and 20.9% DM), which clearly highlights the great spatial variability of the pasture quality in the Montado ecosystem.

Table 1. Date collection, field code, mean, standard deviation (SD) and range of the pasture NDF and CP reference values.

Date	Field Code	N	FDN %		CP %	
			Mean ± SD	Range	Mean ± SD	Range
30/03/2021	Mitra A	12	40.7 ± 2.0	38.8–45.5	16.9 ± 2.6	14.2–20.9
30/03/2021	Mitra B	12	41.0 ± 2.7	37.6–46.8	11.6 ± 1.6	11.0–15.1
01/04/2021	Mitra C	24	43.2 ± 4.8	33.0–51.5	11.9 ± 2.1	8.2–17.2
08/04/2021	Azinhal	8	56.5 ± 1.4	53.7–57.1	8.5 ± 0.3	8.2–8.9
08/04/2021	Grous	8	46.8 ± 2.9	42.4–49.8	11.4 ± 0.8	10.6–12.9
09/04/2021	Murteiras	8	49.4 ± 2.7	46.4–54.5	13.3 ± 1.6	10.4–15.0
09/04/2021	Padres	8	52.8 ± 2.9	46.9–54.5	13.7 ± 1.2	12.4–14.9
13/04/2021	Tapada dos Números	8	56.9 ± 2.0	52.7–58.6	12.1 ± 2.2	11.2–16.3

NDF—neutral detergent fibre; CP—crude protein; N—number of samples.

3.3. Evaluation of Near-Infrared Spetroscopy (NIRS) Data

Table 2 shows the statistical indicators for the various calibration and validation models used. Four regression models were developed: raw spectra, SNV, 1st derivative and SNV+1st derivative. After observing the statistical indicators, it was decided to choose the raw spectra for presenting the best indicators: NDF (R^2 of 0.73; RMSE of 3.302 for calibration model and R^2 of 0.69; RMSE of 3.628; Bias of 0.056 and RPD of 1.75 for internal validation model) and CP parameters (R^2 of 0.51; RMSE of 2.073 for calibration model and R^2 of 0.36; RMSE of 2.368; Bias of 0 and RPD of 1.26 for internal validation model).

Table 2. Statistical indicators of the internal calibration and validation models for the NDF and the CP through the use of the micro NIR sensor in the pasture and partial least squares regression (PLSR).

Pre_Processing	Calibration Model			Internal Validation Model				
NDF	**LV**	**R^2**	**RMSE**	**LV**	**R^2**	**RMSE**	**Bias**	**RPD**
raw spectra	5	0.730	3.302	5	0.690	3.628	0.056	1.75
SNV	5	0.639	3.996	5	0.473	4.962	−0.279	1.35
1st derivative	5	0.745	3.142	5	0.649	3.834	−0.024	1.64
SNV+1st derivative	6	0.693	3.371	6	0.496	4.26	0.098	1.44
CP								
raw spectra	5	0.510	2.073	5	0.360	2.368	0.000	1.26
SNV	4	0.405	2.450	4	0.299	2.690	0.008	1.36
1st derivative	3	0.309	2.378	3	0.200	2.584	0.001	1.36
SNV+1st derivative	2	0.325	2.506	2	0.263	2.722	0.079	1.13

LV—latent variables; R^2—coefficient of determination; RMSE—root–mean–square error; Bias—average difference between predicted and actual values; RPD—residual predictive deviation.

Figure 4 represents an example of pasture spectra measured directly with the micro-NIR sensor. These spectra are the starting point for the prediction of pasture NDF and CP content. As can be seen in Figure 4, the wavelength varies between 1093 nm and 1657 nm.

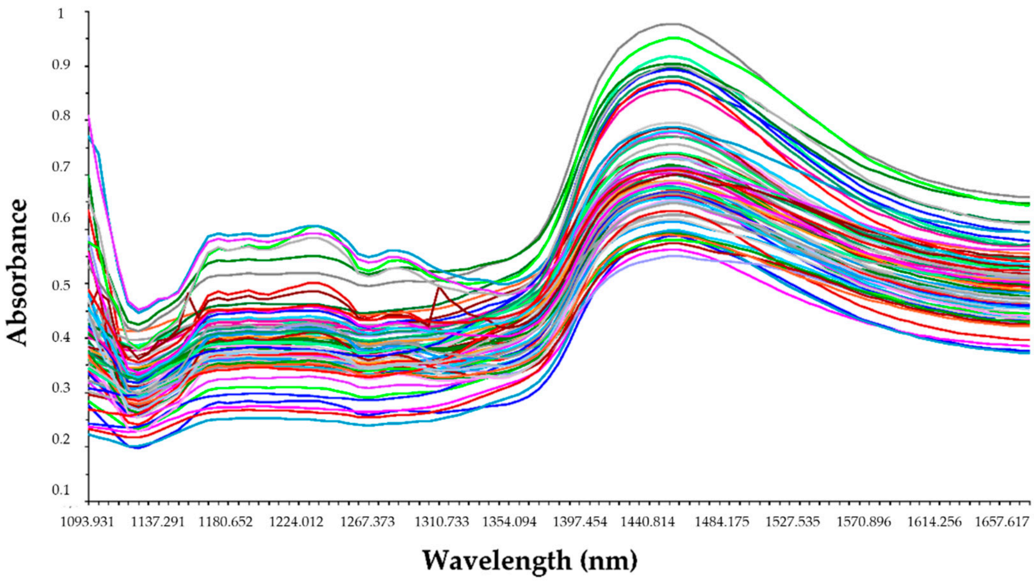

Figure 4. Example of pasture spectra measured with the micro-NIR sensor to predict pasture neutral detergent fibre (NDF) and crude protein (CP).

Figure 5 shows the reference and predicted values of NDF (a) and CP (b) resulting from the calibration and validation models. The calibration and validation points for the NDF are relatively close to each other, which means that the models can be considered good (R^2 of 0.71 for calibration and 0.69 for validation). As for the CP, the calibration and validation points do not fit so well, which is a reflection of the R^2 values of the calibration and validation models (0.51 and 0.36, respectively).

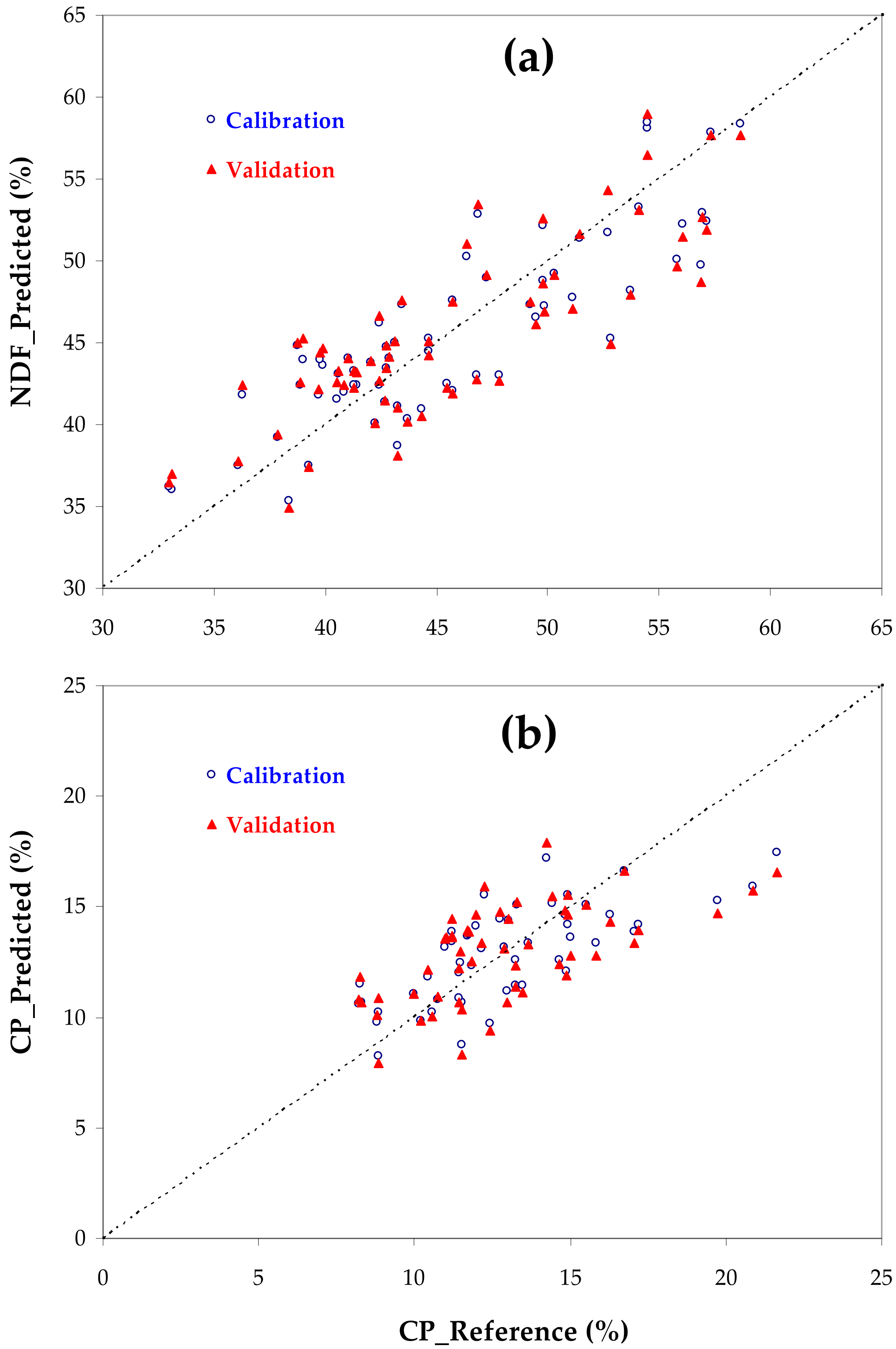

Figure 5. Plot of the calibration and internal validation phases between reference and predict values of fibre (NDF, **a**) and crude protein (CP, **b**).

4. Discussion

4.1. Variability of Crude Protein and Fibre (NDF) Reference Data

In this study CP and NDF variability fit within the ranges of variation of these parameters published in other works. This variability is a function of the diversity of plant species that constitute pastures in the Mediterranean region and the different growth rates, which in turn are dependent on temperature and precipitation in each field, as well as on the spatial variability of soil fertility [12]. Also, Pullanagari et al. [28] state that pasture spatial and temporal diversity is related to the diversity of species, the interactions with grazing animals, natural environmental conditions and management production systems. Serrano et al. [37], carried out a study throughout the pasture vegetative cycle (autumn, winter and spring) and obtained CP values between 10.4% and 24.3% and NDF between 29.4% and 60.2%. Safari et al. [43], in permanent pastures in Germany, obtained CP values between 5% and 22.6%, from May to October. Similar values (CP between 6.1% and 25.6%) were obtained by Pullanagari et al. [44] in a study carried out during the vegetative cycle in mixed pastures. Also, Lobos et al. [45] in a study carried out on permanent pastures with heterogeneous floristic composition in Chile, obtained CP values between 17.8% and 29.0% and NDF values between 37.9% and 50.3%. This variability, which in this study is magnified by the inclusion of samples from various experimental fields, with different climatic, soil and management conditions, is important and necessary to validate and increase the robustness of calibration models [24]. Also, Parrini et al. [33] state that sample variability is essential, both to develop NIRS calibration models and to assess their applicability in future predictions of the nutritive value of a pasture. In this sense, Bell et al. [11] report that there is considerable spatial and temporal variation in pasture production and quality, which is still not well understood, especially in terms of nutrient concentration of different types of pasture.

4.2. NIRS Models Accuracy: Calibration and Validation

The most accurate models are those that have a high R^2 and RPD, a low RMSE and Bias [12,28,37,46]. The coefficients of determination obtained in this study can be considered good for NDF (0.73 for the calibration model and 0.69 for the validation model, with RPD of 1.75) and moderate for CP (0.51 for calibration and 0.36 for internal validation, with RPD of 1.26). The values obtained from RPD are considered low [47]; however, these are expected and acceptable in experimental work involving field measurements [9]. In this discussion we have focused our attention particularly on the coefficient of determination (R^2).

The NIRS technique can be used in two ways: (i) with laboratory bench NIR equipment (LBNE); (ii) in field with portable spectrometer (micro-NIR). The first requires pasture sample pre-preparation (consisting of dehydration followed by crushing and grinding, or at least crushing/homogenization), the second is non-invasive, carried out in the field without any disturbance to the pasture.

There are many works published with results of the use of LBNE to estimate the quality of plant material, whether pasture or other plant types. For example, Fontaneli et al. [10] in a study to calibrate and validate a LBNE to estimate the quality of grasses with pre-processing samples, obtained R^2 values of 0.97–0.98 for both calibration and validation models of CP and NDF. Also, Swart et al. [14], in a study in which they intended to calibrate a LBNE to predict the chemical composition of feed for ostrich, found very high calibration correlations with pre-processing samples (R^2 = 0.96 and 0.94, respectively for CP and NDF). In relation to biodiverse pastures, the study of Serrano et al. [37] showed significant correlation between calibration models obtained with LBNE and reference methods for quantifying pasture quality parameters, with greater accuracy from dry and pre-processing samples (R^2 = 0.936 for CP and R^2 = 0.914 for NDF) than fresh samples (without sample pre-preparation; R^2 = 0.702 for CP and R^2 = 0.720 for NDF). Also, with LBNE, Parrini et al. [33] obtained very strong correlations in analysis of green pasture (fresh samples) for both, CP and NDF (R^2 values of 0.96 and 0.84, respectively). Lobos et al. [45], in a study carried out in heterogeneous pastures in Chile, used a LBNE to predict various parameters of the fresh pasture, including CP (R^2 = 0.84) and NDF (R^2 = 0.78).

With regard to the use of portable spectrometers (micro NIR), no published works were found referencing pastures in the Montado ecosystem, which makes it difficult to compare the results obtained in this study. However, there are works with other plants, such as in durum wheat grain CP content (R^2 of 0.98 to calibration and validation with samples previously homogenized; [31]). In field measurements in pastures, without pre-processing, accuracy is normally low. For example, to estimate pasture CP, Mendarte et al. [48] obtained calibration R^2 of 0.63, while Safari et al. [43] obtained R^2 values of 0.58 and 0.56, for calibration and for cross validation, respectively. The best results were published by Pullanagari et al. [28], twho estimated various parameters of pasture quality in New Zealand, including CP (R^2 of 0.82 and 0.78 for calibration and validation models, respectively), and NDF (R^2 of 0.77 and 0.75 for calibration and validation models, respectively).

One factor that can help explain these values obtained with the micro-NIR spectrometer is that the readings can be influenced by the water that exists on the surface of the pasture/soil [29]. NIR is more accurate with pre-dried samples than with fresh samples [27]. The obscuration effect, caused by the moisture's absorption of NIR light, is a factor that negatively influences the quality of the calibration and validation models with samples not previously dehydrated [24,49]. According to Corson et al. [26] the peak absorbance for water occurs at 1450 nm, precisely where the micro-NIR used in this study shows a high peak (Figure 4). As the measurements took place directly in the pasture and, at the peak of its productivity, it is possible that the water present on the plants influenced this absorbance peak in this spectral region.

Another aspect that may be relevant is related to the spectral range of the micro-NIR sensor, further developed in the below section.

4.3. NIRS Models Accuracy: Spectral Range

Biodiverse pastures usually present a greater spectral range due to variations in the species of plants that make up the pasture and the soil background [28]. Lignin, protein, starch, cellulose and hemicellulose, pasture constituents, have fundamental molecular bonds between O–H and C–H. Absorptions above 1960 nm are responsible for the molecular bonds O–H, N–H, O=H and O–H, C–H, C–H and O–H [50], which are precisely the main bonds of pasture quality parameters [28]. Pullanagari et al. [28] consider that bands of visible region (500 to 750 nm) are those where the highest correlations with CP and NDF occur. Similarly, Biewer et al. [9] report that in the spectral region between 620 and 1000 nm, CP can be predicted with good results. Also, Safari et al. [43] report that visible region (below 700 nm) represents the bands that correlate best with pasture CP. Furthermore, Pullanagari et al. [28] also refer to the correspondence of near-infrared (800 to 1000 nm) and infrared (1900 to 2400 nm) spectral regions with pasture quality parameters. Pullanagari et al. [44] report that the sensitive spectral bands for CP are located between 505 nm and 1000 nm, and between 2013 nm and 2420 nm, with absorption peaks at 1500 nm and 1935 nm. Corson et al. [26] and Givens & Deaville [25] also highlight the importance of 2100 to 220 nm bands for estimating pasture CP. These data can help to explain the low R^2 values for CP obtained in this study, since the spectral range of useful micro=NIR is restricted to wavelengths between 1093 nm and 1670 nm.

Despite this limitation in the range of portable spectrometer, Malegori et al. [51] concluded that this equipment is sufficiently robust for directly application in the field. In this study the good correlations obtained for NDF (R^2 of 0.73 and 0.69 for calibration and validation, respectively) open up good perspectives for practical application, given the importance of fibre in animal feed, particularly for ruminants. These better results obtained with fibre, relative to CP, may be due to the fact that the most important spectral region for the prediction of NDF varies between the 1370 nm and 1418 nm [37] spectral bands provided by the micro-NIR. Also, according to Corson et al. [26] and Givens and Deaville [25] the spectral regions between 1650–1670 nm and 2260–2280 nm are correlated with C–H molecular bonds for lignin and cellulose, which may help to explain the better correlations with NDF in this study, since lignin and cellulose are two of the main constituents of this parameter. The micro NIR sensor used in this study covers the first of these wavelengths' ranges.

4.4. Perspectives for NIRS Approach

Actually, the use of proximal sensors is already a reality and should increase, with the reduction of sensor costs and complexity [52]. Due to the low cost, speed and reliability attributed to the NIR technique to estimate the quality of pastures, it is predictable that its adoption in the future will be great, providing more timely information to assist the farmers in their decision making [11,28]. The adoption of NIR technologies to estimate the quality parameters of pastures, especially using portable sensors, will help to improve the management of pastures and their nutrients, reducing production costs and losses [11]. It is expected that this adoption will mainly involve the use of a portable spectrometer, since it implies less processing time, less labour and real-time results. For the use of these technologies by farmers to be a reality, it is necessary to carry out research in the context of a real farm, in order to identify the advantages and barriers to adoption by agricultural managers [52]. As was the case in the Pullanagari et al. [28] study, the present study also focused on the evaluation of a micro-NIR sensor—a sensor never before used in pastures in the Montado ecosystem—in the prediction of CP and NDF in real farms. Yet, as already mentioned in the materials and methods section, this study was limited to the peak of production and pasture quality under Mediterranean conditions, thus, there is one measurement and harvest date for each plot. The internal calibration and validation models of the current study may not be as robust as desirable, due, as mentioned by Cecchini et al. [31], to the fact that the dataset is not particularly large. Therefore, we suggest that a similar study be carried out, under the same conditions, with a larger number of samples and throughout the entire production cycle of the pasture in Mediterranean region (autumn, winter and spring).

5. Conclusions

Dryland pastures productivity and quality is influenced by the interaction between the amount and the distribution of precipitation and the air temperature, which, in the Mediterranean climate, vary greatly throughout the year and from year to year. For agricultural managers to be able to make decisions about grazing management, animal supplementation, application of fertilizers, etc., it is essential to know a pasture's nutritional value. Visual assessments, based on management field experience and not having the real values of pasture quality parameters (such as CP and NDF), can hinder the manager's decision-making. The CP and NDF laboratory determinations require the cutting, transporting and pre-processing of pasture samples, with a considerable delay to obtain the results, in addition to the many human and monetary resources needed for this work. Therefore, the calibration and validation of new technologies to predict parameters of pastures' nutritive values in real-time is fundamental and of great importance. The results of this study show the potential of micro-NIR to predict pasture fibre content (NDF) in the Montado ecosystem (internal validation model with R^2, RMSE, RPD and Bias of 0.69, 3.628, 1.753 and 0.56, respectively). For pasture protein content (CP), micro-NIR showed less precision (internal validation model with R^2, RMSE and RPD of 0.36, 2.368 and 1.26, respectively), which points to the need to extend this study to a larger pasture sample, one more representative of the temporal and spatial variability of pastures characteristic of the Montado ecosystem in the Mediterranean region. Micro-NIR appears to be a promising tool, since it is light, small and easily transportable, giving values in real-time, thus contributing to a more informed decision-making by the agricultural manager.

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References

1. Batista, T.; Mascarenhas, J.M.; Mendes, P. Montado's ecosystem functions and services: The case study of Alentejo Central—Portugal. *Landsc. Ecol. Eng.* **2017**, *44*, 15–27.
2. Pinto-Correia, T.; Ribeiro, N.; Potes, J. *Livro Verde dos Montados. Edição: ICAAM-Instituto de Ciências Agrárias e Ambientais Mediterrânicas*; Universidade de Évora: Évora, Portugal, 2013.
3. Serrano, J. Utilização eficiente dos recursos no Montado: Sensores próximos e detecção remota no apoio à tomada de decisão. *Bol. CCDR Alentejo Perspect. 2020* **2019**, *32*, 18–25.
4. Serrano, J.; Peça, J.; Silva, J.M.; Shahidian, S.; Carvalho, M. Phosphorus dynamics in permanente pastures: Differential fertilizing and the animal effect. *Nutr. Cycl. Agroecosys.* **2011**, *90*, 63–74.
5. David, T.S.; Pinto, C.A.; Nadezhdina, N.; Kurz-Besson, C.; Henriques, M.O.; Quilhó, T.; Cermak, J.; Chaves, M.M.; Pereira, J.S.; David, J.S. Root functioning, tree water use and hydraulic redistribution in Quercus suber trees: A modeling approach based on root sap flow. *For. Ecol. Manag.* **2013**, *307*, 136–146, https://doi.org/10.1016/j.foreco.2013.07.012.
6. Serrano, J.; Shahidian, S.; Da Silva, J.M. Monitoring Seasonal Pasture Quality Degradation in the Mediterranean Montado Ecosystem: Proximal versus Remote Sensing. *Water* **2018**, *10*, 1422, https://doi.org/10.3390/w10101422.
7. Miao, F.; Guo, Z.; Xue, R.; Wang, X.; Shen, Y. Effects of Grazing and Precipitation on Herbage Biomass, Herbage Nutritive Value, and Yak Performance in an Alpine Meadow on the Qinghai–Tibetan Plateau. *PLoS ONE* **2015**, *10*, e0127275, https://doi.org/10.1371/journal.pone.0127275.
8. Efe Serrano, J. *Pastures in Alentejo: Technical Basis for Characterization, Grazing and Improvement*; Universidade de Évora—ICAM, Ed.; Gráfica Eborense: Évora, Portugal, 2006; pp. 165–178.
9. Biewer, S.; Fricke, T.; Wachendorf, M. Development of Canopy Reflectance Models to Predict Forage Quality of Legume-Grass Mixtures. *Crop Sci.* **2009**, *49*, 1917–1926, https://doi.org/10.2135/cropsci2008.11.0653.
10. Fontaneli, R.S.; Scheffer-Basso, S.M.; Dürr, J.W.; Appelt, J.V.; Bortolini, F.; Haubert, F.A. Predição da composição química de bermudas (*Cynodon* spp.) pela espectroscopia de reflectância no infravermelho proximal. *Rev. Bras. Zootec.* **2004**, *33*, 838–842, https://doi.org/10.1590/s1516-35982004000400003.
11. Bell, M.J.; Mereu, L.; Davis, J. The Use of Mobile Near-Infrared Spectroscopy for Real-Time Pasture Management. *Front. Sustain. Food Syst.* **2018**, *2*, 1–10, https://doi.org/10.3389/fsufs.2018.00076.
12. Serrano, J.; Shahidian, S.; Carapau, Â.; Rato, A. Near-Infrared Spectroscopy (NIRS) and Optical Sensors for Estimating Protein and Fiber in Dryland Mediterranean Pastures. *AgriEngineering* **2021**, *3*, 73–91, https://doi.org/10.3390/agriengineering3010005.
13. Pullanagari, R.; Yule, I.; King, W.; Dalley, D.; Dynes, R. The use of optical sensors to estimate pasture quality. *Int. J. Smart Sens. Intell. Syst.* **2011**, *4*, 125–137, https://doi.org/10.21307/ijssis-2017-430.
14. Swart, E.; Brand, T.; Engelbrecht, J. The use of near infrared spectroscopy (NIRS) to predict the chemical composition of feed samples used in ostrich total mixed rations. *South Afr. J. Anim. Sci.* **2012**, *42*, https://doi.org/10.4314/sajas.v42i5.22.
15. Decruyenaere, V.; Lecomte, P.; Demarquilly, C.; Aufrere, J.; Dardenne, P.; Stilmant, D.; Buldgen, A. Evaluation of green forage intake and digestibility in ruminants using near infrared reflectance spectroscopy (NIRS): Developing a global calibration. *Anim. Feed. Sci. Technol.* **2009**, *148*, 138–156, https://doi.org/10.1016/j.anifeedsci.2008.03.007.
16. Pullanagari, R.R.; Yule, I.J.; Tuohy, M.P.; Hedley, M.J.; Dynes, R.A.; King, W.M. Proximal sensing of the seasonal variability of pasture nutritive value using multispectral radiometry. *Grass. Forage Sci.* **2013**, *68*, 110–119.
17. Evangelista, C.; Basiricò, L.; Bernabucci, U. An Overview on the Use of Near Infrared Spectroscopy (NIRS) on Farms for the Management of Dairy Cows. *Agriculture* **2021**, *11*, 296, https://doi.org/10.3390/agriculture11040296.
18. Zanine, A.M.; Santos, E.M.; Ferreira, D.J. Principales métodos de evaluación de pasturas—Methods main of evaluation of pastures—Principais métodos de avaliação de pastagens. *Rev. Electron. Vet.* **2006**, 7, 1–13. REDVET ISSN 1695-7504.
19. Serrano, J.M.; Shahidian, S.; Da Silva, J.R.M. Monitoring pasture variability: Optical OptRx® crop sensor versus Grassmaster II capacitance probe. *Environ. Monit. Assess.* **2016**, *188*, 117, https://doi.org/10.1007/s10661-016-5126-5.
20. Gebremedhin, A.; Badenhorst, P.; Wang, J.; Spangenberg, G.C.; Smith, K.F. Prospects for Measurement of Dry Matter Yield in Forage Breeding Programs Using Sensor Technologies. *Agronomy* **2019**, *9*, 65, https://doi.org/10.3390/agronomy9020065.

21. Liu, N.; Parra, H.A.; Pustjens, A.; Hettinga, K.; Mongondry, P.; van Ruth, S.M. Evaluation of portable near-infrared spectroscopy for organic milk authentication. *Talanta* **2018**, *184*, 128–135, https://doi.org/10.1016/j.talanta.2018.02.097.
22. Bagchi, T.B.; Sharma, S.; Chattopadhyay, K. Development of NIRS models to predict protein and amylose content of brown rice and proximate compositions of rice bran. *Food Chem.* **2016**, *191*, 21–27, https://doi.org/10.1016/j.foodchem.2015.05.038.
23. Lanza, I.; Conficoni, D.; Balzan, S.; Cullere, M.; Fasolato, L.; Serva, L.; Contiero, B.; Trocino, A.; Marchesini, G.; Xiccato, G.; et al. Assessment of chicken breast shelf life based on bench-top and portable near-infrared spectroscopy tools coupled with chemometrics. *Food Qual. Saf.* **2021**, *5*, 1–11, https://doi.org/10.1093/fqsafe/fyaa032.
24. Murphy, D.J.; Brien, B.O.; Donovan, M.O.; Condon, T.; Murphy, M.D. A near infrared spectroscopy calibration for the prediction of fresh grass quality on Irish pastures. *Inf. Process. Agric.* **2021**, Available online 4 May 2021, https://doi.org/10.1016/j.inpa.2021.04.012. (accessed on 10 November 2021)
25. Givens, D.I.; Deaville, E.R. The current and future role of near infrared reflectance spectroscopy in animal nutrition: A review. *Aust. J. Agric. Res.* **1999**, *50*, 1131–1145, https://doi.org/10.1071/ar98014.
26. Corson, D.C.; Waghorn, G.C.; Ulyatt, M.J.; Lee, J. NIRS: Forage analysis and livestock feeding. *Proc. New Zealand Grassl. Assoc.* **1999**, *61*, 127–132, http://www.grassland.org.nz/publications/nzgrassland_publication_507.pdf.
27. Danieli, P.P.; Carlini, P.; Bernabucci, U.; Ronchi, B. Quality evaluation of regional forage resources by means of near infrared reflectance spectroscopy. *Ital. J. Anim. Sci.* **2004**, *3*, 363–376, https://doi.org/10.4081/ijas.2004.363.
28. Pullanagari, R.R.; Yule, I.J.; Tuohy, M.P.; Hedley, M.J.; Dynes, R.A.; King, W. In-field hyperspectral proximal sensing for estimating quality parameters of mixed pasture. *Precis. Agric.* **2012**, *13*, 351–369, https://doi.org/10.1007/s11119-011-9251-4.
29. AlOmar, D.; Fuchslocher, R.; Cuevas, J.; Mardones, R.; Cuevas, E. Prediction of the composition of fresh pastures by near infrared reflectance or interactance-reflectance spectroscopy. *Chil. J. Agric. Res.* **2009**, *69*, 198–206, https://doi.org/10.4067/s0718-58392009000200009.
30. Beć, K.B.; Grabska, J.; Huck, C.W. Principles and Applications of Miniaturized Near-Infrared (NIR) Spectrometers. *Chem. Eur. J.* **2021**, *27*, 1514–1532, https://doi.org/10.1002/chem.202002838.
31. Cecchini, C.; Antonucci, F.; Costa, C.; Marti, A.; Menesatti, P. Application of near-infrared handheld spectrometers to predict semolina quality. *J. Sci. Food Agric.* **2021**, *101*, 151–157, https://doi.org/10.1002/jsfa.10625.
32. Yakubu, H.G.; Kovacs, Z.; Toth, T.; Bazar, G. The recent advances of near-infrared spectroscopy in dairy production—A review. *Crit. Rev. Food Sci. Nutr.* **2020**, 1–22, https://doi.org/10.1080/10408398.2020.1829540.
33. Parrini, S.; Acciaioli, A.; Franci, O.; Pugliese, C.; Bozzi, R. Near Infrared Spectroscopy technology for prediction of chemical composition of natural fresh pastures. *J. Appl. Anim. Res.* **2019**, *47*, 514–520, https://doi.org/10.1080/09712119.2019.1675669.
34. Alomar, D.; Fuchslocher, R.; de Pablo, M. Effect of preparation method on composition and NIR spectra of forage samples. *Anim. Feed. Sci. Technol.* **2003**, *107*, 191–200, https://doi.org/10.1016/s0377-8401(03)00124-x.
35. Suárez, P.L.; Soldado, A.; González-Arrojo, A.; Vicente, F.; de la Roza-Delgado, B. Rapid on-site monitoring of fatty acid profile in raw milk using a handheld near infrared sensor. *J. Food Compos. Anal.* **2018**, *70*, 1–8, https://doi.org/10.1016/j.jfca.2018.03.003.
36. Kademi, H.I.; Ulusoy, B.H.; Hecer, C. Applications of miniaturized and portable near infrared spectroscopy (NIRS) for inspection and control of meat and meat products. *Food Rev. Int.* **2019**, *35*, 201–220, https://doi.org/10.1080/87559129.2018.1514624.
37. Serrano, J.; Shahidian, S.; Da Silva, J.M.; Paixão, L.; Carreira, E.; Carmona-Cabezas, R.; Nogales-Bueno, J.; Rato, A.E. Evaluation of Near Infrared Spectroscopy (NIRS) and Remote Sensing (RS) for Estimating Pasture Quality in Mediterranean Montado Ecosystem. *Appl. Sci.* **2020**, *10*, 4463, https://doi.org/10.3390/app10134463.
38. Serrano, J.; Shahidian, S.; da Silva, J.M.; Paixão, L.; de Carvalho, M.; Moral, F.; Nogales-Bueno, J.; Teixeira, R.; Jongen, M.; Domingos, T.; et al. Evaluation of Near Infrared Spectroscopy (NIRS) for Estimating soil organic matter and phosphorus in Mediterranean Montado Ecosystem. *Sustainability* **2021**, *13*, 2734, https://doi.org/10.3390/su13052734.
39. AOAC. Official Method of Analysis of AOAC International, 18th ed.; AOAC International: Arlington, AT, USA, 2005.
40. Goedhart, P.W. Comparison of multivariate calibration methods for prediction of feeding value by near infrared reflectance spectroscopy. *Neth. J. Agric. Sci.* **1990**, *38*, 449–460, https://doi.org/10.18174/njas.v38i3b.16570.
41. Davies, A.; Fearn, T. Back to basics: Calibration statistics. *Spectrosc. Eur.* **2006**, *18*, 31–32, http://www.eurolabdanmark.dk/documents/Netvaerk/Kemi/SpecEurope_BackToBasics_CalibrationStats_TD.pdf.
42. Almeida, F.M.N. Espectroscopia de Infravermelho Próximo com Transformada de Fourier (FT-NIR) na Caracterização de Farinhas para Alimentação Pueril. Dissertação para obtenção do grau mestre em Engenharia Biológica, Instituto Superior Técnico—Universidade Técnica de Lisboa, Lisboa, Portugal, 2009.
43. Safari, H.; Fricke, T.; Wachendorf, M. Determination of fibre and protein content in heterogeneous pastures using field spectroscopy and ultrasonic sward height measurements. *Comput. Electron. Agric.* **2016**, *123*, 256–263, https://doi.org/10.1016/j.compag.2016.03.002.
44. Pullanagari, R.R.; Kereszturi, G.; Yule, I. Integrating Airborne Hyperspectral, Topographic, and Soil Data for Estimating Pasture Quality Using Recursive Feature Elimination with Random Forest Regression. *Remote Sens.* **2018**, *10*, 1117, https://doi.org/10.3390/rs10071117.
45. Lobos, I.; Inia, I.D.I.A.; Moscoso, C.J.; Pavez, P. Calibration models for the nutritional quality of fresh pastures by nearinfrared reflectance spectroscopy. *Cienc. Investig. Agrar.* **2019**, *46*, 234–242, https://doi.org/10.7764/rcia.v46i3.2020.
46. Hermansen, C.; Norgaard, T.; de Jonge, L.W.; Moldrup, P.; Müller, K.; Knadel, M. Predicting glyphosate sorption across New Zealand pastoral soils using basic soil properties or Vis–NIR spectroscopy. *Geoderma* **2020**, *360*, 114009, https://doi.org/10.1016/j.geoderma.2019.114009.

47. Versari, A.; Laurie, F.; Ricci, A.; Laghi, L.; Parpinello, G.P. Progress in authentication, typification and traceability of grapes and wines by chemometric approaches. *Food Res. Int.* **2014**, *60*, 2–18, https://doi.org/10.1016/j.foodres.2014.02.007.
48. Mendarte, S.; Ibarra, A.; Garbisu, C.; Besga, G. Use of portable NIRS equipment in field conditions to determine the nutritional value of mountain pastures. In Proceedings of the 23th General Meeting of the European Grassland Federation, Kiel, Germany, 29 August–2 September 2010; Schnyder, H., Isselstein, J., Taube, F., Auerswald, K., Schellberg, J., Wachendorf, M., Herrmann, A., Gierus, M., Wrage, N., Hopkins, A., Eds.; pp. 244–246.
49. Reeves, J.B.III. Use of near infrared reflectance spectroscopy. In *Farm Animal Metabolism and Nutrition*; D'Mello, J.P.F., Ed.; CABI Publishing: Wallingford, UK, 2000; pp. 185–207.
50. Curran, P.J. Remote sensing of foliar chemistry. *Remote Sens. Environ.* **1989**, *30*, 271–278, https://doi.org/10.1016/0034-4257(89)90069-2.
51. Malegori, C.; Marques, E.J.N.; de Freitas, S.T.; Pimentel, M.F.; Pasquini, C.; Casiraghi, E. Comparing the analytical performances of Micro-NIR and FT-NIR spectrometers in the evaluation of acerola fruit quality, using PLS and SVM regression algorithms. *Talanta* **2017**, *165*, 112–116, https://doi.org/10.1016/j.talanta.2016.12.035.
52. Ghajar, S.; Tracy, B. Proximal Sensing in Grasslands and Pastures. *Agriculture* **2021**, *11*, 740, https://doi.org/10.3390/agriculture11080740.

CAPÍTULO 5

Efeito da correção do solo, nas necessidades de suplementação de ovinos

agronomy

Article

Can Soil pH Correction Reduce the Animal Supplementation Needs in the Critical Autumn Period in Mediterranean Montado Ecosystem?

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Abstract: Extensive livestock production in Mediterranean climate conditions and acidic soils requires animal feed supplementation. This occurs during the summer and, frequently, also in the autumn and winter, depending on the prevailing rainfall patterns. The purpose of this study was to evaluate the effect of dolomitic limestone application and of tree canopy on availability, quality, and floristic composition of a permanent pasture, grazed by sheep. At the end of autumn, winter, and spring of 2018/2019 and 2019/2020 pasture green and dry matter production (GM and DM, respectively), crude protein (CP), and fiber (neutral detergent fiber) were monitored in 24 sampling points. Half of these points were located in areas amended with dolomitic limestone (COR) and half in unamended areas (UCOR). In each of these, half of the sampling points were located under tree canopy (UTC) and half outside tree canopy (OTC). Pasture floristic composition was monitored in spring 2020. The results show, in autumn, a positive and significant effect (i) of soil pH amendment on pasture DM and CP daily growth rate (kg·ha^{-1}·day^{-1}) (+28.8% and +42.6%, respectively), and (ii) of tree canopy on pasture CP daily growth rate (+26.4%). Both factors affect pasture floristic composition. Pasture species were identified as potential bio-indicators, characteristic of each field area. These results show the practical interest of the soil pH correction to reduce the animal supplementation needs in the critical autumn period in the Mediterranean montado ecosystem.

Keywords: montado ecosystem; dolomitic limestone; tree canopy; pasture; dry matter; crude protein; floristic composition

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1. Introduction

Montado (dehesa in Spain) is an agro-silvo-pastoral ecosystem characteristic of the southern region of the Iberian Peninsula [1], with an important role in natural resource conservation and carbon sequestration, reducing soil erosion, and mitigating the effects of climate change [2]. In this ecosystem, pasture, considered a low-cost feed [3], is the main food resource for extensive livestock production [4]. This resource provides adequate nutritional value but only for a part of the year [5] because it does not have constant productivity and quality [3]. The Mediterranean climate is a bioclimatic variant of the temperate climate with a marked seasonal and inter-annual variability, characterized by winter cold stress and summer drought stress. These are periods when pasture species do not grow [4], due to the physiologic and metabolic limitations that inhibit normal plant functions [6]. Therefore, ruminants that depend solely on natural pasture start the grazing period with forage of high quality (low levels of fiber and high levels of protein), but after the blooming period and the peak biomass production in late spring, there is a sharp drop in pasture quality associated with a decrease of the pasture feed value (reduction in the proportion of leaves and high tissue lignification) which may lead to the worsening of the animal's corporal condition [5].

These periods, in which animal diets need to be supplemented, normally last about six months (summer and autumn seasons) but can go on for longer if rainfall patterns in autumn and winter seasons are below normal [4]. Under these circumstances, supplementation is inevitable to meet nutritional deficiencies, ensuring greater average daily gain, and to mitigate the fluctuation of pasture quality and dry matter production over the year [3]. However, this strategy is expensive and unviable from an economic point of view, so alternatives should be sought to improve food self-sufficiency, thus reducing production costs [7].

In Portugal, this ecosystem is based on Cambisoils of the Alentejo region [8], whose genesis derives from granitic bedrock. As a result, these are normally shallow and stony soils with low fertility and pH, thus with very clear handicaps in terms of productivity [9]. Soil acidity restricts agricultural production mainly due to nutrient deficiency and toxicity by metals such as manganese, Mn [10] and, due to the different tolerance of botanical species, with significant impact on the pasture floristic composition [11] and pasture quality [9]. Various pasture species are considered to be very sensitive to Mn toxicity and affected by the presence of high levels of Mn, while others are considered to be relatively tolerant to soil acidity [9]. For example, the development of legumes in general is inhibited in acidic soils, and they can benefit from soil amendments [11] but also from the application of phosphate fertilizers, which result in an increase in the total biomass production of the pasture [12].

The recommended procedure for the recovery of these soils is the installation of permanent pastures and the increase of soil fertility through the application of chemical phosphate fertilizers [9]. According to Carvalho et al. [10], one of the low-cost alternatives suggested in this context is the application of dolomitic limestone as a way of improving soil fertility and, consequently, pasture productivity and quality, while avoiding the dependence on supplementation. Some studies have shown, however, that soil acidity amendment based on dolomitic limestone application is a slow and gradual process [12], recommending the application of limestone systematically and, at least every two years until the soil pH stabilized at close to neutral [9]. A recent study [12], in the same experimental field and referring to only one year (2018/2019), showed a positive influence of soil amendment on pasture quality in terms of CP availability. However, few studies explore the development of the montado ecosystem as a result of soil pH correction, under and outside tree canopy. Soil parameters have long been recognized as the main drivers of vegetation growth [13], so one would expect that the existing variability in soil fertility conferred by the tree canopy will also play a decisive role in vegetation growth [14]. Despite the greater fertility normally associated with areas under the canopy (UTC), competition for resources (water, light, and nutrients) between tree and pasture roots is the main reason for decreased crop yields UTC [15,16]. Additionally, there are patterns of distribution of certain botanical species that can influence the quality and productivity of the pasture UTC and outside tree canopy (OTC) [17,18].

The purpose of this study was to evaluate, in two vegetative cycles (2018/2019 and 2019/2020), the effect of dolomitic limestone application and of tree canopy on: (i) pasture daily grown rate (DM, kg·ha^{-1}·day^{-1}); (ii) pasture daily grown rate quality (CP, kg·ha^{-1}·day^{-1}); and pasture floristic composition.

2. Materials and Methods

2.1. Experimental Field and Sampling Scheme

The experimental field (Figure 1), with 4.0 ha, is located at Mitra Farm (38°53.10 N; 8°01.10 W). This figure shows the amended area ("COR"; approximately 2 ha) and the unamended area ("UCOR"; approximately 2 ha) and, in each of these, the six trees used as a reference in the sampling process. For each reference tree two sampling points were geo-referenced, one UTC and the other OTC. In each of these twenty-four sampling points, a wooden grazing exclusion cage (dimensions 0.5 m × 0.5 m × 0.5 m) was installed.

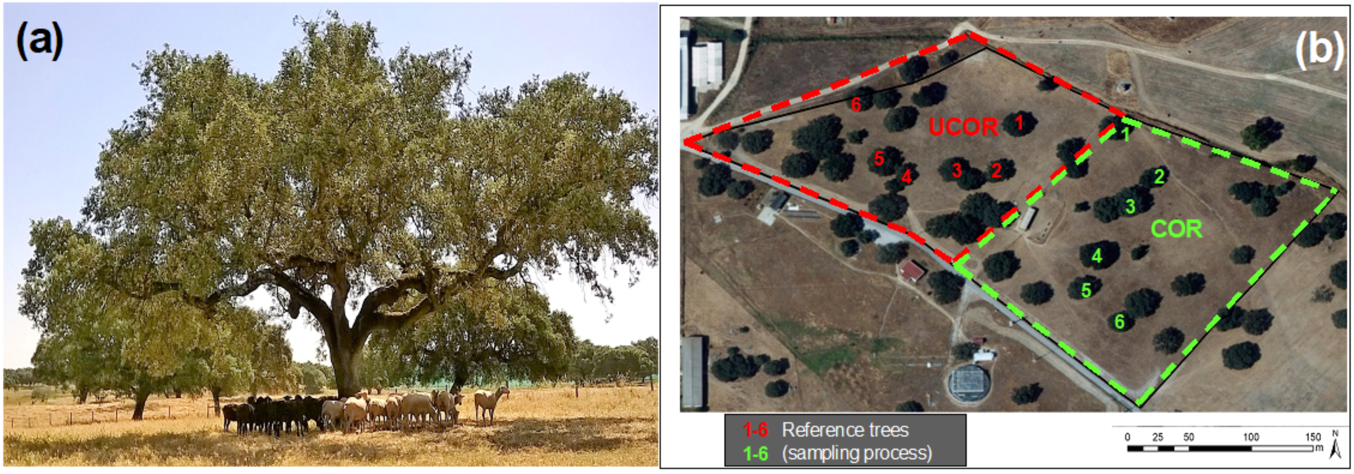

Figure 1. Experimental field: (**a**) picture of montado ecosystem; (**b**) sampling areas, amended and unamended (COR and UCOR, respectively) and the six trees used in each area as reference in sampling process.

The predominant soil of this field is classified as Cambisol, derived from granite, usually cultivated under mixed, agro-forestry production systems [8]. This Montado ecosystem consists of dryland biodiverse pastures, *Quercus ilex ssp. rotundifolia* Lam. trees, and is grazed by adult sheep in a rotational regime (variable stocking rate throughout the year). These types of soils are generally characterized as shallow soils with low fertility. In this case, soil analyses performed in this same field in October 2015 [19] revealed a sandy loam texture (sand = 80.6 ± 2.3%; silt = 10.1 ± 1.7%; and clay = 9.3 ± 1.4%), small cation exchange capacity (CEC = 7.3 cmol kg^{-1}), low pH (5.4 ± 0.3), medium organic matter content (2.0 ± 0.8%), high levels of potassium (K_2O = 270 ± 136 mg kg^{-1}), of phosphorus (P_2O_5 = 93 ± 62 mg kg^{-1}), of magnesium (Mg = 96 ± 44 mg kg^{-1}) and manganese (Mn = 76 ± 45 mg kg^{-1}).

2.2. Characterization of the Climate

The Mediterranean climate is characterized by a high concentration of rainfall in the winter and very dry, hot summers. Rainy autumns, very cold winters (with minimum temperatures close to 0 °C between December and February), uneven springs, and very hot summers (maximum temperatures above 40 °C) are characteristic of this region and climate, with significant impact on the vegetative cycle of dryland pastures. The annual accumulated precipitation in the region varies between 300 and 650 mm, distributed mainly between October and March. Figure 2 illustrates the thermo-pluviometric diagram of the Meteorological Station of Mitra (Évora, Portugal). This figure shows the evolution of the monthly mean temperature and monthly rainfall between July 2018 and June 2020. These are very different years in terms of accumulated precipitation, the first very dry (accumulated rainfall of 315 mm) and the second relatively rainy, with practically double the accumulated rainfall (627 mm). This difference is particularly accentuated in autumn (186 mm in 2018 and 330 mm in 2019) and in spring (56 mm in 2019 and 168 mm in 2020) seasons and confirms the inter-annual irregularity responsible for low productivity and poor quality of dryland pastures in this region.

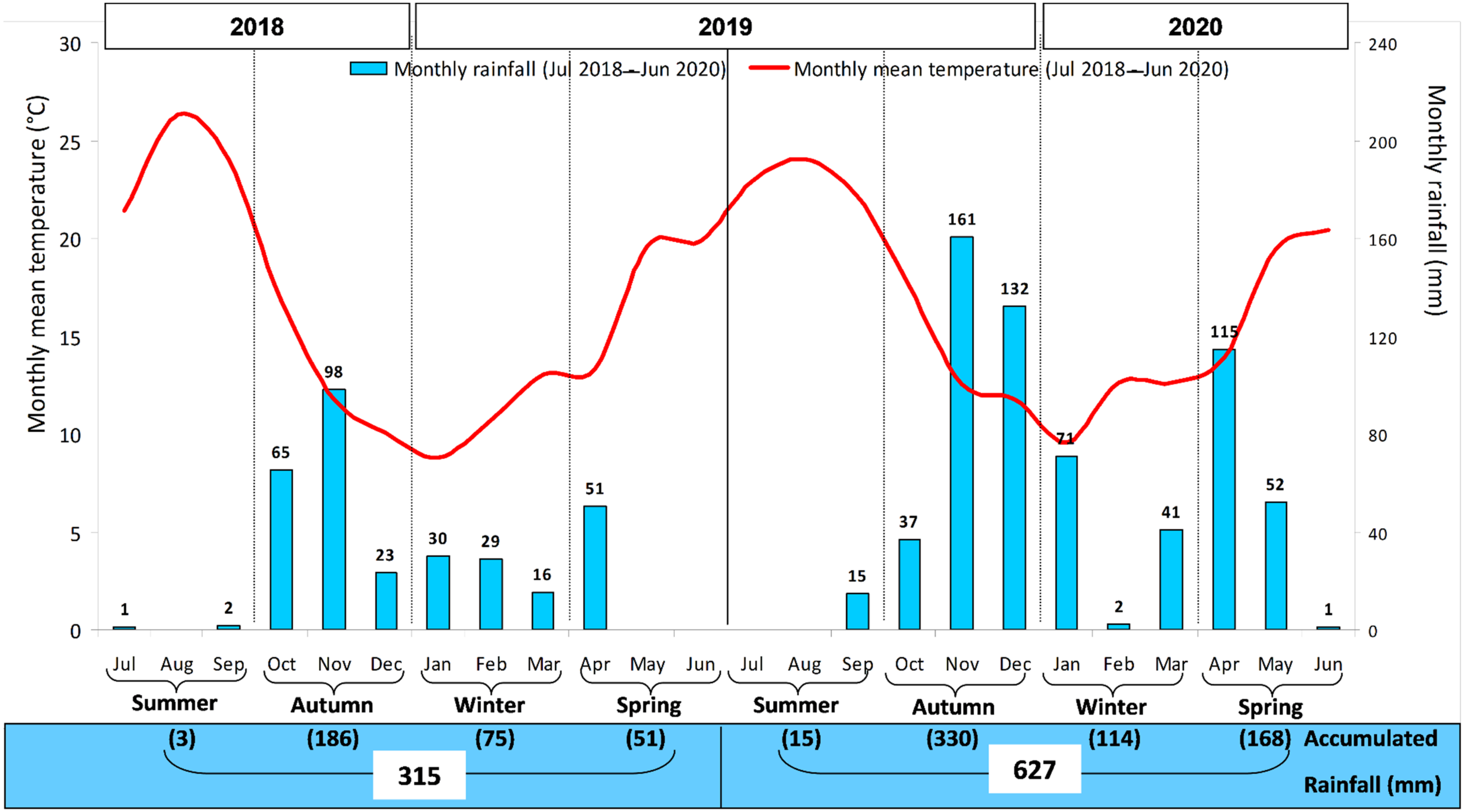

Figure 2. Thermo-pluviometric diagram of Meteorological Station of Mitra (Évora, Portugal) between July 2018 and June 2020. Is also indicates the accumulated rainfall by season and year.

2.3. Chronological Sequence of the Interventions and Measurements in the Experimental Field

Figure 3 shows the chronological diagram of the activities carried out in this work for monitoring the montado ecosystem at the Mitra experimental field, between October 2015 and June 2020. Soil sampling carried out in October 2015 marked the beginning of this project having identified a low pH (mean pH_{H2O} = 5.4 ± 0.3) and low ratio Mg/Mn (approximately 1.3) [19]. Soil interventions consisted of two differential amendments (November 2017 and June 2019), with the application of 2000 kg ha^{-1} of dolomitic limestone (42% calcium oxide, CaO and 10% magnesium oxide, MgO) only in "COR" areas, and a uniform fertilizer application in all experimental field (December 2018), with the application of 100 kg ha^{-1} of ammonium phosphate (18% of nitrogen and 46% of phosphorous). In October 2018 [19] and in March 2020, twenty-four geo-referenced soil samples were collected, twelve in each area ("COR" and "UCOR"), half UTC, and the other half OTC. The effect of soil interventions (amendment and fertilization) was evaluated outside and under tree canopy at the level of pasture productivity and quality. Pasture sampling processes were carried out in two vegetative cycles: 2018/2019 and 2019/2020.

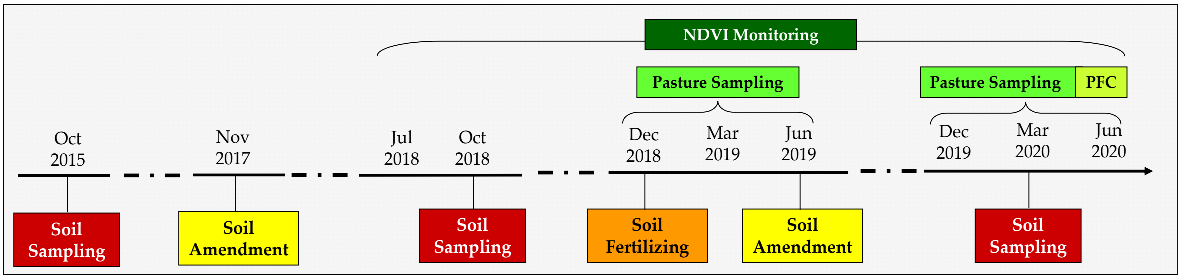

Figure 3. Chronological sequence of the interventions and measurements in the experimental field between October 2015 and June 2020. PFC—Evaluation of pasture floristic composition.

2.4. Soil Sample Collection and Analysis

Soil samples were collected in a depth range of 0–0.30 m, on three occasions: October 2015 [19], October 2018 [12], and March 2020. One composite soil sample was taken in each of the geo-referenced sampling points, comprising four subsamples from within 1 m of the center of the exclusion cage. Soil samples were kept in plastic bags and, in the laboratory, air-dried, and sieved. In March 2020, with the objective of evaluating the effect of dolomitic limestone application (November 2017 and June 2019) on soil pH, Mg, and Mn availability, the fraction with diameter <2 mm was characterized in terms of pH in 1:2.5 (soil: water) suspension, using the potentiometric method and Mg and Mn were measured using atomic absorption spectrometry [20].

2.5. Pasture Samples Collection and Analysis

Pasture sampling processes were carried out at the end of autumn (December), of winter (March), and of spring (June) in two consecutive vegetative cycles: 2018/2019 and 2019/2020. Pasture samples collected at twenty-four exclusion cages were subjected to standard analysis of wet chemistry according to the Association of Official Analytical Chemists [21] to obtain the following pasture parameters: (i) productivity (green matter, GM, and dry matter, DM, in kg·ha^{-1}) and (ii) quality (crude protein, CP, and neutral detergent fiber, NDF, in % of DM). DM and CP are expressed as daily growth rate, in kg·ha^{-1}·day^{-1}, calculated from Equations (1) and (2), respectively. The number of days (n) used in these equations in each pasture vegetative cycle (2018/2019 and 2019/2020) was: (i) in autumn, the number of days between the beginning of vegetative cycle (the moment of plant emergence—10 days after an accumulated rainfall of 30 mm since September of each year) and the day of pasture collection; (ii) in winter, the number of days between the beginning of the vegetative cycle and the second pasture collection; (iii) in spring, the number of days between the beginning of the vegetative cycle and the third pasture collection. The daily growth rates variations (DM_{var} and CP_{var}), expressed graphically, indicate the variation of *DM* and *CP* (in kg·ha^{-1}) in the respective period.

$$DM\left(\text{kg·ha}^{-1}\text{·day}^{-1}\right) = \frac{DM\left(\text{kg·ha}^{-1}\right)}{n} \quad (1)$$

$$CP\left(\text{kg·ha}^{-1}\text{·day}^{-1}\right) = \frac{CP(\%) \times DM\left(\text{kg·ha}^{-1}\text{·day}^{-1}\right)}{100} \quad (2)$$

where "*DM*" is pasture dry matter, "*CP*" is pasture crude protein, and "*n*" is the number of days of each temporal period considered.

Pasture vegetation index (Normalized Difference Vegetation Index, NDVI) was monitored monthly between July 2018 and June 2020. Measurements were carried out in all twenty-four sampling points with an active optical sensor (AOS, OptRxTM, Ag Leader, Ames, IA, USA). The sensor measures "RED" (670 nm) and "Near InfraRed" (NIR, 775 nm) spectral bands, which allow the calculation of NDVI (Equation (3)). The average monthly value of NDVI in the set of twenty-four sampling points of the experimental field, between July 2018 and June 2020, was calculated to characterize graphically its evolution during the pasture vegetative cycle.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (3)$$

During the pasture flowering period of the 2019/2020 vegetative cycle (May 2020), a floristic inventory of species and families present in each of the sampling points was carried out by an expert in conservation biology based on the phytosociological method of Braun-Blanquet [22]. In each sampling area (0.25 m^2), the percentage of coverage by each species was recorded.

2.6. Statistical Analysis of the Data

Descriptive statistical analysis (mean, standard variation, and range) was performed for soil and pasture parameters. Then, ANOVA of the data was carried out considering a two-factor experiment (soil amendment, COR vs. UCOR, and influence of tree canopy, UTC vs. OTC), using "MSTAT-C" software with a 95% significance level ($p < 0.05$). Because soil amendment was not geographically, the interactions between fields and replicas were used to generate the error to compare the two fields. The "Fisher" ("Fisher's least significant difference, LSD") test was applied whenever the ANOVA results presented significant differences between factors.

Data of PFC were submitted to a multilevel pattern analysis (Indicator Species Analysis- ISA), a specific package for "R" statistic software (St. Louis, MO, USA) [23]. ISA involves the calculation of an indicator value (IV) for species, corresponding to the product of the relative abundance (specificity) and relative frequency (fidelity), expressed as the degree (in percentage) [24–26]. The indicator value ranges between 0 (species absent in a given group) and 100 (species that occurs in all samples within the group and does not occur in other groups) [26]. In order to identify bio-indicator species, characteristic of each study area, three approaches were taken in this analysis: (i) soil pH correction (COR and UCOR) factor; (ii) tree canopy (UTC and OTC) factor; and (iii) the combination of the two previous factors (COR, UCOR, UTC, and OTC). Statistical significance was assessed using $\alpha = 0.05$.

3. Results

3.1. Temporal and Spatial Variability Pattern of the Soil Parameters

Taking as reference the soil data obtained in October 2015 and in March 2020 (Table 1), there was a slight increase in pH (on average from 5.4 to 5.7). This improvement in pH was significantly more evident, as expected, in the areas where the dolomitic limestone was applied ($pH_{COR} = 5.8 \pm 0.4$; $pH_{UCOR} = 5.6 \pm 0.2$; $p = 0.0225$; Table 1) and accentuates the pattern of improvement that the October 2018 results also evidenced ($pH_{COR} = 5.6 \pm 0.2$;

pH_{UCOR} = 5.3 ± 0.2; *p* = 0.0193; Table 1). However, these results also show that the surface application of amendments has a slow positive effect on the soil pH.

Still spatially, a positive and significant effect of the tree canopy on the soil pH is also evident.

Table 1 shows that dolomitic limestone (which has 10% of MgO in its composition) application also had a positive effect on the Mg/Mn ratio: overall the ratio increased from 1.26 in 2015 to 2.36 in 2020. In the COR areas this ratio reached an average of 3.33, compared to 1.38 in UCOR areas. This improvement resulted mainly from the reduction of Mn levels: in global terms, the Mn levels decreased from 76.4 ± 44.9 mg kg^{-1} in 2015 to 40.1 ± 17.3 mg kg^{-1} in 2020.

The improvement in the Mg/Mn ratio materialized in a similar way in UTC areas (on average, it increased from 1.15 to 2.15 in 2020) and in OTC areas (on average it went from 1.45 in 2015 to 2.32 in 2020).

Table 1. Descriptive (mean ± standard deviation) and inferential statistics of soil parameters in experimental field (0–0.30 m depth).

Soil Parameters	GLOBAL	COR	UCOR	Prob.	UTC	OTC	Prob.	Ref.
October 2015								
pH	5.4 ± 0.3	-	-	-	5.4 ± 0.4	5.3 ± 0.2	ns	[19]
Mg (mg kg^{-1})	95.6 ± 43.7				115.0 ± 38.8	76.3 ± 40.9	0.0503	
Mn (mg kg^{-1})	76.4 ± 44.9				100.0 ± 45.7	52.8 ± 30.1	0.0131	
October 2018								
pH	5.4 ± 0.2	5.6 ± 0.2	5.3 ± 0.2	0.0193	5.5 ± 0.2	5.3 ± 0.2	0.0232	[12]
Mg (mg kg^{-1})	78.1 ± 33.0	82.9±32.1	73.3±34.6	ns	84.2 ± 21.2	72.1 ± 41.8	ns	
Mn (mg kg^{-1})	50.2 ± 29.7	33.6±16.1	66.8±31.4	0	38.4 ± 23.4	62.1 ± 31.5	0	
March 2020								
pH	5.7 ± 0.3	5.8 ± 0.4	5.6 ± 0.2	0.0225	5.8 ± 0.2	5.6 ± 0.4	0.0331	-
Mg (mg kg^{-1})	94.8 ± 29.2	108.1 ± 22.3	71.3 ± 16.8	0.0442	102.4 ± 25.8	79.8 ± 19.3	0.0215	
Mn (mg kg^{-1})	40.1 ± 17.3	32.5 ± 13.6	51.6 ± 24.6	0.0182	47.6 ± 22.3	34.3 ± 16.1	0.0441	

GLOBAL—All area; COR—Amended areas; UCOR—Unamended areas; UTC—Under tree canopy areas; OTC—Outside tree canopy areas; SD—Standard deviation; Prob.—Significance (Probability) at level 0.05; ns—Not significant; Ref.—Reference; Mg—Magnesium; Mn—Manganese.

3.2. Variability Pattern of Pasture Productivity and Quality

Spatially, dolomitic limestone application tended to have a positive effect on pasture productivity (Table 2), however, this was significant for both GM and DM only in Winter 2018/2019 and in Autumn 2019/2020. In terms of pasture quality, CP showed no significant change due to the application of dolomitic limestone, while NDF in winter showed lower values in COR areas. Tree canopy areas (UTC), on the other hand, showed a significant and positive effect on GM and DM in autumn. This trend is reversed in winter and especially in spring, with clearly greater productivity OTC. Tree canopy also showed a significant and positive effect on pasture quality (with higher values of CP and lower values of fiber UTC).

Table 2. Descriptive (mean ± standard deviation) and inferential statistics of pasture parameters of the experimental field.

Pasture Parameters	COR	UCOR	Prob.	UTC	OTC	Prob.	COR × UTC	COR × OTC	UCOR × UTC	UCOR × OTC
GM (t ha^{-1})										
2018/2019, Autumn	7.9 ± 3.4	6.8 ± 2.4	ns	6.9 ± 3.5	7.9 ± 2.9	ns	7.9a	7.8a	5.6b	8.0a
Winter	16.3 ± 9.8	8.7 ± 4.9	0.0486	9.2 ± 8.1	15.8 ± 7.8	0.0205	13.7a	18.8a	4.6b	12.8a
Spring	4.9 ± 2.6	4.7 ± 2.8	ns	2.7 ± 1.4	6.9 ± 1.9	0.0001	3.3b	6.6a	2.2b	7.2a
2019/2020, Autumn	8.3 ± 3.4	5.1 ± 2.2	0.0277	7.6 ± 3.8	5.8 ± 2.4	0.0959	9.5a	7.2b	5.7bc	4.4c
Winter	14.4 ± 6.7	13.0 ± 5.5	ns	12.5 ± 5.3	14.8 ± 6.7	ns	14.1a	14.7a	10.9b	15.0a
Spring	12.7 ± 4.6	14.7 ± 8.7	ns	9.8 ± 2.5	17.8 ± 7.4	0.0010	9.3b	16.2a	9.9b	19.4a
DM (t ha^{-1})										
2018/2019, Autumn	1.1 ± 0.6	0.9 ± 0.2	ns	1.0 ± 0.6	1.0 ± 0.3	ns	1.2a	1.0a	0.9a	1.1a
Winter	2.3 ± 0.9	1.4 ± 0.4	0.0198	1.6 ± 0.8	2.1 ± 0.8	0.0307	2.1ab	2.6a	1.1c	1.6bc
Spring	3.0 ± 1.8	3.1 ± 1.9	ns	1.7 ± 0.9	4.5 ± 1.3	0.0002	1.8b	4.2a	1.5b	4.7a
2019/2020, Autumn	1.3 ± 0.4	0.8 ± 0.4	0.0226	1.1 ± 0.5	1.0 ± 0.4	ns	1.2a	1.3a	0.9b	0.8b
Winter	2.1 ± 1.0	1.8 ± 0.4	ns	1.9 ± 0.7	2.0 ± 0.9	ns	2.0a	2.1a	1.8b	1.9b
Spring	2.9 ± 1.7	2.9 ± 1.3	ns	1.7 ± 0.5	4.1 ± 1.0	0.0000	1.5b	4.4a	2.0b	3.8a
CP (%)										
2018/2019, Autumn	24.7 ± 8.6	21.0 ± 3.2	ns	25.1 ± 8.0	20.5 ± 3.9	0.0708	28.5a	20.9b	21.8ab	20.2b
Winter	19.6 ± 6.2	19.1 ± 4.8	ns	20.3 ± 6.1	18.4 ± 4.7	ns	23.5a	15.7b	17.1b	21.2ab
Spring	10.5 ± 5.1	8.9 ± 1.9	ns	12.2 ± 4.0	7.2 ± 1.3	0.0004	14.1a	6.8c	10.2b	7.6bc
2019/2020, Autumn	19.3 ± 4.8	18.8 ± 4.1	ns	22.1 ± 3.4	16.0 ± 2.8	0.0015	22.5a	16.0b	21.8a	15.9b
Winter	14.4 ± 4.0	15.7 ± 3.3	ns	15.53 ± 4.2	14.6 ± 3.2	ns	15.6a	13.2b	15.5a	15.9a
Spring	13.7 ± 6.2	13.0 ± 3.9	ns	17.4 ± 3.5	9.3 ± 2.5	0.0000	19.1a	8.2b	15.7a	10.4b
NDF (%)										
2018/2019, Autumn	48.5 ± 9.7	50.4 ± 6.9	ns	52.2 ± 6.6	46.7 ± 9.2	ns	50.7a	46.3a	53.8a	47.1a
Winter	43.1 ± 6.9	48.7 ± 9.0	0.0424	50.6 ± 9.1	41.2 ± 3.8	0.0014	44.7b	41.5b	56.7a	40.8b
Spring	63.6 ± 5.0	65.6 ± 2.8	ns	62.7 ± 4.0	66.5 ± 3.4	0.0457	60.6b	66.7a	64.9ab	66.3a
2019/2020, Autumn	36.3 ± 8.8	39.0 ± 6.8	ns	35.5 ± 7.4	39.9 ± 8.0	0.0976	34.8b	37.9b	36.2b	41.9a
Winter	41.6 ± 6.3	48.7 ± 4.3	0.0126	43.1 ± 5.0	47.3 ± 7.2	0.0452	40.2c	43.1bc	46.0b	51.5a
Spring	57.3 ± 6.9	58.7 ± 6.2	ns	53.9 ± 5.7	62.1 ± 4.3	0.0002	51.5b	63.2a	56.3ab	61.1a

N—Number of samples; COR—Amended areas; UCOR—Unamended areas; Prob.—Probability at level 0.05; UTC—Under tree canopy; OTC—Outside tree canopy; GM—Green matter; DM—Dry matter; CP—Crude protein; NDF—Neutral detergent fiber; Different lowercase letters in the interactions indicate significant differences in the mean of pasture parameters for the "Fisher's" test (Prob. <0.05).

The pattern of evolution of DM (Figure 4a) and CP (Figure 4b) in the experimental field, based on the average of these parameters during two vegetative cycles (2018/2019 and 2019/2020; Table 3) show that COR areas have a greater tendency, in autumn and winter, towards greater DM than UCOR areas. Unamended areas tend to recover in late spring (Figure 4a). This parameter (DM) is influenced more by tree canopy than soil pH correction, showing, between winter and spring, a very significant increase in OTC and, during the same period, a slight decrease in UTC. Pasture quality (measured as CP in % DM; Figure 4b), on the other hand, shows a decrease between autumn and summer of the following year. It is also evident that (i) the highest CP values are obtained UTC throughout the entire vegetative cycle; and (ii) that soil pH correction anticipates the availability of protein in the autumn (with higher CP values in COR areas), an effect which tends to fade by the end of the vegetative cycle (late spring).

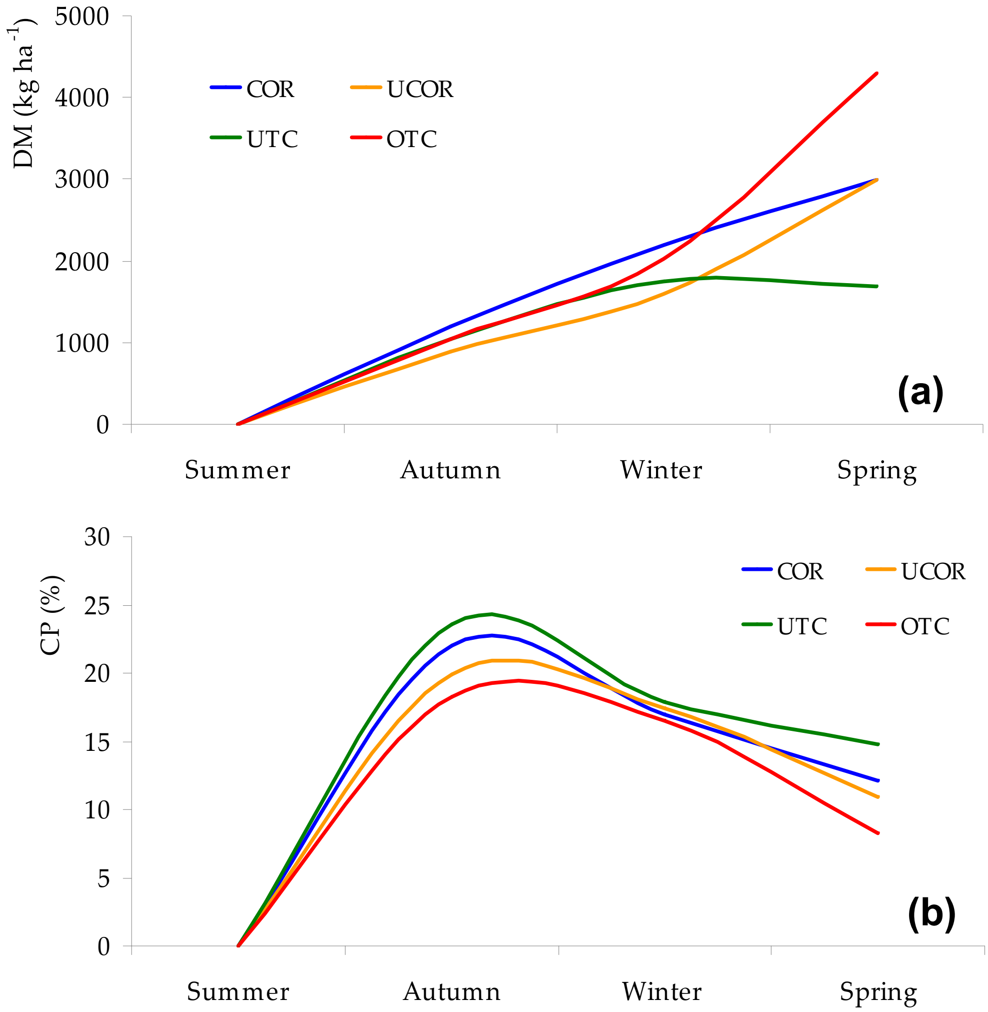

Figure 4. Evolution of pasture dry matter (DM; (**a**)) and crude protein (CP; (**b**)) in the experimental field: average values of 2018/2019 and 2019/2020 vegetative cycles.

Table 3. Floristic composition (botanical species and family mean cover, %) of pasture of the experimental field in spring 2020.

FAMILY	***Botanical* Species**	**COR**		**UCOR**	
		UTC	**OTC**	**UTC**	**OTC**
Vegetation cover		65.8 ± 14.3	91.7 ± 7.5	64.2 ± 15.3	98.3 ± 4.1
Bare soil		34.2 ± 14.3	8.3 ± 7.5	35.8 ± 15.3	1.7 ± 4.1
APIACEA	*Daucus carota*	5.3 ± 13.0	0	6.9 ± 13.1	0
	Scandix pecten-veneris	4.3 ± 6.7	0	11.8 ± 26.3	0
ARACEAE	*Arum italicum*	1.0 ± 2.5	0	1.5 ± 3.7	0
ASTERACEAE	*Chamaemelum mixtum*	0	0.3 ± 0.4	0	3.2 ± 3.1
	Leontodon taraxacoides	0	8.1 ± 9.2	0	5.6 ± 8.1
	Senecio jacobae	2.6 ± 5.5	5.3 ± 1.9	0	2.0 ± 1.9
	Tolpis barbata	0	1.3 ± 3.2	0	0.7 ± 1.7
BRASSICACEAE	*Diplotaxis catholica*	0	1.5 ± 3.8	0	6.9 ± 5.5
	Raphanus raphanistrum	0	2.1 ± 3.8	0	0.7 ± 1.8
BORAGINACEAE	*Echium plantagineum*	0	3.0 ± 7.2	0	0
CARYOPHYLLACEAE	*Cerastium glomeratum*	0	1.3 ± 3.2	1.1 ± 2.2	1.9 ± 2.1
	Spergula arvensis	0	0	0	3.7 ± 4.1
FABACEAE	*Medicago polymorpha*	0.2 ± 0.4	0	0	0
	Ornithopus pinnatus	0	0	0	1.1 ± 1.8
	Ornithopus sativus	0	0	0	5.3 ± 6.6
	Trifolium repens	0	4.3 ± 9.4	0	0.7 ± 1.8
GERANIACEAE	*Erodium botrys*	38.0 ± 24.2	18.6 ± 26.5	22.6 ± 26.4	9.7 ± 11.2
	Erodium cicutarium	2.8 ± 3.2	6.5 ± 8.7	0	0
	Geranium dissectum	0	0.6 ± 1.6	0	4.8 ± 3.4
	Geranium molle	0	1.5 ± 2.3	17.8 ± 18.1	5.0 ± 6.6
IRIDACEAE	*Gynandrisis sisyrinchium*	0	0.6 ± 1.6	0	0.1 ± 0.3
PLANTAGINACEAE	*Plantago lanceolata*	0	0	0.2 ± 0.4	1.4 ± 1.6
POACEAE	*Avena barbata*	25.6 ± 31.5	2.6 ± 4.1	16.7 ± 23.9	0.7 ± 1.8
	Bromus diandrus	12.0 ± 12.1	6.9 ± 14.9	7.6 ± 13.4	1.0 ± 1.8
	Bromus hordeaceus	0	0.4 ± 0.9	0	0
	Hordeum murinum	1.8 ± 4.4	28.6 ± 20.3	7.0 ± 10.9	41.3 ± 12.3
	Lolium multiflorum	2.3 ± 3.0	0.6 ± 1.6	0	0
	Lolium rigidum	0	0.4 ± 0.9	0	0
	Poa annua	0.2 ± 0.5	0	0	0.1 ± 0.4
	Vulpia geniculata	1.3 ± 1.8	3.3 ± 2.6	3.0 ± 4.1	0.7 ± 0.3
POLYGONACEAE	*Rumex angiocarpus*	0	0	0	3.0 ± 4.6
	Rumex bucephalophorus	0	1.0 ± 1.7	0	0.3 ± 0.4
	Rumex conglomeratus	0	0.5 ± 1.1	2.4 ± 4.4	0
RUBIACEAE	*Sherardia arvensis*	0	0.6 ± 1.6	0	0
URTICACEAE	*Urtica urens*	2.5 ± 4.8	0	1.4 ± 2.6	0

COR—Amended areas; UCOR—Unamended areas; UTC—Under tree canopy; OTC—Outside tree canopy.

The transformation of DM and CP data into daily growth rate (DM_{var} and CP_{var}, in kg ha^{-1} day^{-1}; Figures 5 and 6, respectively, shows that soil amendment resulted, in autumn, in significantly higher DM_{var} and CP_{var} (+28.8% and +42.6%, respectively, in an average of two years; Figure 5). The tree canopy effect (Figure 6) was significant and positive in CP daily growth rate at autumn (+26.4% in average of two years).

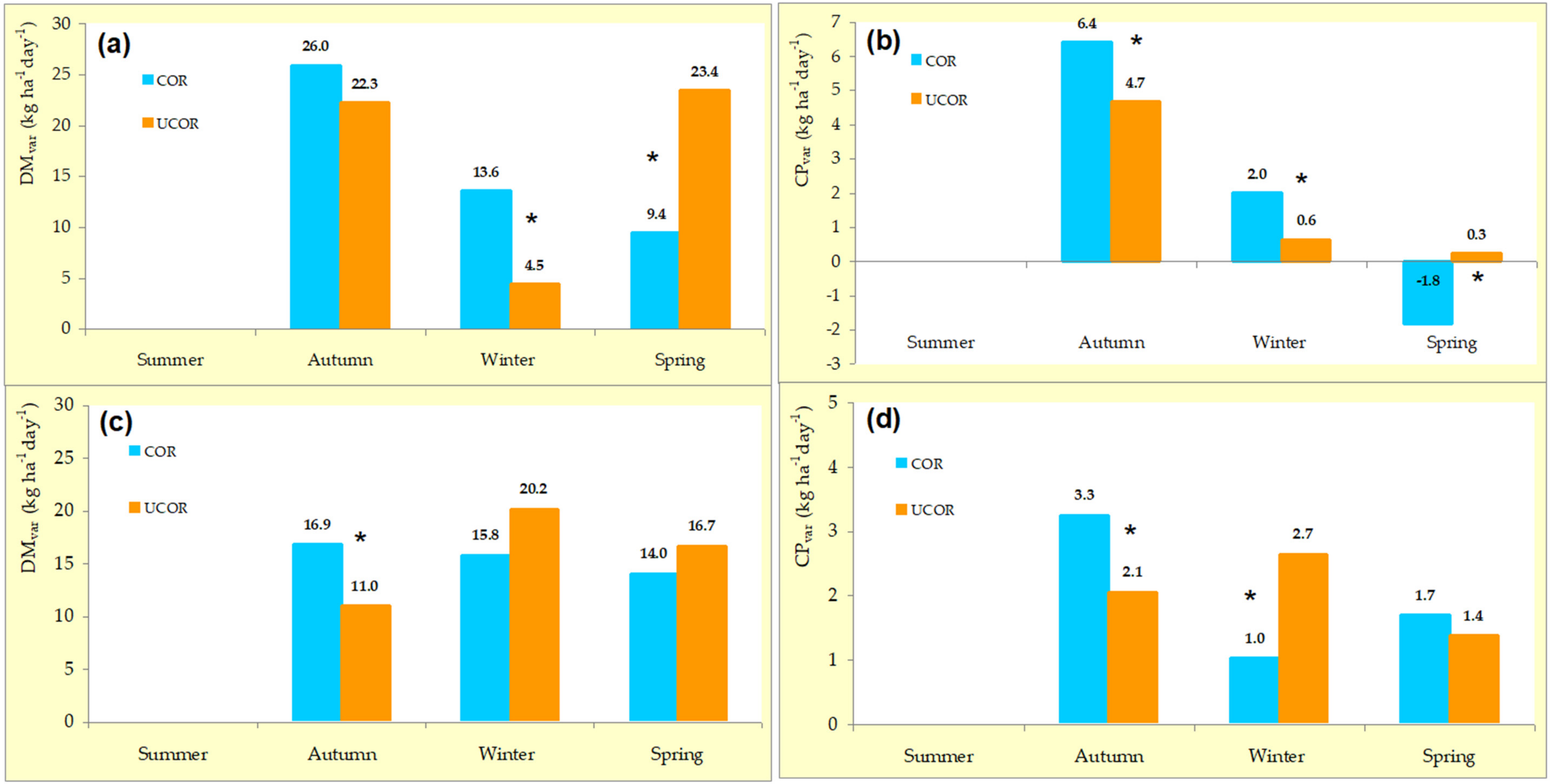

Figure 5. Pasture daily growth rate (kg·ha^{-1}·day^{-1}) in amended areas (COR) and unamended areas (UCOR), in the vegetative cycles of 2018/2019 ((**a**,**b**), respectively dry matter, DMvar and crude protein, CPvar) and 2019/2020 ((**c**,**d**), respectively dry matter, DMvar and crude protein, CPvar). * Significant at the 0.05 level.

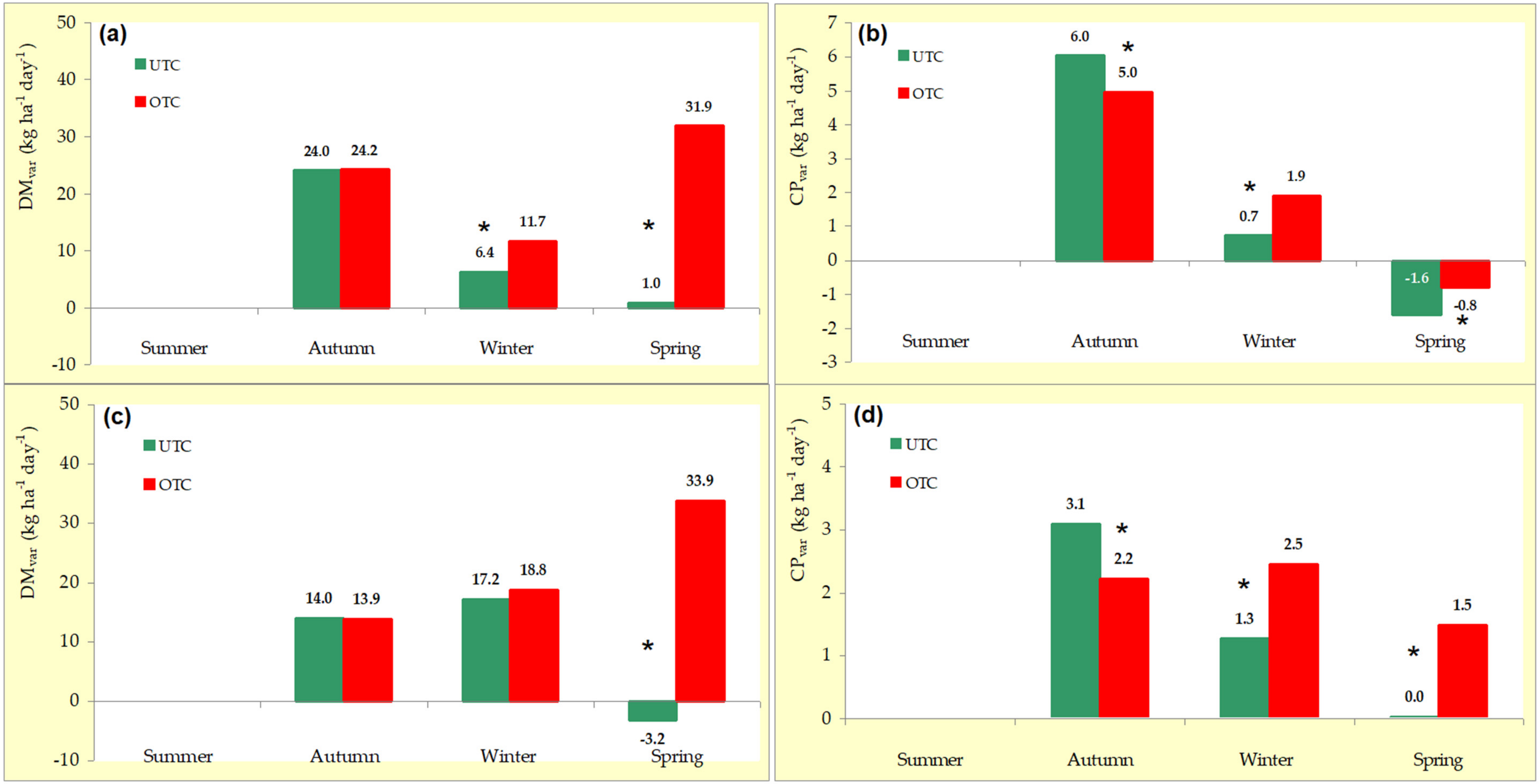

Figure 6. Pasture daily growth rate (kg·ha^{-1}·day^{-1}) under tree canopy (UTC) and outside tree canopy (OTC), in the vegetative cycles of 2018/2019 ((**a**,**b**), respectively dry matter, DMvar and crude protein, CPvar) and 2019/2020 ((**c**,**d**), respectively dry matter, DMvar and crude protein, CPvar). * Significant at the 0.05 level.

3.3. Temporal Pattern of Evolution of Normalized Difference Vegetation Index (NDVI)

The typical pattern of evolution of monthly mean NDVI at the experimental field measured with an active optical sensor "OptRx" during pasture vegetative cycles of 2018/2019 and 2019/2020 (Figure 7) reflects the combined effect of temperature and rainfall on the vegetative vigor of rainfed plants. In the hot and dry summer months (July–September) there is a low vegetative index (NDVI < 0.2). This is the most stable period over the years since the absence of precipitation in this period is a characteristic pattern of the Mediterranean climate. Autumn months (October–December) are decisive, since the first rains and the consistency of their distribution, associated with average temperatures in the 12–18 °C range (Figure 2) precipitate mark the emergence of the plants and the beginning of the vegetative cycle. Figure 7 shows that, between October and November, the average two-year values of NDVI practically doubled (NDVI: 0.332 →0.598). The winter period, due to low temperatures, is normally a period of vegetative dormancy, keeping plants with high vegetative vigor, which, associated with greater soil coverage, leads to the maximum NDVI value (around 0.80) between February and March. Between April and May, the rise in average temperature (about 10 °C; Figure 2) and a drop in rainfall (and, consequently, in soil moisture content) accelerates the pasture vegetative cycle, resulting in the flowering of a large part of the flora. These factors lead to an important breakdown of NDVI between May and June (NDVI: 0.579 →0.359). The period in which NDVI is below 0.60, in the case of Figure 7 between June and November (because it rained early in autumn 2018 and 2019), but sometimes for longer periods depending on the distribution of precipitation in the autumn months, requires animal feed supplementation.

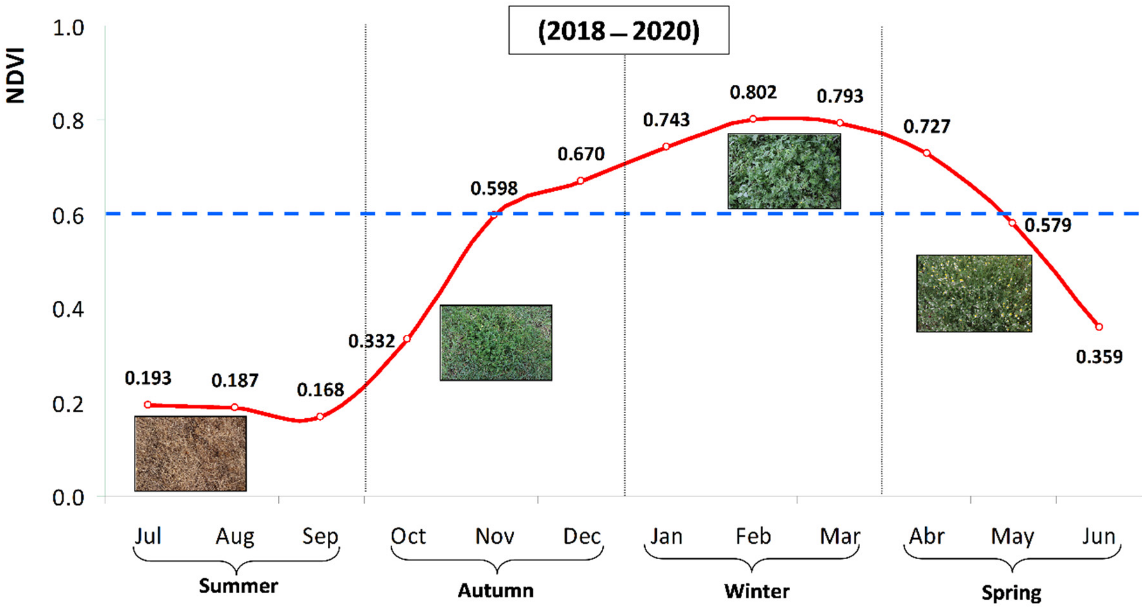

Figure 7. Evolution of monthly mean normalized difference vegetation index (NDVI) at the experimental field during pasture vegetative cycles of 2018/2019 and 2019/2020. The broken line (NDVI = 0.6) correspond to the sheep CP maintenance requirements [27].

3.4. Spatial Variability of Pasture Floristic Composition (PFC)

In the experimental field, 35 botanical species were identified (Table 3). A general descriptive analysis reveals that the two more representative species (shaded values in Table 3) are *Erodium botrys* and *Hordeum murinum*. The first is of great interest for animal grazing and, at the same time, an indicator of good soil fertility, hence more representative UTC areas (38.0 ± 24.2% in COR areas; 22.6 ± 26.4% in UCOR areas). The second is more representative in OTC areas (28.6 ± 20.3% in COR areas; 41.3 ± 12.3% in UCOR areas). Together they account for about two-thirds of the soil vegetation cover (67% of COR areas and 64% of UCOR areas).

In terms of the number of species present, there is a clear negative effect of tree canopy on pasture species diversity (14 species UTC and 24 species OTC) and a very slight effect of soil amendment (30 species in COR areas and 28 species in UCOR areas). Figure 8 shows the eight species (and their families) with a greater presence in amended (a) and unamended (b) areas, accounting for more than 80% of UTC areas and approximately 70% of OTC areas. Apart from the two aforementioned species (*Erodium botrys* and *Hordeum murinum*), two other species, *Avena barbata* (25.6 ± 31.5% in COR areas and 16.7 ± 23.9% in UCOR areas) and *Geranium molle*, are prevalent in UTC areas, although only in uncorrected areas (17.8 ± 18.1%).

These results also show that vegetation cover is clearly higher in OTC areas (mean of 95%) than in UTC areas (mean of 65%), but very similar in COR areas (mean of 78.8%) and UCOR areas (mean of 81.3%) (Figure 9a). Other relevant aspects in this field are: (i) the absence of legumes in UTC areas; (ii) very low representativeness of legumes in OTC areas (mean of 5.7%) (Figure 9b); and (iii) the clear preponderance of two families, Poaceae (mean 41%) and Geraniaceae (mean of 32%) (Figure 9c).

After this general descriptive analysis, are presented in Figure 10 the results of three approaches of ISA in order to identify the bio-indicators species of each study area. In the factor soil pH correction (COR and UCOR) were identified four species characteristics, two responded well to the soil dolomitic limestone application, COR areas (*Erodium circutarium* and *Senecio jacobae*), and two to the UCOR areas (*Geranium molle* and *Plantago lanceolata*). In the factor tree canopy (UTC and OTC) were identified seven species characteristics, two indicators of good adaptation to the microclimate provided by tree canopy, UTC areas (*Avena barbata* and *Urtica urens*), and five of OTC areas (*Hordeum murinum*, *Geranium dissectum*, *Leontodon taraxacoides*, *Diplotaxis catholica*, and *Chamaemelum mixum*). In the combination of the two previous factors (soil pH correction and tree canopy) were identified eight species characteristics, one of UCOR × UTC areas (*Geranium molle*), one of COR and UCOR × OTC areas (*Hordeum murinum*) and six of UCOR × OTC areas (*Geranium dissectum*, *Chamaemelum mixum*, *Diplotaxis catholica*, *Spergula arvensis*, *Plantago lanceolata*, and *Ornithopus sativus*). Of all these, *Hordeum murinum* and *Geranium dissectum* species stand out, with IV > 75%, the first strong indicator of OTC areas (COR and UCOR) and the second strong indicator also of OTC areas, but only in UCOR areas.

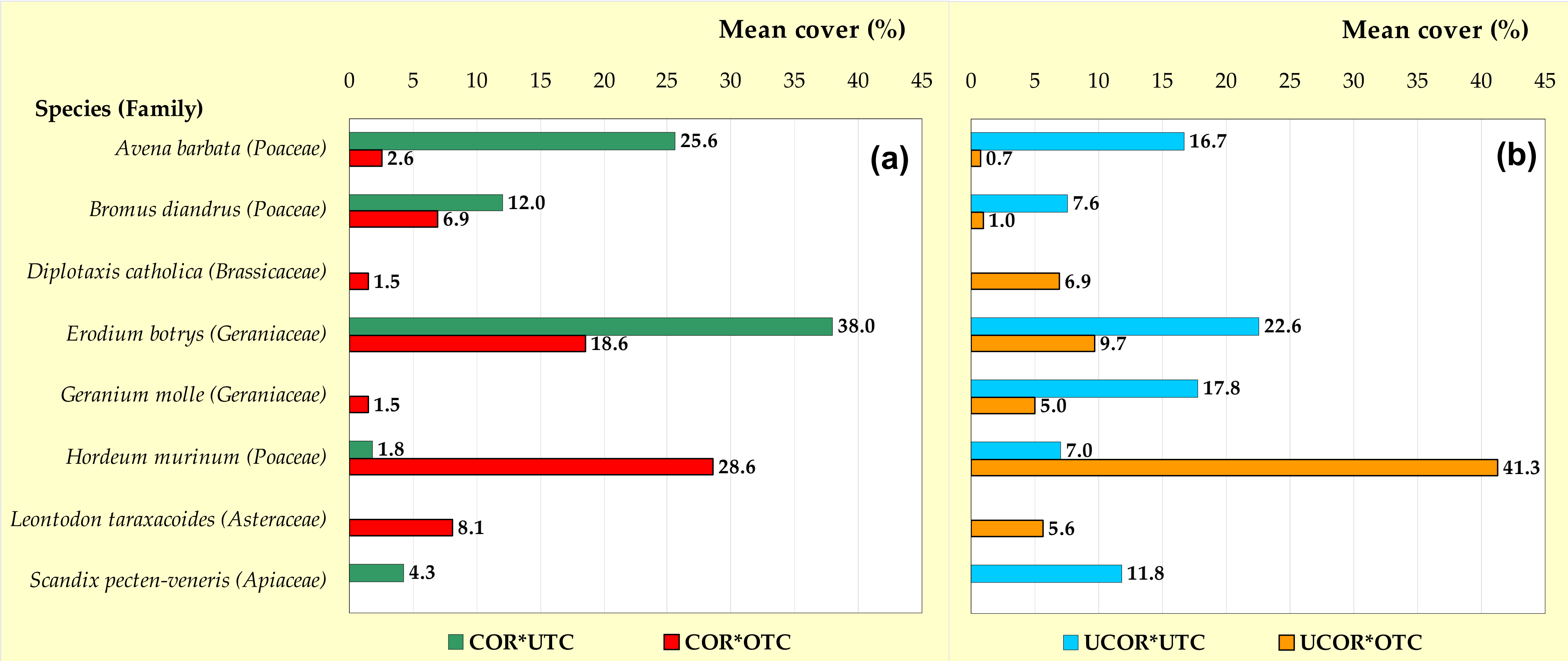

Figure 8. Species (and their families) with greater representation in amended areas (COR; (**a**)) and in unamended areas (UCOR; (**b**)), under tree canopy (UTC) and outside tree canopy (OTC).

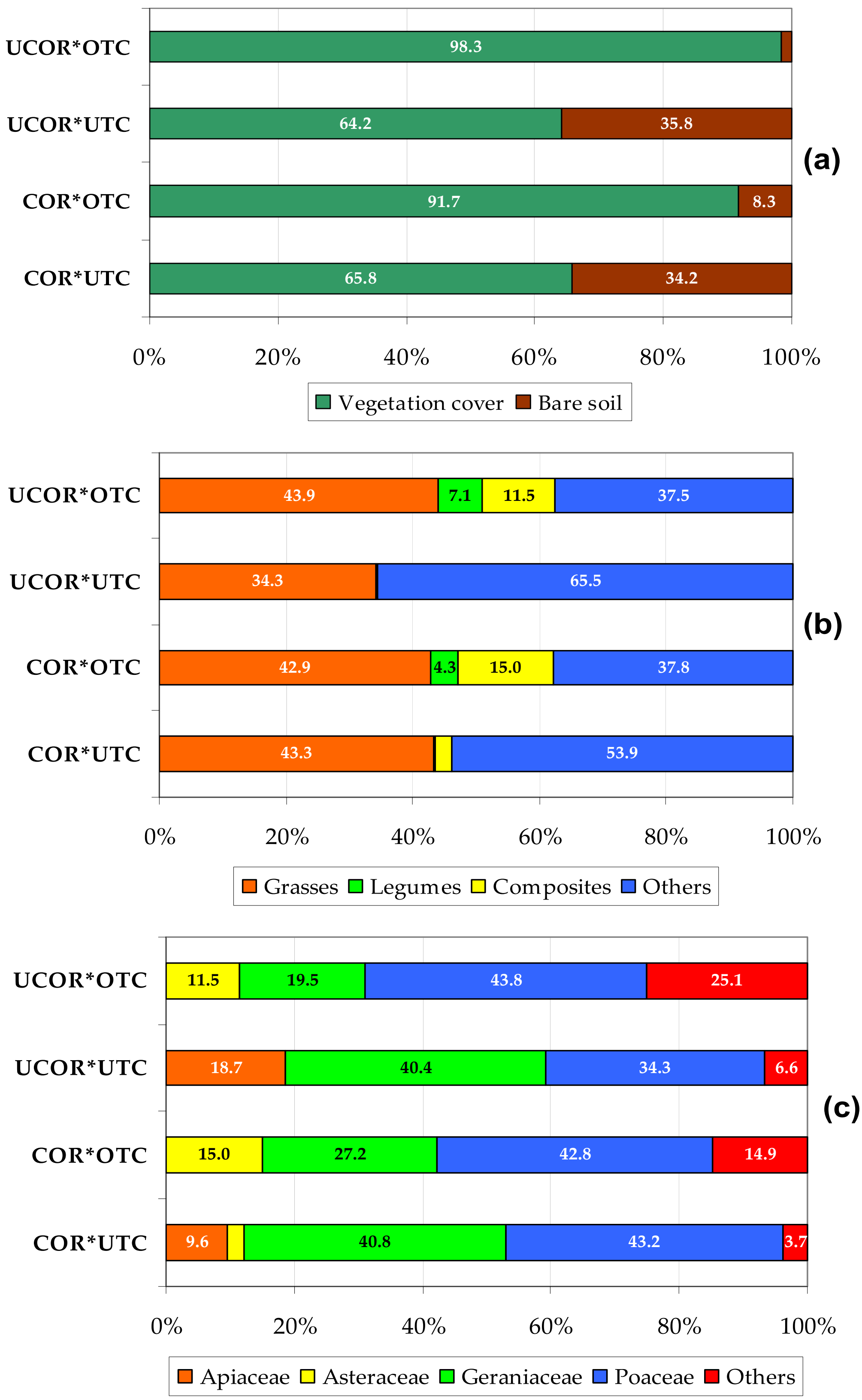

Figure 9. Pasture characteristics of the experimental field in spring 2020, in amended (COR) and unamended areas (UCOR), under tree canopy (UTC) and outside tree canopy (OTC): (**a**) vegetation cover (%); (**b**) floristic composition by groups; (**c**) floristic composition by families.

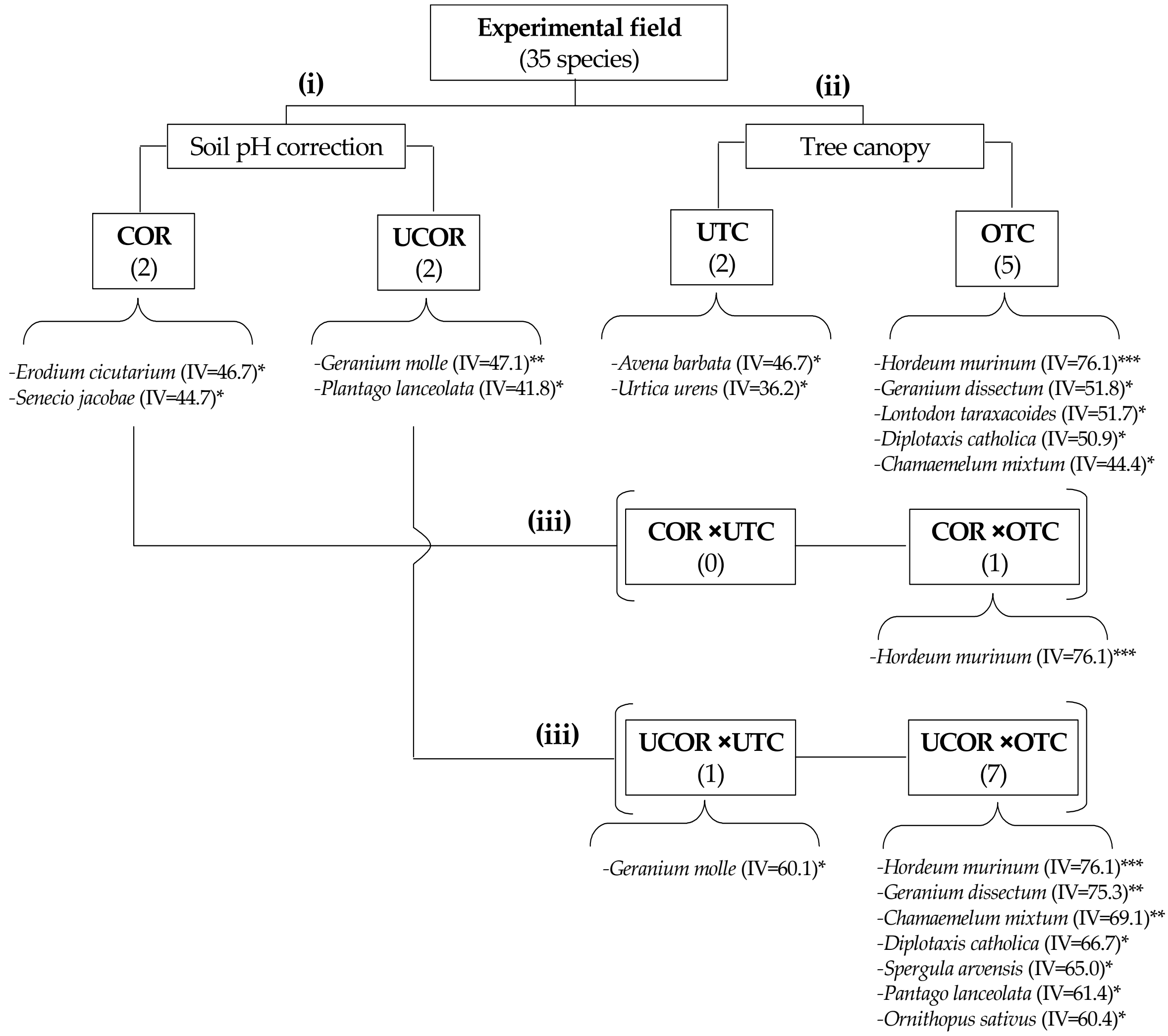

Figure 10. Dendogram representing the results of ISA in three approaches: (i) soil pH correction factor, (ii) tree canopy factor and (iii) combination of the two previous factors. COR—Amended area; UCOR—Unamended area; UTC—Under tree canopy; OTC—Outside tree canopy; IV—Indicator value; ***—Probability < 0.001; **—Probability < 0.01; *—Probability <0.05.

4. Discussion

This study focuses on the montado ecosystem, covering about 3.5 million ha in the South-East region of the Iberian Peninsula [28]. This occupies mainly acid soils, which represent ≈50% of the world's arable land [29]. Soil acidity and the toxicity associated with some elements (namely the Al and the Mn) are a very common stress factor in arable lands around the world [30], and in particular, they are some of the most important limiting factors to plant productivity in the South of Portugal [31].

The central question presented in this paper ("Can soil pH correction reduce the animal supplementation needs in the critical autumn period in Mediterranean montado ecosystem?"), finds an answer based on two approaches, interconnected in its discussion: (i) the variability of pasture productivity and quality; and (ii) the variability of spatial patterns of pasture floristic composition.

4.1. Variability Pattern of Pasture Productivity and Quality

Globally, as in other studies carried out on pastures integrated in agro-silvo-pastoral systems [9,15], there is a high spatial variability in pasture productivity (GM and DM; CV = 40–70%) and quality (CP; CV = 23–39%; NDF; CV = 6–21%).

Another aspect to be highlighted is related to the inter-annual variability in productivity. GM and DM were clearly higher in 2019/2020, which reflects the positive effect of the greater amount of precipitation that occurred in that year (627 mm verses 315 mm 2018/2019) [9]. In pasture cropping systems, production increases with rainfall [32]. In all years, higher productivity (in terms of DM) is observed in the spring compared to the other seasons, which is also in line with expectations, since it is the period when temperatures are most favorable for plant development [9]. The optimal temperature for growth of plants characteristic of temperate regions range between 15–23 °C, with various studies reporting a reduction in photosynthesis and growth outside of this range [6].

On the other hand, in both vegetative cycles corresponding to this study, pasture quality follows a pattern already identified in several works [1,9,12,15,19]: a progressive decrease in the relative contents of CP and an increase in the relative content of fiber (NDF) resulting in lower CP and higher NDF values in late spring.

Pasture is the main food resource in extensive livestock production systems [4] and can be considered a low-cost feed [3], but supplementation is inevitable in the Mediterranean climate [3]. The pattern of NDVI in the two years under study (Figure 7) showed that between June and November, but sometimes for longer periods depending on the distribution of precipitation in the autumn months, animal feed supplementation is required so that the animals do not lose body condition [33]. A critical threshold is defined by an NDVI value of 0.6, below which CP content in these dryland and biodiverse pastures corresponds to the sheep maintenance requirements of 9.4% [27].

The surface application (not incorporated into the soil through mobilization) of amendments does not result in an immediate and significant increase in the soil pH, but rather in a gradual increase over time [34,35]. However, the benefit of soil pH correction observed in these fields, in terms of anticipating CP availability in the autumn, after several months of supplementation, is a key aspect in terms of ecosystem management and economic and environmental sustainability. Pasture crude protein availability (CP_{var}, in kg ha^{-1} day^{-1}) is a very practical indicator because it integrates both pasture productivity (DM) and pasture quality (CP) [12].

Regarding the effect of tree canopy on pasture productivity, the competition for resources water, light, and nutrients are considered as the main reason for decreased yields UTC in winter and especially in spring [15,16]. However, given that tree canopy contributes to less pasture evapotranspiration and, as a consequence, guarantees higher soil moisture content [19], and also because UTC areas are usually more fertile [19], the critical factor for the lower pasture productivity under tree canopy must result from the combination of four sub-factors: (i) lower incidence of solar radiation, which affects directly the physiological processes of plants and net DM production [15], since light interception by plant leaves is used in photosynthesis to provide energy for plant maintenance, to grow new leaves and roots, and to produce carbohydrates [36]; (ii) lower land cover, due to the release of inhibitory substances resulting from leaves and other tree residues [32]; (iii) development of less productive botanical species; Graß et al. [16] highlight the shadow inhibitor effects specifically on the growth of legumes; and (iv) livestock grazing, which, according to Hussain et al. [37] can have an important influence on sward composition, quality and production UTC and OTC.

Relatively to pasture quality, throughout the entire vegetative cycle, the highest CP values are obtained in UTC areas comparing to OTC areas, which finds support on the influence of tree canopy on microclimate and soil properties [15,19,38]. Sousa et al. [39] attributed the higher quality of pasture UTC in terms of CP levels to the delay in the ontogenic development of shady plants (less advanced state of vegetative development), keeping them younger physiologically and allowing the maintenance of higher metabolic levels for a longer period of time. Herbage quality is mainly determined by plant species (and functional groups; e.g., legumes have more protein than grasses [40]), but also influenced by plant parts (leaves/stems) and plant maturity, with young plants having higher protein and mature plants higher fiber content [41].

Agroforestry systems, as is the case of Montado, the most common production system in the Alentejo region in Southern Portugal [10], are often described as an innovative, multifunctional, and sustainable option due to their multiple several environmental benefits, e.g., soil protection, biodiversity, nutrient conservation, mitigation of climate change by C-sequestration and enhanced adaptation to climate change [16]. To this environmental vision must be added the perspective of economic sustainability of extensive livestock production. These results show, on the one hand, the positive and combined effect of soil correction and tree canopy on the availability of CP at the beginning of the vegetative cycle (autumn), which will reduce the need for supplementation. On the other hand, animals find at the end of the vegetative cycle (late spring) in OTC areas the greatest availability of pasture (DM), which allows them to maintain their body condition without the need for supplementation in early summer (July), using the shade UTC for rest and well-being in view of the high temperatures that occur in this season.

4.2. Variability of Spatial Pattern of Pasture Floristic Composition (PFC)

Composition and functional diversity are among the most significant ecological attributes of a particular ecosystem [42]. One of the aspects that should be highlighted in the spatial variability pattern of PFC of this experimental field is the smaller vegetation cover UTC relatively to OTC areas. This aspect is particularly important because it has a direct and negative effect on pasture productivity. Modifications to vegetation cover and botanical composition under tree canopy are caused by changes in the microclimate, soil properties, and livestock grazing [15]. Gómez-Rey et al. [43], for example, reported that the soil UTC presents higher density and lower porosity as a result of the greater compaction caused by the animals. The smaller number of species present UTC may, therefore, reveal the reduced capacity of some botanical species to sustain animal grazing, especially with moist soil in autumn and winter, or the effect of tree shade. On the other hand, tree litter, mainly leaves, overlaying the pasture and the subsequent incorporation and decomposition into the soil can immobilize nitrogen and contribute to reduced pasture growth [44]. Additionally, deleterious effects of substances (allelopathic agents) exuded from leaves or roots may retard plant growth near the trees [32].

Although it is possible to identify bio-indicators that confirm that tolerance to soil acidity depends on the plant species [11], in this study, the effect of tree canopy on PFC was stronger than the effect of soil pH correction. ISA identified only four species that are characteristic of soil pH correction factor (two in COR areas and two in UCOR areas), in contrast with seven species identified in the tree canopy factor (two in UTC areas and five in OTC areas). This is, however, an expected scenario, since soil correction in this experimental field is a relatively recent intervention, and it is known that soil acidity amendment using dolomitic limestone is a slow and gradual process [12]. The tree effect is, on the other hand, the accumulated consequence of several decades. Nevertheless, based on the criteria proposed by Dufrêne and Legendre [24], all identified species can be considered strong bio-indicators for each group (IV > 25%).

In terms of balance, the clear preponderance in this experimental field of vegetation belonging to the syntaxonomic unit "Stellarietea mediae" (six of the eight species with greater representation) and the "Poaceae" family (Figure 9c), which usually have low nutritional value for animal grazing, indicates a low pasture quality. The presence in the list of the eight more representative species, of only one species of syntaxonomic unit "Poetea bulbosae" (*Erodium botrys*), of great interest for animal grazing and representing a coverage area of 10–38% (especially in more fertile soils, in COR areas and UTC) and one species of syntaxonomic unit "Tuberarietea guttatae" (*Leontodon taraxacoides*), representing a coverage area of only 6–8% (only in OTC areas) indicate the need for pasture improvement and rehabilitation. The main indicator regarding the degradation of pasture quality is the very small presence of the legumes functional group [40], family "Fabaceae" (*Trifolium repens; Ornithopus sativus*, and *Ornithopus pinnatus*), representing 4–7% of coverage area and only OTC. The lower legume contribution may be a consequence of shadow effects of grasses, taller upright, which inhibit the growth of the prostrate legumes, through reduced radiation, putting them at an unfavorable competitive position [16]. According to Paço et al. [11] Mn toxicity is one of the most important constraints to plant growth in acid soils, especially for legumes dependent on N2-fixing symbiosis. The reduced presence of legumes in this ecosystem calls into question not only the soil fertility, because it compromises the atmospheric capture of nitrogen through symbiotic fixation by rhizobia [9], but also the nutritional value of pasture [45] and justifies, in this case, the differential application of nitrogen fertilizer and the reseeding of legumes to restore the pasture balance [9]. Improving the symbiotic performance of rhizobia with legumes growing in highly acidic and high Mn soils through sustainable agricultural practices is a great challenge [11]. Other effective ways to reverse land degradation and improve pasture biodiversity include implementation of dynamic grazing management [12], a holistic approach that in the coming years will greatly benefit from the development of technologies associated with Precision Agriculture, namely, proximal and remote sensing and global navigation satellite systems.

This possibility of using botanical species as bio-indicators of greater or lesser adaptability to changes in soil pH or to tree canopy effect justifies continuing their monitoring in future studies while integrating into this complex dynamic the inter-annual irregularity of rainfall that is characteristic of the Mediterranean climate.

5. Conclusions

Extensive livestock production in Mediterranean climate conditions and acidic soils requires animal feed supplementation over a considerable period of the year, with high costs. Strategies that can improve the pasture productivity and quality in these critical periods and reduce the dependence on supplementation, contribute to the increase of the profit margin of farmers and to the environmental sustainability of these ecosystems. The results of this study show the positive and combined effect of dolomitic limestone application and tree canopy on the DM and CP daily growth rate (in kg ha^{-1} day^{-1}) at the beginning of the vegetative cycle (autumn). Thus, anticipating pasture availability and reducing the need for animal supplementation. This study also shows the importance of monitoring pasture floristic composition, as a bio-indicator of the effect of soil pH correction and tree canopy. The very weak expression of the functional group legumes (only 4–7% of coverage area) is the main indicator of degradation of this pasture and justifies, in this case, the differential application of nitrogen fertilizer and the reseeding of legumes to restore the pasture balance and to improve the ecosystem response to the rehabilitation strategies.

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References

1. Serrano, J.; Sales-Baptista, E.; Shahidian, S.; Marques da Silva, J.; Ferraz de Oliveira, I.; Lopes de Castro, J.; Pereira, A.; Cancela d'Abreu, M.; Carvalho, M. Proximal sensors for monitoring seasonal changes of feeding sites selected by grazing ewes. *Agroforest. Syst.* **2018**, *95*, 55–69. [CrossRef]
2. Hanson, J.; Ellis, R.H. Progress and Challenges in Ex Situ Conservation of forage germplasm: Grasses, herbaceous legumes and fodder trees. *Plants* **2020**, *9*, 446. [CrossRef]
3. Santos, S.K.; Falbo, M.K.; Sandini, I.E.; Pacentchuk, F.; Neumann, M.; Garbossa, G. Concentrate supplementation strategies in ryegrass pasture for productive performance in lambs. *Span. J. Agric. Res.* **2018**, *16*, 1–6. [CrossRef]
4. Polo, J.L.M.; Bellido, I.G.; Rodriguez, M.E.S. Plant production and nutritive quality of savannah-like grasslands (dehesas) in semi-arid zones of the province of Salamanca. *Span. J. Agric. Res.* **2003**, *1*, 41–49. [CrossRef]
5. Scocco, P.; Piermarteri, K.; Malfatti, A.; Tardella, F.M.; Catorci, A. Effects of summer rainfall variations on sheep body state and farming sustainability in sub-Mediterranean pastoral systems. *Span. J. Agric. Res.* **2016**, *14*, 1–4. [CrossRef]
6. Perera, R.S.; Cullen, B.R.; Eckard, R.J. Growth and physiological responses of temperate pasture species to consecutive heat and drought stresses. *Plants* **2019**, *8*, 227. [CrossRef]
7. Ruiz, F.A.; Vázquez, M.; Camuñez, J.A.; Castel, J.M.; Mena, Y. Characterization and challenges of livestock farming in Mediterranean protected mountain areas. *Span. J. Agric. Res.* **2020**, *18*, 1–14. [CrossRef]
8. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014*; International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. Update 2015; World Soil Resources Report 106; Food and Agriculture Organization (FAO): Rome, Italy, 2015; 188p.
9. Efe Serrano, J. *Pastures in Alentejo: Technical Basis for Characterization, Grazing and Improvement*; Universidade de Évora—ICAM, Ed.; Gráfica Eborense: Évora, Portugal, 2006; pp. 165–178. (In Portuguese)
10. Carvalho, M.; Goss, M.J.; Teixeira, D. Manganese toxicity in Portuguese Cambisols derived from granitic rocks: Causes, limitations of soil analyses and possible solutions. *Rev. Cienc. Agrar.* **2015**, *38*, 518–527. [CrossRef]
11. Paço, A.; da-Silva, J.R.; Torres, D.P.; Glick, B.R.; Brígido, C. Exogenous ACC Deaminase is key to improving the performance of pasture legume-rhizobial symbioses in the presence of a high manganese concentration. *Plants* **2020**, *9*, 1630. [CrossRef]
12. Serrano, J.; Shahidian, S.; Marques da Silva, J.; Moral, F.; Carvajal-Ramirez, F.; Carreira, E.; Pereira, A.; Carvalho, M. Evaluation of the effect of dolomitic lime application on pastures—Case study in the Montado Mediterranean ecosystem. *Sustainability* **2020**, *12*, 3758. [CrossRef]
13. Demarchi, L.O.; Scudeller, V.V.; Moura, L.C.; Dias-Terceiro, R.G.; Lopes, A.; Wittmann, F.K.; Piedade, M.T.F. Floristic composition, structure and soil-vegetation relations in three white-sand soil patches in central Amazonia. *Acta Amaz.* **2018**, *48*, 46–56. [CrossRef]
14. Serrano, J.; Shahidian, S.; da Silva, J.M.; Carvalho, M. A holistic approach to the evaluation of the Montado ecosystem using proximal sensors. *Sensors* **2018**, *18*, 570. [CrossRef]
15. Benavides, R.; Douglas, G.B.; Osoro, K. Silvopastoralism in New Zealand: Review of effects of evergreen and deciduous trees on pasture dynamics. *Agrofor. Syst.* **2009**, *76*, 327–350. [CrossRef]
16. Graß, R.; Malec, S.; Wachendorf, M. Biomass performance and competition effects in an established temperate agroforestry system of willow and grassland—Results of the 2nd rotation. *Agronomy* **2020**, *10*, 1819. [CrossRef]
17. Ramírez, N.; Dezzeo, N.; Chacón, N. Floristic composition, plant species abundance, and soil properties of montane savannas in the Gran Sabana, Venezuela. *Flora* **2007**, *202*, 316–327. [CrossRef]
18. Irume, M.V.; Morais, M.L.C.S.; Zartman, C.E.; Amaral, I.L. Floristic composition and community structure of epiphytic angiosperms in a terra firme forest in central Amazonia. *Acta Bot. Bras.* **2013**, *27*, 378–393. [CrossRef]
19. Serrano, J.; Shahidian, S.; da Silva, J.M.; Sales-Baptista, E.; de Oliveira, I.F.; de Castro, J.L.; Pereira, A.; d'Abreu, M.C.; Machado, E.; Carvalho, M. Tree influence on soil and pasture: Contribution of proximal sensing to pasture productivity and quality estimation in montado ecosystems. *Int. J. Remote Sens.* **2018**, *39*, 4801–4829. [CrossRef]
20. Egner, H.; Riehm, H.; Domingo, W.R. Untersuchungen über die chemische Bodenanalyse als Grudlage für die Beurteilung des Nahrstoffzunstandes der Boden. II: Chemische extraktion methoden zur phosphor- und kalium-bestimmung. *K. Lantbrhogsk. Annlr* **1960**, *26*, 199–216. (In German)
21. AOAC. *Official Method of Analysis of AOAC International*, 18th ed.; AOAC International: Arlington, AT, USA, 2005.
22. Braun-Blanquet, J. *Pflanzensoziologie*, 3rd ed.; Grundzüge der Vegetationskunde; Springer: Vienna, Austria; New York, NY, USA, 1964.
23. Shore, A. DESeq and Indicator Species Analysis R script. *Figshare. Software.* **2020**. [CrossRef]
24. Dufrêne, M.; Legendre, P. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecol. Monogr.* **1997**, *67*, 345–366. [CrossRef]
25. McGeoch, M.A.; Chown, S.L. Scaling up the value of bioindicators. *Trends Ecol. Evol.* **1998**, *13*, 46–47. [CrossRef]
26. Bakker, J.D. Increasing the utility of Indicator Species Analysis. *J. App. Ecol.* **2008**, *45*, 1829–1835. [CrossRef]
27. National Research Council. *Nutrient Requirements of Sheep*, 6th ed.; National Academy Press: Washington, DC, USA, 1985; Volume 5.
28. Pinto-Correia, T.; Ribeiro, N.; Sá-Sousa, P. Introducing the montado, the cork and holm oak agroforestry system of Southern Portugal. *Agrofor. Syst.* **2011**, *82*, 99. [CrossRef]

29. Sade, H.; Meriga, B.; Surapu, V.; Gadi, J.; Sunita, M.S.; Suravajhala, P.; Kavi Kishor, P.B. Toxicity and tolerance of aluminum in plants: Tailoring plants to suit to acid soils. *Biometals* **2016**, *29*, 187–210. [CrossRef]
30. Kochian, L.V.; Piñeros, M.A.; Hoekenga, O.A. The physiology, genetics and molecular biology of plant aluminum resistance and toxicity. *Plant Soil* **2005**, *274*, 175–195. [CrossRef]
31. Alho, L.; Carvalho, M.; Brito, I.; Goss, M.J. The effect of arbuscular mycorrhiza fungal propagules on the growth of subterranean clover (Trifolium subterraneum L.) under Mn toxicity in ex situ experiments. *Soil Use Manag.* **2015**, *31*, 337–344. [CrossRef]
32. Luna, I.M.; Fernández-Quintanilla, C.; Dorado, J. Is Pasture Cropping a Valid Weed Management Tool? *Plants* **2020**, *9*, 135. [CrossRef]
33. Serrano, J.; Shahidian, S.; da Silva, J.M. Monitoring seasonal pasture quality degradation in the Mediterranean montado ecosystem: Proximal versus remote sensing. *Water* **2018**, *10*, 1422. [CrossRef]
34. Halim, N.; Abdullah, R.; Karsani, S.; Osman, N.; Panhwar, Q.; Ishak, C. Influence of soil amendments on the growth and yield of rice in acidic soil. *Agronomy* **2018**, *8*, 165. [CrossRef]
35. Li, G.D.; Conyers, M.K.; Helyar, K.R.; Lisle, C.J.; Poile, G.J.; Cullis, B.R. Long-term surface application of lime ameliorates subsurface soil acidity in the mixed farming zone of south-eastern Australia. *Geoderma* **2019**, *338*, 236–246. [CrossRef]
36. Rayburn, E.B.; Griggs, T.C. Light interception and the growth of pastures under ideal and stressful growing conditions on the Allegheny Plateau. *Plants* **2020**, *9*, 734. [CrossRef]
37. Hussain, Z.; Kemp, P.D.; Horne, D.J. Pasture production under densely planted young willow and poplar in a silvopastoral system. *Agrofor. Syst.* **2009**, *76*, 351–362. [CrossRef]
38. Marcos, G.M.; Obrador, J.J.; Garcia, E.; Cubera, E.; Montero, M.J.; Pulido, F.; Dupraz, C. Driving competitive and facilitative interactions in oak dehesas through management practices. *Agrofor. Syst.* **2007**, *70*, 25–40. [CrossRef]
39. Sousa, L.F.; Maurício, R.M.; Moreira, G.R.; Gonçalves, L.C.; Borges, I.; Pereira, L.G.R. Nutritional evaluation of "Braquiaro" grass in association with "Aroeira" trees in a silvopastoral system. *Agrofor. Syst.* **2010**, *79*, 189–199. [CrossRef]
40. Avdiu, B.; Aliu, S.; Fetahu, S.; Zeka, D.; Rusinovci, I. The floristic composition of the natural pastures in Massive of Novoberba. *Agric. For.* **2018**, *64*, 235–241.
41. Sales-Baptista, E.; Oliveira, I.F.; Santos, M.B.; Castro, J.A.; Pereira, A.; Rafael, J.; Serrano, J. Tecnologia GNSS de baixo custo na monitorizacão de ovinos em pastoreio. *Rev. Cienc. Agrar.* **2016**, *39*, 251–260. (In Portuguese) [CrossRef]
42. Solefack, M.C.M.; Fedoung, E.F.; Temgoua, L.F. Factors determining floristic composition and functional diversity of plant communities of Mount Oku forests, Cameroon. *J. Asia Pac. Biodiver.* **2018**, *11*, 284–293. [CrossRef]
43. Gómez-Rey, M.X.; Garcês, A.; Madeira, M. Soil organic-C accumulation and N availability under improved pastures established in Mediterranean Oak Woodlands. *Soil Use Manag.* **2012**, *28*, 497–507. [CrossRef]
44. Guevara-Escobar, A.; Kemp, P.D.; Mackay, A.D.; Hodgson, J. Pasture production and composition under poplar in a hill environment in New Zealand. *Agrofor. Syst.* **2007**, *3*, 199–213. [CrossRef]
45. Ferraz de Oliveira, M.I.; Lamy, E.; Bugalho, M.N.; Vaz, M.; Pinheiro, C.; Cancela d'Abreu, M.; Capela e Silva, F.; Sales-Baptista, E. Assessing foraging strategies of herbivores in Mediterranean oak woodlands: A review of key issues and selected methodologies. *Agrofor. Syst.* **2013**, *87*, 1421–1437. [CrossRef]

1

CAPÍTULO 6

Influência do tipo de pastoreio por ovinos e da correção com calcário dolomítico na composição florística da pastagem

animals

MDPI

Article

Effect of Sheep Grazing, Stocking Rates and Dolomitic Limestone Application on the Floristic Composition of a Permanent Dryland Pasture, in the Montado Agroforestry System of Southern Portugal

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Simple Summary: The Montado is a characteristic ecosystem of the Mediterranean region, where agricultural activities, animal production and forestry coexist alongside tourism, hunting and leisure activities. Animal grazing is fundamental for the conservation of the Montado, and it is imperative to clearly understand its interactions with the pasture floristic composition (PFC) of the Montado. The objective of this study was to evaluate the effect of sheep grazing, stocking rates and dolomitic limestone application on the floristic composition of permanent dryland pastures, in the Montado agroforestry system of Southern Portugal. The type of grazing influences the PFC, which may be positively or negatively impacted, depending on the adopted system. Deferred grazing seems to benefit the disappearance of undesirable plants and the appearance of desired plants. The results of this study allow for more informed management decisions and a potential increase in animal production but also improve the knowledge of conservation strategies in the Montado.

Abstract: The Montado is a complex agroforestry–pastoral ecosystem due to the interactions between soil–pasture–trees–animals and climate. The typical Montado soil has an acidic pH and manganese toxicity, which affect the pasture's productivity and pasture floristic composition (PFC). The PFC, on the other hand, can also be influenced by the type and intensity of grazing, which can lead to significant decreases in the amount of biomass produced and the biodiversity of species in the pasture. The objective of this study was to evaluate the effect of grazing type, by sheep, and different stocking rates on the PFC throughout the vegetative pasture cycle in areas with and without dolomitic limestone application. Thus, four treatments (P1UC to P4TC) were constituted: P1UC—without limestone application (U) and continuous grazing (CG); P2UD—U and deferred grazing (DG); P3TD—with the application of limestone (T) and DG; P4TC—T and CG. In DG plots, the placement and removal of the animals were carried out as a function of the average height of the pasture (placement—10 cm; removal—3 to 5 cm). The PFC was characterized in winter, at the peak of spring and in late spring. The PFC data were subjected to a multilevel pattern analysis (ISA). The combination of rainfall and temperature influenced the pasture growth rates and consequently the height of the pasture at different times of the year. Therefore, with the different growth rates of the pasture throughout the year, the sheep remain for different periods of time in the deferred grazing treatments. In the four treatments, 103 plant species were identified. The most representative botanical families in the four treatments were Asteraceae, Fabaceae and Poaceae. ISA identified 14 bioindicator species: eight for the winter period, three for the late spring vegetative period and three for the TC treatment.

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Keywords: sheep; deferred grazing; continuous grazing; botanical composition; liming; dryland pasture; Montado

1. Introduction

1.1. Overview of the Montado Ecosystem

The Montado is a multifunctional agro–silvo–pastoral ecosystem, characteristic of the Alentejo region (Southern Portugal). It is considered an ecosystem of “High Natural Value”, for the different productive and non-productive activities that it supports, as well as for being located in a region with low population density and scarce resources [1]. Agricultural, livestock and forestry activities are balanced in the Montado, as well as activities related to tourism and leisure, hunting, beekeeping, mushrooms and cork [1]. Thus, the Montado is associated with high complexity [2]. This complexity results from the interactions between the Mediterranean climate and the four fundamental components of the Montado: soil, pasture, trees and animals [2,3]. This complexity increases further due to the diversity of plant species in the pasture [4]. Most soils where the Montado is located are stony, acidic, poor in nutrients and suffer from nutritional imbalances, especially in terms of the magnesium/manganese ratio [2]. The Alentejo region, where the Montado is located, has a Mediterranean type of climate. This climate type is characterized by hot, dry summers and rainy winters, with mild temperatures [5], significant seasonality and variability [3]. Prolonged natural droughts often impair pasture production. Moreover, the precipitation variability, either in quantity or in seasons, affects pasture productivity and quality [6]. The spontaneous pastures of the Montado ecosystem generally have low productivity [7]. One of the agronomic techniques to improve this natural pasture’s productivity involves applying phosphate fertilizers [8] and correcting manganese toxicity [9], through the application of dolomitic limestone. On the other hand, the low yield of animal production is associated with extensive production systems. Consequently, low investment in these systems leads to little knowledge of the relationship between the effects of different types of grazing and pasture productivity [10]. Thus, it is crucial to carry out different trials to better understand the impact of limestone and stocking rate on the biodiversity of the pasture, the evolution of the plant species and the existing families [4].

1.2. Effects and Relationship of Different Grazing Systems on Pasture Floristic Composition

The grazing system and the way in which it is managed can determine the pasture floristic composition (PFC), even in overseeded pastures [11], where, for example, in a grass pasture with white clover (50/50), the percentage of white clover can vary from 1 to 80% after a few years, depending on the number of weeks between each grazing event: if grazing is carried out every week, its percentage is 80%; if grazing takes place every 4 weeks, its percentage is 50%; if it takes place only every 12 weeks, its percentage is only 1% [12]. Plant community compositions are affected by selective grazing, stocking rate and grazing seasons [13]. In a livestock system with multiple species, there is a tendency towards selectivity in the consumption of the same species, which varies according to the phenological stages of the different species throughout the year. Increasing the instantaneous stocking rates can help to reduce selectivity and thus avoid the overgrazing of more edible species and undergrazing of less palatable species, preventing them from becoming dominant in the pasture [14]. Moreover, the rest periods of grazing are essential for the plants to develop, become vigorous and produce seeds. This is most beneficial for the more palatable species, and results in the high production of grasses [15].

Currently, the most common grazing systems are continuous grazing (CG) and rotational grazing (RG) [16]. We refer to CG and deferred grazing (DG) in the present study. DG, in this case, is associated with longer or shorter grazing periods, with instantaneous stocking rates, depending on the pasture’s quantity. In rotational grazing, the animals remain for a fixed period in each pasture plot and there is an absence period that depends on the number of plots. In deferred grazing, the stays differ depending on the pasture's biomass and the exclusion criteria (which can vary depending on the species and their growth habits).

The main problem of CG is the selectivity displayed by the animals, which results in areas that are heavily grazed and others that are not grazed [15,17]. However, animals select different plants and parts of the plants depending on the season [15]. DG allows plants in preferred areas to grow and recover [17], which would not be possible under CG. In New Zealand, DG was applied successfully to improve productivity, resilience and pasture recovery [14]. DG leads to pasture improvement, through increased dry matter (DM) production, ryegrass percentage and soil cover, without negative impacts on pasture quality after the removal of the animals [18]. On the other hand, when we increase the grazing pressure (higher stocking rate), we delay the vegetative cycle of the plants, providing a greater number of green leaves and, consequently, an increase in the quality of the pasture [19]. Mccallum et al. [20] report that pastures grazed under DG produced an additional 2.7 ton DM/ha when compared to pastures under RG. In a research work, which compared CG with a low biotic load and RG with high biotic loads, the results showed that pasture production is higher when the animal load is higher [16]. Moreover, Brougham [11] mentioned that DM production is higher in a grazing system with higher biotic loads in winter than in grazing with low biotic loads. However, according to Heady [15], in grazing systems where animals have more difficulty choosing their diet, as is the case of DG, by forcing animals to consume diets of better nutritional value, we can also improve their productive performance.

PFC is a good field indicator of biodiversity as well as pasture quality. Pastures composed of multiple species are more resilient to the climatic variations that are so common and may present advantages in the complementary growth that they present, enabling biomass with acceptable nutritional value for the animals [21]. To change the PFC of different pasture plant communities, we need to understand the effects of grazing management on the restoration of seedlings [22]. The grazing system chosen by the livestock producer affects the PFC and the performance of the different plant species [11]. Even if a pasture is overseeded with a mixture of high-quality seeds, if the pasture is poorly managed, it quickly turns into a degraded pasture with many unwanted plants for animals [12]. Pasture degradation leads to a decrease in biomass productivity and increased risk of erosion by wind and rain [23]. Grazing with sheep, with high stocking rates, can harm pastures, leading to a reduction in the diversity of species [24]. However, this is not always the case; it is necessary to carry out studies to understand better the interactions among the type of animals, the type of grazing, stocking rates, season, duration and initial PFC [24]. This study is one of the first to assess the effects of grazing type and the application of dolomitic lime to the soil on the evolution of the PFC throughout the year, under the Montado ecosystem. On the other hand, adequate pasture management makes it possible to recover degraded areas, in good-quality pastures. Although CG and RG are managed differently, even if the stocking rates are similar, the effects on the pasture will be different [25]. In regions where the climate is irregular, as is the case of the Alentejo region, it is not possible to improve the plant communities simply by removing the animals in specific periods (DG), since the response of plants is rather unpredictable [26,27] and dependent on precipitation distribution and temperature. For DG to contribute to the improvement of the PFC, the amount of desirable plant species should be at least 20%, and sufficient livestock should be available to graze adequately and quickly at the right time [28], so that there is a similar removal of biomass throughout the plot, without any preferred areas. DG is a flexible and inexpensive technique that improves pastures [20]. Nevertheless, according to Edwards et al. [25], the survival of seedlings of some edible good species (such as *Lolium perenne* L. and *Trifolium repens* L.) and less edible species such as *Cirsium vulgare* (Savi) Ten., *Rumex obtusifolius* L. and *Plantago lanceolata* L. in winter was higher in CG treatments than in RG treatments.

Considering that, during pasture regrowth, in RG systems, the pasture changes in biomass height and soil cover, it can be inferred that this grazing system is more favorable to the emergence of seedlings, when compared to the CG system [25].

However, according to Voisin and Lecomte [12], DG is the best technique to recover degraded pastures and improve their PFC, leading to an increase in the percentage of legumes, namely white clover. In DG systems, in order to improve the PFC, in early spring, before the production of the inflorescence of grasses, it is crucial to carry out grazing with a high animal load [28], to try to lengthen the vegetative cycle of the pasture.

Animal production, based on grazing, contributes to the maintenance and improvement of soil fertility, reducing animal feed costs [29]. Furthermore, it is essential to develop grazing systems that reconcile the need for agricultural productivity with environmental aspects [23].

This study aimed to evaluate the effect of the type of sheep grazing (continuous vs. deferred) with different stocking rates on the floristic composition of permanent dryland pastures in the Southern Alentejo region. This evaluation was performed in areas with and without the application of dolomitic limestone in winter, at the peak of spring and in late spring.

2. Materials and Methods

2.1. Study Area Framework

This study sequences other trials conducted from 2015 to monitor the effect of dolomitic limestone application on soil, tree, pasture and sheep grazing interactions over time (Figure 1), which resulted in some scientific articles [4,30–33].

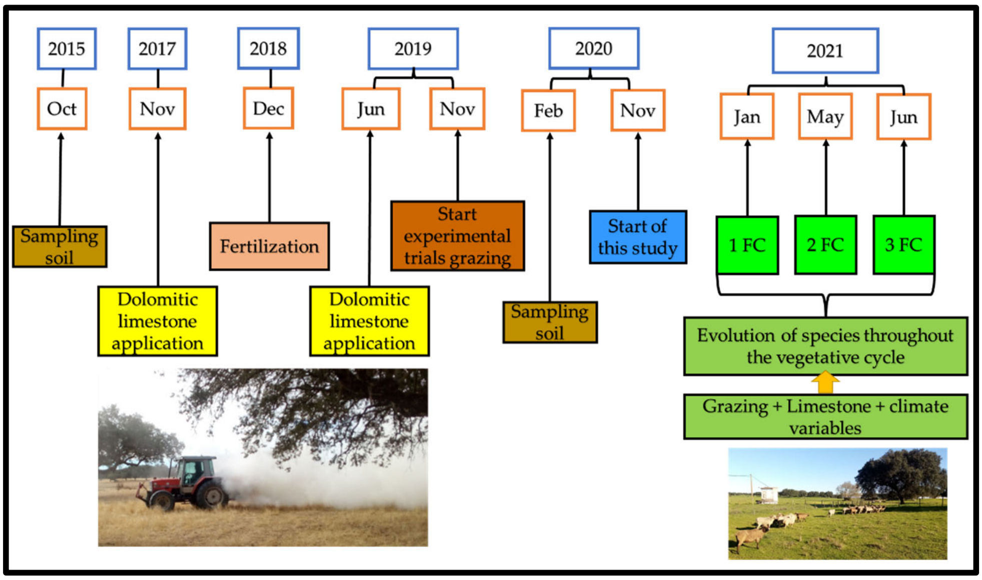

Figure 1. Chronological diagram of the study, with its framework in the research project of soil and pasture monitoring, in the Montado ecosystem (FC—characterization of floristic composition).

The predominant soils of this region are classified as Cambisol, derived from granite, which commonly has low fertility [34]. The study area is in a large patch of holm oak (*Quercus rotundifolia* Lam.), with an average density of 9–10 trees per hectare [35], over an understory of dryland pastures, mostly used for extensive animal production, especially to produce beef cattle and sheep. The Alentejo is affected by the Mediterranean climate. This climate is characterized by hot and dry summers, with maximum temperatures above 40 °C, and wet and cold winters, with minimum temperatures below 0 °C [32,33]. The irregular rain distribution and total year precipitation variation are also characteristic of the Mediterranean climate. In this region, the total amount of annual precipitation varies from 300 mm to 650 mm [33], with most of this precipitation occurring in autumn, winter and spring. In summer, if there is any precipitation, it will always have residual values.

The present study was carried out between November 2020 and June 2021. In this region, there is a large area of the Montado, mostly used for extensive cattle and sheep production systems.

2.2. Study Design Description

The study took place in an area of approximately 4 ha, subdivided into 4 plots of 1 hectare each (Figure 2) (38°32.2′ N; 8°1.1′ W), located in the Mitra farm in the Alentejo region, Portugal.

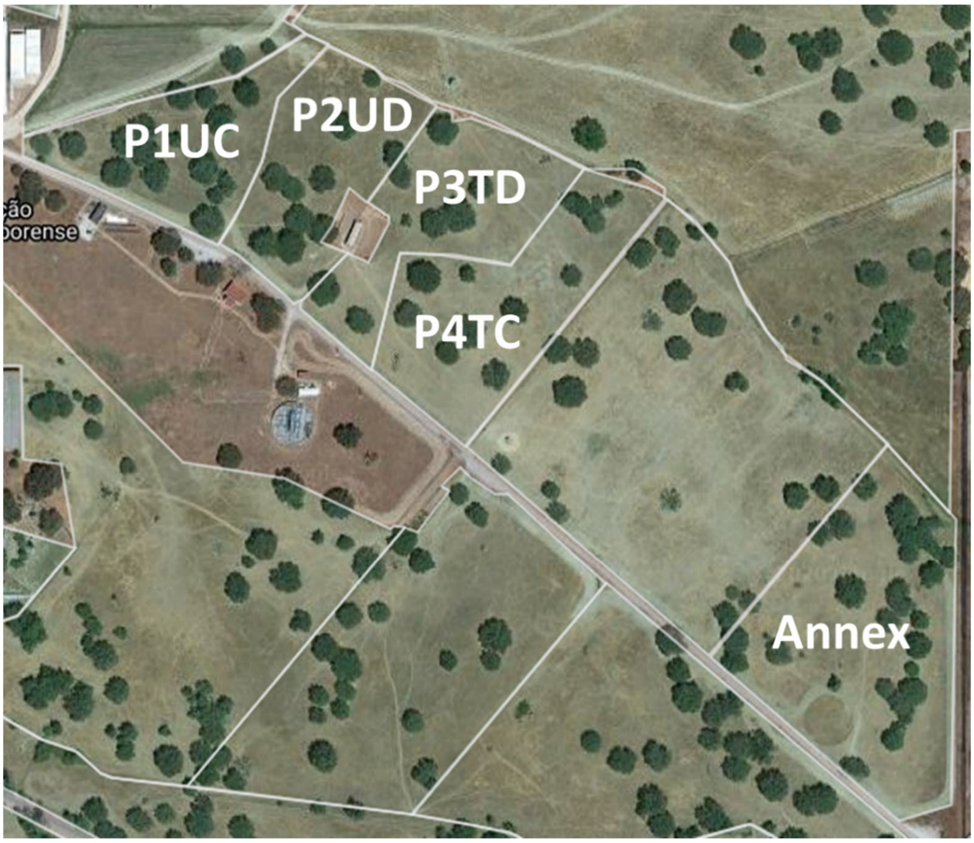

Figure 2. Four areas corresponding to four treatments are represented by U—without dolomitic limestone, T—with dolomitic limestone, C—continuous grazing, D—deferred grazing within the study area and remaining annex area.

The characterization of the surface layer of the soil (0–0.30 m depth), carried out in October 2015, revealed an acidic pH (average value of 5.4±0.3), so two amendments with lime were carried out (2 ton/ha of dolomitic limestone) in half the area (P3TD and P4TC) in November 2017 and June 2019. In December 2018, the whole study area (P1UC, P2UD, P3TD and P4TC) received 100 kg/ha of binary fertilizer (18-46-0). The experimental design was based on a factorial scheme, with two plots subjected to the application of dolomitic limestone and two others serving as controls (UC treatments). Within each treatment with and without amendment with dolomitic limestone, two grazing systems were applied: CG with continuous grazing and a moderate stocking rate and DG with deferred grazing and a high stocking rate (2 times that applied in the continuous grazing scenario). The four treatments were as follows: Plot 1 (P1UC)—without dolomitic limestone application and CG (7 sheep/ha); Plot 2 (P2UD)—without dolomitic limestone application and DG (16 sheep/ha); Plot 3 (P3TD)—with dolomitic limestone application and DG (16 sheep/ha); Plot 4 (P4TC) (7 sheep/ha)– with dolomitic limestone application and CG.

2.3. Grazing Management

The project that allowed the development of this study began in 2018, with the collection of elements regarding soil evolution and the influence of trees on the pasture's growth and nutritional value [4,31–33]. During this period, this pasture was grazed by the same herd that were studied in 2020 and 2021. The grazing was carried out with non-pregnant or lactating adult White Merino and Black Merino ewes (Figure 3). All ewes had similar body conditions at the beginning of the trial. All animals had a mean body condition score (BCS) of 3.5, with a standard deviation of 0.5. The scale used is from 1 to 5, where 1 is very thin and 5 is obese [36].

Figure 3. White Merino and Black Merino sheep in a plot of the study area.

The sheep in the P2UD and P3TD plots started grazing at the beginning of the experimental period, but according to a DG system. The presence or absence of animals was linked to pasture conditions following the "put and take" method used by [37,38]. Grazing management criterion was a function of the average pasture height in each plot, measured with a precision digital caliper. When the pasture's average height was less than 3 to 5 cm, the animals were removed and placed in an annex plot outside the study area (Figure 2), where they were fed until the pasture recovered and reached a mean height of 10 cm.

Pasture heights were measured in the 4 plots before and after each grazing period. Pasture samples were collected to estimate the productivity of green matter (GM) and dry matter (DM), both in Kg ha^{-1}. At the same time, the crude protein CP and neutral detergent fiber, NDF, were evaluated based on the methodology proposed by [39,40]. Every month, all the animals were evaluated in terms of their body condition to highlight possible weight loss or variations among the animals' body conditions [41], in the different plots.

2.4. Characterization of the Floristic Composition

Forty-eight sampling points were chosen to identify variations throughout the year in the relative proportions of the different species, 12 in each treatment (Figure 4). Each sampling point was permanently marked with a numbered flag (1 to 12 in each plot) (Figure 4).

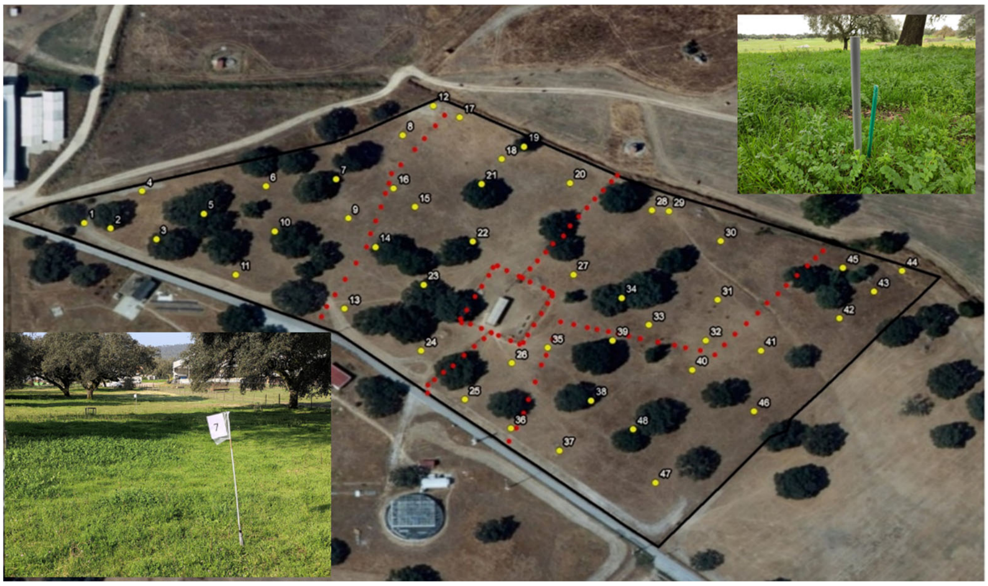

Figure 4. Representative sampling points of different pasture plant communities and sample point marking example.

Each of these 12 points represents, in each plot, a plant community, with species that vary in diversity and occurrence. The characterization of the floristic composition was carried out on January 14th (winter—WI), May 4th (peak of spring—SP1) and June 17th (late spring—SP2) of 2021. This characterization involved the identification of different plant species on each date in an area of 1 m^2. For each species, presence or absence was noted in each of the 12 points. The relative abundance of the various species present was also measured. However, the results will be presented in the following article, where the behavior and food preferences of the sheep will be analyzed.

2.5. Statistics Analyses

Data were first organized and processed in a spreadsheet for descriptive analysis. In addition, species were organized by family and by occurrence vs. absence in each study plot.

Subsequently, the data were subjected to a statistical analysis, namely multilevel pattern analysis (Indicator Species Analysis—ISA), a specific package in the "R" statistic software (St. Louis, MO, USA) [42]. The ISA involves the calculation of an indicator value (IV) for plant species, corresponding to the product between relative abundance (specificity) and relative frequency (fidelity) expressed in degrees (in percentage) [43]. However, as our data were merely the presence/absence of species and not the percentage of each species relative to others, the data had to be transformed by the Beals Smoothing transformation method [44], aiming to understand whether the treatments (CG vs. DG and limestone application vs. no application) impacted pasture biodiversity (i.e., the number of species present), rather than quantifying the percentages of each species. This team has already used this approach to quantify the percentages for each species in other published works. It requires exhaustive, time-consuming monitoring, which is incompatible with the demand for quick responses at the scale of plots corresponding to large areas.

To reduce the problem of data analysis in which we only have information regarding the presence (1) or absence (0) of species, the "sociological favorability index" (SFI) was used [44]. This index assesses the probability of occurrence of each species in each location based on their joint occurrence with other species [45]. With this transformation, each cell value (1 or 0) was replaced by the occurrence probability of each species in each sample unit. A bioindicator species was carried out based on time (1- WI, 2- SP1, 3- SP2) and treatment (T1=P1UC, T2=P2UD, T3=P3TD, T4=P4TC). A significance level (α= 5%) was used.

3. Results

3.1. Meteorological Conditions

Figure 5 represents the thermopluviometric graph for Mitra, between September 2020 and June 2021. The total amount of precipitation in this period was 627.8 mm, distributed very erratically over the various months, affecting the growth and development of the pasture. As shown in Figure 5, in September, the 40 mm of precipitation, together with the 133 mm in October, provided the moisture necessary for the germination and growth of the pasture. In March, precipitation was almost absent, with a residual value of 12 mm. In addition, the spring of 2021 was quite arid, with 7.7 mm and 10.4 mm of rainfall in May and June, respectively. In Figure 5, the grey line represents the monthly average maximum temperature, the orange line represents the monthly average minimum temperature, and the yellow line represents the monthly mean temperature. It is worth highlighting the temperature values for September and October, with a monthly average of 22.4 °C and 16.3 °C, respectively. The lowest temperatures and, therefore, the most limiting period for pasture growth occurred in January, with a minimum average of 3.4 °C. During this month, the average monthly temperature was 8.1 °C, and the average maximum was 13.7 °C. In this spring period, the average maximum temperature was 25.9 °C and 29.9 °C for May and June, respectively. The average minimum temperature was 9.9 °C and 12.5 °C for May and June, respectively. As we can see in Figure 5, the lowest temperatures occurred in winter, when there was greater water availability in the soil. On the other hand, in the spring months, water availability in the soil was relatively limited due to low precipitation in this period.

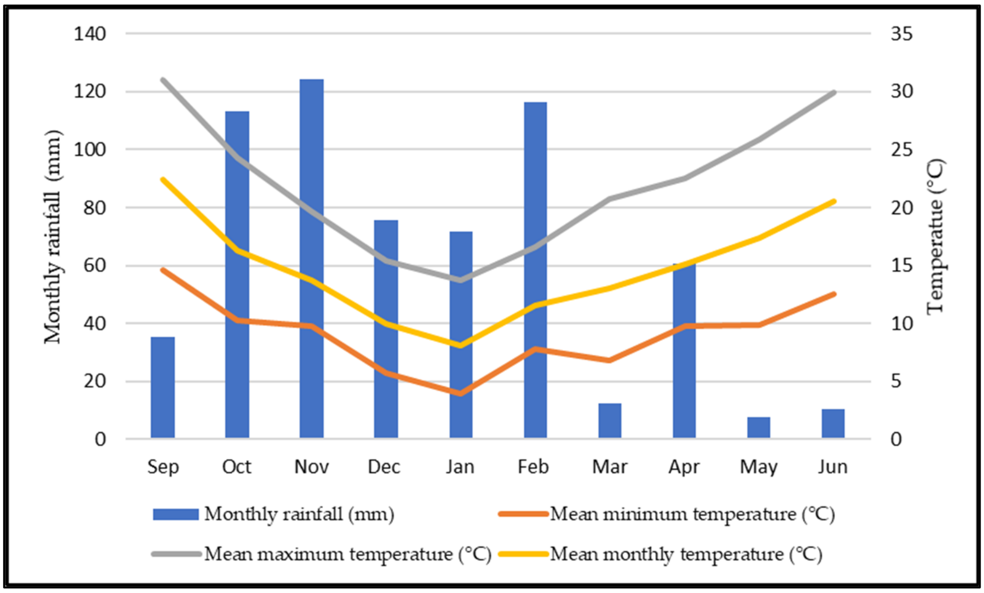

Figure 5. Thermopluviometric graph for Mitra station (Évora) between September 2020 and June 2021.

3.2. Grazing Days

Figure 6 shows the number of grazing days in each plot over the months, and Figure 7 shows the total grazing days. In December, in the P2UD plot, the animals only grazed until the 11th and in the P3TD plot until the 17th. We must highlight here the month of January, where, in the plots designated as DG (P2UD and P3TD), the animals were not present during the whole month. Moreover, in February and March, the plots intended for DG were left vacant during roughly half of each month, so that the pasture could recover. In February and March, the numbers of grazing days for P2UD and P3TD were 17 and 14, respectively, for each month. In May and June, in all plots, the grazing days were the same. In the month of April, at P2UD and P3TD, the animals were only out for 8 days. In P1UC and P4TC, the total grazing days were 236. In the P2UD plot, the animals grazed for 151 days, and in the P3TD plot, the grazing days were 158. In other words, P3TD had 7 more grazing days than P2UD.

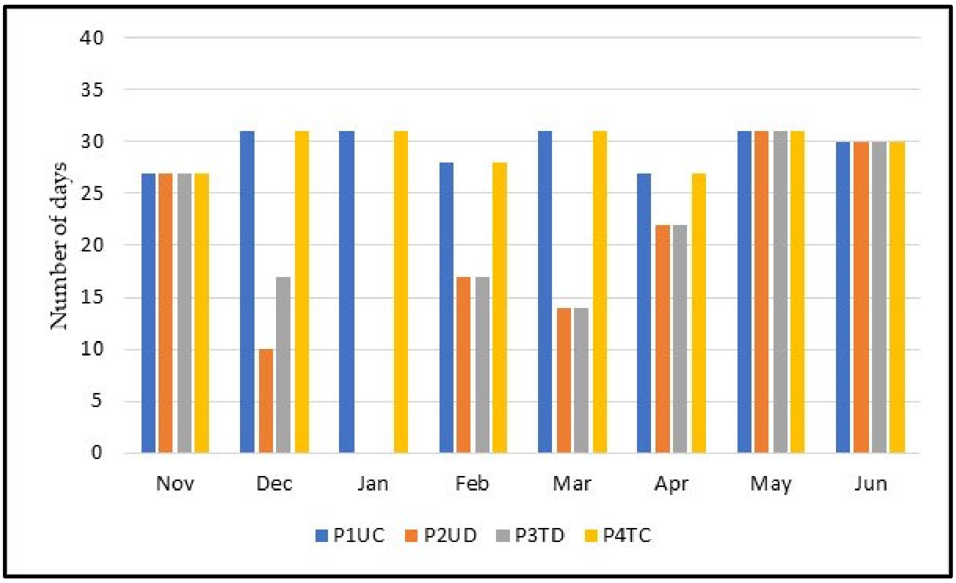

Figure 6. Number of grazing days in each treatment, per month.

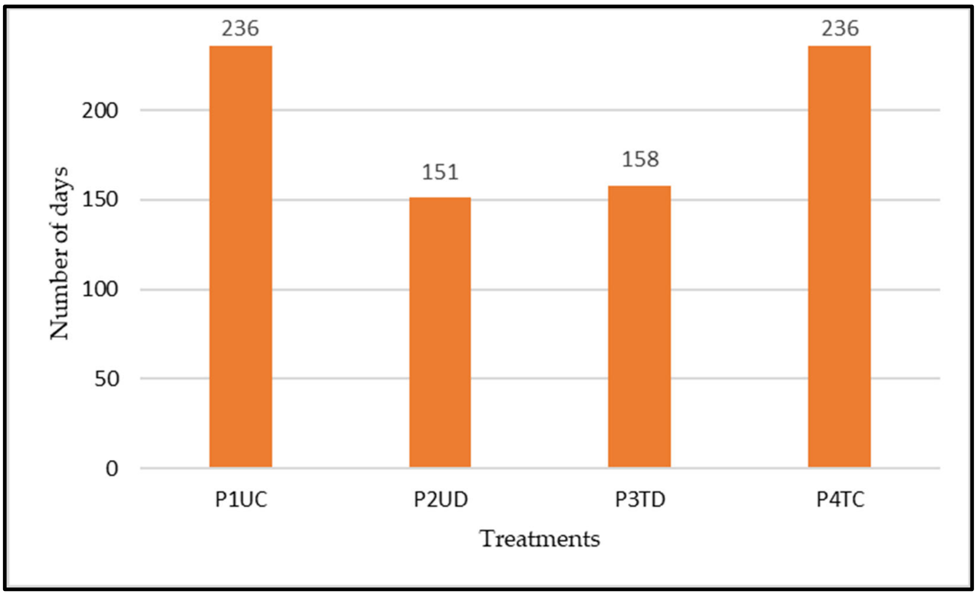

Figure 7. Total grazing days in each treatment.

3.3. Characterization of the Floristic Composition

3.3.1. Descriptive Analysis

In total, in WI, SP1 and SP2, 103 plant species were identified, belonging to 25 families.

The plant species that were identified in this study in each plot and in WI are shown in Table A1 (Appendix A). A total of 51 different species were identified, belonging to 15 botanical families. The most common species, in all plots, was *Vulpia geniculate* L. Other species, such as *Bromus diandrus* Roth, *Diplotaxis catholica* (L.) DC., *Echium plantagineum* L., *Erodium cicutarium* subsp. *bipinnatum* (Cav.) Tourlet, *Geranium molle* L. or *Leontodon taraxacoides* (Vill.) Mérat and *Senesio vulgaris* L., were also identified in all plots in WI, at many of the sampling points.

Table A2 (Appendix A) shows the plant species that were identified in each plot, in SP1. A total of 78 species were identified, belonging to 23 botanical families. In SP1, *Bromus diandrus* was not identified at any sampling point. However, the number of species with a more significant presence was higher in SP1 than in WI. The following can be noted: *Bromus hordeaceus* L., *Chamaemelum mixtum* L., *Crepis capillaris* (L.) Wallr., *Diplotaxis catholica*, *Echium plantagineum*, *Erodium cicutarium* subsp. *bipinnatum*, *Geranium molle*, *Hedypnois cretica* (L.) Dum.-Courset, *Hordeum murinum* subsp. *leporinum* (Link) Arcang., *Plantago coronopus* L., *Plantago lagopus* L., *Rumex bucephalophorus* L., *Tolpis umbellata* Bertol., *Trifolium campestre* Schreb., *Trifolium glomeratum* L. and *Vulpia geniculata* (most numerous).

The plant species identified in the four plots in SP2 are indicated in Table A3 (Appendix A). On this date, 53 species belonging to 17 families were identified. The most prominent species continued to be *Vulpia geniculata*. The following species are also highlighted: *Agrostis pourretii* Willd., *Chamaemelum mixtum*, *Crepis capillaris*, *Echium plantagineum*, *Hordeum murinum* subsp. *leporinum*, *Plantago lagopus* and *Tolpis umbellata*.

Figure 8a represents the number of plant species per family observed in WI, SP1 and SP2 at P1UC. In this plot, 76 different plant species were identified. In the plot, three families had the highest number of species in the three seasons: Asteraceae, Fabaceae and Poaceae. In the Asteraceae family, the most significant number of species occurred in WI, with 12 species, followed by 10 species in SP1 and 9 species in SP2. In the Fabaceae family, the most significant number of species occurred in SP1 (10 species), followed by SP2 (7 species) and WI (3 species). In the Poaceae family, eight species were identified in SP1 and SP2, and only four in WI. It should be noted that no plant species were identified in the P1UC belonging to the families Cucurbitaceae and Cyperaceae. In many other families, as shown in Figure 8a, only one or two species were identified in at least one season.

Moreover, in P2UD, the most numerous plant families were Asteraceae, Fabaceae and Poaceae (Figure 8b). The Asteraceae family comprised 10 species in WI, 9 in SP1 and 4 in SP2. The Fabaceae family was very numerous in SP1, with nine identified species, while only two and oone species were present in WI and SP2, respectively. The Poaceae family comprised six species in WI and eight in SP1 and SP2. As in the case of the P1UC and the P2UD plots, not all of the species identified in the total study area were observed. Thus, from the families Apiaceae, Cyperaceae, Fagaceae, Orobanchaceae and Ranunculaceae, no species were identified in P2UD (Figure 8b). In this plot, 64 different plant species were recognized.

As was the case in P1UC and P2UD, in P3TD, the botanical families Asteraceae, Fabaceae and Poaceae stand out, with the highest number of identified species (Figure 8c). In this case, the Asteraceae family represented 7 species in WI, 10 in SP1 and 6 in SP2. Regarding the Fabaceae family, the highlight values were observed in SP1, with nine identified species. From the Poaceae family, five species were identified in WI, six in SP1 and seven in SP2. No species were identified in the P3TD plot from the botanical families Cucurbitaceae, Cyperaceae, Fagaceae, Lythraceae, Orobanchaceae and Rubiaceae (Figure 8c). In this plot, 65 different plant species were identified.

The most prominent botanical families in P4TC are Asteraceae, Fabaceae and Poaceae (Figure 8d). The Asteraceae family comprised six species in WI and eight in SP1 and SP2. From the Fabaceae family, seven species were observed in SP1 and only one in WI and SP2. The most significant family was Poaceae, with 6 species identified in WI, 11 in SP1 and 10 in SP2. From the families Apiaceae, Araceae, Cucurbitaceae, Fagaceae, Iridaceae, Juncaceae, Lythraceae, Myrsinaceae, Orobanchaceae and Rubiaceae, no species were identified in P4TC, as can be seen in Figure 8d. In this plot, only 60 different plant species were identified.

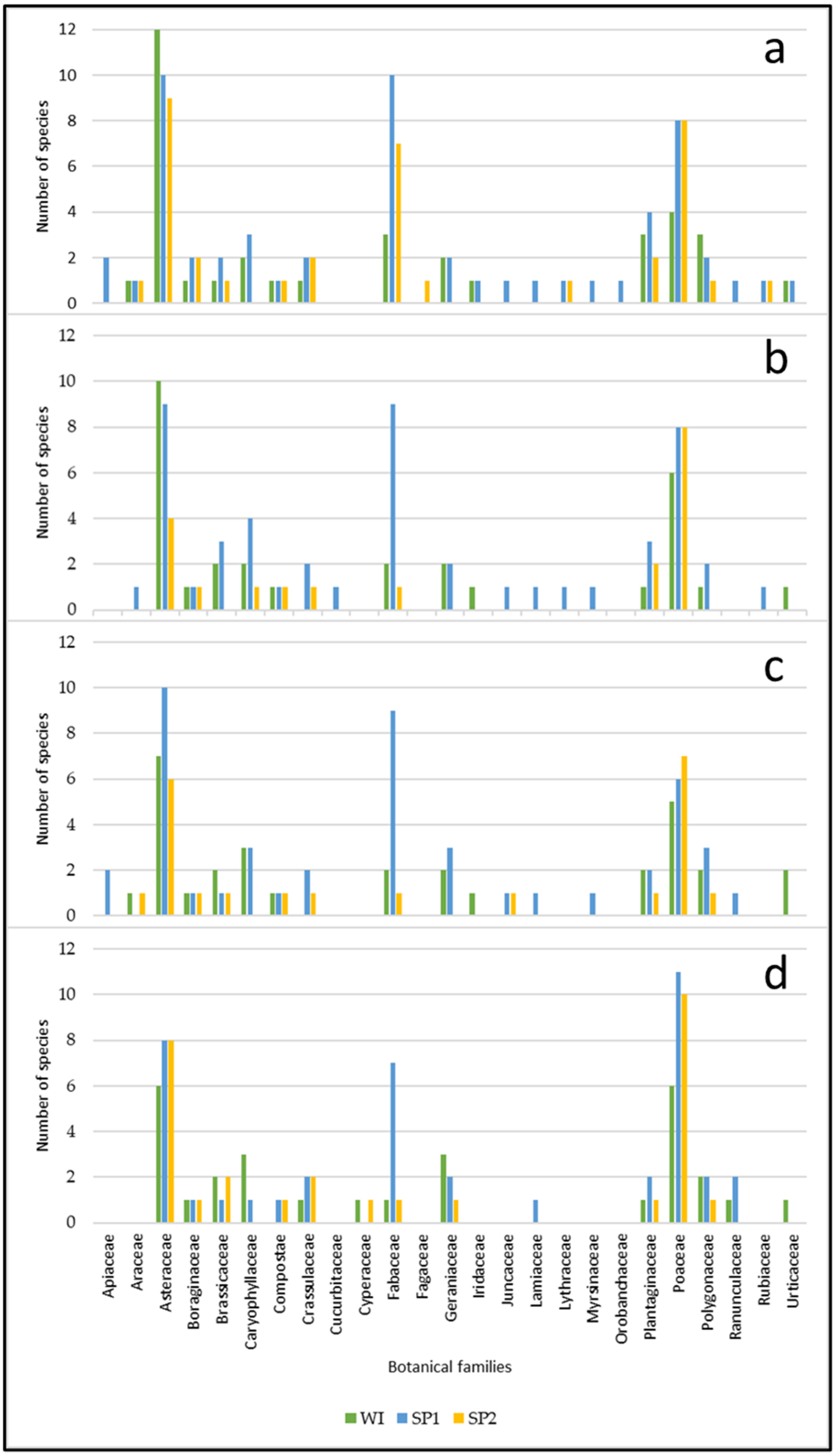

Figure 8. Number of plant species per family for P1UC (**a**), P2UD (**b**), P3TD (**c**) and P4TC (**d**) in WI, SP1, SP2.

3.3.2. Seasonal Bioindicators

Of the 103 plant species observed during the experimental study (51 in WI, 78 in SP1 and 53 in SP2), 18 species can be considered bioindicators (Figure 9). Bioindicators are plant species that are characteristic of a determinate treatment or season of the year [4,36]. Figure 9 represents a diagram of the bioindicator species in each season (WI, SP1 and SP2) according to the ISA application. There were eight bioindicator species in WI and three in SP2, and no significant differences were observed for any species in SP1. In the WI_SP1 combination, there were three bioindicator species, and in the SP1_SP2 combination, there were four bioindicator species (Figure 9).

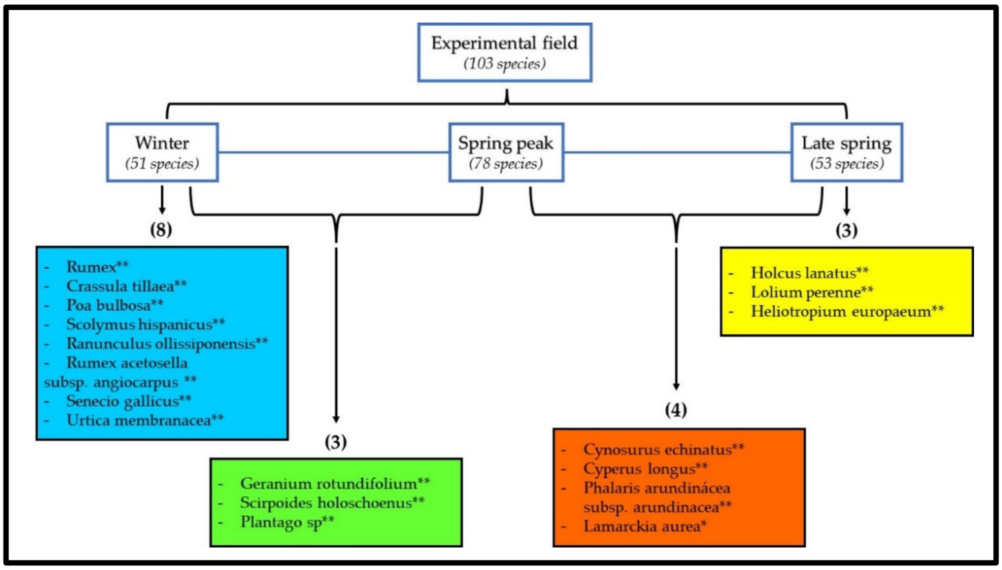

Figure 9. Representative diagram of the analysis of indicator species (ISA), for each season of the year (WI, SP1 and SP2), and their combinations. **—Probability < 0.01; *—Probability < 0.05.

Figure 10 presents the analysis diagram of the ISA application to verify the existence of bioindicator plants for each treatment (P1UC, P2UD, P3TD and P4TC). As shown in Figure 10, only P4TC had bioindicator species: a total of three bioindicator species. Furthermore, in the P1UC_P2UD combination, there is one bioindicator species. Thus, only four species proved to be bioindicators of the four treatments.

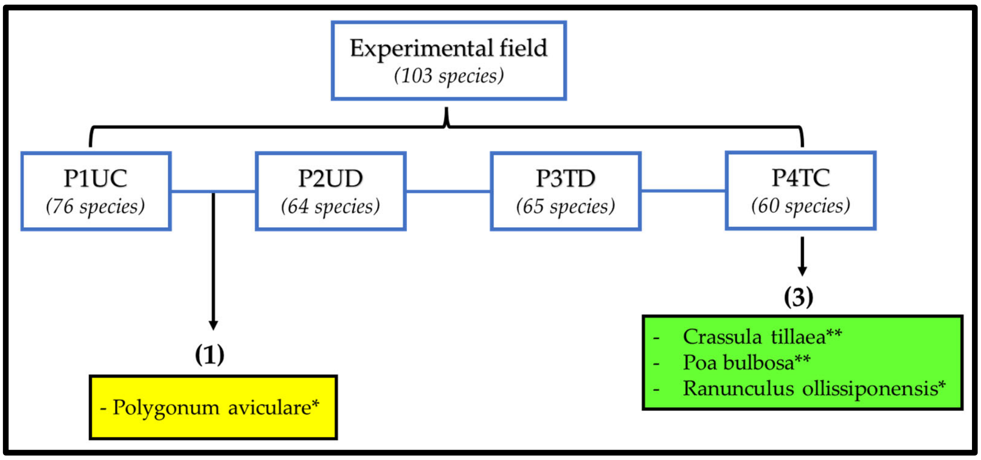

Figure 10. Representative diagram of the analysis of indicator species (ISA), for each plot (P1UC, P2UD, P3TD and P4TC) and their combinations. **—Probability < 0.01; *—Probability < 0.05.

Table 1 refers to the analysis diagram of the ISA application to verify the existence of bioindicator plants for the different combinations between seasons (WI, SP1 and SP2) and treatments (P1UC, P2UD, P3TD and P4TC). In total, 25 bioindicator species were identified for different combinations, as seen in Table 1.

Table 1. Analysis of indicator species (ISA) for bioindicator species for the combinations between season (WI, SP1 and SP2) and treatment (P1UC, P2UD, P3TD and P4TC).

Combinations: Seasons and Plots	Species	*p*-Value
WI_P1UC; WI_P2UD; WI_P3TD	*Urtica membranacea*	0.005 **
WI_P1UC; WI_P2UD; WI_P3TD; WI_P4TC	*Rumex* sp.	0.005 **
	Crassula tillaea	0.005 **
	Poa bulbosa	0.005 **
	Ranunculus ollissiponensis	0.005 **
	Silene gallica	0.005 **
WI_P1UC; WI_P2UD; WI_P3TD; WI_P4TC; SP1_P3TD	*Plantago* sp.	0.005 **
WI_P1UC; WI_P2UD; WI_P3TD; WI_P4TC; SP1_P1UC; SP1_P3TD	*Scolymus hispanicus*	0.005 **
WI_P1UC; WI_P2UD; WI_P3TD; WI_P4TC; SP1_P2UD; SP1_P3TD; SP1_P4TC	*Rumex acetosella* subsp. *angiocarpus*	0.005 **
SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Holcus lanatus*	0.005 **
SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC; SP1_P4TC	*Cyperus longus*	0.005 **
	Phalaris arundinacea subsp. *arundinacea*	0.005 **
	Lolium perenne	0.005 **
SP1_P1UC; SP1_P2UD; SP1_P4TC; SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Cynosurus echinatus*	0.005 **
WI_P1UC; WI_P2UD; WI_P3TD; WI_P4TC; SP1_P1UC; SP1_P2UD; SP1_P3TD; SP1_P4TC	*Geranium rotundifolium*	0.005 **
	Scirpoides holoschoenus	0.005 **
	Leontodon tuberosus	0.005 **
WI_P1UC; WI_P2UD; SP1_P1UC; SP1_P4TC; SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Heliotropium europaeum*	0.035 *
WI_P4TC; SP1_P1UC; SP1_P2UD; SP1_P3TD; SP1_P4TC; SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Tolpis barbata*	0.005 **
WI_P2UD; WI_P4TC; SP1_P1UC; SP1_P2UD; SP1_P3TD; SP1_P4TC; SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Orobanche* sp.	0.01 **
WI_P1UC; WI_P2UD; WI_P3TD; WI_P4TC; SP1_P1UC; SP1_P2UD; SP1_P3TD; SP1_P4TC; SP2_P1UC; SP2_P3TD; SP2_P4TC	*Stellaria media*	0.005 **
	Sonchus oleraceus	0.02 *
WI_P1UC; WI_P3TD; WI_P4TC; SP1_P1UC; SP1_P2UD; SP1_P3TD; SP1_P4TC; SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Quercus rotundifolia*	0.005 **
WI_P2UD; WI_P3TD; WI_P4TC; SP1_P1UC; SP1_P2UD; SP1_P3TD; SP1_P4TC; SP2_P1UC; SP2_P2UD; SP2_P3TD; SP2_P4TC	*Bromus tectorum*	0.005 **
	Lolium rigidum subsp. *rigidum*	0.005 **

**—Probability < 0.01; *—Probability < 0.05.

4. Discussion

Management of the Montado ecosystems is highly complex, as it comprises several interconnected subsystems that influence each other. The diversity of plant species in the Montado pastures increases the complexity of this ecosystem [4]. Pasture degradation is often associated with a high animal stocking rate. Sometimes, there is confounding between high stocking rates and poor pasture management. Poor management of pastures and high stocking rates can contribute to overgrazing, reduced available biomass and the degradation of pasture and soil [29]. However, other studies show that a high animal stocking rate, per se, is not a factor in soil and pasture degradation, as long as the response capacity of the pasture is taken into account and the regrowth capacity in the more critical seasons is preserved [14,23,29].

4.1. Relationship between Climatic Variables, Pasture Development and Grazing Days

The irregularity of the Mediterranean climate influences the germination and growth dynamics of annual pastures' species. In this study field, precipitation and temperature showed significant climatic variability since 2015, with some very dry autumns delaying the pasture germination and others with large amounts of precipitation [4]. Moreover, the same phenomena occur in the spring: some years have rainy springs and others are very arid [4]. Autumn 2020's precipitation values did not compromise the germination and development of the pasture since, between September and October, the precipitation value was 148 mm. For the pasture to germinate in autumn, 50 mm of precipitation is required [46]. However, the late of rain in September implied a generalized delay in germination. This lower biomass availability during October led the animals to start grazing only in November, when the average pasture height was around 10 cm.

The minimum temperatures in December and especially January had a negative effect on the development of the pasture. In some periods of January, a pause in the growth of the pasture was noticeable. This low temperature reduced the use of the pasture in the month of December in deferred grazing systems and the absence of animals during the whole of January. The growth of most of the species that composed this natural pasture, with temperatures as low as 8 to 10 °C, was reduced [47].

In February, the average temperature (11.5 °C), combined with a high value of precipitation (116.5 mm), allowed the regrowth of the pasture and, consequently, grazing in the P2UD and P3TD plots during the last 17 days of the month, extending into the middle of March.

During the experimental period, spring was also quite dry, which may have compromised the length of the vegetative cycle of the pasture.

Although the average temperature (13 °C) in March was favorable to pasture growth, the total precipitation (12 mm) compromised its growth. In addition to this low value of precipitation, the strong wind that occurred on some days also negatively affected plant growth, which interrupted the DG for a few days. Added here is the negative effect of the minimum average temperature in March, which recorded a value of 6.8 °C.

However, the amount of precipitation in April (around 60 mm), with an average temperature of around 15 °C, permitted pasture growth and the lengthening of this vegetative cycle for a few more days. Rainfall in April is significant for the growth and development of the pasture [46]. These low values of precipitation in the spring, together with the increase in temperatures, may have affected the phenological cycle of the different species of the pasture. Moreover, the temperatures in the months of May and June could have enabled the development of the pasture, as well as the extension of the vegetative cycle, were it not for the low precipitation values (7.7 mm and 10 mm, in May and June, respectively) of this period. In any case, the precipitation in April, combined with the spring temperatures, promoted the growth of the pasture, which allowed the grazing in P2UD and P3TD, during May and June. Furthermore, temperatures in May were not very high, thus reducing pasture evapotranspiration. This allowed for the maintenance of soil moisture for a longer time. Grazing days have always depended on pasture growth. In WI, the limiting factor was temperature, while in SP1 and SP2, it was precipitation.

4.2. Evolution of the Floristic Composition: Field Observations

The results of this study reflect the effect of differentiated grazing over a period of two years and the application of dolomitic limestone since 2017.

In this study, 103 different plant species were identified, pertaining to 25 botanical families. The botanical families Asteraceae, Fabaceae and Poaceae were the most represented in all the studied plots and in all seasons, although with some variations. However, the families Plantaginaceae and Polygonaceae also had considerable representation.

According to Serrano et al. [4], the pH in P3TD and P4TC in March 2020 was 5.7, with a small increase compared to October 2015, when the pH value was 5.4. This increase in pH due to the two soil amendments performed in the field may not have been enough to cause significant changes in the PFC. On the other hand, the Mg/Mn ratio also increased [4], which may have benefited the emergence of some plant species, namely legumes. However, Mn toxicity's influence on plants depends on the species and cultivars [48].

The number of species in the Fabaceae family was always much higher in SP1 than in other seasons. Soil acidity and Mn toxicity harm leguminous plants [48]. However, in this study, DG seems to have exerted a positive effect on legumes since, in P2UD, where no soil amendment was applied, the number and species of legumes in WI, SP1 and SP2 were precisely equal to the plot P3TD, where 2 ton/ha of dolomitic limestone was applied, which did not occur in P1UC. This may be explained by the fact that deferred grazing with a high stocking rate allows grasses to be ingested more because they are more palatable than legumes during the winter, and thus provides more plentiful access to light for legumes. In a similar study, after 3 years of DG, the density of perennial grasses increased to 88%, decreasing the density of annual grasses up to 58%, contributing to increased pasture DM production and improved PFC, soil cover and system resilience [28]. Nevertheless, this same study also reports that DG did not affect the density of legumes. In P4TC, the number of legume species was significantly reduced, with only one in WI and SP1 and seven in SP2. It is likely that this is due to the application of the soil amendment in this plot, and, despite the CG, the stocking rate was low, which led to the substantial initial growth of grasses in the autumn, which tends to shade out the leguminous plants, limiting their growth. When the animal stocking rate is high enough to ingest the produced biomass, the competition for light is reduced, thus allowing the growth of plants of the Fabaceae family [49]. Ferreira et al. [50] reported that the exclusion of grazing had a negative effect on prostrate plants, where some legumes are included. In our study, in P4TC, although there was CG, there were few animals to remove the pasture production, and thus prostrate plants, such as legumes, were affected. This probably occurred due to the lack of light in the lower layers of the pasture. The sample points where the pasture presented lower and more uniform height were also those where the greatest presence of legumes was observed. For example, this effect was observed in P4TC, which can be associated with the animal's preferred grazing, where the legumes are more competitive for light access (unpublished data). According to Heady [15], when grazing, sheep seek species that are rich in crude protein and have a low content of crude fiber. This selectivity can lead to better animal performance [39]. At an early stage in the growing cycle, sheep do not eat legumes and have a clear preference for grasses and other species. Moreover, in the other plots, leguminous species were identified mainly in the grazing areas preferred by the animals, although, in the plots destined for DG, the selectivity was very low. Nonetheless, grazing with a high stocking rate during the winter enhances most pasture species' growth, especially ryegrass and red clover [11].

4.3. Evolution of the Floristic Composition: Field Observations vs. Indicator Species Analysis

In the statistical analyses (ISA), there were no significant differences between plots or seasons for the Fabaceae family. In a study carried out by Nie and Zollinger [28], in which they compared the application of fertilizer and amendments (50 Kg P + 2 ton/ha dolomitic limestone), with no application of fertilizer or amendments, they found that the first treatment contributed to the increase in the density of leguminous plants by 60%, without any effect on other plant families. In a study in New Zealand, in natural pastures, the effect of CG vs. RG was not significant in any species of pasture plant [25]. However, in the same study, in pastures overseeded with five species (*Cirsium vulgare*, *Lolium perenne*, *Plantago lanceolata*, *Rumex obtusifolius* and *Trifolium repens*), seedling density was higher in RG plots when compared to plots with CG. Leguminous plants are directly related to the nutritional quality of the pasture. In this study, *Trifolium repens* was observed during SP1 at many sampling points, in plots with DG. In P4TC, it was only observed in SP1 and at sampling points preferred by the animals. DG with high instantaneous biotic loads appears to be relevant for increasing rangeland biodiversity, increasing desirable plants and reducing undesirable ones. Leguminous plants, especially *Trifolium repens*, are essential in pastures since they provide high-quality food and fix nitrogen in the soil [19]. Furthermore, *Trifolium repens* is quite tolerant to grazing and treading [19], which means that DG does not restrain its development.

In this study, the plant species diversity was higher in P1UC (36 in WI, 58 in SP1 and 37 in SP2). On the contrary, the lowest botanical diversity was observed in P4TC, with only 29, 41 and 29 plant species identified in WI, SP1 and SP2, respectively. For SP1, all species have the same chance of appearing in all treatments in that season. It should be noted that *Lolium perenne* is a SP2 bioindicator species despite being a grass (*Poaceae* family). However, we must point out here that bioindicators can be negative—that is, certain species not being bioindicators can be an advantage for the improvement of PFC. For example, species of the genus *Rumex* were not bioindicators in SP1 or SP2, or in any of the four treatments, which means that they tend to disappear, which is advantageous for sheep production systems, as these plants are unpalatable and have low nutritional value. Regarding DG, in P2UD, 30, 51 and 19 plant species were identified in WI, SP1 and SP2, respectively; in P3TD 31, 47 and 22 species were identified in WI, SP1 and SP2, respectively. At the end of the vegetative cycle, the botanical diversity was higher in the CG plots than in the DG plots. Similarly, the same happened in the studies of Edwards et al. [25] and Marley et al. [37], where the species diversity was higher with CG than with RG. *Diplotaxis catholica* is considered a weed plant in Mediterranean pastures, and is only consumed by grazing animals in the first phenological stages, always before maturation and, above all, if the instantaneous animal stocking rate is high. In this study, this species was no longer observed in SP2, except in P2UD. The presence of this species may indicate that the high animal stocking rate and the consequent reduction in selectivity led to its total consumption during SP1. *Echium plantagineum* was present in all plots and in all seasons. Another species that was also present in all plots in WI and SP1 was *Erodium cicutarium*. However, in SP2, it was only identified in P4TC, probably because this species, at the end of the vegetative cycle, has sharp structures (stubble) that prevent animals from eating it, which may have led to it not being ingested. In the other plots, this did not occur because the animals ingested the plants before this phenological stage. Sometimes, the dominant plants in a pasture are unwanted plants with reduced palatability and nutritional value for animals. As they are not consumed or preferred, they become dominant, leading to pasture degradation. Grazing with a high stocking rate during winter boosts all pasture species' growth, especially ryegrass and red clover [11].

4.4. Evolution of the Floristic Composition: Effects of Different Gazing Management

Grazing management is essential for maintaining functional ecosystems and contributes to the biodiversity of species. A study carried out by Mendes et al. [49] in an area dominated by *Cistus ladanifer* L. shrubs, with five types of management—abandonment; initial cutting and grazing with 2 to 3 normal heads/ha; cutting every two years; fire after five years of abandonment; soil mobilization (and abandonment)—showed that only cutting and grazing led to a significant reduction in shrubs and increased herbaceous species, especially from the Poaceae and Fabaceae families. Moreover, Ferreira et al. [50] reported that excluding grazing harms species diversity.

In P2UD and P3TD, the number of grazing days and the interval between each grazing period depended on the height and quality of the pasture. Ferreira et al. [50] state that the interval between grazing periods depends on the place and the season of the year, i.e., it depends on the conditions of the pasture.

DG, in which grazing periods are defined according to pasture conditions, is the most effective method for increasing perennial grasses and reducing annual ones, which can help to improve the PFC more quickly [28]. Mendes et al. [49] reported that proper grazing management tends to decrease invasive shrubs (*Cistus ladanifer*) and increase the Poacea and Fabacea families, especially *Poetea bulbosae*, *Poa bulbosa* L., *Trifolium subterraneum* L., *Erodium botrys* (Cav.) Bertol., *Trifolium glomeratum* and *Trifolium tomentosum* L. Seven months without grazing led to a 72 to 87% reduction in the density of grasses, clovers and other species [51].

The plant species that make up the pasture can affect the feeding efficiency of the animals [29], as well as the grazing system. Moreover, the plant families determine the feeding quality of the pasture, and according to [21], legumes generally have better nutritional value than grasses: the more legumes in the pasture, the greater will be its quality [52].

The sheep's body condition was not affected during the experimental period. During the production cycle, monitoring of the energy balance and quantification of the animal body's reserve changes are essential and were performed in the field by estimating the body condition (BCS) and its variations [41]. This method evaluates the fat tissue thickness and the muscle on the waist and spine. The BCS is described as the ratio of total fat and other tissues on a live animal, and it is crucial to obtain the desired performance in certain physiological states in extensive sheep systems. There can be variable scores within different genotypes and physiological statuses of ewes (Biçer, 1991) cited by [53].

Sometimes, differences are observed in the performance of animals in pastures where there are only grasses, which is due to different proportions of leaves, stems, seeds and/or inflorescences, which vary between grass species [21].

5. Conclusions

Extensive livestock production systems, based on rainfed pastures under the Montado, are based on high complexity, resulting from the interactions between soil, pasture, trees and animals, together with precipitation and temperature, throughout the year. Despite pasture being the cheapest food for ruminants, its production and improvement in terms of quality and nutritional value are not always easy to implement in a complex production system such as the Montado. An essential component still poorly studied is the PFC and the interactions between it, the animals, the type of grazing and soil properties (namely acidity and Mn toxicity). The PFC of the pasture is responsible, above all, for its quality.

Statistically, there were no significant differences in the probability of occurrence of certain species in P1UC, P2UD and P3TD. However, in P4TC, three plant species were identified as bioindicators of this treatment (*Crassula tillaea* Lest.-Garl., *Poa bulbosa* and *Ranuncullus ollissiponensis* Pers.). For each season of the year and for their combinations, several bioindicator plants were identified. The most representative botanical families in all study plots were Asteraceae, Fabaceae, Poaceae, Plantaginaceae and Polygonaceae. The Fabacea family was widely present in SP1.

DG appears to be beneficial for eliminating undesirable species and the consequent increase in desirable species, and from the sheep's point of view, there seems to be no disadvantage as the nutritional value tends to be higher.

The application of dolomitic limestone combined with CG proved to be inefficient in increasing the biodiversity of the pasture, as well as in increasing the number of prostrate-sized plant species, such as those belonging to the genus Trifolium. The sheep's body condition during the experimental period did not differ among treatments.

A better understanding of the effects of sheep grazing, stocking rates and dolomitic limestone application on PFC can have a strong impact on the improvement of extensive livestock production systems in the Mediterranean region. Thus, this work can significantly contribute to more informed decision-making among farmers, ensuring the efficiency and the sustainability of the Montado ecosystem.

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Appendix A

Table A1. Plant species identified in WI.

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Agrostis castellana Boiss. & Reut.	Poaceae	N	L	L	L
Agrostis pourretii Willd.	Poaceae	L	L	L	L
Arum italicum subsp. *italicum*	Araceae	L	N	L	N
Bromus diandrus Roth	Poaceae	M	M	M	H
Calendula arvensis L.	Asteraceae	M	N	N	L
Carduus tenuiflorus Curtis	Compostae	L	L	L	N
Cerastium glomeratum Thuill.	Caryophyllaceae	N	N	L	L
Chamaemelum fuscatum (Brot.) Vasc.	Asteraceae	L	L	L	L
Chamaemelum mixtum L.	Asteraceae	L	L	N	N
Crassula tillaea Lest.-Garl.	Crassulaceae	N	N	N	L
Crepis vesicaria subsp. *taraxacifolia* (Thuill.) Thell.	Crassulaceae	L	N	N	N
Cynodon dactylon (L.) Pers.	Poaceae	L	L	L	L
Diplotaxis catholica (L.) DC.	Brassicaceae	M	H	H	H
Echium plantagineum L.	Boraginaceae	L	M	M	H
Erodium cicutarium subsp. *bipinnatum* (Cav.) Tourlet	Geraniaceae	H	M	H	H
Geranium molle L.	Geraniaceae	M	M	L	L
Geranium rotundifolium L.	Geraniaceae	N	N	N	L
Hypochaeris glabra L.	Asteraceae	L	L	L	L
Hypochaeris radicata L.	Asteraceae	L	L	N	N
Iris xiphium L.	Iridaceae	L	L	L	N
Leontodon taraxacoides (Vill.) Mérat	Asteraceae	L	M	L	M
Leontodon tuberosus L.	Asteraceae	N	L	L	N
Logfia gallica (L.) Coss. & Germ.	Asteraceae	N	L	N	N
Medicago polymorpha L.	Fabaceae	L	N	N	N
Ornithopus compressus L.	Fabaceae	L	L	L	L
Plantago coronopus L.	Plantaginaceae	1	N	N	N

Table A1. *Cont*.

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Plantago lagopus L.	Plantaginaceae	N	N	L	N
Plantago lanceolata L.	Plantaginaceae	L	M	L	L
Plantago sp.	Plantaginaceae	L	N	N	N
Poa annua L.	Poaceae	N	L	N	N
Poa bulbosa L.	Poaceae	N	N	N	L
Pulicaria odora (L.) Rchb.	Asteraceae	L	L	L	N
Ranunculus ollissiponensis subsp. *Ollissiponensis* Pers.	Ranunculaceae	N	N	N	L
Raphanus raphanistrum L.	Brassicaceae	N	L	L	L
Rumex acetosella subsp. *angiocarpus* (Murb.) Murb.	Polygonaceae	N	N	L	N
Rumex bucephalophorus L.	Polygonaceae	N	N	N	L
Rumex crispus L.	Polygonaceae	L	N	N	N
Rumex pulcher subsp. *woodsii* (De Not.) Arcang.	Polygonaceae	L	L	L	L
Rumex sp.	Polygonaceae	L	N	N	N
Scirpoides holoschoenus (L.) Soják	Cyperaceae	N	N	N	L
Scolymus hispanicus L.	Asteraceae	L	N	N	N
Senecio gallicus Vill.	Asteraceae	L	N	N	N
Senecio jacobaea L.	Asteraceae	L	L	L	L
Senecio vulgaris L.	Asteraceae	M	H	H	M
Sonchus oleraceus L.	Asteraceae	L	N	N	N
Spergula arvensis L.	Caryophyllaceae	L	L	L	L
Stellaria media (L.) Vill.	Caryophyllaceae	L	L	L	L
Trifolium repens L.	Fabaceae	L	L	L	N
Urtica membranacea Poir.	Urticaceae	N	N	L	N
Urtica urens L.	Urticaceae	L	L	L	L
Vulpia geniculata L.	Poaceae	L	H	M	H

N—not present; L, M and H—present (L—low; M—medium; H—high, respectively, in 1 to 4 points; in 5 to 8 points; in 9 to 12 points).

Table A2. Plant species identified in each plot, in SP1.

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Agrostis castellana Boiss. & Reut.	Poaceae	N	N	N	M
Agrostis pourretii Willd.	Poaceae	L	N	N	N
Anagallis arvensis L.	Myrsinaceae	L	L	L	N
Andryala integrifolia L.	Asteraceae	L	N	N	N
Anthriscus caucalis M.Bieb.	Apiaceae	L	N	L	N
Arum italicum subsp. *italicum*	Araceae	L	L	N	N
Avena barbata subsp. *lusitanica* (Tab.Morais) Romero Zarco	Poaceae	L	N	N	L
Biserrula pelecinus L.	Fabaceae	L	L	L	L
Bromus hordeaceus L.	Poaceae	M	L	H	H
Bromus sterilis L.	Poaceae	L	L	L	L
Bryonia dioica Jacq.	Cucurbitaceae	N	L	N	N

Table A2. *Cont.*

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Callitriche stagnalis	Plantaginaceae	L	L	N	N
Carduus tenuiflorus Curtis	Compostae	L	L	L	L
Cerastium glomeratum Thuill.	Caryophyllaceae	L	L	L	L
Chamaemelum fuscatum (Brot.) Vasc.	Asteraceae	L	L	L	L
Chamaemelum mixtum	Asteraceae	M	H	M	M
Crepis capillaris (L.) Wallr.	Crassulaceae	L	M	M	M
Crepis vesicaria subsp. *taraxacifolia* (Thuill.) Thell.	Crassulaceae	M	L	L	L
Cynodon dactylon (L.) Pers.	Poaceae	L	L	L	L
Daucus carota subsp maximus L.	Apiaceae	L	N	L	N
Diplotaxis catholica (L.) DC.	Brassicaceae	M	M	H	M
Echium plantagineum L.	Boraginaceae	M	M	H	M
Erodium cicutarium subsp. *bipinnatum* (Cav.) Tourlet	Geraniaceae	M	M	M	M
Galactites tomentosus Moench	Asteraceae	N	N	N	L
Geranium molle L.	Geraniaceae	M	L	M	L
Geranium purpureum Vill.	Geraniaceae	N	N	L	N
Hedypnois cretica (L.) Dum.-Courset	Asteraceae	M	M	L	L
Heliotropium europaeum L.	Boraginaceae	L	N	N	N
Hordeum murinum subsp. *leporinum* (Link) Arcang.	Poaceae	M	L	M	1++
Hypochaeris glabra L.	Asteraceae	L	L	L	N
Hypochaeris radicata L.	Asteraceae	L	L	L	L
Iris xiphium L.	Iridaceae	L	N	N	N
Juncus bufonius L.	Juncaceae	L	L	M	N
Lamarckia aurea (L.) Moench	Poaceae	N	L	N	N
Lathyrus angulatus L.	Fabaceae	L	N	L	N
Leontodon taraxacoides (Vill.) Mérat	Asteraceae	M	L	M	L
Logfia gallica (L.) Coss. & Germ.	Asteraceae	N	L	N	N
Lolium rigidum subsp. *Rigidum* Gaudin	Poaceae	N	N	N	L
Lotus parviflorus Desf.	Fabaceae	N	L	N	N
Lythrum borysthenicum (Schrank) Litv.	Lythraceae	L	L	N	N
Medicago polymorpha L.	Fabaceae	L	L	L	L
Mentha pulegium L.	Lamiaceae	L	N	L	L
Ornithopus compressus L.	Fabaceae	L	L	L	L
Orobanche sp.	Orobanchaceae	L	N	N	N
Plantago coronopus L.	Plantaginaceae	L	M	L	L
Plantago lagopus L.	Plantaginaceae	M	M	H	M
Poa annua L.	Poaceae	L	L	N	N
Poa bulbosa L.	Poaceae	N	N	N	L
Pulicaria odora (L.) Rchb.	Asteraceae	N	N	L	N
Poa trivialis L.	Poaceae	N	N	N	L
Polycarpon tetraphyllum (L.) L.	Caryophyllaceae	N	L	L	N
Ranunculus ophioglossifolius Vill.	Ranunculaceae	N	N	N	L
Ranunculus parviflorus L.	Ranunculaceae	L	N	L	L

Table A2. *Cont.*

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Raphanus raphanistrum L.	Brassicaceae	N	L	N	N
Rumex bucephalophorus L.	Polygonaceae	M	M	L	L
Rumex crispus L.	Polygonaceae	N	N	L	N
Rumex pulcher subsp. *woodsii* (De Not.) Arcang.	Polygonaceae	L	L	L	L
Senecio jacobaea L.	Asteraceae	L	L	L	L
Sherardia arvensis L.	Rubiaceae	L	L	N	N
Silene gallica L.	Caryophyllaceae	M	L	L	N
Sisymbrium officinale (L.) Scop.	Brassicaceae	L	L	N	N
Sonchus oleraceus L.	Asteraceae	L	N	L	N
Spergula arvensis L.	Caryophyllaceae	N	L	N	N
Stachys arvensis (L.) L.	Lamiaceae	L	L	M	N
Stellaria media (L.) Vill.	Caryophyllaceae	L	N	N	N
Tolpis umbellata Bertol.	Asteraceae	L	M	M	L
Trifolium campestre Schreb.	Fabaceae	N	M	L	L
Trifolium glomeratum L.	Fabaceae	L	H	M	L
Trifolium medium subsp. *médium* L.	Fabaceae	N	N	L	N
Trifolium repens L.	Fabaceae	L	H	H	L
Trifolium resupinatum L.	Fabaceae	L	L	L	L
Trifolium scabrum L.	Fabaceae	L	N	N	N
Trifolium subterraneum L.	Fabaceae	L	M	N	N
Urtica urens L.	Urticaceae	L	N	N	N
veronica sp.	Plantaginaceae	L	N	N	N
Vicia disperma DC.	Fabaceae	L	N	N	N
Vulpia bromoides (L.) S.F.Gray	Poaceae	N	L	L	L
Vulpia geniculata L.	Poaceae	H	H	H	H

N—not present; L, M and H—present (L—low; M—medium; H—high, respectively, in 1 to 4 points; in 5 to 8 points; in 9 to 12 points).

Table A3. Plant species identified in each plot, in SP2.

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Agrostis castellana Boiss. & Reut.	Poaceae	N	N	N	L
Agrostis pourretii Willd.	Poaceae	H	H	M	M
Andryala integrifolia L.	Asteraceae	L	N	L	N
Arum italicum subsp. *italicum*	Araceae	L	N	L	N
Avena barbata subsp. *lusitanica* (Tab.Morais) Romero Zarco	Poaceae	M	L	N	M
Biserrula pelecinus L.	Fabaceae	L	N	L	N
Bromus diandrus L.	Poaceae	N	N	L	H
Bromus hordeaceus L.	Poaceae	N	L	N	N
Bromus sterilis L.	Poaceae	N	N	N	L
Bromus tectorum L.	Poaceae	L	L	N	L

Table A3. *Cont.*

Plant Taxa	Family	P1UC	P2UD	P3TD	P4TC
Carduus tenuiflorus Curtis	Compostae	L	L	L	L
Chamaemelum fuscatum (Brot.) Vasc.	Asteraceae	L	N	N	L
Chamaemelum mixtum L.	Asteraceae	M	L	M	M
Crepis capillaris (L.) Wallr.	Crassulaceae	M	M	H	L
Crepis vesicaria subsp. *taraxacifolia* (Thuill.) Thell.	Crassulaceae	L	N	N	L
Cynodon dactylon (L.) Pers.	Poaceae	L	L	L	L
Cynosurus echinatus L.	Poaceae	L	N	L	N
Cyperus longus L.	Cyperaceae	N	N	N	L
Diplotaxis catholica (L.) DC.	Brassicaceae	L	N	L	L
Echium plantagineum L.	Boraginaceae	M	L	L	M
Erodium cicutarium subsp. *bipinnatum* (Cav.) Tourlet	Geraniaceae	N	N	N	L
Galactites tomentosus Moench	Asteraceae	N	N	N	L
Hedypnois cretica (L.) Dum.-Courset	Asteraceae	L	N	N	L
Heliotropium europaeum L.	Boraginaceae	L	N	N	N
Holcus lanatus L.	Poaceae	N	L	N	N
Hordeum murinum subsp. *leporinum* (Link) Arcang.	Poaceae	M	L	M	M
Hypochaeris glabra L.	Asteraceae	N	N	N	L
Hypochaeris radicata L.	Asteraceae	M	L	L	L
Juncus bufonius L.	Juncaceae	N	N	L	N
Leontodon taraxacoides (Vill.) Mérat	Asteraceae	L	L	L	N
Lolium perenne L.	Poaceae	L	N	N	N
Lythrum borysthenicum (Schrank) Litv.	Lythraceae	L	N	N	N
Medicago polymorpha L.	Fabaceae	L	N	N	N
Ornithopus compressus L.	Fabaceae	L	N	N	L
Phalaris arundinacea subsp. *arundinacea*	Poaceae	N	N	N	L
Plantago coronopus L.	Plantaginaceae	L	L	N	N
Plantago lagopus L.	Plantaginaceae	M	M	H	L
Pulicaria odora (L.) Rchb.	Asteraceae	L	N	L	N
Polycarpon tetraphyllum (L.) L.	Caryophyllaceae	N	L	N	N
Polypogon maritimus Willd.	Poaceae	N	N	L	N
Quercus rotundifolia Lam.	Fagaceae	L	N	N	N
Raphanus raphanistrum L.	Brassicaceae	N	N	N	L
Rumex bucephalophorus L.	Polygonaceae	N	N	N	L
Rumex crispus L.	Polygonaceae	N	N	L	N
Rumex pulcher subsp. *woodsii* (De Not.) Arcang.	Polygonaceae	L	N	N	N
Sherardia arvensis L.	Rubiaceae	L	N	N	N
Tolpis barbata (L.) Gaertn	Asteraceae	L	N	N	L
Tolpis umbellata Bertol.	Asteraceae	M	L	M	L
Trifolium campestre Schreb.	Fabaceae	L	L	N	N

Table A3. *Cont.*

Trifolium glomeratum L.	Fabaceae	L	N	N	N
Trifolium scabrum L.	Fabaceae	L	N	N	N
Trifolium subterraneum L.	Fabaceae	L	N	N	N
Vulpia geniculata L.	Poaceae	H	H	H	H

N—not present; L, M and H—present (L—low; M—medium; H—high, respectively, in 1 to 4 points; in 5 to 8 points; in 9 to 12 points).

References

1. Pinto-Correia, T.; Ribeiro, N.; Potes, J. Livro verde dos Montados. In *Edição: ICAAM—Instituto de Ciências Agrárias e Ambientais Mediterrânicas*; Universidade de Évora: Évora, Portugal, 2013.
2. Serrano, J.M. Utilização eficiente dos recursos no Montado: Sensores próximos e detecção remota no apoio à tomada de decisão. *Bol. CCDR Alentejo Perspetiva* **2020**, *32*, 18–25.
3. David, T.S.; Pinto, C.A.; Nadezhdina, N.; Kurz-Besson, C.; Henriques, M.O.; Quilhó, T.; Cermak, J.; Chaves, M.M.; Pereira, J.S.; David, J.S. Root functioning, tree water use and hydraulic redistribution in Quercus suber trees: A modeling approach based on root sap flow. *For. Ecol. Manag.* **2013**, *307*, 136–146. [CrossRef]
4. Serrano, J.; Shahidian, S.; Machado, E.; Paniagua, L.L.; Carreira, E.; Moral, F.; Pereira, A.; de Carvalho, M. Floristic Composition: Dynamic Biodiversity Indicator of Tree Canopy Effect on Dryland and Improved Mediterranean Pastures. *Agriculture* **2021**, *11*, 1128. [CrossRef]
5. Feio, M. *Clima e Agricultura: Exigências Climáticas das Principais Culturas e Potencialidade Agrícolas do Nosso Clima*; Ministério da Agricultura, Pescas e Alimentação: Lisboa, Portugal, 1991; ISBN 972-9175-25-X.
6. Carreira, E.; Serrano, J.; Shahidian, S.; Nogales-Bueno, J.; Rato, A.E. Real-Time Quantification of Crude Protein and Neutral Detergent Fibre in Pastures under Montado Ecosystem Using the Portable NIR Spectrometer. *Appl. Sci.* **2021**, *11*, 10638. [CrossRef]
7. Belo, C.C.; Coelho, I.; Rolo, J.; Reis, P. Sistemas agroflorestais em Portugal continental. Parte II: Montados, condições de uso do solo e evolução. *Rev. Ciências Agrárias* **2014**, *37*, 122–130.
8. Daniels, M.B.; Delaune, P.; Moore, P.A.; Mauromoustakos, A.; Chapman, S.L.; Langston, J.M. Soil Phosphorus Variability in Pastures: Implications for Sampling and Environmental Management Strategies. *J. Environ. Qual.* **2001**, *30*, 2157–2165. [CrossRef] [PubMed]
9. Carvalho, M.; Goss, M.J.; Teixeira, D. Manganese toxicity in Portuguese Cambisols derived from granite: Causes, limitations of soil analyses and possible solutions. *Rev. Ciências Agrárias* **2015**, *38*, 518–527. [CrossRef]
10. Serrano, J.; Roma, L.; Shahidian, S.; Belo, A.D.F.; Carreira, E.; Paniagua, L.L.; Moral, F.; Paixão, L.; da Silva, J.M. A Technological Approach to Support Extensive Livestock Management in the Portuguese Montado Ecosystem. *Agronomy* **2022**, *12*, 1212. [CrossRef]
11. Brougham, R.W. The effects of frequent hard grazings at different times of the year on the productivity and species yields of a grass-clover pasture. *N. Z. J. Agric. Res.* **1960**, *3*, 125–136. [CrossRef]
12. Voisin, A.; Lecomte, A. *La Vaca y la Hierba: Cómo Obtener Buenos Rendimientos del Ganado Vacuno*; Tecnos: Madrid, Spain, 1968.
13. Xiao, X.; Zhang, T.; Angerer, J.P.; Hou, F. Grazing Seasons and Stocking Rates Affects the Relationship between Herbage Traits of Alpine Meadow and Grazing Behaviors of Tibetan Sheep in the Qinghai–Tibetan Plateau. *Animals* **2020**, *10*, 488. [CrossRef]
14. Nie, Z.N.; Barker, D.J.; Mackay, A.D.; Valentine, I.; Hodgson, J. Influence of the timing and duration of pastoral fallowing and nitrogen fertiliser on pasture and white clover (*Trifolium repens*) growth in hill country. *N. Z. J. Agric. Res.* **1998**, *41*, 19–29. [CrossRef]
15. Heady, H.F. Continuous vs. Specialized Grazing Systems: A Review and Application to the California Annual Type. *Rangel. Ecol. Manag.* **1961**, *14*, 182. [CrossRef]
16. Zhou, Y.; Gowda, P.H.; Wagle, P.; Ma, S.; Neel, J.P.S.; Kakani, V.G.; Steiner, J.L. Climate Effects on Tallgrass Prairie Responses to Continuous and Rotational Grazing. *Agronomy* **2019**, *9*, 219. [CrossRef]
17. Holechek, J.L. Considerations concerning grazing systems. *Rangelands* **1983**, *5*, 208–211.
18. Tozer, K.N.; Müller, K.; Craven, T.; Tarbotton, I.; Coster, A.; Burke, R.; Sherlock, J.; Cameron, C. Effect of deferred grazing during late spring and summer on pasture productivity in Waikato and Bay of Plenty hill country. *J. N. Z. Grasslands* **2020**, *82*, 111–119. [CrossRef]
19. Lambert, M.; Clark, D.; Litherland, A. Advances in pasture management for animal productivity and health. *N. Z. Vet. J.* **2004**, *52*, 311–319. [CrossRef]
20. McCallum, D.; Thomson, N.; Judd, T. Experiences with deferred grazing at the Taranaki Agricultural Research Station. *Proc. N. Z. Grassl. Assoc.* **1991**, *53*, 79–83. [CrossRef]
21. Lambert, M.; Litherland, A. A practitioner's guide to pasture quality. *Proc. N. Z. Grassl. Assoc.* **2000**, *115*, 111–115. [CrossRef]
22. Watkinson, A.R.; Ormerod, S.J. Grasslands, grazing and biodiversity: Editors' introduction. *J. Appl. Ecol.* **2001**, *38*, 233–237. [CrossRef]
23. Lin, L.; Dickhoefer, U.; Müller, K.; Wang, C.; Glindemann, T.; Hao, J.; Wan, H.; Schönbach, P.; Gierus, M.; Taube, F.; et al. Growth of sheep as affected by grazing system and grazing intensity in the steppe of Inner Mongolia, China. *Livest. Sci.* **2011**, *144*, 140–147. [CrossRef]

24. Stewart, G.B.; Pullin, A.S. The relative importance of grazing stock type and grazing intensity for conservation of mesotrophic 'old meadow' pasture. *J. Nat. Conserv.* **2008**, *16*, 175–185. [CrossRef]
25. Edwards, G.R.; Hay, M.J.M.; Brock, J.L. Seedling recruitment dynamics of forage and weed species under continuous and rotational sheep grazing in a temperate New Zealand pasture. *Grass Forage Sci.* **2005**, *60*, 186–199. [CrossRef]
26. Buttolph, L.P.; Coppock, D.L. Influence of deferred grazing on vegetation dynamics and livestock productivity in an Andean pastoral system. *J. Appl. Ecol.* **2004**, *41*, 664–674. [CrossRef]
27. Beetz, A.E.; Rinehart, L. rotational grazing [n]. In *Encyclopedic Dictionary of Landscape and Urban Planning*; Springer: Berlin/Heidelberg, Germany, 2010; p. 857. [CrossRef]
28. Nie, Z.N.; Zollinger, R.P. Impact of deferred grazing and fertilizer on plant population density, ground cover and soil moisture of native pastures in steep hill country of southern Australia. *Grass Forage Sci.* **2012**, *67*, 231–242. [CrossRef]
29. Di Grigoli, A.; Todaro, M.; Di Miceli, G.; Genna, V.; Tornambé, G.; Alicata, M.L.; Giambalvo, D.; Bonanno, A. Effects of continuous and rotational grazing of different forage species on ewe milk production. *Small Rumin. Res.* **2012**, *106*, S29–S36. [CrossRef]
30. Serrano, J.; Shahidian, S.; Da Silva, J.M.; Sales-Baptista, E.; De Oliveira, I.F.; De Castro, J.L.; Pereira, A.; De Abreu, M.C.; Machado, E.; de Carvalho, M. Tree influence on soil and pasture: Contribution of proximal sensing to pasture productivity and quality estimation in *montado* ecosystems. *Int. J. Remote Sens.* **2018**, *39*, 4801–4829. [CrossRef]
31. Serrano, J.; Shahidian, S.; da Silva, J.M.; Paixão, L.; Carreira, E.; Pereira, A.; Carvalho, M. Climate Changes Challenges to the Management of Mediterranean Montado Ecosystem: Perspectives for Use of Precision Agriculture Technologies. *Agronomy* **2020**, *10*, 218. [CrossRef]
32. Serrano, J.; Shahidian, S.; Da Silva, J.M.; Moral, F.; Carvajal-Ramirez, F.; Carreira, E.; Pereira, A.; De Carvalho, M. Evaluation of the Effect of Dolomitic Lime Application on Pastures—Case Study in the Montado Mediterranean Ecosystem. *Sustainability* **2020**, *12*, 3758. [CrossRef]
33. Serrano, J.; Shahidian, S.; Costa, F.; Carreira, E.; Pereira, A.; Carvalho, M. Can Soil pH Correction Reduce the Animal Supplementation Needs in the Critical Autumn Period in Mediterranean Montado Ecosystem? *Agronomy* **2021**, *11*, 514. [CrossRef]
34. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014, International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; Update 2015; World Soil Resources Report 106; Food and Agriculture Organization (FAO): Rome, Italy, 2015; 188p.
35. Serrano, J.; Shahidian, S.; da Silva, J.M. Monitoring Seasonal Pasture Quality Degradation in the Mediterranean Montado Ecosystem: Proximal versus Remote Sensing. *Water* **2018**, *10*, 1422. [CrossRef]
36. Russel, A. Body condition scoring of sheep. *Practice* **1984**, *6*, 91–93. [CrossRef]
37. Marley, C.L.; Fraser, M.D.; Fisher, W.J.; Forbes, A.B.; Jones, R.; Moorby, J.M.; Macrae, J.C.; Theodorou, M.K. Effects of continuous or rotational grazing of two perennial ryegrass varieties on the chemical composition of the herbage and the performance of finishing lambs. *Grass Forage Sci.* **2007**, *62*, 255–264. [CrossRef]
38. Walton, P.D.; Martinez, R.; Bailey, A.W. A Comparison of Continuous and Rotational Grazing. *Rangel. Ecol. Manag.* **1981**, *34*, 19. [CrossRef]
39. Santos, M.; Afonso, L.; Carvalho, B.; Rêgo, A.; Queiroz, G.; Medica, J.; Moraes, L.; Carmo, L. Apparent selectivity of sheep in deferred marandu palisadegrass pastures with variable initial heights. *Arq. Bras. Med. Vet. Zootec.* **2019**, *71*, 1727–1734. [CrossRef]
40. Houlbrooke, D.J.; Drewry, J.J.; Monaghan, R.M.; Paton, R.J.; Smith, L.C.; Littlejohn, R.P. Grazing strategies to protect soil physical properties and maximise pasture yield on a Southland dairy farm. *N. Z. J. Agric. Res.* **2009**, *52*, 323–336. [CrossRef]
41. Cannas, A.; Boe, F. Prediction of the relationship between body weight and body condition score in sheep. *Ital. J. Anim. Sci.* **2003**, *2* (Suppl. 1), 527–529. [CrossRef]
42. Shore, A. *DESeq and Indicator Species Analysis R Script*, Figshare Software: Cambridge, MA, USA, 2020.
43. Oksanen, J.; Blanchet, F.G.; Friendly, M.; Kindt, R.; Legendre, P.; McGlinn, D.; Wagner, H. *Vegan: Community Ecology Package*; R Package Version 2.5-3; The Comprehensive R Archive Network: Wien, Austria, 2018.
44. Beals, E.W. Bray-Curtis Ordination: An Effective Strategy for Analysis of Multivariate Ecological Data. *Adv. Ecol. Res.* **1984**, *14*, 1–55. [CrossRef]
45. De Cáceres, M.; Legendre, P. Beals smoothing revisited. *Oecologia* **2008**, *156*, 657–669. [CrossRef]
46. Carvalho, M. A Seca E a Intensificação Sustentável Dos Sistemas Agro-Pecuários: Desafios E Soluções. Dossier Secas e Cheias—Como Gerir. 2018, pp. 24–27. Available online: http://dspace.uevora.pt/rdpc/bitstream/10174/23541/1/ (accessed on 7 July 2022).
47. Moreira, N. *Agronomia das Forragens e Pastagens*; Sector Editorial; Universidade de Trás-os-Montes e Alto Douro: Vila Real, Portugal, 2002; 183p.
48. Paço, A.; Da-Silva, J.R.; Torres, D.P.; Glick, B.R.; Brígido, C. Exogenous ACC Deaminase Is Key to Improving the Performance of Pasture Legume-Rhizobial Symbioses in the Presence of a High Manganese Concentration. *Plants* **2020**, *9*, 1630. [CrossRef]
49. Mendes, P.; Meireles, C.; Vila-Viçosa, C.; Musarella, C.; Pinto-Gomes, C. Best management practices to face degraded territories occupied by *Cistus ladanifer* shrublands—Portugal case study. *Plant Biosyst.* **2015**, *149*, 494–502. [CrossRef]
50. Ferreira, P.M.A.; Andrade, B.O.; Podgaiski, L.; Dias, A.C.; Pillar, V.D.; Overbeck, G.E.; Milton, D.S.M.; Boldrini, I.I. Long-term ecological research in southern Brazil grasslands: Effects of grazing exclusion and deferred grazing on plant and arthropod communities. *PLoS ONE* **2020**, *15*, e0227706. [CrossRef]
51. Nie, Z.; Valentine, I.; Mackay, A.; Barker, D.; Hodgson, J. Long-term effects of pastoral fallowing on the distribution and performance of white clover (*Trifolium repens* L.) in a hill country pasture. *NZGA: Res. Pract. Ser.* **1996**, *6*, 75–78. [CrossRef]

52. Avdiu, B.; Aliu, S.; Fetahu, S.; Zeka, D.; Rusinovci, I. THE FLORISTIC COMPOSITION OF THE NATURAL PASTURES IN MASSIVE OF NOVOBERDA. *J. Agric. For.* **2018**, *64*, 235–241. [CrossRef]
53. Köycü, E.; Sezenler, T.; Özder, M.; Karadağ, O. The Relationship Between Body Weight and Body Condition Score in Karacabey Merino Ewes. *J. Tekirdag Agric. Fac.* **2008**, *5*, 61–65.

CAPÍTULO 7

Influência do tipo de pastoreio por ovinos e da correção com calcário dolomítico nas escolhas das áreas de pastoreio

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Sustainable Intensification of the Montado Ecosystem: Evaluation of Sheep Grazing Systems and Soil Amendment

Emanuel Carreira * , João Serrano , Shakib Shahidian , Paulo Infante , Luís L. Paniagua , Francisco J. Moral , Luís Paixão , Carlos Pinto Gomes , José Lopes de Castro , Mário Carvalho , Alfredo Franco Pereira

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Keywords: Deferred grazing; continuous grazing; floristic composition; Dolomitic limestone; preferred location; grazing; observations grazing; soil compaction.

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Article

Sustainable Intensification of the Montado ecosystem: Evaluation of Sheep Grazing Systems and Soil Amendment

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Abstract: The objective of this study was to determine how application with dolomitic limestone and grazing type (continuous or deferred) affect sheep grazing location and feed preference when the pasture growth rate is maximum. A 4ha field was divided into 4 plots: P1 and P2- without application of dolomitic limestone, continuous (CG) and deferred grazing (DG), respectively; P3 and P4- with application of dolomitic limestone, DG (1AUE), and CG (2.4 AUE), respectively. In DG, animals were placed and removed from the plots depending on the height of the pasture. In each plot, 12 georeferenced sampling points were identified. Throughout the pasture's vegetative cycle (autumn, winter, spring, and early summer) several measurements of pasture height and cut were carried out. From the beginning of March to the beginning of June, animal behavior was observed, by trained observers, through binoculars on six dates. Animals' activity grazing and location was recorded. The results show that: (i) the application of dolomitic limestone combined with CG provided higher values of pasture height; (ii) there were no significant differences in pasture quality between treatments; (iii) Deferred grazing led to 50% more sheep grazing days than continuous grazing; (iv) there were no significant differences in soil compaction between CG and DG; (v) the type of grazing and the treatment with dolomitic limestone did not seem to change the grazing pattern between treatments. This work contributes to understanding the relationships between different types of grazing in dryland pastures, with and without application of dolomitic limestone, and preferred grazing locations for sheep. This work could help agricultural managers make more informed decisions with the aim of promoting the sustainable intensification of livestock production in the Montado ecosystem.

Keywords: deferred grazing; continuous grazing; floristic composition; dolomitic limestone; preferred location; grazing; observations grazing; soil compaction

1. Introduction

Montado (or Dehesa in Spain) is an agro-silvo-pastoral ecosystem, characteristic of the Alentejo region – Portugal. This ecosystem is associated with various agricultural and leisure activities with

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environmental and social value, thus considered of High Natural Value [1]. Montado is considered as complex ecosystem, due to the interrelations between its fundamental components – climate, soil, pasture, trees, and animals [2]. Montado is influenced by the Mediterranean climate, with rainy and mild winters and, hot and dry summers with great variability and seasonality [3]. During the dry summer, temperatures can reach 40° C and minimum temperatures can drop below 0° C during winter [3]. In this climate, often severe droughts can occur for long periods of time. The soils of this region are classified mainly as Cambisols, derived from granite [4]. These soils usually are degraded, due to erosion and loss of nutrients have fertility limitations and are shallow, stony, acidic, poor in nutrients, with micronutrient imbalances, namely the magnesium (Mg)/manganese (Mn) ratio, which cause Mn toxicity [5]. As a way of mitigating Mn toxicity and the effect of acidity, dolomitic limestone can be applied [6], together with phosphorus fertilization [7]. The typical pastures of the Montado, which tend to be of poor quality associated with low productivity [8], are greatly affected by the amount and the distribution of rain throughout the year and, by the combination of temperatures and rain. Grazing is a key issue for pasture management quality and nature conservation [9,10]. Plants, floristic composition, and biodiversity depends on the animal species, type, and intensity of grazing [10,11]. In the Montado, some farmers practice continuous grazing (CG) system on their farms, while others choose deferred grazing (DG) system, with no common pattern. The DG involves the use of pasture on a given plot, in longer or shorter periods of grazing, depending on the pasture biomass. In this type of grazing, the stocking rate is much higher than that of CG. In large plots, CG tends to prevail [1]. The CG with low stoking rates, enables more selectivity, resulting in higher heterogeneity of pasture consumption, where over- and under-grazed areas can occur simultaneously [12]. Traditionally, pastures are generally managed with relatively low grazing pressures, in both continuous or deferred grazing systems, allowing animals to choose their diet [13]. Selective grazing, stocking rate and grazing seasons influence the range and communities of plant species [14]. Teague et al. [15] reported that DG, provides satisfactory results in productive, ecological, and economic aspects. The DG can contribute to an increase in the coverage percentage of legumes in the pasture, improving the floristic composition and reducing the number of unwanted species of low nutritional value [16]. Heavy grazing can lead to soil degradation (by exaggerated trampling) and loss of biodiversity, while underutilization can lead to a greater preponderance of less palatable species with lower nutritional value and loss of habitat, overlapping a shrub layer [17]. However, Barriga [18], working with cattle, refer that CG has various advantages over DG, such as the return of nutrients to the soil through urine and feces. Also, a decrease in shrubs and increase in grassland species with good nutritional value, and an improvement of animal performances because they can select their diet, are some advantages of CG compared to DG [19,20,21]. The knowledge of the nutritional value of pastures and their availability, throughout the grazing seasons, can lead to improvements in production and management systems for grazing ruminants [22]. In addition to the nutritional value, the height of the pasture also influences the intake, selectivity, and performances of grazing animals [18].

The improvement of feed efficiency, of grazing animals is the major goal of livestock producers [23]. Ecosystems, such as the Montado, where animals have grazed for many centuries, achieve their biological characteristics and balance through interactions between livestock and vegetation [24]. The behavior of ruminants, in grazing, is a function of the characteristics of the plant communities and grazing management decisions [25]. Therefore, the choice of grazing areas is also related to the physical and thermal characteristics of the plot since the animals prioritize their primary physiological needs - water consumption and thermal regulation [26]. Riedel et al. [24] state that the way in which grazing occurs, in each area, depends on the physical environment of that same area, which includes the productivity and quality of pastures, accessibility to certain areas and, the availability of water - very important in the Mediterranean regions mainly in late spring and summer. The season of the year affects the floristic composition of the pasture and its chemical composition, which in turn affect the behavior of grazing animals [14]. In small patches and when the stocking rate is high and, there are plant species of high nutritional value, it can lead to animals always being closer to these areas [27].

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Knowledge of animal preferences in pasture and their selectivity is crucial to a better understand of the relationship between animals, grazing and pasture [28]. The use of pastures requires the animals to adapt to their diversity, thus being based on preferences for grazing locations, depending on variety and availability of vegetation [26]. The sheep do not graze continuously, but rather their grazing is interspersed with periods of rumination and rest [23]. The sheep could adjust their behavior on the pasture to maintain group cohesion, if the space provided for each animal is greater than 200 m^2 [27]. The choice of grazing areas on a plot is related to the animal's ability to select suitable diets, considering the height of the species, the phenological state, their nutritional value, floristic composition, and palatability of the plants [26]. Meteorological conditions also influence the grazing behavior. High temperatures, such as those found in summer in the Alentejo, tend to reduce the amount of daily time spent on grazing and rumination [29]. In sheep, ingestion periods tend to be shorter, and rumination and leisure time are longer and occur during the hottest part of the day. In regions with a hot and dry summer, most grazing periods occur in the early morning, late afternoon, and night [26].

Often, the method for monitoring animal preferences and behavior in the pasture involves direct observation. Observing the behavior of animals during the day, through direct visual observation, is simple, although it time-consuming [23,30], forcing many observations throughout the day at least 10-minute intervals [29,31,32].

The study aims to determine how application dolomitic limestone and continuous or deferred grazing, affect grazing location and preference when pasture presents the highest growth rate.

2. Materials and Methods

2.1. Study Area

This study is integrated in a long-term project to monitor the Montado ecosystem, which started in 2015 (Figure 1), being the culmination of all interventions in the study area since that date and their influence on the animals' food preferences. Figure 1 shows the chronological scheme, for the whole study, resulting in several publications [3,6,7, 33-38]. These studies have been conducted to monitor the effect of dolomitic limestone application on soil, tree, pasture, and sheep grazing interactions over time.

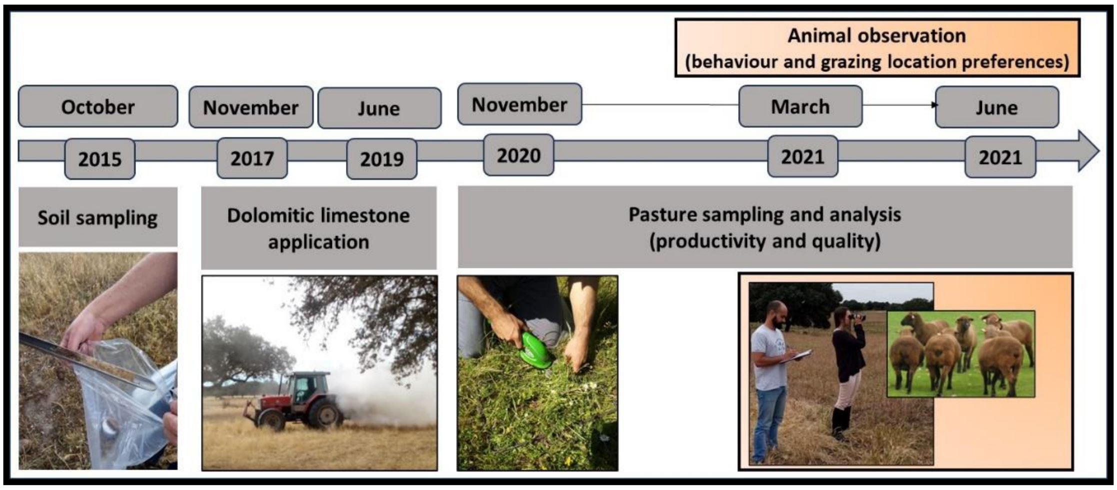

Figure 1. Chronological diagram of the global study, including soil, pasture, and animal monitoring, in the Montado ecosystem.

The predominant soils of this region are classified as Cambisol, derived from granite. The study area is in a large patch of holm oak (*Quercus rotundifolia* Lam.), with dryland pastures in the Montado system, mostly used for extensive animal production, especially to produce beef cattle and sheep.

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The Alentejo is affected by the Mediterranean climate. This climate is characterized by hot and dry summers, and wet and cold winters. The irregular rain distribution and total year precipitation variation are also characteristic of the Mediterranean climate. Most of this precipitation occurring in autumn, winter, and spring. In summer, the precipitation, it will always have residual values.

The study began in November and ended in June, with two phases. In the first phase, from November to February, evaluations were carried out on pastures and measurements of grazing days in the different plots. The second phase began in March with the evaluation of the sheep's grazing behavior, which lasted until late June. The results of height and nutritional value were obtained from November 2020 to June 2021.

This study took place in a 4ha experimental area (38°32.2′ N; 8°1.1′ W), called ECO-SPAA, located at the Mitra experimental farm, University of Évora – Portugal. The 4 ha experimental area was divided into four plots with 1ha each, corresponding following treatments: P1UC - without application of dolomitic limestone and continuous grazing (7 sheep/ha); P2UD - without application of dolomitic limestone and deferred grazing (16 sheep/ha); P3TD - with application of dolomitic limestone and deferred grazing (16 sheep/ha); P4TC - with application of dolomitic limestone and continuous grazing (7 sheep/ha) (Figure 2).

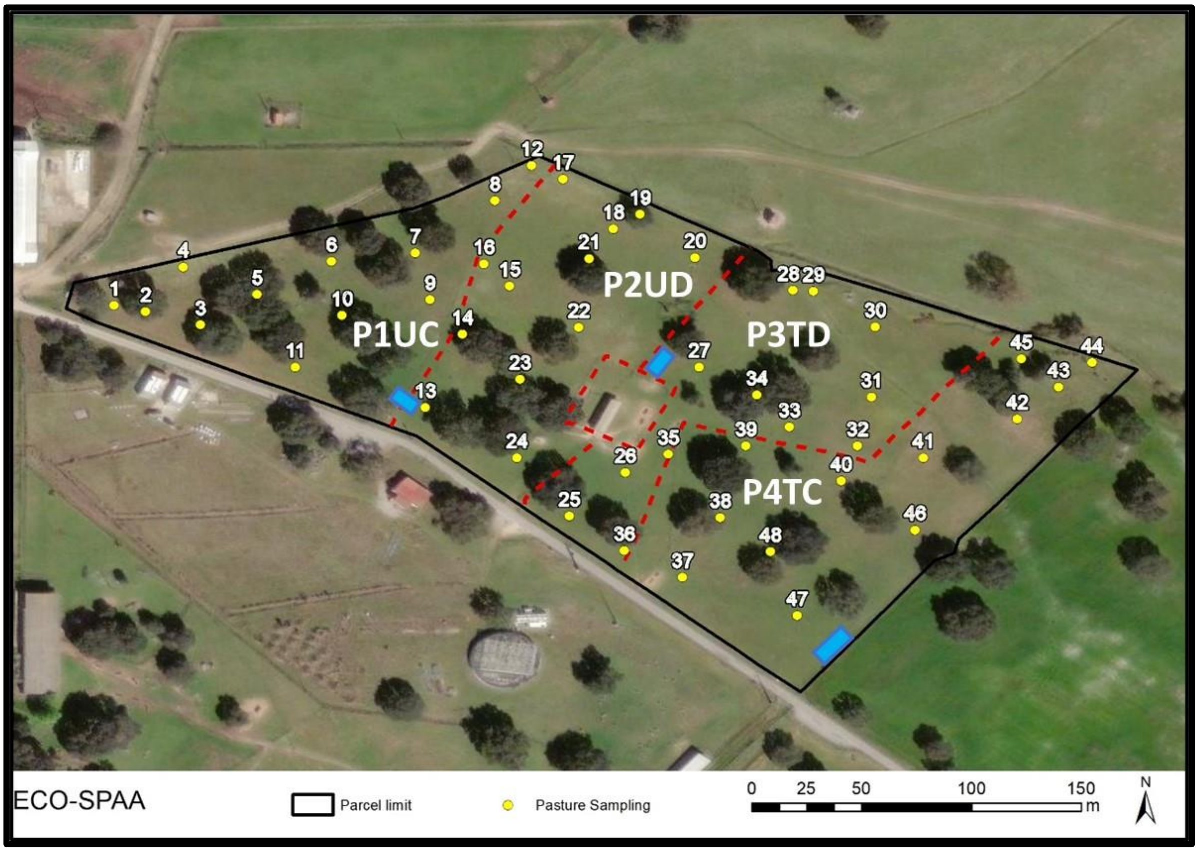

Figure 2. Sampling areas of the experimental field and plots of study. The blue rectangles represent drinking trough.

The characterization of the surface layer of the soil (0-0.30 m depth), carried out in October 2015, revealed acidic pH (average value of 5.4±0.3), so two applications with dolomitic limestone were carried out (2 tons/ha of dolomitic limestone) in half the area (P3TD and P4TC) in November 2017 and June 2019. In December 2018, the whole study area (P1UC, P2UD, P3TD and P4TC) received 100 kg/ha of binary fertilizer (18-46-0). The experimental design was based on a factorial, with two plots subjected to application of dolomitic limestone and two other serving as control (U Treatments). Within each treatment with and without amendment with dolomitic limestone, two grazing systems were applied: CG with continuous grazing and moderate stocking rate and DG with a deferred grazing and high stocking rate (2.3 times the applied in the CG).

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2.2. Grazing Management, Pasture Measurements and Sampling

The grazing experiment was carried out with non-pregnant and non-lactating adult White Merino and Black Merino ewes. The ewes were always the same in each treatment throughout the experimental trial. All ewes had similar body conditions at the beginning and the end of the trial. Every month, all the animals were evaluated in terms of their body condition score (BCS) to highlight possible weight loss or heterogeneities between the animals' body conditions in the different plots. All animals had a mean BCS of 3.5, with a standard deviation less than 0.5. The scale used is from 1 to 5, where 1 is very thin and 5 is obese [39]. Changes in body conditions score are related to changes in animal weight [40]. The animals always had clean water and mineral supply at their disposal.

Different stocking rates were calculated for the treatments. The stocking rate is the number of animals on a given land over a certain period. The stocking rate is generally expressed as animal units per unit of land area. Carrying capacity is the sustainable stocking rate over time per unit of land area. The stocking density calculation was based on the animal Unit for sheep, which was based on adult animals weighing around 55kg. Thus, the stocking rate was calculated based on the animal unit equivalent (AUE) for sheep. The AUE helps estimate the potential forage demand for different kinds of animals based on the standard animal unit and considers physiological differences. To estimate the stocking rate, the number of animals in the area was considered (AUE/ha), corresponding to 7, 16, 16 and 7 animals in the plots P1UC, P2UC, P3TD and P4TC, respectively. In the case of deferred grazing, a correction factor was introduced corresponding to the percentage of days the animals remained in the respective fences during the grazing season period (AUE/ha*.days). These elements were then used for statistical calculations and corrections.

In plots in the DG system, the presence or absence of animals was linked to pasture height following the "put and take" method [41,42]. Grazing management criterion was a function of the average pasture height in each plot, the animals remained in the whenever the average height of the pasture exceeded 50 mm. Whenever this value was reached, the animals were removed and only returned when the average pasture height was at least 100 mm. Pasture height was measured with an electronic caliper. Pasture above 250mm was measured using a ruler with a scale in mm, to which a horizontal plastic stick was attached to simplify measurements.

Pasture heights were measured in the treatments of the study before and after each grazing period. Pasture samples were also collected to estimate the quality (crude protein CP, and neutral detergent fiber, NDF).

To represent the different existing plant communities, 48 sampling points were georeferenced, 12 in each of the four plots of the study (Figure 2). These 48 representative points were identified, by a botanical specialist, and permanently marked with a numbered flag and identified with a number (1 to 48). These points represent the plant communities identified previously, with species that vary in diversity and occurrence. The characterization of the floristic composition was carried out in January (winter), May (peak of spring) and June (summer). This characterization involved the identification of different plant species on each date in an area of $1m^2$.

The elevation of the experimental field is represented on the altimetric map in Figure 3.

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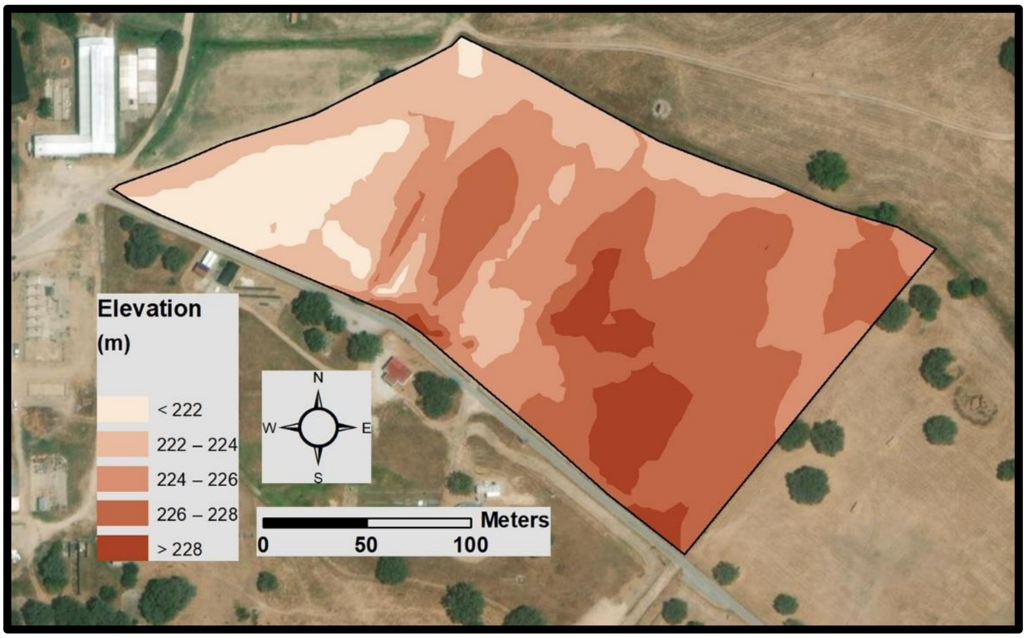

Figure 3. Altimetry map of the experimental field.

The following procedures and respective analyses were carried out to characterize the pastures in the four treatments. Pasture sampling (for pasture quality) was conducted on nine dates grouped into four periods. Period 1 corresponds to autumn (03/nov and 11/dec); period 2 corresponds to winter (10/feb and 12/mar); period 3 corresponds to the beginning and peak of spring (10/apr, 24/apr and 8/may); and period 4 corresponds to late spring and early summer (22/may and 05/jun). In the periods 3 and 4 the samples were taken concomitantly with animal behavior observations. The pasture height was taken at each sample point (**in 3 representative locations of the point, with 3 measurements for each location**), followed by pasture cutting in a known area (frame of "0.40 m × 0.25 m."). All the 12 samples in each treatment were mixed, thus making a total of 4 composite samples (one for each treatment). During the animal behavior observation phase, these pasture procedures were carried out the day before each behavior observation. The pastures samples were conducted to the Animal Nutrition and Metabolism Laboratory - MED Mediterranean Institute for Agriculture, Environment and Development, for they were placed in an oven at 65 °C, for 72 hours, to be dehydrated. Next, the dehydrated samples were weighed and ground in a Perten instrument mill equipped with a 1 mm sieve, for subsequent determination values of CP and NDF, expressed in percentage on a dry weight basis of samples, using conventional wet chemistry methods according to the AOAC [43].

2.3. Cone Index Measurements

To evaluate soil compaction, due to animal trampling, in CG and DG, soil resistance to penetration (Cone Index, CI, in kPa) was measured with an electronic cone penetrometer "FieldScout SC 900" (Spectrum Technologies, Aurora, IL, USA) equipped with an ultrasonic depth sensor. This assessment was carried out in October 2021. Such as Serrano et al. [38], for each sampling point (1m^2 area), 5 measurements were taken (one in the center and one at each of the vertices of the quadrant) with the CI, at a depth of 0 to 30 cm. After, the mean value of the five measurements was calculated for each of the 48 sampling points, at depths of 0-15 and 15-30cm. To avoid variability in soil moisture (which could affect penetration resistance measurements), all measurements at the 48 sampling points, with CI, were carried out on the same day. When measuring resistance to soil penetration, soil samples were taken at the central point of each sampling point. To do this, a gouge auger and a hammer were used. In this way, soil moisture was characterized at a depth of 0 to 30cm. Then the soil samples were weighed and placed in an oven at 70°C for 48 hours. After dehydration, the samples were weighed again to establish the soil moisture content (SMC).

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2.4. Observation of Sheep's Grazing Behavior and Spots Preferences

Between March 13th and June 7th, sheep grazing behavior was monitored for twelve days to identify their favorite spots. Considering that the grazing systems were different among treatments during autumn and winter, with potentially different levels of selectivity, it is essential to understand whether the disposition of the animals' favorite spots in the pasture differs in the spring when the maximum growth rate occurs. Sheep behavior was observed approximately every 15 days. Each date observation corresponds to two repetitions on two consecutive days:

Date 1- March 13th (Start – 8 a.m.; End – 7 p.m.).
Date 2- March 28th (Start – 7 a.m.; End – 7 p.m.).
Date 3- April 25th (Start – 7 a.m.; End – 8 p.m.).
Date 4- May 9th (Start – 7 a.m.; End – 8 p.m.).
Date 5- May 23rd (Start – 7 a.m.; End – 8:30 p.m.).
Date 6- June 6th (Start – 7 a.m.; End – 8:30 p.m.).

2.4.1. Animal Observations

Four trained observers carried out behavioral observations simultaneously. Observations using binoculars were carried out every 10 minutes, from sunrise to sunset, which, represents about 12 hours per day. The observers were placed far enough from the animals so as not to interfere with their natural behavior [14,29]. At each moment of observation, for each of the 4 plots (P1UC, P2UD, P3TD, P4TC), the location of the animals was referenced to the 12 sampling points. Combining with the local site, individual grazing activity was registered.

2.5. Meteorological Conditions

Meteorological conditions are presented in **Figure 4**, which shows the temperature and rain graph for Mitra meteorological station (Évora) between September 2020 and June 2021. The greatest amount of precipitation occurred in September and February (537 mm), while only 91 mm of precipitation was recorded during spring and early summer (when temperatures were more favorable for pasture growth and extension of its vegetative cycle).

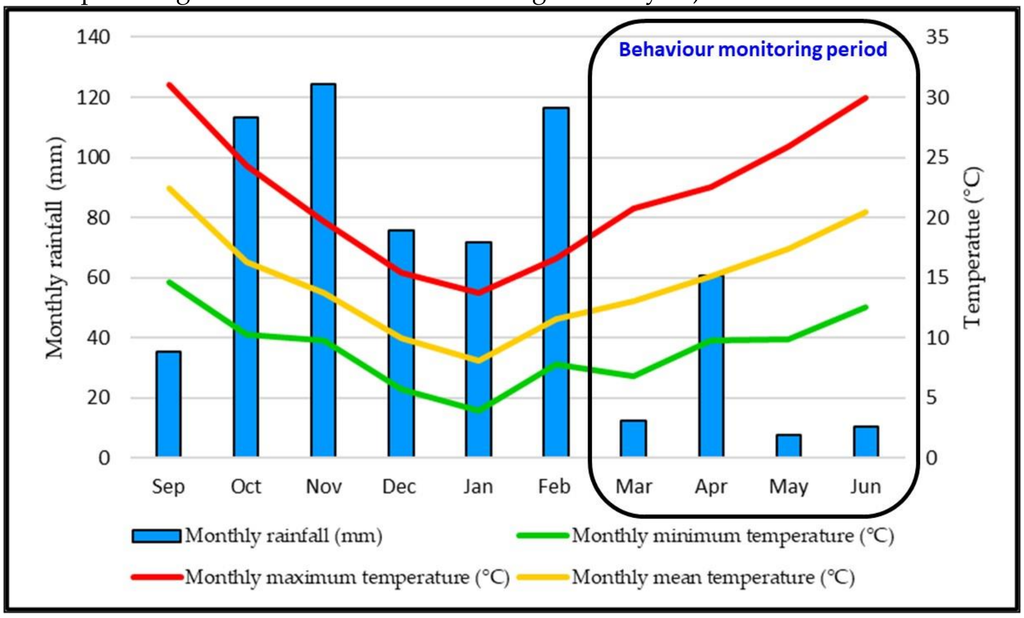

Figure 4. Thermopluviometric graph for the Mitra meteorological station (Évora), between September 2020 and June 2021.

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2.6. Statistical Analysis of Data

2.6.1. Pasture Height and Quality

Considering that in P3TD, in December, the animals remained grazing for 7 more days than in P2UD, height measurement in P3TD was carried out once more than in the other plots. On the day the sheep left P3TD (December), height measurements were taken only in this plot, which meant that the number of measurements between P3TD and the remaining plots was different. For the statistical analysis of pasture height and quality, two different approaches were used. One for pasture height, and different approach for CP and NDF.

1) For pasture height a "Generalized Mixed Additive Model" (GMAM) was used with a Gamma response. A logarithmic link function was adjusted for pasture height. Treatments were entered into the model as fixed parametric factors and their effect was controlled for mean temperature (as smooth variable modelled with thin plate regression spline), cumulative precipitation (as smooth variable modelled with thin plate regression spline) and for the number of animals per grazing days (animals/(grazing days+1)) - as smooth variable modelled with thin plate regression spline). Plot/spot pairs were entered as a random factor, as this is where repeated measurements occur.

This model was better than the corresponding Generalized Linear Mixed Model (GLMM), also with gamma response and logarithmic link function, as it presented lower AIC and BIC values, a better fit to the data and a better explanatory capacity (it can explain 65.1% of total deviance).

The assumptions of independence, homoscedasticity and normality of the residuals were verified, as well as the normality of random effects. Through the "Estimated Marginal Means" (Emmeans R) package it was possible to perform multiple comparison tests adjusting for "Tukey" test.

2) For CP and NDF it was not possible to use a GLM model as the residuals are correlated. The best approach was the use of a GLMM (Generalized Linear Mixed Model) if the random effect was the treatment itself, which made the main objective, of comparing the 4 treatment levels as a fixed effect, unfeasible. Therefore, a comparison was made between the levels of treatments 2 by 2, using the t-test for paired samples (normality was verified for the samples of differences by combining the observation of the "qq-Plot" and the "Shapiro-Wilk" test), adjusting the p-values by "Holm" correction. To evaluate the effect of the Period, we consider mixed linear models (GLMM), adjusted by restricted maximum likelihood (REML) with the plot as a random effect, adjusting for the mean temperature (in the logarithmic transformation), animals per grazing day (logarithmic transformation of the quotient between the number of animals and the number of grazing days plus 0.5, this because there are cases in which there were no animals) and the accumulated precipitation (also in the logarithmic transformation corrected plus 0.5, as there are cases in which there was no precipitation). All models fitted the data well and satisfied the assumptions of homoscedasticity and normality of the residuals, as well as the normality of the random effects.

2.6.2. Cone Index

An analysis of variance (ANOVA) was carried out between the types of grazing (CG and DG) and between CI depths (0-15 and 15-30cm). These analyzes were performed using the IBM SPSS Statistics package for Windows (version 28.0, IBM Corp., Armonk, NY, USA). The Tukey's HSD test was also performed to compare the means.

The maps of soil variables (SMC and CI) and the altimetric map were carried out through geostatistical analyzes with the Geostatistical Analyst" extension of ArcGIS software (version 10.5, ESRI, Inc., Redlands, CA, USA).

2.6.3. Animal's Location Preferences

The behavior analysis was carried out by observation date, based on animal presence or absence near each sampling point and in each plot. For this purpose, cross-tabulations of the animals' permanence at the sampled points in each plot were created based on the observations every 10

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minutes on each observed day. Statistical analyses of data on animal locations on the pasture, were carried out using the IBM SPSS 25.

With the aim of visualizing the animal distributions throughout the experimental field and during different dates, animal presence was estimated at any un-sampled location. As a continuous variable was necessary, an area of 1 m^2 was associated with any location and, in consequence, animal density was mapped. Kriged maps showing the spatial distributions of animals in each date were generated.

Using geostatistical techniques, in this case ordinary kriging, estimated values were obtained for all unsampled locations based on the point measurements distributed throughout the experimental field. This allowed visualization of the spatial patterns of the variables considered, and finally, raster maps were obtained with a spatial resolution of 1 m^2.

That resolution was logically selected and introduced as an input parameter in ArcGIS when converting from vector (point) to raster format.

The ArcGIS software (version 10.5, ESRI Inc., Redlands, CA, USA) was used to model the spatial variation of grazing. Interpolation analyses were performed with the ordinary kriging algorithm utilizing the Geostatistical Analyst extension in ArcGIS.

3. Results

3.1. Grazing Days, Stocking Rate and Pasture Height

Regarding grazing days, Figure 5 compares the number of days per month that the sheep stayed in DG plots P2UD and P3TD with the total number of days that sheep stayed in CG plots (P1UC and P4TC), and **Figure 6** displays the total grazing days per treatment. In the plots subject to DG, there were approximately 80 fewer days of grazing (pasture recovery days) than those subject to CG. However, in these plots the stocking rate was much higher. The application of dolomitic limestone provided 7 more days of grazing than non-application in plots subject to DG (Figure 6). Figure 7 shows the sheep grazing days for each treatment. Although the grazing days in the P2UD and P3TD plots were lower than in the remaining plots, when we multiply these days by the number of animals on each day and in each plot, we find that the sheep grazing days in the plots subject to DG are much higher (around 50%).

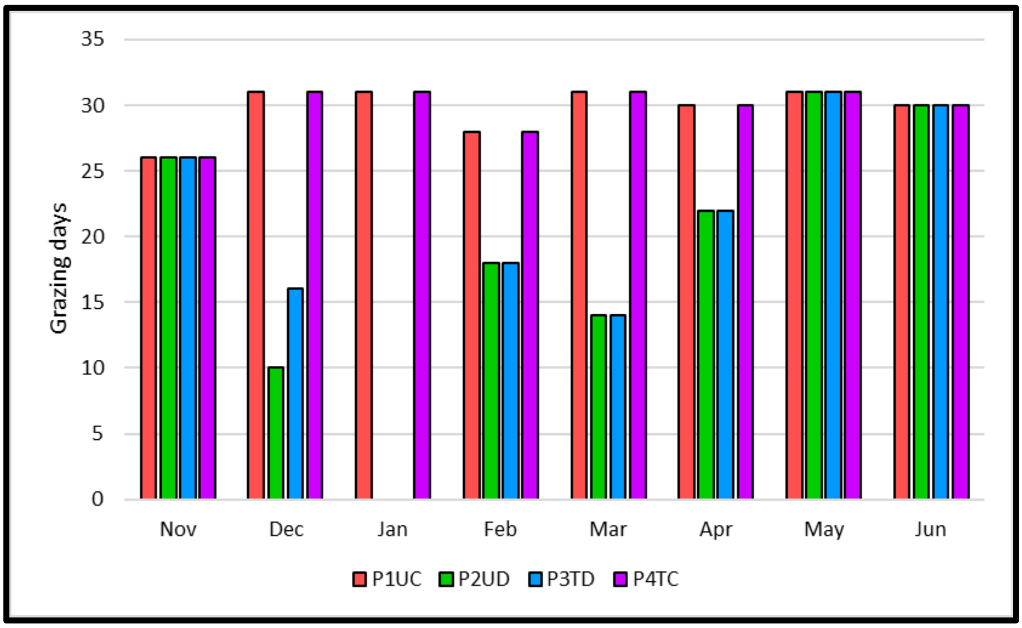

Figure 5. Number of grazing days in each treatment, per month.

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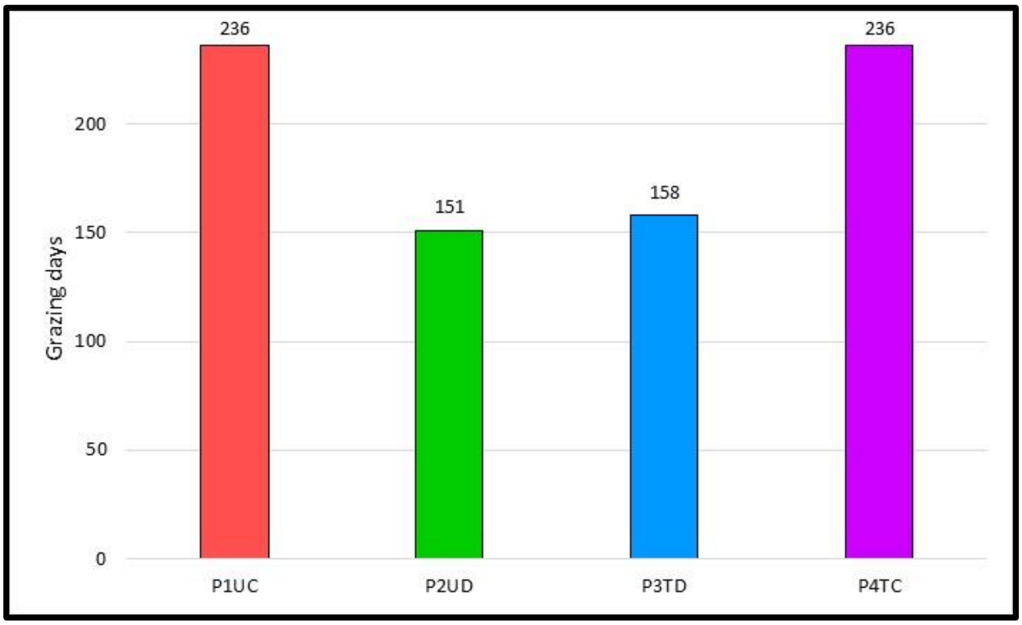

Figure 6. Total grazing days in each treatment.

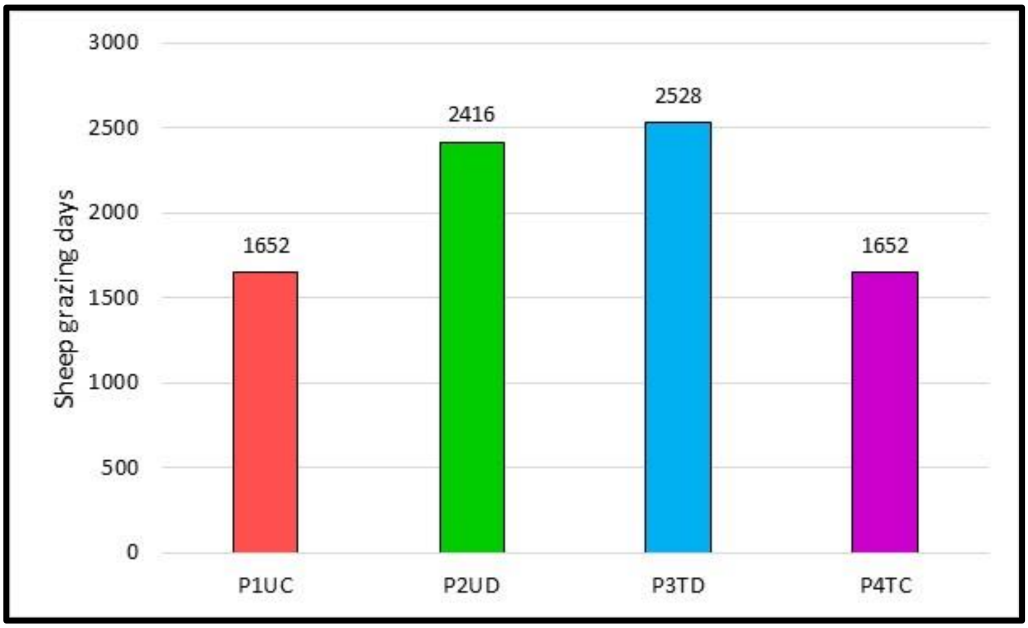

Figure 7. Sheep grazing days in each treatment.

Figure 8 shows the dispersion of pasture height values (minimum, median, maximum and quartiles) by date and plot, throughout the pasture's vegetative cycle (autumn, winter, spring, and early summer). Despite the different number of grazing days in DG treatments, there was no significant interaction between treatments and dates for pasture height. Generally, as expected, the treatments associated with CG had higher pasture heights; on some dates, pasture heights were significantly higher. Within the CG treatments (P1UC and P4TC), the average heights were significantly higher in the P4TC treatment on most dates. However, when the model is inserted with the correction for the number of grazing days and the number of animals, the differences between the treatments are not significant, mainly due to the dispersion of the pasture height within plots, as can be seen in Figure 8.

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At the beginning of April, the pasture's growth rate exceeded the sheep's intake rate in all plots, which was reflected in a significant increase in pasture height in both treatments with a moderate animal load (P1UC and P4TC) as well as the treatment with a higher animal load (P2UD and P3TD).

All plots reached maximum pasture height in May and June, with some values exceeding 550 mm. It should be noted that, in all plots, many pasture areas reached heights of over 500 mm, while other areas remained close to 70 mm, indicating a reduced growth rate or greater preference by the animals.

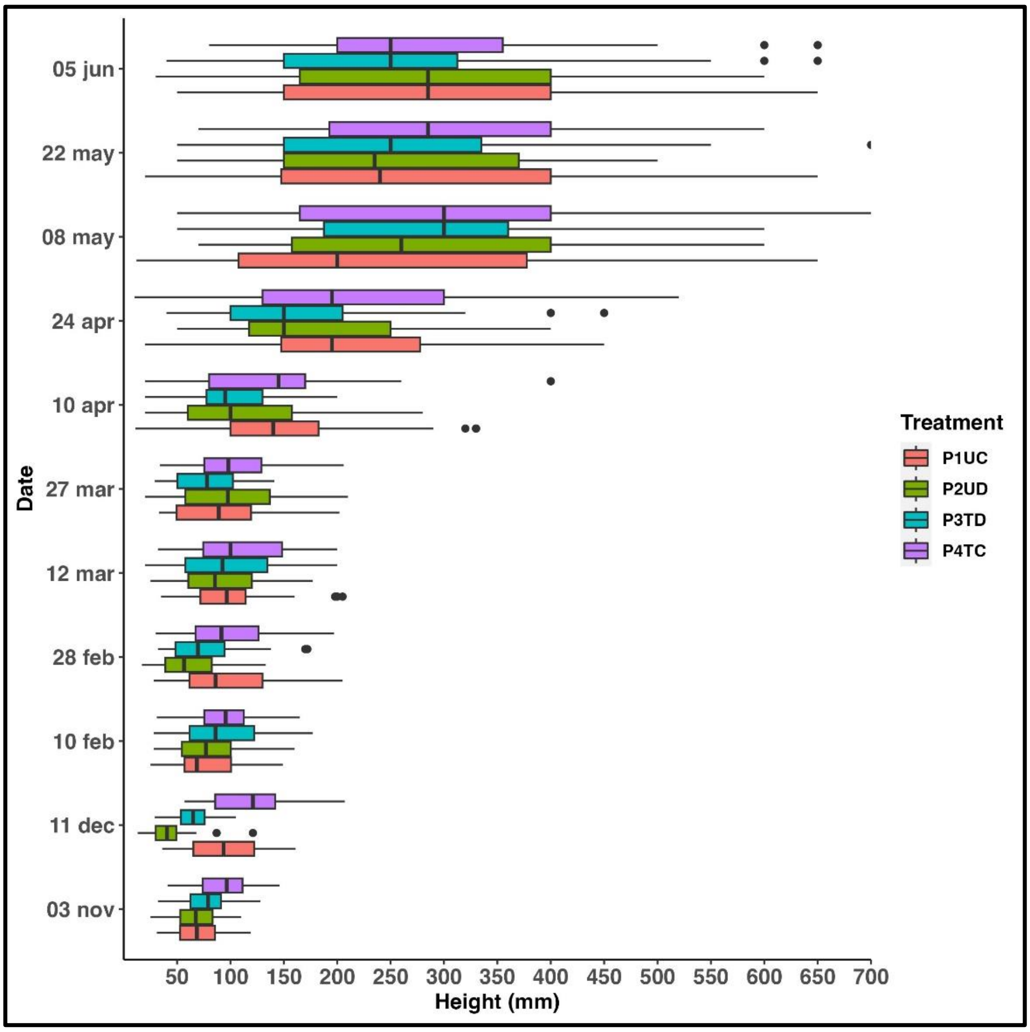

Figure 8. Dispersion of pasture height values (minimum, median, maximum and quartiles) by date and by plot, throughout the pasture's vegetative cycle (autumn, winter, spring, and early summer). The black points correspond to outliers.

3.2. Characterization of the Nutritional Value

Figure 9a shows the average percentage of CP of the pasture in each treatment, throughout the animal observation period. At the end of winter and spring, the highest percentage of CP occurred in the P3TD plot (20.1%, 13.4%, respectively). The highest percentage of CP occurred at the end of winter, with 15.9%, 18.8%, 20% and 18.9%, for the plots P1UC, P2UD, P3TD and P4TC, respectively. On the other hand, the lowest values were observed at the beginning of summer, with values of 7.3%, 7.2%, 6.2% and 6.1%, for the plot P1UC, P2UD, P3TD and P4TC, respectively. Figure 9b shows the percentage of NDF in each treatment, throughout the animal observation period. As it can be seen, at the beginning of summer occurred to higher NDF values (62.2%, 63.4%, 66.0% and 65.9%, for P1UC, P2UD, P3TD and P4TC, respectively), while at the end of winter had the lowest values (46.7%, 47.4%, 42.4% e 44.7%, for P1UC, P2UD, P3TD and P4TC, respectively). at the beginning of summer, the P1UC treatment showed the lowest value (62.2%).

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Figure 10a shows the CP dispersion of pastures (minimum, median, maximum and quartiles) for each treatment. No significant interactions in CP were observed between treatments and periods. Figure 10b shows the dispersion of pasture NDF values (minimum, median, maximum and quartiles) for each treatment. No significant interactions in NDF were observed between the factor's treatments and periods. There were also no significant differences between the treatments for CP and NDF (P>0,05).

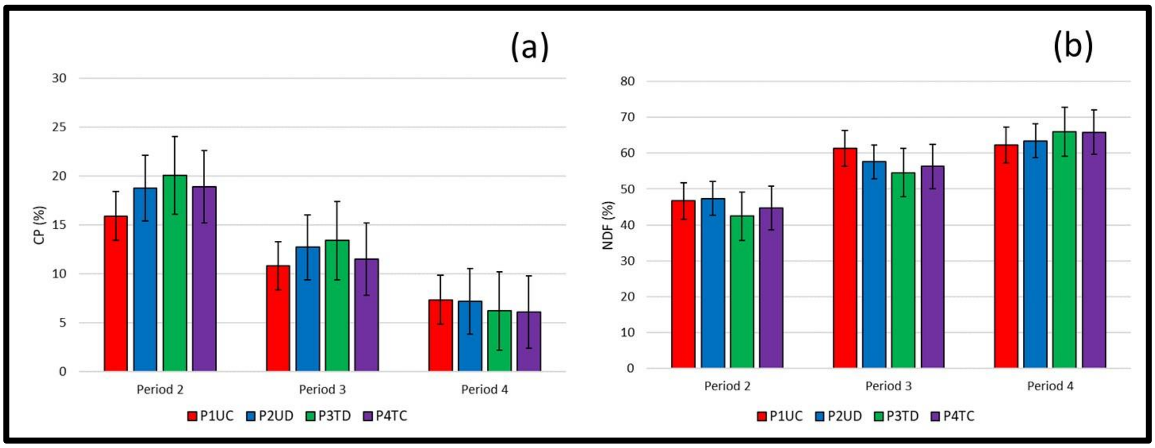

Figure 9. Average percentage in each treatment throughout the animal observation period, for CP (a) and NDF (b).

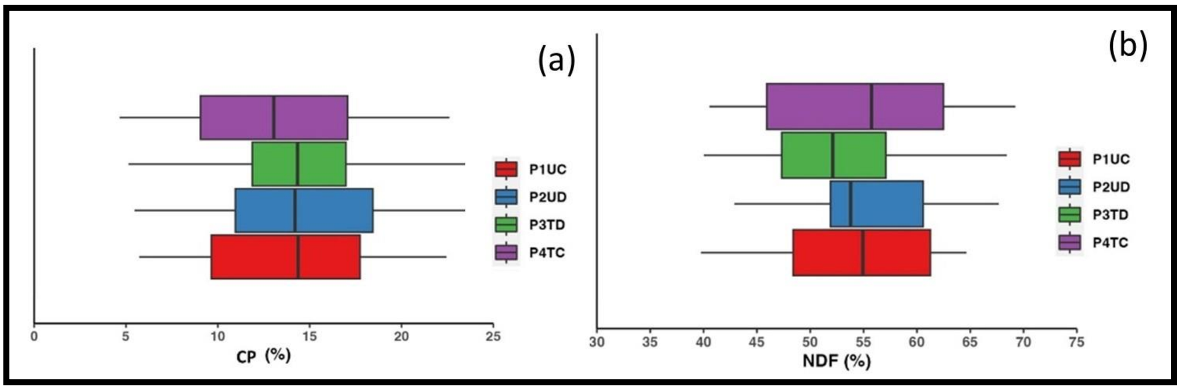

Figure 10. Comparison between median values and respective quartiles in each treatment for CP (a) and NDF (b).

3.3. Preferred Grazing Locations versus Average Height of Pasture

Figures 11, 12 and 13 are composite figures representing the preferred grazing areas on the twelve days of observation, based on the 12 georeferenced points in each plot (according to Figure 2). In these figures it is possible to observe the evolution of height of pasture per point and preferred grazing areas throughout the observation period (end of winter, spring and beginning of summer). The maps have up to 4 graduations, from lightest to darkest, which correspond to the following: no or low preference, medium preference, high preference, and very high preference, respectively.

In the P1UC plot, sheep stayed mainly in the lower part of the field, where the pasture was not always the highest. The spots most preferred by sheep were 8 and 12, extending to spots 5, 7, 9, and 10. After the third observation date, the space became more evenly frequented, regardless of the height of the pasture, with spots 5 and 11 being the most grazed on the fourth observation date. Points 1 and 2 were the least sough after throughout the observation period.

In the P2UD plot, sheep grazing pattern was similar throughout the observation dates. The sheep preferred spots 17, 18, 19 and 20 throughout most observations. After the fourth observation date, the animals showed more dispersed grazing behavior throughout the available area, except for spot

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23, which was less preferred on all observation dates. The animals did not choose spots according to the height of the pasture; other variables, possibly the species and its nutritional value, may have driven the different preferences for the various spots. Spots 13, 14 (except on the last observation date and in warmer weather), 15, 23 and 24 were the least grazed throughout all observations.

In the P3TD plot, a more restricted grazing area is visible. The most preferred spots during the first observation dates were 30, 31 and 32, with a lower frequency for spots 33 and 34. After the 3rd and fourth observation dates, a more extensive range of grazed areas was observed. Sheep did not show a particular preference for areas where the height of the pasture was higher; in many cases, their preference was for lower pastures. Finally, on the last two observation dates, there was a return to the areas that were initially most grazed. The observations showed a clear tendency for spots 25, 26 and 35 to be grazed less.

In the P4TC plot, the sheep's preferences were somewhat more heterogeneous. On the first observation dates, there was a clear preference for spots 40, 41, 45, 46, and 47. The pattern changed on the third and fourth observation dates, restricting preferences to spots 41 and 42 adding spot 45 on date 5. Like what was observed in the other treatments, the motivations for choosing the spots were not just related to the height of the pasture. On observation date six, there was more dispersion across the available area, with spots 37, 38, 39, 47 and 48 remaining negligibly preferred.

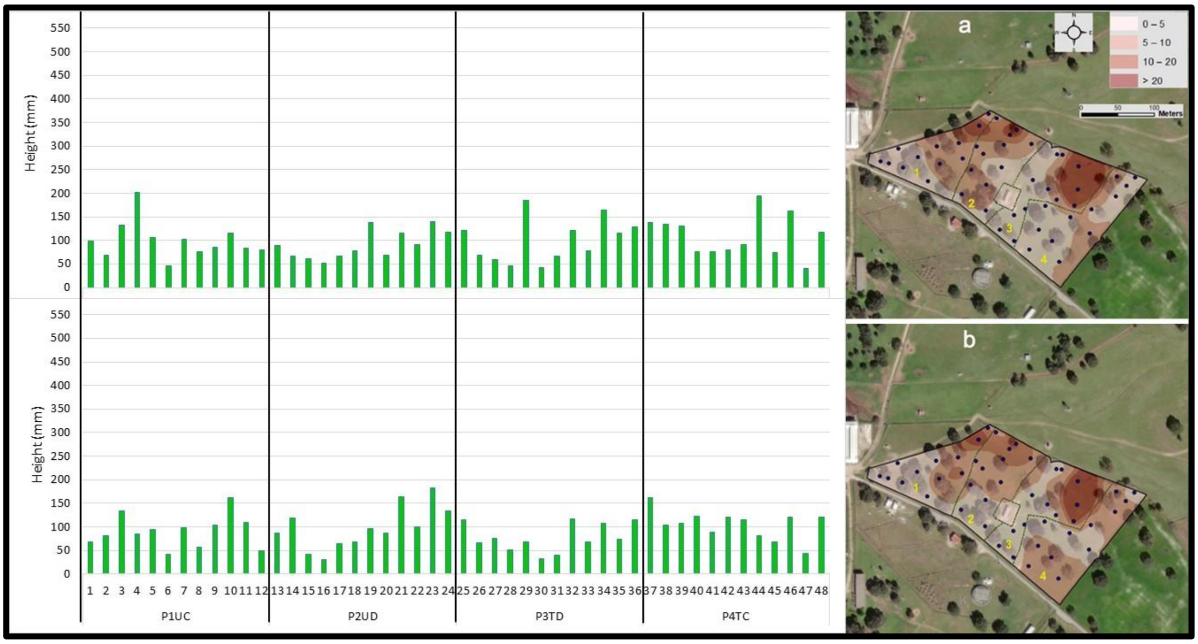

Figure 11. Average pasture height on each observation date by plot and by sampling point and respective maps with preferred grazing areas (a- date 1; b- date 2). The numbers, on the graphs, correspond to the 12 georeferenced points in each plot (1 - P1UC; 2- P2UD; 3- P3TD; 4- P4TC).

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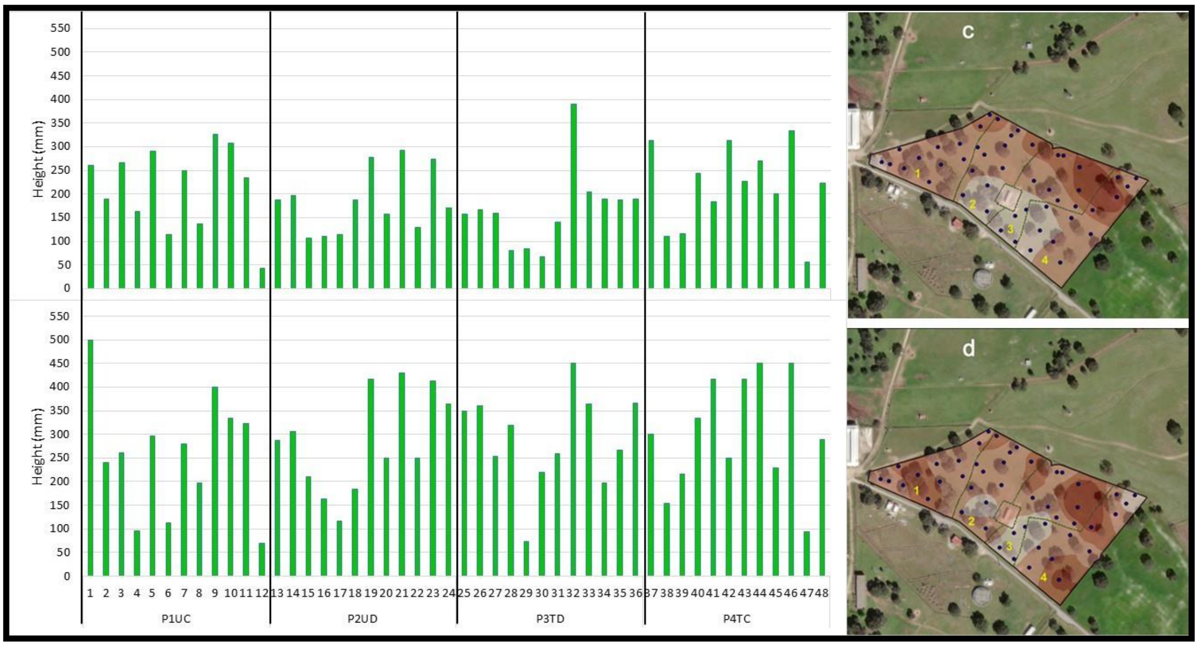

Figure 12. Average pasture height on each observation date by plot and by sampling point and respective maps with preferred grazing areas (c- date 3; d- date 4). The numbers, on the graphs, correspond to the 12 georeferenced points in each plot (1 - P1UC; 2- P2UD; 3- P3TD; 4- P4TC).

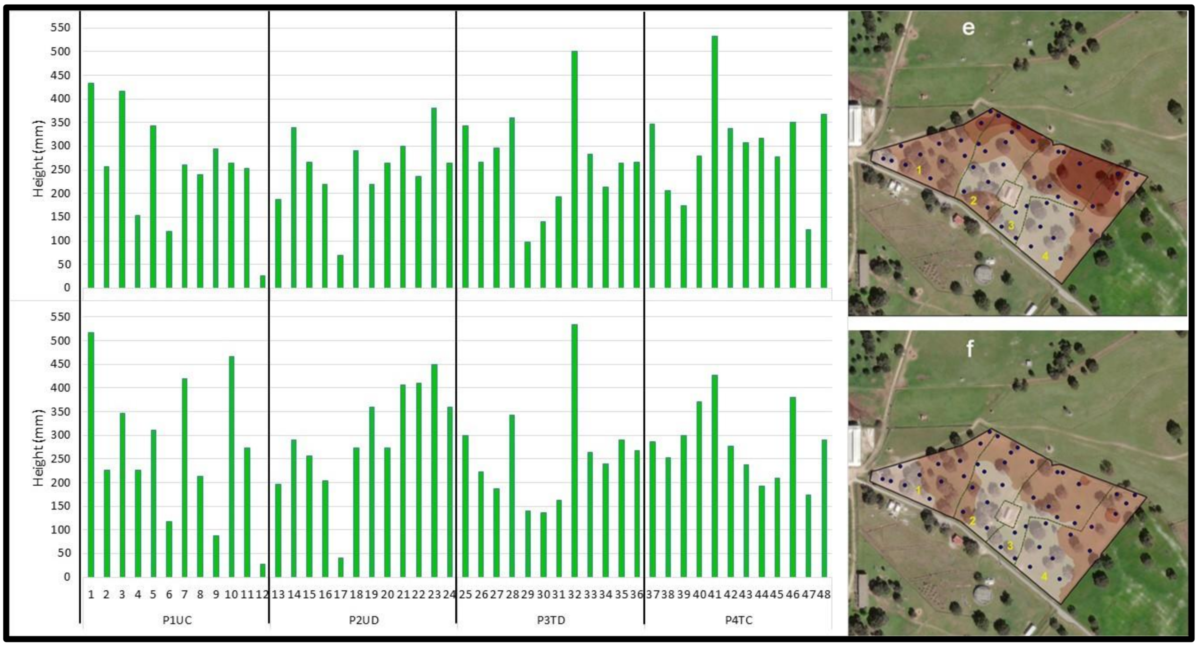

Figure 13. Average pasture height on each observation date by plot and by sampling point and respective maps with preferred grazing areas (e- date 5; f- date 6). The numbers, on the graphs, correspond to the 12 georeferenced points in each plot (1 - P1UC; 2- P2UD; 3- P3TD; 4- P4TC).

3.4. Relationship between Preferred Grazing Locations and Floristic Composition

Figure 14 shows the information accumulated over all the observation dates. In P1UC, spots 1, 2 and 3 are very poorly grazed, unlike spot 8, which is the most preferred. In the other plots, it is important to highlight an extensive area with very little daily grazing time, especially spots 13, 23, 25, 26, 35 and 37 - It should also be noted that the spots most consistently preferred by the animals were 30, 31 and 42, and, with some relevance, spots 41 and 45.

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Table A1 (Appendix A) shows the botanical species identified, in January, in the sheep's favorite grazing spots, during the month of March. Table A2 (Appendix A) shows the botanical species identified, at the beginning of May, in the sheep's favorite grazing spots, in the May observations. As we can see in these tables, floristic diversity was high in all treatments, and in May, a greater number of botanical species were identified.

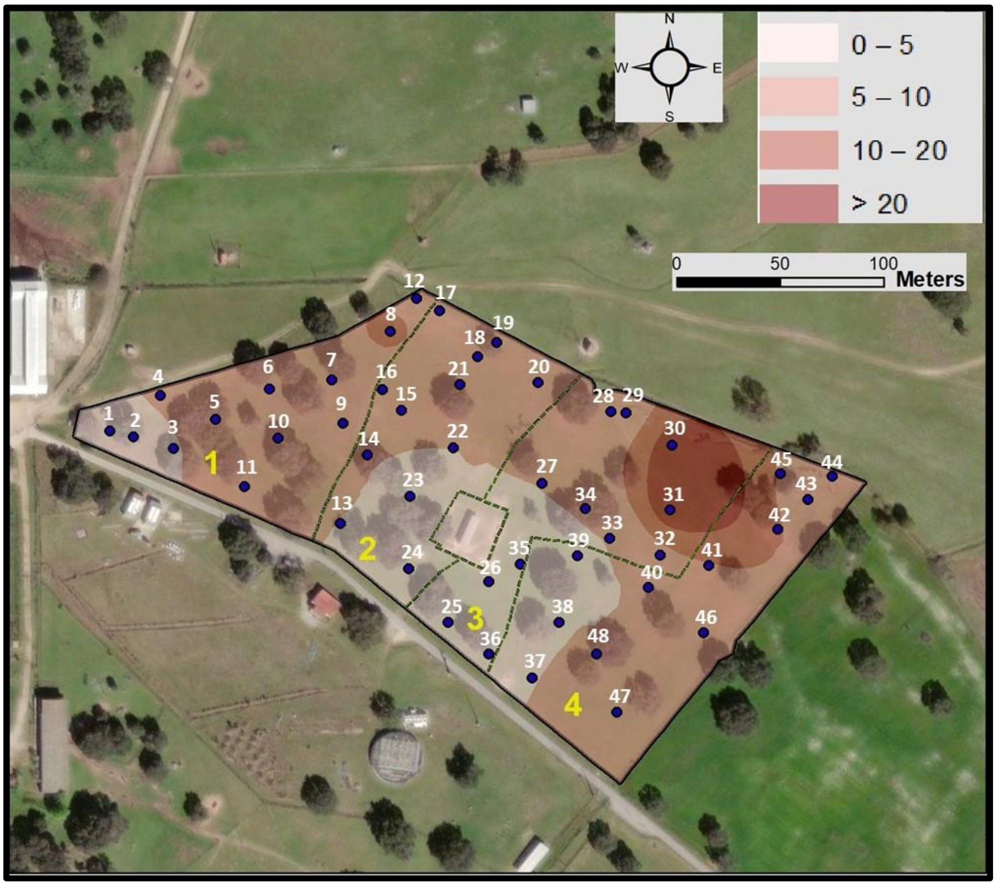

Figure 14. Map with accumulated data over time of observation, for the locations preferred for grazing by the animals (date 1 to date 6). Yellow numbers on the maps correspond to each plot: 1 - P1UC; 2- P2UD; 3- P3TD; 4- P4TC. Black circular shapes represent sampling points (white numbers).

3.5. Soil Compaction Measured by Cone Index

Figure 15 shows soil compaction (cone index) in the two types of grazing and at the two depths (0 to 15 and 15 to 30 cm). Although the stocking rate doubled in the DG, relative to the CG, and the CI values were higher in the DG, there were no statistically significant differences ($p > 0.05$). The average SMC values were 14.7% ± 2.9% for the CG area and 15.2% ± 2.3% in the DG area (depth 0-30cm). Figures 16a and 16b show soil compaction maps from 0 to 15 and 15 to 30 cm.

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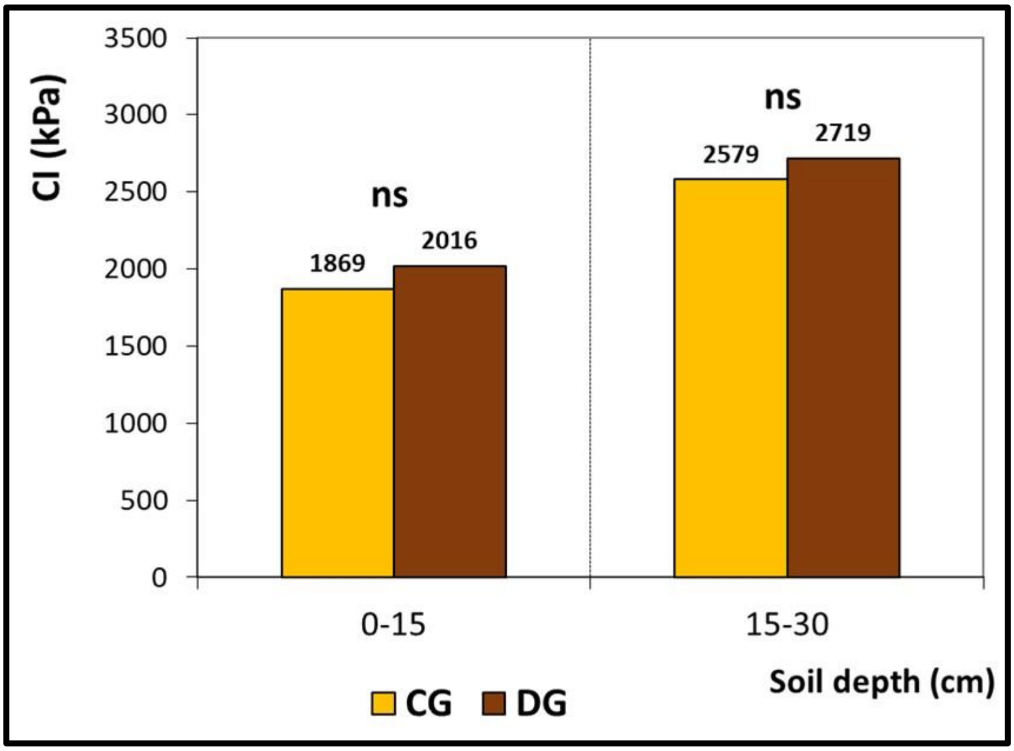

Figure 15. Average cone index (CI, in kPa) for continuous (CG) versus deferred grazing (CG) at 0–15 cm and 15–30 cm soil depths. “ns”—Not significant.

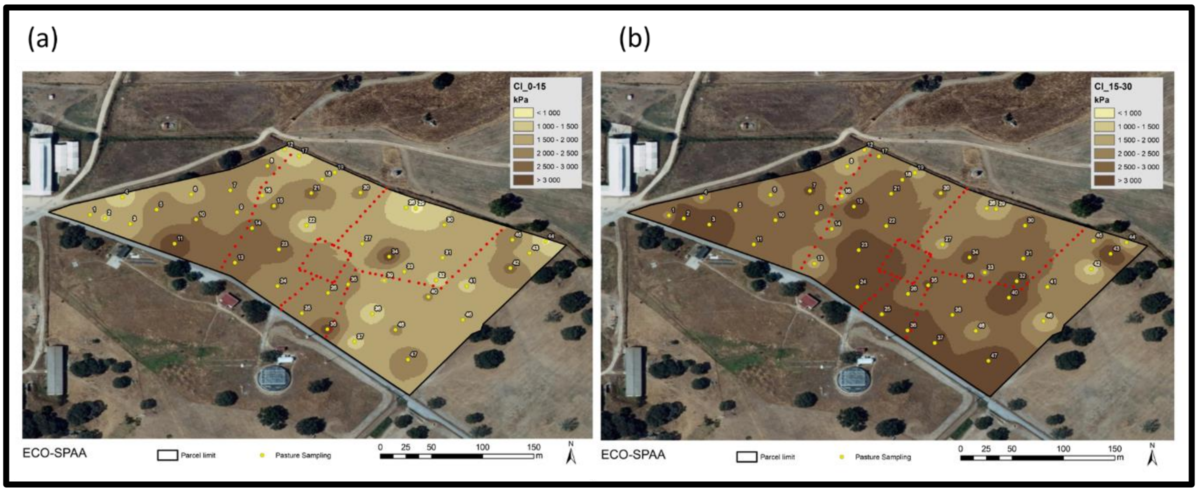

Figure 16. Cone index (CI) map (a) at 0–15 cm and (b) 15 - 30 cm depth.

4. Discussion

4.1. Relationship among Climatic Variables and, Height and Pasture Quality

During autumn, the combination of temperature and rainfall was sufficient to allow the pasture to germinate and grow satisfactorily. During winter, especially in January, the low temperatures limited pasture growth, and this continued until February. The average pasture height in the plots subject to DG, in mid-December, was 42.5 mm in P2UD and 44 mm in P3TD, which meant that the animals had to be removed from both plots and only returned on February 11th, when the average height in P2UD and in P3TD was nearly 100 mm. The absence of animals for nearly two months allowed some pastures to recover despite the slow growth rate. Pasture resting periods are essential

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after each grazing period to allow the plants to restore their reserves and produce new leaves [16]. The same authors state that recovery time depends on the plants' response capacity, soil humidity, and temperature. Measuring pasture height, **as an** indirect **indicator of** photosynthetically active leaf area, is crucial for managing the pasture itself, as well as grazing, showing high correlations with pasture biomass production [44,45]. Furthermore, Bell et al. [22] state that pastures with an average height of less than 70 mm tend to have low nutritional value. Iason et al. [46] found that daily pasture intake, by sheep in CG, was limited when the pasture was 30 mm height, which did not occur above 55 mm.

At the beginning of the spring, as temperatures rose, there was a lack of rainfall, penalizing pasture growth rate. These typical winter irregularities in pasture growth, with meagre growth rates, were greatly accentuated by the lack of rainfall in March, leading to the animals in DG having to be removed from their plots.

The application of dolomitic lime appears to have a positive influence on pasture height, resulting in greater heights in the plots P3TD and P4TC, when compared to plots P2UD and P1UC, respectively. Between P2UD and P3TD treatments, the variations in height amplitudes were quite similar. However, considering that both treatments have the same grazing intensity, given the additional decrease in pasture height in the P2UD, a lower pasture growth rate can be inferred, which could be attributed to the application of dolomitic lime. According to Carvalho [47], the application of dolomitic lime in some soils can increase the production of dryland pastures up to five times. In previous work carried out, by our team in this test field, there was a positive effect of liming in the soil, although very slow, on pH and the Mg/Mn ratio. Therefore, the continuation of these studies in the long term is justified.

4.2. Relationship between Preferred Grazing Locations, Type of Grazing, Stocking Rate, Floristic Composition, and Pasture Height, during the Observation Period

The stocking rate used in CG was higher than in the usual production systems (2 to 3 sheep per hectare) [48]. Even so, biomass availability in all plots meant that sheep could choose the areas with the most preferred species (CG and DG).

Grazing systems with high stocking rates are often identified as responsible for the degradation of soil, pasture, and trees in the Montado ecosystem. Animal trampling due to high stocking rates is correlated with negative effects on soil properties [15]. However, in our case, there were no significant differences between the two grazing systems tested (CG and DG), which encourages producers in the Montado ecosystem to intensify sheep production, with a greater number of animals per hectare, in DG (grazing periods depending on pasture height). Although the CI values in the plots subject to DG were higher than those recorded in CG, the fact that there were no significant differences takes us to the concept of sustainable intensification. Higher CI values were recorded at depths of 15 to 30 cm. However, several studies report that soil compaction due to animal trampling occurs mainly in the surface layers of the soil [49-51].

The greater amplitudes in pasture heights in the CG treatments indicate a tendency towards more selectivity. In the DG, this amplitude is smaller, although there are areas where the pasture has been consumed more than others. In general, the spots with the lowest grazing preference were those with the highest pasture heights. Furthermore, according to Di Grigoli et al. [52], even in the most preferred areas, where biomass availability decreases, sheep end up ingesting growing plants (due to delay in phenological cycles) with high CP content and low NDF content. The distribution of sheep grazing, across the pasture, depends on external factors, such as topography, and climate [27].

On the six observation dates (**Figure 13**), in all treatments, there was a tendency for the lowlands to be preferred grazing areas, where legume plants prevailed [37]. In heavily grazed areas, all plants can have access to light, with benefits for *Fabaceae* family [19]. On the other hand, on the six observation dates and treatments, the areas less grazed by sheep were those near the road (Figure 13). This explanation is only partially valid for P3TD and P4TC. In fact, the animals at P2UC and P1UC tended to avoid areas closer to the road; however, when the favored species began to congregate at other points, the animals increased their frequency in those areas. The fact that sheep

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graze less time near the road can be a result of frightening factors related to passing by cars and trucks changing their behavior. Clair & Forrest [53] states that vehicle traffic alters the natural behavior of elk, reducing their normal behavioral patterns and increasing levels of vigilance. Incidental observations were made that allow us to infer that these points were grazed during the night, or at the end of the day and in the early hours of the morning, when the passage of vehicles was almost non-existent.

During the observation period in P2UD, there was some avoidance of the areas along the road, except for point 13, where the watering trough is located.

On the first dates of observation, the frequency of drinking was low, but as spring progressed (from April), the higher fiber content of the pasture and the higher temperature led to a greater frequency of visits to the watering trough. As a result, the animals tended to graze much closer to this area. In the dryland pastures, the choice of a grazing area, often reflects the effort to reduce energy expenditure when walking, rather than a true feed preference [23].

In P3TD there was an area highly preferred by sheep for graze (points 30 and 31). In this same plot, the points in the high and middle zone were the least preferred. Sheep prefer to graze areas with an average pasture height of 60mm rather than 300mm [54].

In P4TC, the preferred area for grazing, on all observation dates, was in the lowland area, where more leguminous species were identified. Only the area near points 38 and 39 was less grazed (characterized by high pasture close to the road).

In winter (January 14th), at the peak of spring (May 4th), the botanical species were identified at each sampling point. In this work we include only the inventory of botanical species identified in the places preferred by sheep to graze.

Of the plants identified at the sampling points, which are most preferred for grazing, some, such as *Senecio vulgaris L.*, *Senecio jacobaea L.*, *Echium plantagineum L.*, *Iris xiphium L.*, *Ranunculus ollissiponensis* subsp *ollissiponensis Pers.* are toxic to ruminants in certain phenological states, and sheep avoided them [55]. On the other hand, other botanical species belonging to the *Fabaceae* family (clovers and *Ornithopus compressus* L.*)* are not very palatable in the first phenological stages and are only consumed by sheep in the middle and late spring and summer as dry feed.

In April, preferred grazing areas expanded to almost all the plots. This fact may have occurred due to the decrease in the amount of water in the soil and the wind that was felt at the end of March and beginning of April, which harmed the development of the pasture, leading to the early maturation of some species. In areas with a high availability of biomass, sheep will tend to prefer places where the species have a higher nutritional value, trying to select plants that have a higher CP and a lower fiber content [56]. Different preferred grazing locations, throughout the season, may reflect different pasture characteristics in terms of quality and quantity [28]. Also, the floristic composition of the pasture is affected by grazing, namely through selectivity, stocking rate and grazing season [14].

In points 3, 4, 5, 10 and 11, several botanical species characteristics of nitrophilous zones, with low palatability, low nutritional value or even toxicity, were also identified. The *Poa* genus shows significant initial growth but tends to have a short cycle, reducing its palatability early on. Sheep appreciate the *Cynodon* genus at certain stages of its phenological state. Still, they soon show high levels of fiber and significant reductions in CP content, causing sheep to reduce their preference for these plants. The plants of the genus *Rumex* and *Arum* are toxic, and normally avoided by animals as well as *Urtica* genus [55]. These areas have a high density of *Urtica* spp., which sheep tend to avoid. Similar situations were observed in P2UC at points 23 and 24 and in P3TD at points 25 and 36. On the other hand, other parts of these locations had shade from the tree canopy, which may protect the pasture from wind and sun, thus preserving a higher soil moisture level. These plants display more green leaves, corresponding to an early stage in the phenological cycle. The higher percentage of organic matter (due to the tree leaves and branches) and the shade provided greater soil moisture in spring and a consequent delay in the plants' phenological cycles. This probably occurred at the end of May, in the upper part of the plot P4TC, when grazing animals were observed near the watering

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trough, and under the tree shade. Also, animals prefer plants in their initial phenological stages when they contain less fiber and more protein [56].

In June, the vegetation was dry, and sheep grazed at a greater variety of locations, suggesting that they had no natural preference for a particular area, confirming Santos [26] description that grazing selectivity decreases as pasture quality decreases. According to Carreira et al. [37] there were no significant differences in the probability of occurrence of most of the identified plants in the four treatments. However, the DG tends to favor the appreciation of plants with greater palatability and nutritional value, also contributing to the reduction of botanical species of lower feed value for sheep.

5. Conclusions

In the treatments associated with deferred grazing, the dolomitic lime provided higher pasture growth rates, resulting in fewer days where animals were absent from in this plot. The lower number of grazing days (around 80) in the plots subject to deferred grazing was compensated by the greater number of sheep per hectare in these plots, compared to continuous grazing. In this sense, when we calculated sheep grazing days, we found that in plots subject to deferred grazing, pasture consumption was 50% higher. Pasture quality was not affected by the type of grazing and the application of dolomitic lime.

Throughout the period of sheep grazing observations, a similar pattern of preferred grazing areas was observed among the four treatments, with the lowland areas presenting more grazing density.

At the beginning of summer (June), the pasture was almost dry, and sheep grazed more evenly across the plots, with no evident areas of preferential grazing. Higher stocking rates (P2UD and P3TD) did not provide a more homogeneous distribution of grazing area across the fences. Even with 16 sheep per hectare, highly preferred areas were observed, especially in P3TD, which means that if there are no biomass limitations, there will always be areas of the pasture and species that the sheep prefer to graze first. The floristic composition does not seem to have been decisive for the choice of grazing locations.

The fact that in deferred grazing, soil compaction is not statistically different from that in continuous grazing, shows that the sustainable intensification of sheep production in the Montado is possible, without degrading this ecosystem.

The results indicate that higher stocking rates, wisely used to maintain adequate recovery periods, tend to favor a more uniform biomass growth, revealing greater species homogeneity and variability. However, given climate variability and the trend towards higher levels of aridity, studies will be needed over several years to analyze the evolution of soil organic matter and compaction and the monitoring of species and their relative preponderance to preserve biodiversity.

This study can be the source for more informed decision-making by agricultural managers, to promote the sustainability of the Montado ecosystem, as well as the efficiency of ruminant production systems, aiming for animal welfare.

Supplementary Materials: Not applicable.

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Appendix A

Table A1. Botanical species identified (winter) in preferred grazing spots on each plot in March.

Botanical Specie	spot 8	spot 9	spot 18	spot 19	spot 30	spot 31	spot 32	spot 45	spot 47
Chamaemelum mixtum	0	0	1	0	0	0	0	0	0
Erodium cicutarium subsp. *bipinnatum*	0	1	1	1	1	0	1	0	1
Calendula arvensis	0	1	0	0	0	0	0	0	0
Chamaemelum fuscatum	1	0	0	0	0	0	0	0	0
Diplotaxis catholica	1	1	1	0	1	0	1	0	1
Echium plantagineum	1	0	1	1	1	0	1	1	1
Geranium molle	0	1	0	0	0	0	0	0	0
Hypochaeris glabra	0	1	0	0	0	0	0	0	0
Iris xiphium	0	1	0	0	0	0	0	0	0
Leontodon taraxacoides	0	0	1	0	0	0	0	1	1
Ornithopus compressus	1	0	0	0	0	1	0	1	0
Plantago lanceolata	0	0	0	1	0	0	0	0	0
Plantago sp	0	1	0	0	0	0	0	0	0
Ranunculus ollissiponensis subsp. *ollissiponensis*	0	0	0	0	0	0	0	1	0
Senecio jacobaea	0	0	0	0	1	0	0	0	0
Senecio vulgaris	1	1	1	1	1	0	1	0	0
Spergula arvensis	1	0	0	0	0	0	0	0	0
Stachys arvensis	0	0	0	0	1	0	1	0	0
Stellaria media	0	0	0	1	0	0	0	0	0
Urtica urens	0	0	0	1	0	0	0	0	0
Genus Trifolium	1	0	0	0	0	1	0	0	0
Several grass species	1	0	0	1	1	0	1	1	1

1-presence; 2-absence.

Table A2. Botanical species identified (Spring) in preferred grazing spots on each plot in May.

Botanical Specie	spot 3	spot 4	spot 5	spot 8	spot 10	spot 11	spot 12	spot 17	spot 20	spot 30	spot 31	spot 41	spot 47
Agrostis castellana Boiss. & Reut.	0	0	0	0	0	0	0	0	0	0	0	0	1

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Agrostis pourretii Willd.	0	1	0	0	0	0	1	0	0	0	0	0	0
Anagallis arvensis L.	0	0	1	0	0	0	0	0	0	0	1	0	0
Anthriscus caucalis M.Bieb.	0	0	1	0	0	0	0	0	0	0	0	0	0
Arum italicum subsp. *italicum*	0	0	1	0	0	0	0	0	0	0	0	0	0
Avena barbata subsp. *lusitanica* (Tab.Morais) Romero Zarco	0	0	0	0	0	1	0	0	0	0	0	0	0
Bromus hordeaceus L.	0	0	0	1	1	1	0	0	0	1	1	1	1
Bromus sterilis L.	1	0	1	0	1	0	0	0	0	0	0	0	0
Callitriche stagnalis	0	0	0	0	0	0	1	1	0	0	0	0	0
Carduus tenuiflorus Curtis	1	0	1	0	0	0	0	0	1	0	0	0	0
Cerastium glomeratum Thuill.	1	0	1	0	0	0	0	1	0	1	1	0	0
Chamaemelum fuscatum (Brot.) Vasc.	0	1	0	0	0	0	1	1	0	0	0	0	0
Chamaemelum mixtum	0	1	0	1	1	1	0	1	1	1	1	1	1
Crepis capillaris (L.) Wallr.	0	0	0	1	1	0	0	0	0	0	1	0	0
Crepis vesicaria subsp. *taraxacifolia* (Thuill.) Thell.	1	1	0	0	1	1	0	0	0	0	1	0	0
Cynodon dactylon (L.) Pers.	0	0	0	0	0	0	1	1	0	1	0	0	0
Diplotaxis catholica (L.) DC.	1	1	0	1	0	1	0	0	1	0	1	1	1
Echium plantagineum L.	0	1	0	1	0	1	0	1	1	1	1	1	0
Erodium cicutarium subsp. *bipinnatum* (Cav.) Tourlet	0	0	1	0	0	0	0	0	1	0	0	0	1
Geranium molle L.	1	0	1	0	1	1	1	0	0	1	0	0	0
Geranium purpureum Vill.	0	0	0	0	0	0	0	0	0	1	0	0	0
Hedypnois cretica (L.) Dum.-Courset	1	0	0	0	1	1	0	0	1	0	0	0	0
Hordeum murinum subsp. *leporinum* (Link) Arcang.	1	0	1	1	0	1	0	0	0	0	0	1	1
Hypochaeris glabra L.	0	0	0	0	1	0	0	0	1	0	0	0	0
Hypochaeris radicata L.	0	0	0	0	1	0	0	1	0	1	1	0	0

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Juncus bufonius L.	0	0	0	0	0	0	1	1	0	1	1	0	0
Lathyrus angulatus L.	0	0	0	0	0	0	0	0	0	1	1	0	0
Leontodon taraxacoides (Vill.) Mérat	0	0	0	0	1	1	0	1	0	1	1	0	0
Lythrum borysthenicum (Schrank) Litv.	0	1	0	0	0	0	1	1	0	0	0	0	0
Medicago polymorpha L.	1	0	1	0	0	1	0	0	0	0	0	0	0
Mentha pulegium L.	0	1	0	0	0	0	0	0	0	0	0	0	0
Ornithopus compressus L.	0	0	0	0	1	0	0	0	0	1	0	0	0
Plantago coronopus L.	0	1	0	0	0	1	1	1	0	0	1	0	0
Plantago lagopus L.	0	0	0	1	1	1	0	0	1	1	1	0	0
Plantago lanceolata L.	0	0	0	0	0	0	0	0	0	0	1	0	0
Poa annua L.	0	1	0	0	0	0	1	1	0	0	0	0	0
Polygonum aviculare L.	0	0	0	0	0	0	1	0	0	0	0	0	0
Polypogon maritimus Willd.	0	0	0	0	0	0	0	1	0	0	0	0	0
Ranunculus parviflorus L.	1	0	1	0	0	0	0	0	0	0	1	0	1
Rumex bucephalophorus L.	0	0	0	1	1	1	1	0	0	0	1	0	0
Rumex pulcher subsp. *woodsii* (De Not.) Arcang.	1	1	1	0	0	0	0	1	0	0	0	0	1
Senecio jacobaea L.	0	1	0	0	1	0	1	1	0	1	0	0	0
Sherardia arvensis L.	1	0	0	0	0	0	0	0	0	0	0	0	0
Silene gallica L.	0	0	0	1	0	1	0	0	0	0	1	0	0
Sisymbrium officinale (L.) Scop.	0	0	1	0	0	0	0	0	0	0	0	0	0
Stachys arvensis (L.) L.	0	0	0	0	0	1	0	0	0	1	1	0	0
Tolpis umbellata Bertol.	0	0	0	0	0	0	0	0	1	1	0	0	0
Trifolium campestre Schreb.	0	0	0	0	0	0	0	0	1	0	0	1	0
Trifolium glomeratum L.	0	0	0	1	0	0	1	1	1	1	1	0	0
Trifolium medium subsp. *medium*	0	0	0	0	0	0	0	0	0	1	0	0	0
Trifolium repens L.	0	0	0	0	1	0	0	1	1	1	1	0	0
Trifolium resupinatum L.	0	0	0	0	0	0	1	1	0	0	0	0	0
Trifolium scabrum L.	0	1	0	0	0	0	0	0	0	0	0	0	0
Trifolium subterraneum L.	0	0	0	0	0	0	1	1	1	0	0	0	0
veronica sp	0	0	1	0	0	0	0	0	0	0	0	0	0
Vulpia bromoides (L.) S.F.Gray	0	0	0	0	0	0	0	0	0	1	0	0	0

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Vulpia geniculata	1	1	1	1	1	1	1	1	1	1	1	1	1

1-presence; 2-absence.

References

1. Pinto-Correia, T., Ribeiro, N., & Potes, J. (2013). Livro Verde dos Montados. In *Instituto de Ciências Agrárias e Ambientais Mediterrânicas - Universidade de Évora* (Issue January). http://www.icaam.uevora.pt/Noticias-e-Informacoes/Temas-e-Eventos-Arquivo/Livro-Verde-dos-Montados
2. David, T. S., Pinto, C. A., Nadezhdina, N., Kurz-Besson, C., Henriques, M. O., Quilhó, T., Cermak, J., Chaves, M. M., Pereira, J. S., & David, J. S. (2013). Root functioning, tree water use and hydraulic redistribution in Quercus suber trees: A modeling approach based on root sap flow. *Forest Ecology and Management*, *307*, 136–146. https://doi.org/10.1016/j.foreco.2013.07.012
3. Feio, M. (1991). Clima e Agricultura: exigências climáticas das principais culturas e potencialidade agrícolas do nosso clima. Ministério da agricultura, pescas e alimentação. Lisboa. ISBN 972 – 9175 – 25 – X
4. IUSS Working Group WRB. World Reference Base for Soil Resources 2014, International Soil Classification System for Naming Soils and Creating Legends for Soil Maps; Update 2015; World Soil Resources Report 106; Food and Agriculture Organization (FAO): Rome, Italy, 2015; 188p
5. Serrano, J. (2019). *Utilização eficiente dos recursos no Montado: sensores próximos e detecção remota no apoio à tomada de decisão*. Perspectiva 2020. 18–25.
6. Carvalho, M., Goss, M. J., & Teixeira, D. (2015). Manganese toxicity in Portuguese Cambisols derived from granitic rocks: causes, limitations of soil analyses and possible solutions Toxicidade de manganês nos Cambissolos derivados de rochas graníticas em Portugal: causas, limitações das análises de solo . *Revista de Ciências Agrárias*, *38*(4), 518–527. http://dspace.uevora.pt/rdpc/bitstream/10174/18708/1/
7. Daniels, M. B., Delaune, P., Moore, P. A., Mauromoustakos, A., Chapman, S. L., & Langston, J. M. (2001). Soil Phosphorus Variability in Pastures: Implications for Sampling and Environmental Management Strategies. *Journal of Environmental Quality*, *30*(6), 2157–2165. https://doi.org/10.2134/jeq2001.2157
8. Belo, C. C., Coelho, I., Rolo, J., & Reis, P. (2014). Sistemas agroflorestais em Portugal continental. Parte II: montados, condições de uso do solo e evolução. *Revista de Ciências Agrárias*, *37*(2), 122–130.
9. Sternberg, M., Gutman, M., Perevolotsky, A., Ungar, E. D., & Kigel, J. (2000). Vegetation response to grazing management in a Mediterranean herbaceous community: A functional group approach. *Journal of Applied Ecology*, *37*(2), 224–237. https://doi.org/10.1046/j.1365-2664.2000.00491.x
10. Watkinson, A. R., & Ormerod, S. J. (2001). Grasslands, grazing and biodiversity: Editors' introduction. *Journal of Applied Ecology*, *38*(2), 233–237. https://doi.org/10.1046/j.1365-2664.2001.00621.x
11. Brougham, R. W. (1960). The effects of frequent hard grazings at different times of the year on the productivity and species yields of a grass-clover pasture. *New Zealand Journal of Agricultural Research*, *3*(1), 125–136. https://doi.org/10.1080/00288233.1960.10419866
12. Teague, W. R., & Dowhower, S. L. (2003). Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. *Journal of Arid Environments*, *53*(2), 211–229. https://doi.org/10.1006/jare.2002.1036
13. Norman, H. C., Wilmot, M. G., Thomas, D. T., Barrett-Lennard, E. G., & Masters, D. G. (2010). Sheep production, plant growth and nutritive value of a saltbush-based pasture system subject to rotational grazing or set stocking. *Small Ruminant Research*, *91*(1), 103–109. https://doi.org/10.1016/j.smallrumres.2009.11.022
14. Xiao, X., Zhang, T., Angerer, J. P., & Hou, F. (2020). Grazing seasons and stocking rates affects the relationship between herbage traits of alpine meadow and grazing behaviors of tibetan sheep in the Qinghai–Tibetan plateau. *Animals*, *10*(3). https://doi.org/10.3390/ani10030488
15. Teague, R., Provenza, F., Norton, B., Steffens, T., Barnes, M., Kothmann, M., & Roath, R. (2008). Benefits of multi-paddock grazing management on rangelands: Limitations of experimental grazing research and knowledge gaps. *Grasslands: Ecology, Management and Restoration*, 41–80.
16. Voisin, A., & Lecomte, A. (1968). *La vaca y la hierba : Cómo obtener buenos rendimientos del ganado vacuno*. Editorial Tecnos.
17. Barcella, M., Filipponi, F., & Assini, S. (2016). A simple model to support grazing management by direct field observation. *Agriculture, Ecosystems and Environment*, *234*, 107–117. https://doi.org/10.1016/j.agee.2016.04.027
18. Barriga, P. A. B. (2019). *Produção de novilhos em pastagem de inverno com diferentes intensidades de pastejo e adubação nitrogenada em integração lavoura-pecuária*. Tese de doutoramento. Programa de Pós-graduação em Agronomia, Universidade Tecnológica Federal do Paraná, Câmpus Pato Branco
19. Mendes, P., Meireles, C., Vila-Viçosa, C., Musarella, C., & Pinto-Gomes, C. (2015). Best management practices to face degraded territories occupied by Cistus ladanifer shrublands – Portugal case study. *Plant Biosystems*, *149*(3), 494–502. https://doi.org/10.1080/11263504.2015.1040483
20. Holechek, J. L. (1983). Considerations concerning grazing systems. *Rangelands*, *5*(5), 208–211.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 March 2024 doi:10.20944/preprints202403.1294.v1

21. Santos, M. E. R., Afonso, L. E., Carvalho, B. H. R., do Rêgo, A. C., Queiroz, G. J. da S., Médica, J. A. de A., de Moraes, L. S., & do Carmo, L. L. S. (2019). Apparent selectivity of sheep in deferred marandu palisadegrass pastures with variable initial heights. *Arquivo Brasileiro de Medicina Veterinaria e Zootecnia*, *71*(5), 1727–1734. https://doi.org/10.1590/1678-4162-10750
22. Bell, M. J., Mereu, L., & Davis, J. (2018). The Use of Mobile Near-Infrared Spectroscopy for Real-Time Pasture Management. *Frontiers in Sustainable Food Systems*, 2(November). https://doi.org/10.3389/fsufs.2018.00076
23. Sales-Baptista, E., Ferraz-de-Oliveira, M. I., Terra-Braga, M., de Castro, J. A. L., Serrano, J., & d'Abreu, M. C. (2022). Characterization of grazing behaviour microstructure using point-of-view cameras. *Plos One*, *17*(3), e0265037. https://doi.org/10.1371/journal.pone.0265037
24. Riedel, J. L., Casasús, I., & Bernués, A. (2007). Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem. *Livestock Science*, *111*(1–2), 153–163. https://doi.org/10.1016/j.livsci.2006.12.013
25. Hirata, M., Kunieda, E., & Tobisa, M. (2010). Short-term ingestive behaviour of cattle grazing tropical stoloniferous grasses with contrasting growth forms. *Journal of Agricultural Science*, *148*(5), 615–624. https://doi.org/10.1017/S0021859610000353
26. Santos, B., Voltolini, T., & Salla, L. (2010). Comportamento de Pastoreio - Behavior of grazing. *Revista Electrónica de Veterinaria REDVET*, *11*(4), 1–33.
27. Sibbald, A. M., Shellard, L. J. F., & Smart, T. S. (2000). Effects of space allowance on the grazing behaviour and spacing of sheep. *Applied Animal Behaviour Science*, *70*(1), 49–62. https://doi.org/10.1016/S0168-1591(00)00145-3
28. Zhang, H., Liu, N., Yang, G. W., Badgery, W. B., Guo, Y. P., & Zhang, Y. J. (2022). Diet selection of sheep shifted from quality to quantity characteristics of forages as sward availability decreased. *Animal*, *16*(6), 100546. https://doi.org/10.1016/j.animal.2022.100546
29. Du, W. C., Yan, T., Chang, S. H., Wang, Z. F., & Hou, F. J. (2017). Seasonal hogget grazing as a potential alternative grazing system for the Qinghai-Tibetan plateau: Weight gain and animal behaviour under continuous or rotational grazing at high or low stocking rates. *Rangeland Journal*, *39*(4), 329–339. https://doi.org/10.1071/RJ16119
30. Fan, X., Xuan, C., Zhang, M., Ma, Y., & Meng, Y. (2022). Estimation of Spatial-Temporal Distribution of Grazing Intensity Based on Sheep Trajectory Data. *Sensors*, *22*(4). https://doi.org/10.3390/s22041469
31. Jamieson, W. S., & Hodgson, J. (1979). The effect of daily herbage allowance and sward characteristics upon the ingestive behaviour and herbage intake of calves under strip-grazing management. *Grass and Forage Science*, *34*(4), 261–271. https://doi.org/10.1111/j.1365-2494.1979.tb01478.x
32. Pulido, R. G., & Leaver, J. D. (2003). Continuous and rotational grazing of dairy cows - The interactions of grazing system with level of milk yield, sward height and concentrate level. *Grass and Forage Science*, *58*(3), 265–275. https://doi.org/10.1046/j.1365-2494.2003.00378.x
33. Serrano, J., Shahidian, S., da Silva, J. M., & de Carvalho, M. (2018). A holistic approach to the evaluation of the montado ecosystem using proximal sensors. *Sensors (Switzerland)*, *18*(2), 1–24. https://doi.org/10.3390/s18020570
34. Serrano, J., Shahidian, S., da Silva, J. M., Moral, F., Carvajal-Ramirez, F., Carreira, E., Pereira, A., & de Carvalho, M. (2020b). Evaluation of the effect of dolomitic lime application on pastures - Case study in the Montado mediterranean ecosystem. *Sustainability (Switzerland)*, *12*(9). https://doi.org/10.3390/su12093758
35. Serrano, J., Shahidian, S., Costa, F., Carreira, E., Pereira, A., & Carvalho, M. (2021a). Can soil ph correction reduce the animal supplementation needs in the critical autumn period in mediterranean montado ecosystem? *Agronomy*, *11*(3). https://doi.org/10.3390/agronomy11030514
36. Serrano, João, Shahidian, S., Machado, E., Paniagua, L. L., Carreira, E., Moral, F., Pereira, A., & de Carvalho, M. (2021b). Floristic composition: Dynamic biodiversity indicator of tree canopy effect on dryland and improved mediterranean pastures. *Agriculture (Switzerland)*, *11*(11), 1–25. https://doi.org/10.3390/agriculture11111128
37. Carreira, E., Serrano, J., Gomes, C. J. P., Shahidian, S., Paniagua, L. L., Pilirito, A., Lopes Castro, J., Carvalho, M., & Pereira, A. F. (2022). Effect of Sheep Grazing, Stocking Rates and Dolomitic Limestone Application on the Floristic Composition of a Permanent Dryland Pasture, in the Montado Agroforestry System of Southern Portugal. *Animals*, *12*(19), 2506. https://doi.org/10.3390/ani12192506
38. Serrano, João, Carreira, E., Shahidian, S., de Carvalho, M., Marques da Silva, J., Paniagua, L. L., Moral, F., & Pereira, A. (2023). Impact of Deferred Versus Continuous Sheep Grazing on Soil Compaction in the Mediterranean Montado Ecosystem. *AgriEngineering*, *5*(2), 761–776. https://doi.org/10.3390/agriengineering5020047
39. Russel, A. (1984). Body condition scoring of sheep. *Practice*, 6, 91–93.
40. Cannas, A.; Boe, F. (2003). Prediction of the relationship between body weight and body condition score in sheep. *Ital. J. Anim. Sci.*, 2 (Suppl. 1), 527–529.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 March 2024 doi:10.20944/preprints202403.1294.v1

41. Walton, P.D.; Martinez, R.; Bailey, A.W. (1981). A Comparison of Continuous and Rotational Grazing. Rangel. Ecol. Manag. 34, 19.
42. Marley, C.L.; Fraser, M.D.; Fisher, W.J.; Forbes, A.B.; Jones, R.; Moorby, J.M.; Macrae, J.C.; Theodorou, M.K. (2007). Effects of continuous or rotational grazing of two perennial ryegrass varieties on the chemical composition of the herbage and the performance of finishing lambs. Grass Forage Sci. 62, 255–264.
43. AOAC. (2005). Official Method of Analysis of AOAC International, 18th ed.; AOAC International: Arlington, AT, USA.
44. Fonseca, L., Mezzalira, J. C., Bremm, C., Filho, R. S. A., Gonda, H. L., & Carvalho, P. C. d. F. (2012). Management targets for maximising the short-term herbage intake rate of cattle grazing in Sorghum bicolor. *Livestock Science*, *145*(1–3), 205–211. https://doi.org/10.1016/j.livsci.2012.02.003
45. Moraes, A., Carvalho, P. C. de F., Anghinoni, I., Lustosa, S. B. C., Costa, S. E. V. G. de A., & Kunrath, T. R. (2014). Integrated crop-livestock systems in the Brazilian subtropics. *European Journal of Agronomy*, *57*, 4–9. https://doi.org/10.1016/j.eja.2013.10.004
46. Iason, G. R., Mantecon, A. R., Sim, D. A., Gonzalez, J., Foreman, E., Bermudez, F. F., & Elston, D. A. (1999). Can grazing sheep compensate for a daily foraging time constraint? *Journal of Animal Ecology*, *68*(1), 87–93. https://doi.org/10.1046/j.1365-2656.1999.00264.x
47. Carvalho, M. A Seca E a Intensificação Sustentável Dos Sistemas Agro-Pecuários: Desafios E Soluções. Dossier Secas e Cheias—Como Gerir. 2018, pp. 24–27. Available online: http://dspace.uevora.pt/rdpc/bitstream/10174/23541/1/ (accessed on 7 November 2023).
48. Potes, J.M. O Montado no Portugal Mediterrânico; Edições Colibri: Lisboa, Portugal, 2011; 193p.
49. Mayerfeld, D.; Kruger, E.; Gildersleeve, R. & Rickenbach, M. (2022) Impacts of different grazing approaches on woodland ecosystem properties. Agroforestry Systems, 96, 527–540.
50. Sharrow, S. (2007). Soil compaction by grazing livestock in silvopastures as evidenced by changes in soil physical properties. Agroforestry Systems, 71, 215–223.
51. Benavides, R.; Douglas, G.B.; Osoro, K. (2009). Silvopastoralism in New Zealand: Review of effects of evergreen and deciduous trees on pasture dynamics. Agroforestry Systems, 76, 327–350.
52. Di Grigoli, A., Todaro, M., Di Miceli, G., Genna, V., Tornambè, G., Alicata, M. L., Giambalvo, D., & Bonanno, A. (2012). Effects of continuous and rotational grazing of different forage species on ewe milk production. *Small Ruminant Research*, *106*(SUPPL.), S29–S36. https://doi.org/10.1016/j.smallrumres.2012.04.030
53. Clair, C. S., & Forrest, A. (2009). Impacts of vehicle traffic on the distribution and behaviour of rutting elk, Cervus elaphus. *Behaviour*, *146*(3), 393-413.
54. O'reagain, P. J., & Schwartz, J. (1995). Dietary selection and foraging strategies of animals on rangeland. Coping with spatial and temporal variability. In International symposium on the nutrition of herbivores (Vol. 4, pp. 419-424). In *proceedings In: INTERNATIONAL SYMPOSIUM ON THE NUTRITION OF HERBIVORES* (Issue February, pp. 419–424).
55. Quintas, H., Cordeiro, A. & Aguiar, C. (2014). Plantas tóxicas para ruminantes. Publicações ciência & vida. ISBN: 978-972-590-093-2
56. Heady, H. F. (1961). Continuous vs. Specialized Grazing Systems: A Review and Application to the California Annual Type. *Journal of Range Management*, *14*(4), 182. https://doi.org/10.2307/3895147

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CAPÍTULO 8

Efeito de diferentes tipos de pastoreio por ovinos no índice de compactação do solo

AgriEngineering

Article

Impact of Deferred Versus Continuous Sheep Grazing on Soil Compaction in the Mediterranean Montado Ecosystem

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Abstract: Deferred grazing (DG) consists in adapting the number of animals and the number of days grazed to the availability of pasture. Compared to continuous grazing (CG), which is based on a permanent and low stocking rate, DG is a management strategy that aims at optimizing the use of the resources available in the Mediterranean Montado ecosystem. This study with sheep grazing, carried out between 2019 and 2021 on a 4 ha pasture in Alentejo region of the Southern of Portugal, assesses the impact of these two grazing management systems on soil compaction as a result of animal trampling. This area of native natural grassland (a dryland pasture, mixture of grasses, legumes, and composite species) was divided into four grazing parks of 1 ha each, two under DG management and two under CG management. At the end of the study, the cone index (CI, in kPa) was measured in the topsoil layer (0–30 cm) with an electronic cone penetrometer at 48 georeferenced areas (12 in each park). The results of CI measurement showed no significant differences between treatments in all depths measured (0–10, 10–20, and 20–30 cm). These findings are encouraging from the point of view of soil conservation and sustainability, revealing good prospects for the intensification of extensive livestock production. Future work should evaluate the long-term impact and consider, at the same time, other ecosystem services and system productivity indicators.

Keywords: sheep trampling; cone index; deferred grazing; continuous grazing

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1. Introduction

Mediterranean pasture ecosystems are usually extensive, with low use of inputs, while they are utilized predominantly by small ruminants due to their high efficiency in the use of locally available feeding resources and their adaptation to specific environments [1]. The extensive livestock production in Alentejo region of the south of Portugal, particularly sheep husbandry, is characterized by low profit margins as a result of the marginal lands, and consequently, poor pasture productivity and quality [2,3]. The productivity of Mediterranean grazing lands is limited by physical constraints, such as climate and soil conditions [1]. Therefore, the predominant system in this region is the continuous grazing system (CG), a grazing management modality with low animal stocking rates (≤1 unit animal, UA, per hectare, corresponding to approximately 6–7 sheep.ha^{-1}) [2] and without a grazing control based on the amount of effective forage accumulation (height monitoring) [4]. Continuous grazing is characterized by minimal technical input [3,4].

The control of grazing intensity through the management of stocking rates is a key tool to adjust the forage offered to animals in livestock systems [3]. Grazing intensity refers to the frequency with which animals use the pasture and the combination of more animals present for a variable time, which depends on the instantaneous growth rate of the pasture. In recent years, with the aim of improving the use of the resources available in the Mediterranean Montado ecosystem, more dynamic, intensive, and productive strategies for grazing management have been implemented [4], among them deferred grazing (DG), i.e., intermittent grazing [5]. This consists in adapting the number of animals and the number of days grazed to the availability of pasture to manage feed surpluses, especially in the spring period [6]. These grazing systems differ substantially in terms of animal load: while in CG, a small number of animals are permanently in grazing, in DG, in periods of higher pasture availability, a high stocking density (large number of animals) is used in grazing for a restricted period [7]. When grazing availability decreases below a certain threshold, animals are removed from the plot to allow vegetative recovery [7]. This is intended to limit preferential grazing of certain areas and to promote the homogenous and integral grazing of the plot, preventing less interesting botanical species from gaining prevalence after successive pasture vegetative cycles [5–7]. However, the implementation of grazing systems that aim to make homogeneous use of the entire pasture area can lead to large animal loads in sensitive areas of the plots and at critical times [8]. The degree to which grazing increases soil compaction severity (livestock trampling) is affected by several factors, including grazing management (stocking rate, stocking density, timing, etc.), soil type (texture), soil moisture during grazing, and climate [9,10]. Periods following concentrated rainfall events, which are increasingly frequent in the region, are susceptible to pasture degradation and soil compaction, particularly in areas with structural limitations [10]. This is particularly important in the global context: about 20% of the world's pastures and rangelands are considered degraded through overgrazing and compaction [11] and land degradation affects 23% of the world's terrestrial area [3].

As a reference, the estimated force applied by sheep hoofs to the soil surface (static pressure) is approximately 80 kPa [12,13], similar to those of tractor wheels [14]. Several studies have assessed the impact of different grazing systems, more intensive or less intensive, on the productivity, quality, and floristic composition of pasture [5,6,11,15–17]. Nevertheless, the impact of sheep trampling on soil compaction, associated with different grazing systems, is a little-studied process and could become an important tendency indicator of sustainability, which will tend to be considered in future Common Agricultural Policy (PAC) decisions. Within this framework, it will be fundamental to have technological tools that make the decision-making process more expeditious, based on electronic sensors and spatial knowledge of the relevant variables of the Montado ecosystem. The development and application in recent decades of various sensors in *Precision Agriculture* projects associated with global navigation satellite systems (GNSS) today provides the technology to monitor the spatial variability of soil and crops, identifying areas of similar management potential (known as homogeneous management zones, HMZ) [18]. Notable among these are soil electrical conductivity measuring sensors (by contact or electromagnetic induction), which have come to provide smart soil sampling systems [18,19]. The electronic cone penetrometer, which measures soil compaction, is another practical sensor that, complementarily, has the potential to characterize the impact of different grazing management systems from a *Precision Grazing* (PG) perspective [8], and to provide the farmer with the tools necessary to make decisions related to soil physical condition [11]. Soil compaction influences crop yield, wherefore the delimitation of management zones connected with this parameter is of great importance [18]. Since the crop, in this case pasture, is the expression of soil characteristics, as well as climate and animal grazing management, then pasture vegetation growth patterns obtained over time, before and after grazing, through vegetation indices based on images of the Sentinel-2 satellite could be very interesting [20]. Optical remote sensors, capable of measuring vegetation spectral response and time series of vegetative indices, such as NDVI (Normalized Difference Vegetation Index) or NDWI (Normalized Difference Water Index), with variable spatial resolution and sensitive to changes in the vegetation cover [20], are frequently used in agriculture. These can address the goal of measuring, for example, pasture growth rates or post-grazing regrowth [4] in DG treatment, and complement a holistic approach on this soil–pasture–tree and animal ecosystem [8,19]. It is expected that this article can contribute to better support future decision-making by farm managers in regard to the implementation of PG from the perspective of intensification using expedient technological tools, namely, the electronic cone penetrometer, the soil electrical conductivity meter, and satellite imagery.

Despite the fact that in recent years several works have been published that relate soil, pasture, tree, and animal interactions [8,12], to the best of our knowledge, there are no published studies that have quantified the effect of deferring grazing on soil compaction. This study aims to assess the impact that two grazing management strategies (CG versus DG) have on soil compaction as result of animal trampling.

2. Materials and Methods

2.1. Experimental Site Description and Grazing Management

This research was conducted at an experimental pasture called Eco-SPAA which is located in the Mitra farm (38°53.10 N; 8°01.10 W), of University of Évora, in Southern Portugal. The area of study was 4 ha. An overview of the experimental field is given in Figure 1. The study was performed between September 2019 and June 2021.

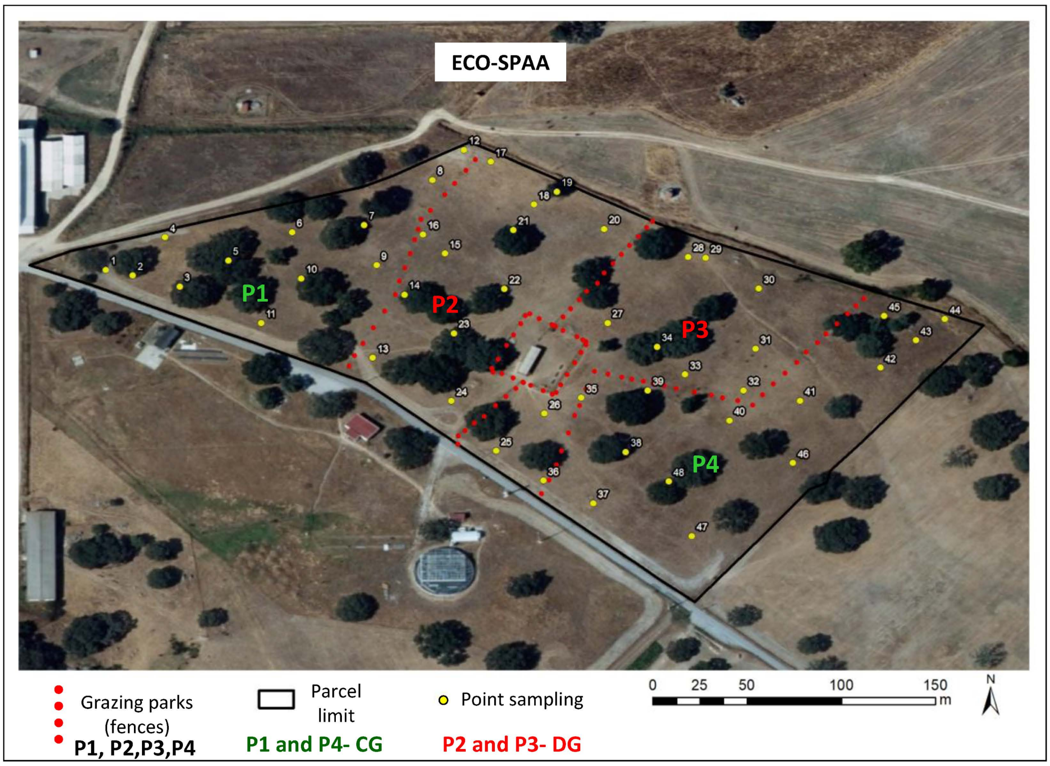

Figure 1. Experimental pasture "Eco-SPAA", located at Mitra farm.

This pasture was subdivided with fences in 2019, as part of a study to evaluate different grazing systems [7], into four parks (P1 to P4), each with an area of approximately 1 hectare. In parks P1 and P4, a continuous grazing system was implemented (CG; stocking rate of 1 UA throughout the whole vegetative cycle of the pasture), while in parks P2 and P3 a deferred grazing system was implemented, and with a higher stocking rate (DG; stocking rate of 2 UA; they entered or left the grazing parks according to the average height of the pasture, left when this was less than 5 cm, and re-entered when this was greater than 10 cm) [7]. A buffer park outside the experimental pasture receives the animals during the grazing rest periods of parks P2 and P3 (DG treatment). To determine the average height of the pasture in each of the 4 grazing parks (P1 to P4), 12 sampling points were geo-referenced from a total of 48 sampling areas (Figure 1). The detail of the separator fence between the two grazing systems under study (CG and DG) and the respective pasture development are presented in Figure 2. The total number of grazing days that animals spent in each treatment (grazing system) in each year (2019/2020 and 2020/2021) is shown in Figure 3. The number of days between years was different because the life cycles of the pastures were different. After all, the onset of autumn rains was different between years. The number of days spent in each treatment is also described across months, highlighting the relationships between the pastures' growth rates and their intake rate.

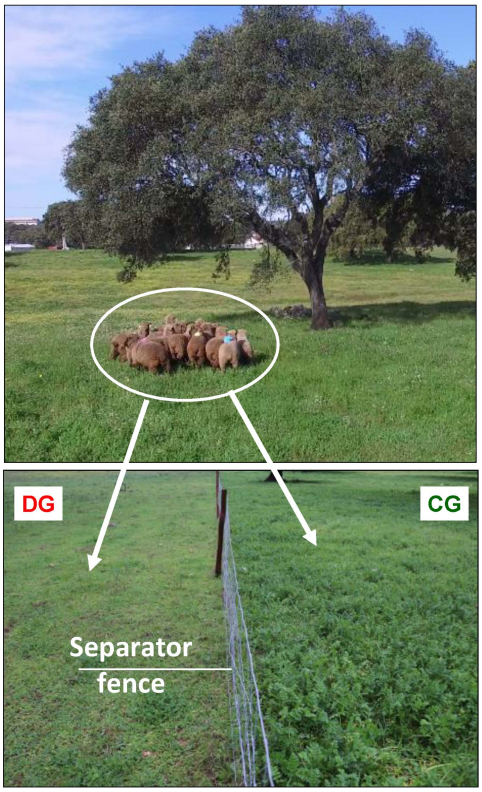

Figure 2. Detail of the separator fence between the two grazing systems under study.

In this area, the soil can be classified as a Cambisol derived from granite [21]. Usually, these acid soils are utilized for grazing and forest land or mixed with arable farming [21]. In this specific case, this pasture was used in extensive sheep grazing systems for over three decades. It integrates the Montado ecosystem, with biodiverse permanent dryland pastures under Holm oak trees (*Quercus ilex* ssp. *rotundifolia* Lam.) with a low density (about 8–10 trees.ha^{-1}). From a textural classification, the soil has a sandy loam texture (mean clay content = 9.3 ± 1.3%); acid (mean pH = 5.4 ± 0.2); rich in potassium (mean = 150.4 ± 51.6 mg kg^{-1}); medium CEC (11.4 ± 2.7 cmol.kg^{-1}) and EC_a (12.4 ± 4.4 mS.m^{-1}), low levels of organic matter (mean = 1.6 ± 0.6%), and phosphorus (mean = 55.6 ± 21.5 mg kg^{-1}) [22].

2.2. Characterisation of the Climate

The climate of the area where the experimental field was located is Mediterranean. It can be classified as Csa (Köppen–Geiger classification; [23]). High inter-annual irregularity and low rainfall (usually <600 mm), mainly in the autumn–winter seasons and practically expressionless during the summer [8].

The evolution of the monthly mean temperature and rainfall between July 2019 and June 2021 are presented in Figure 4. The above-mentioned inter-annual irregularity is very clear: while 2019/2020 recorded a total accumulated rainfall of 627 mm, close to what is common in the region and evenly distributed over the autumn, winter, and spring seasons (213, 205, and 208 mm, respectively), 2020/2021 was a relatively rainy year, with total accumulated precipitation of 778 mm evenly distributed over the autumn and winter (approximately 300 mm in each season), but with low rainfall in spring (total of 135 mm) and abnormal rainfall events in summer. Flooding and the consequent increase in soil compaction by animal trampling are usual due to the rainfall irregularity, particularly the high concentration of rainfall during some events, which is associated with the poor drainage of these soils [8].

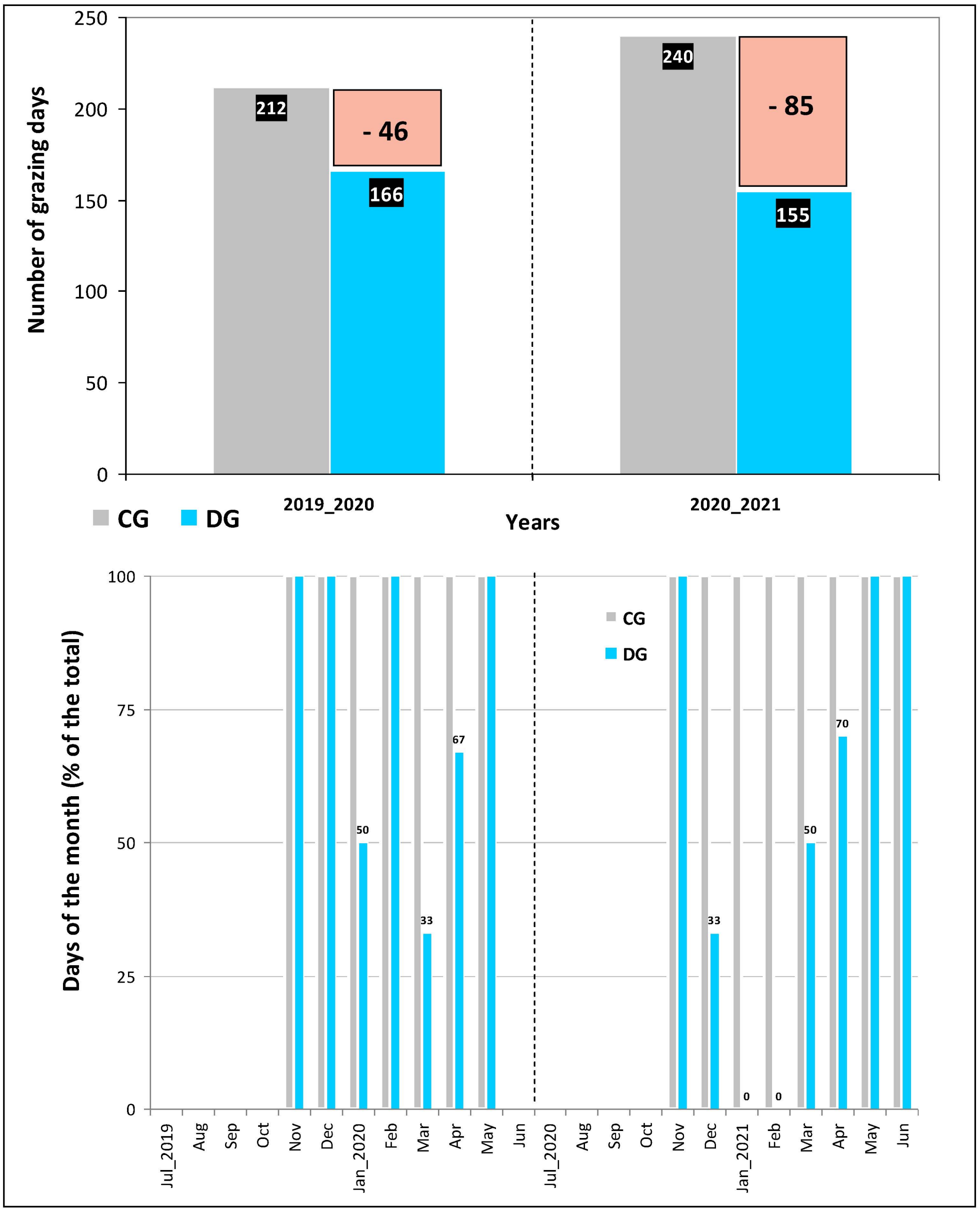

Figure 3. Number of grazing days in each treatment in 2019/2020 and 2020/2021.

2.3. Soil Apparent Electrical Conductivity (EC_a) and Altimetric Surveys

To characterize the soil spatial variability of the experimental pasture, a soil apparent electrical conductivity (EC_a) survey was carried out in October 2019. Topsoil data (0–37.5 cm) obtained by an "EM38" device (Geonics Ltd., Mississauga, ON, Canada) were used. A metal-free sledge was used to mount the EC_a sensor, and it was pulled behind an all-terrain vehicle equipped with a GNSS receiver. Thus, a topographic survey was also provided.

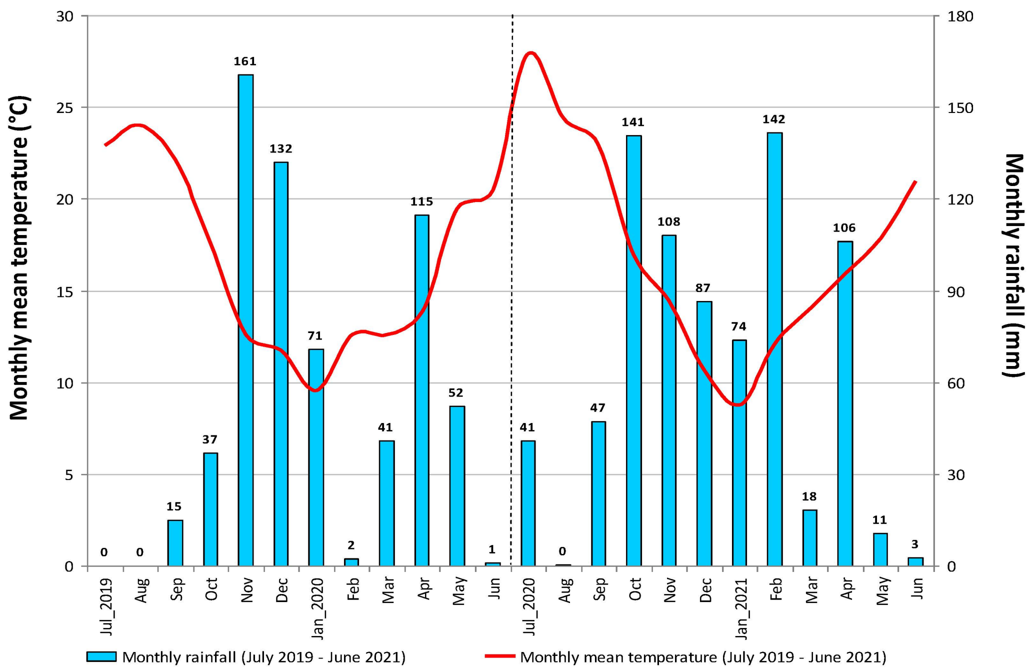

Figure 4. Thermo-pluviometric diagram of Meteorological Station of Mitra (Évora, Portugal) between July 2019 and June 2021.

2.4. Cone Index and Soil Moisture Measurements

With the aim of measuring the soil resistance to penetration (Cone Index, CI, in kPa), an electronic cone penetrometer "FieldScout SC 900" (Figure 5a) (Spectrum Technologies, Aurora, IL, USA) equipped with an ultrasonic depth sensor was used in October 2021. In each of the 48 sampling areas of 1 m^2, five CI measurements were performed between 0 and 45 cm (maximum depth allowed by the device). These measurements were conducted with this pattern: one in the central point of the sampling location, and one in each of its four quadrants (Figure 5b). The same operator performed the measurements to avoid errors from the uncertainty of maintaining a constant penetration rate [8]. After the field measurements, data were processed: (i) outliers were removed with a preliminary analysis; (ii) the mean CI value of the set of five measurements were computed for each sampling location and each depth (0–10, 10–20, 20–30 and 0–30 cm); (iii) the graphic representation of CI as a function of soil depth was generated. Readings for all treatments were taken on the same day to avoid soil moisture variability, which can affect the resistance measurements. A gouge auger and a hammer were used to collect soil samples from the 0–30 cm soil layer with the aim of characterizing the soil moisture content (SMC) at the time of CI measurement in the central point of each measurement area (Figure 5b). Soil samples were weighed and dried at 70 °C for 48 h; then they were weighed again to establish the SMC [8].

2.5. Vegetation Multispectral Measurement: NDVI and NDWI Time Series Reconstruction

From the Copernicus data hub, a multi-temporal Sentinel-2 imagery dataset (between 1 September 2020 and 30 June 2021), free of clouds and atmospherically corrected, was downloaded. Band 8 (B8; near infrared, NIR; 842 nm) and band 4 (B4; RED; 665 nm), both with a 10 m spatial resolution, were utilized to compute the satellite normalized difference vegetation index (NDVI = (B8 − B4)/(B8 + B4)) and for the reconstruction of the mean NDVI trends (NDVI time series records). Band 8A (B8A; NIR; 865 nm) and band 11 (B11; short-wave infrared, SWIR; 1610 nm), both with a 20 m spatial resolution, were utilized to compute the satellite normalized difference water index (NDWI = (B8A − B11)/(B8A + B11)) and for the reconstruction of the mean NDWI trends (NDWI time series records).

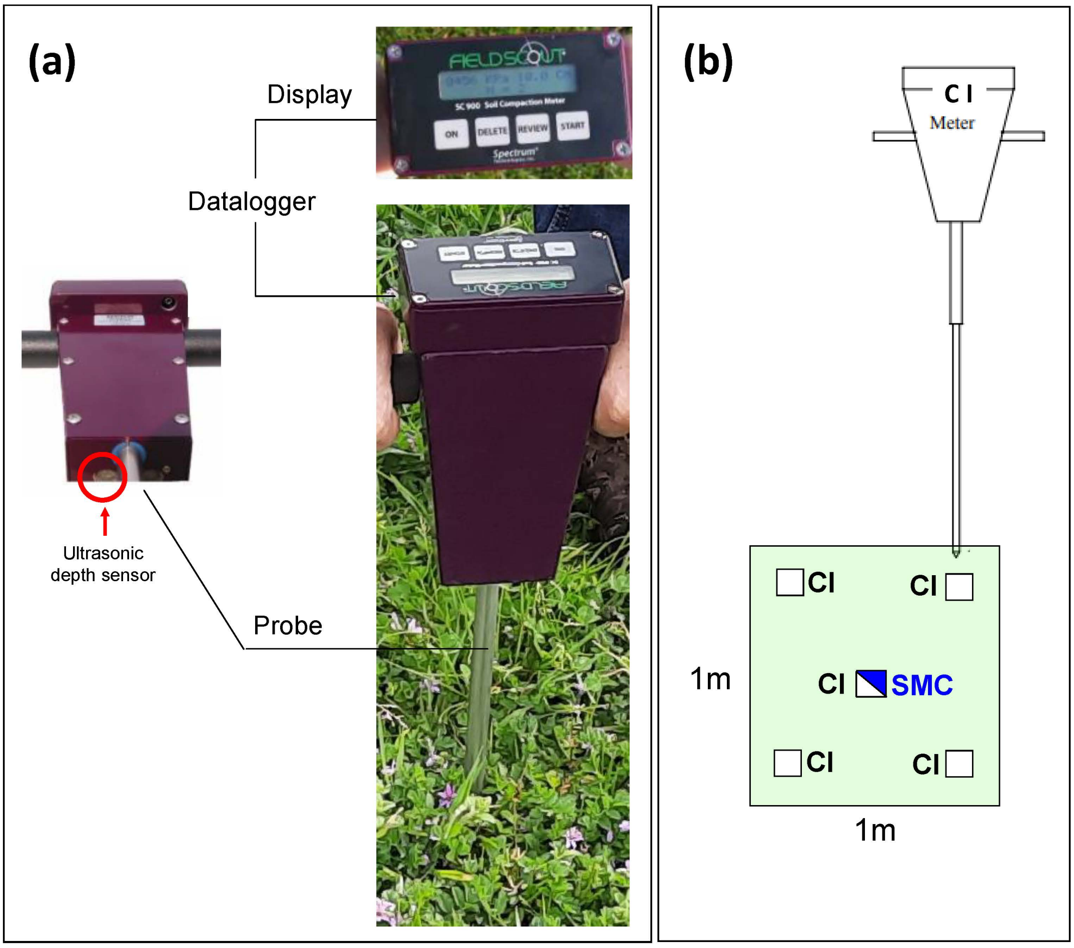

Figure 5. "FieldScout SC 900" cone penetrometer (**a**) and schematic representation of Cone Index (CI) and Soil Moisture Content (SMC) sampling area (**b**).

2.6. Statistical Analysis

A descriptive statistical analysis was conducted for CI. Inferential analysis consisted of: (i) regression analysis between SMC and CI to 0–30 cm data (with a 95% significance level); and (ii) analysis of variance (ANOVA) between treatments (CG versus DG) and between CI depths (0–10, 10–20, 20–30 and 0–30 cm). The IBM SPSS Statistics package for Windows (version 28.0, IBM Corp., Armonk, NY, USA) was used to perform these analyses.

With the aim of analysing the mean separation whenever the variables presented significant differences in the ANOVA ($p < 0.05$), multiple comparisons were conducted using the Tukey's HSD test.

The maps of soil variables (SMC, EC_a, and CI) and the altimetric map were produced through geostatistical analyses with the "Geostatistical Analyst" extension of ArcGIS software (version 10.5, ESRI, Inc., Redlands, CA, USA). Kriged maps were generated using the ArcMap module of ArcGIS.

The calculation of the mean values of these indices took into account, for each grazing park, the set of values of the "10 m × 10 m" Sentinel-2 pixel sampling areas for NDVI (Figure 6a), and the "20 m × 20 m" Sentinel-2 pixel sampling areas for NDWI (Figure 6b).

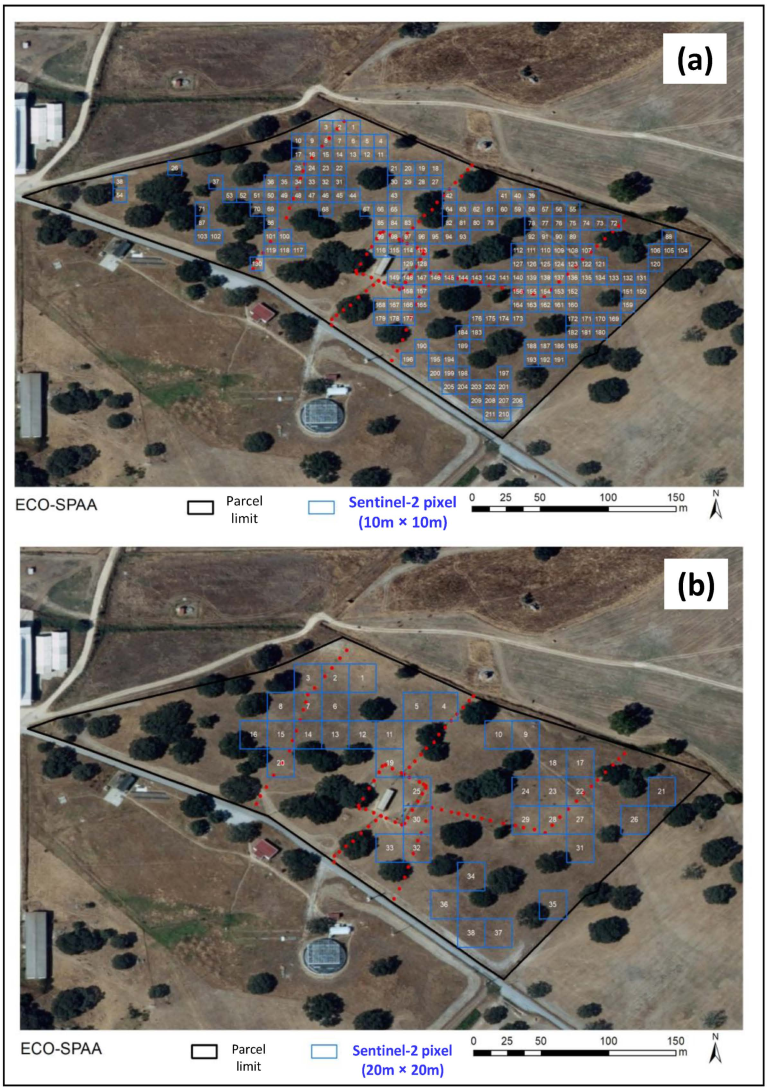

Figure 6. Sentinel-2 pixel sampling areas of the experimental pasture: (**a**) "10 m × 10 m" pixels; (**b**) "20 m × 20 m" pixels.

3. Results

The elevation map (Figure 7a) is representative of the undulating topography characteristic of the region, which is known to have an impact on the spatial variability of soil parameters. This soil spatial variability is also evident in the EC_a map (Figure 7b): although as well as the preponderance of areas with intermediate values (10–15 $mS.m^{-1}$), there are also representative areas with low EC_a (<10 $mS.m^{-1}$) and areas with high EC_a (>15 $mS.m^{-1}$).

The cone index (mean, standard deviation, and range) for different depths in each treatment (CG versus DG) is presented in Table 1. Although average CI values tend to be higher in areas with DG (Figure 8a) at all depths (Figure 8b), the differences obtained are not statistically significant (p = 0.337). The ANOVA showed CI significant differences (p = 0.000) between depths, with higher CI values at 10–20 cm depth (p = 0.000) compared to 0–10 cm depth, and 20–30 cm depth (p = 0.000) compared to 0–10 cm depth. The multiple comparisons showed no significant differences (p = 0.949) between 10–20 cm and 20–30 cm depths. These multiple comparisons also showed no significant differences (p = 0.891) for interactions between treatments and depths.

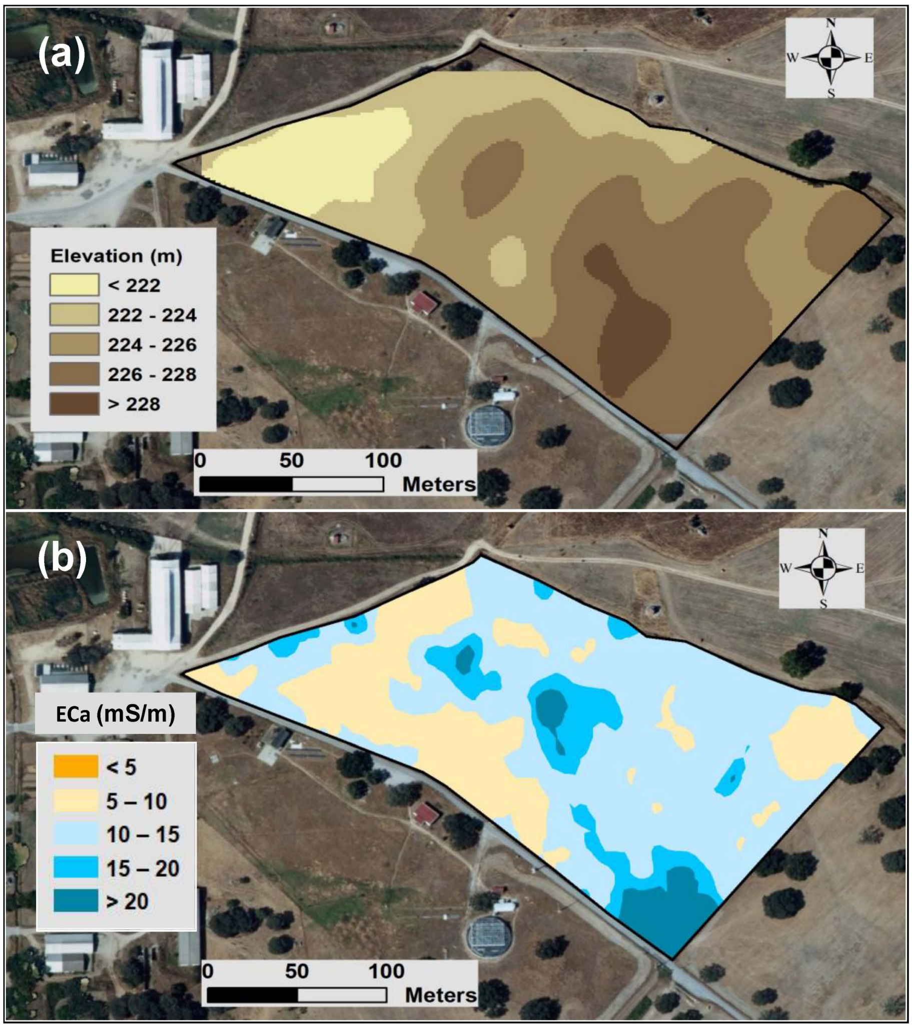

Figure 7. Elevation map (**a**) and soil apparent electrical conductivity (EC_a) map (**b**) of the experimental pasture.

Table 1. Mean, standard deviation (SD) and range of cone index (CI, in kPa) for different depths in each treatment (continuous grazing, CG versus deferred grazing, DG).

Depth	CG		DG	
(cm)	Mean ± SD	Range	Mean ± SD	Range
0–10	1501 ± 617	500–3450	1696 ± 624	837–2795
10–20	2619 ± 655	1334–3536	2664 ± 894	1078–4200
20–30	2520 ± 893	802–4519	2656 ± 886	1483–4511
0–30	2194 ± 484	1303–3214	2338 ± 639	1250–3597

The maps of SMC (a) and CI (b) at 0–30 cm depth are presented in Figure 9. The spatial patterns of these two parameters are relatively opposite, with higher CI values in areas with lower SMC content. This inverse relationship between CI and SMC is evident in Figure 10. The spatial pattern of CI at different depths is presented in Figure 11.

The pattern of NDVI (a) and NDWI (b) time series (CG versus DG) over the pasture vegetative cycle of the 2020/2021 (between 1 September 2020 and 30 June 2021) indicates a trend of higher vegetative vigour (higher NDVI and higher NDWI) in areas under DG (relative to areas under CG) between the beginning of January and the end of May 2021 (Figure 12).

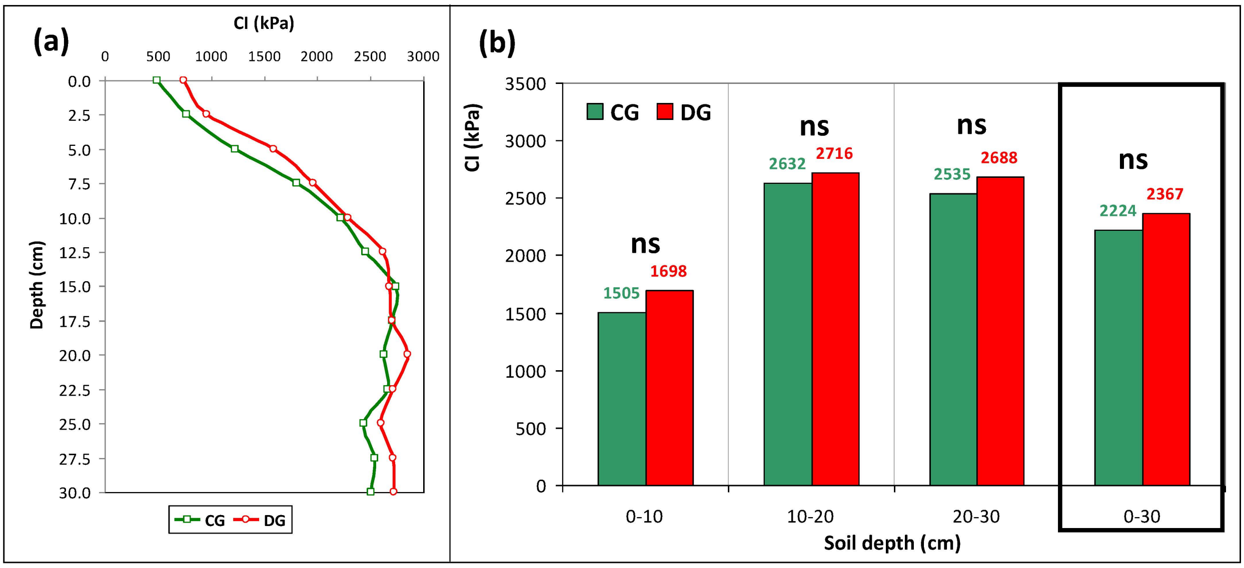

Figure 8. Average cone index (CI, in kPa) for continuous (CG) versus deferred grazing (CG) at: (**a**) 0–30 cm soil depth; (**b**) 0–10 cm, 10–20 cm, 20–30 cm and 0–30 cm soil depths. "ns"—Not significant.

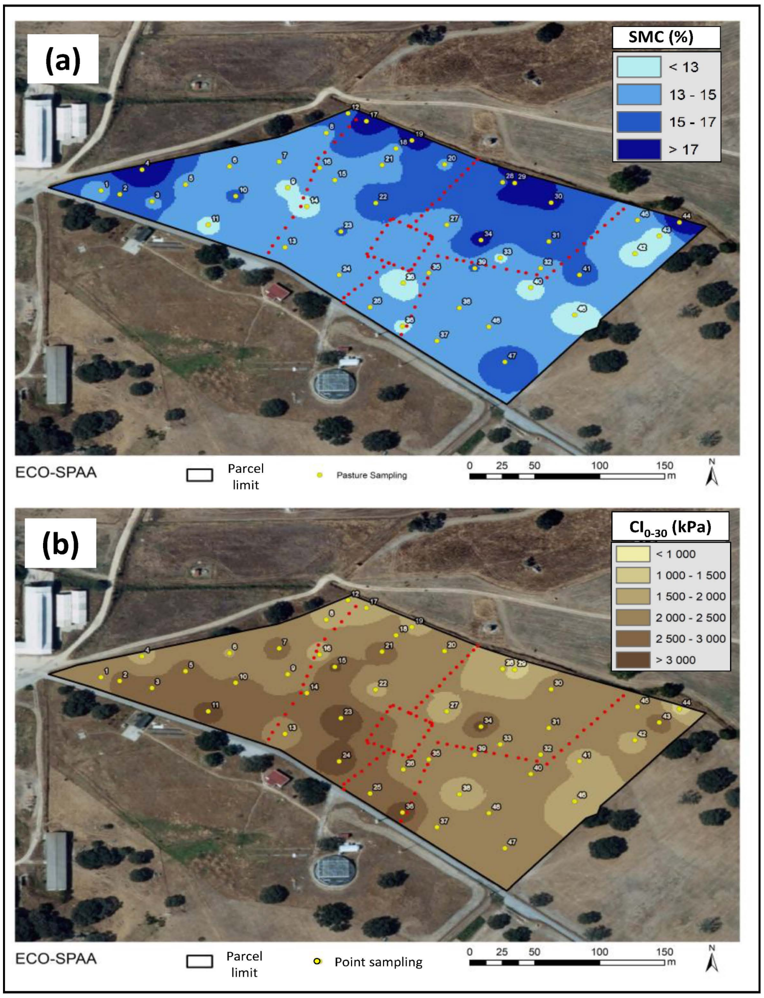

Figure 9. Soil moisture content (SMC) map (**a**) and cone index (CI) map (**b**) at 0–30 cm depth.

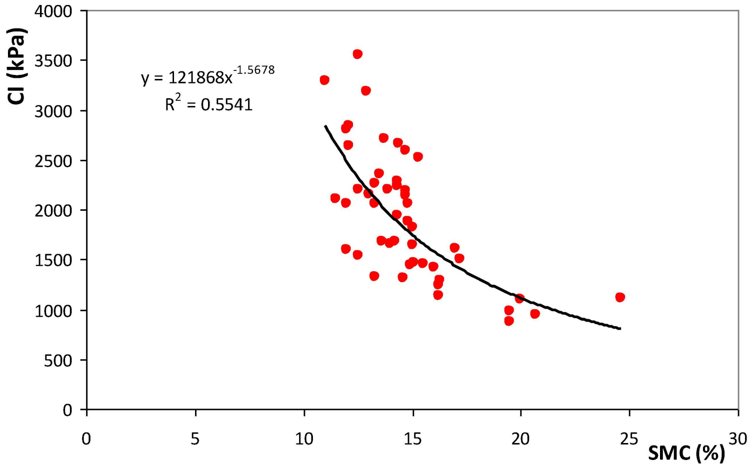

Figure 10. Relationship between soil moisture content (SMC) and mean cone index (CI) in the 0–30 cm soil layer.

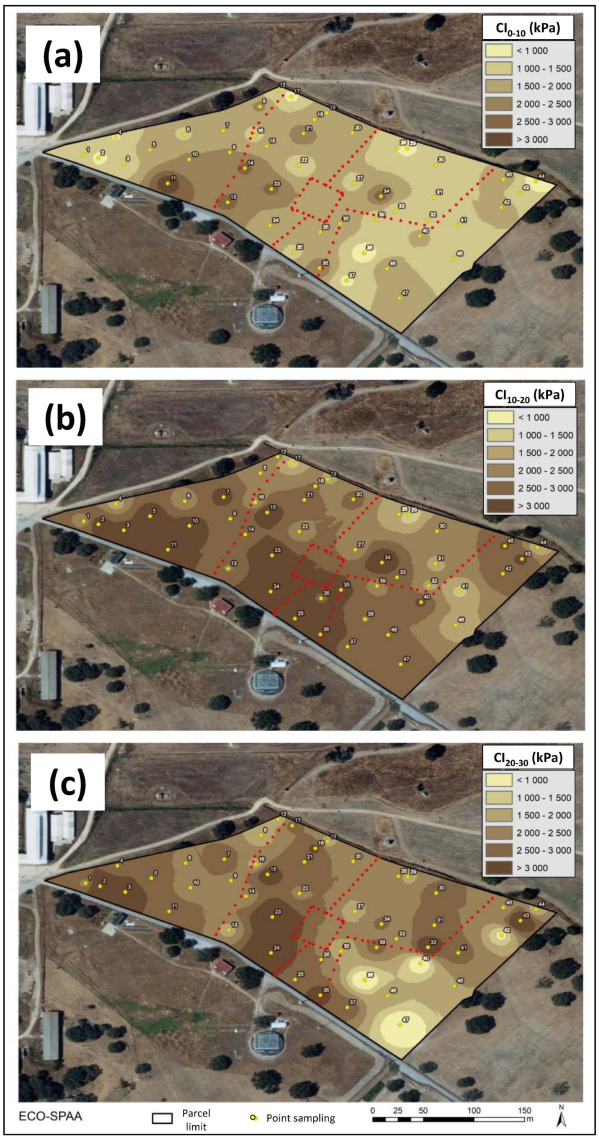

Figure 11. Cone index maps at different depths: (**a**) 0–10 cm; (**b**) 10–20 cm; (**c**) 20–30 cm.

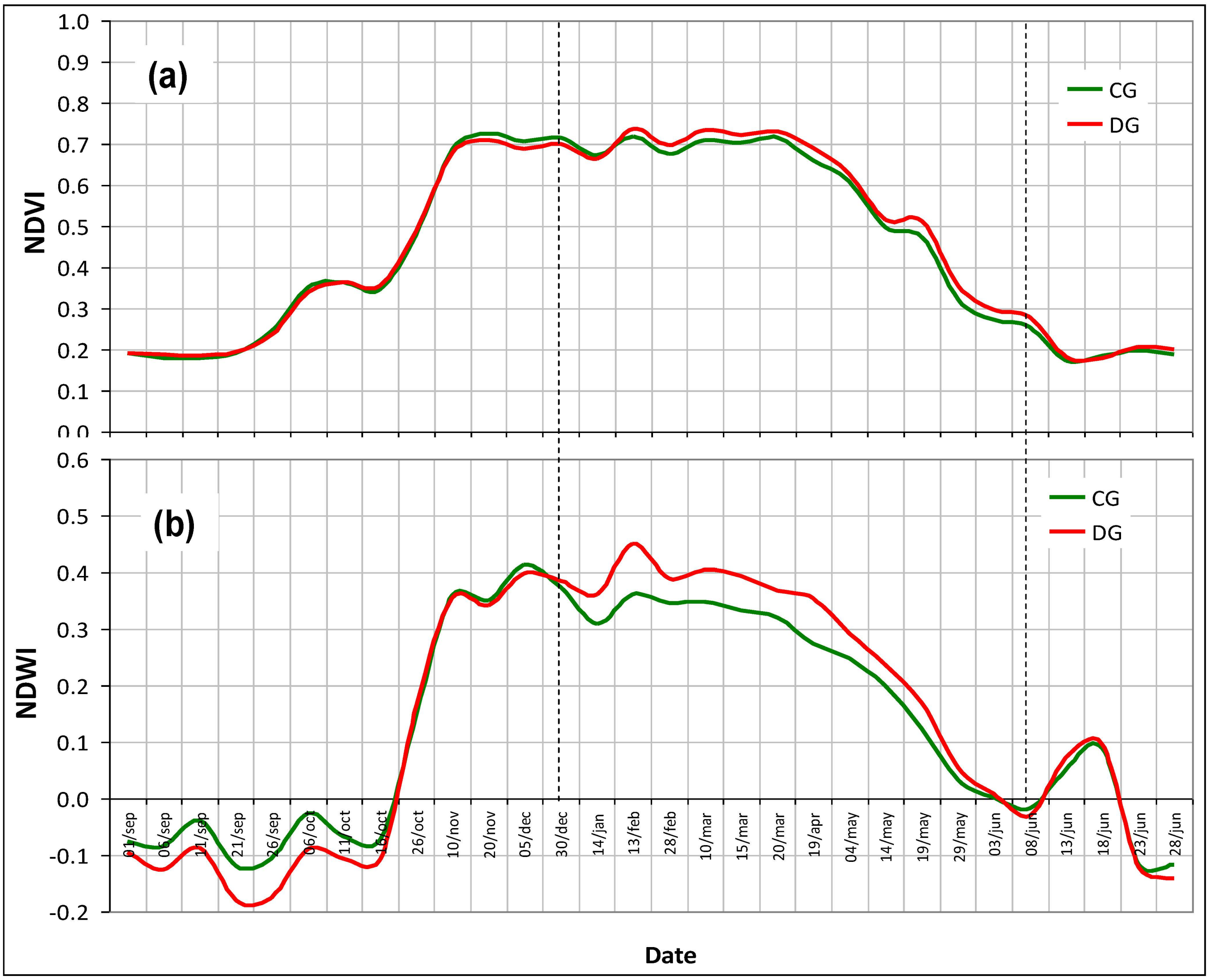

Figure 12. Sentinel-2 time series: (**a**) normalized difference vegetation index (NDVI); and (**b**) normalized difference water index (NDWI), between 1 September 2020 and 30 June 2021.

4. Discussion

It is known that increased stocking rates have negative effects on soil properties and are positively correlated with animal trampling [15]. Donkor et al. [24] suggested that DG systems have associated greater CI than CG systems. Recent studies [8,10] have sought to assess the impact of different cattle management approaches on CI. It is known that sheep have a much lower individual impact on soil compaction than cattle (based in the ratio between the body weight and the soil contact area) [25]; however, this specie has a very marked gregarious behaviour [2], therefore, this pilot study aims to assess the impact that two grazing management strategies (CG versus DG) on soil penetration resistance (CI) as result of sheep trampling. The practical question is: which situation has a greater impact on soil compaction, (i) low stocking rates (few animals) in permanent grazing (CG) or (ii) high stocking rates (many animals) in intermittent grazing with periods, of variable duration, of recovery, i.e., temporary livestock exclusion (DG).

Several works have shown the strong spatial variability of topsoil characteristics in Montado areas in general [26,27], and, in particular, in the pasture used in this study (Mitra farm), either through direct and exhaustive soil sampling [19], and/or by the use of expedient tools, usually based on EC_a surveys with contact sensors [28] or electromagnetic induction sensors [29]. The CI tool has been widely used by researchers and service providers because it is easily used in the field [30], allowing farmer's decision support to adopt sustainable grazing management [28].

This spatial variability is the first condition for differentiated management implementation, a fundamental step in the intensification of forage-based livestock systems [19], characteristic of the Mediterranean region of southern Portugal [2]. Spatial variability reflects the effect of several factors, mainly such as edaphic, climatic and management [2]. Among the edaphic factors, the nature of the original rocks and, consequently, the texture [18], has the potential to identify and predict spatial variability of soil compaction. In this study, predominate coarse-textured soils, typically less susceptible to compaction than silt loam soils [10,30], which demonstrates the interest, in the future, in extending these exploratory studies to other soil types.

The spatial variability in the CI found in this study (CV of 22 to 41%; Table 1) combined with the variability in the soil profile (depths of 0–10; 10–20; 20–30; and 0–30 cm; Figure 8), are similar to those found in a study with cows, in a nearby plot and with very similar characteristics [8]. The scale of magnitude of these CVs shows that the measurement of CI value is influenced by the management system, in addition to the soil intrinsic factors (e.g., soil structure, texture, and moisture) [29].

Although average CI values tend to be higher in areas with DG (Figure 8a) at all depths (Figure 8b), as indicated by the study of Donkor et al. [24], the differences obtained are not statistically significant. These findings are a positive signal in terms of soil conservation and sustainability from the perspective of potential intensification of forage-based livestock systems. These results, that correspond to two years (2019/2020 and 2020/2021), suggest that this could be a dynamic process, with recovery cycles [8], where physical and biological restorative processes may mitigate near surface soil impacts [10,12]. In future works, longer term monitoring of changes in soil penetration resistance may be required [10].

The multiple comparisons showed significant differences (p = 0.000) in CI values between depths, with lower CI values at 0–10 cm depth compared to the other two soil layers considered (10–20 or 20–30 cm). This pattern is different from that registered in other study of animal trampling for the same soil type but carried out with cattle grazing [8], where the highest compaction was recorded in the 10–20 cm soil layer. In this same study, livestock trampling effect was significant at a depth of 0–10 cm. In general, studies report that the highest animal trampling impact occurs at the topsoil layer [10,12,24–26,30–33]: 0–5 cm according to Debiasi et al. [31] and Roesh et al. [25], 0–10 cm according to Sharrow [12], and 0–15 or 0–20 cm according to Donkor et al. [24], Nawaz et al. [30] and Mayerfeld et al. [10]. The CI pattern registered in this study justifies replicating this study of trampling monitoring in other soil types.

Another result of this study confirms the significant and inverse relationship between CI and SMC (R^2 = 0.55): the exponential increase in the CI with the decrease in SMC content, or vice-versa [32]. This pattern, attributed to the lubricating effect of SMC on cone penetration [33] and to the reduction in the cohesive forces between soil clay particles [34], was registered in several works [8,32,33].

The prospect of intensifying extensive forage-based livestock through the adoption of dynamic grazing systems should take into consideration the long-term impact on soil compaction and, mainly, the system's productivity indicators. One of the criteria used in the comparison and evaluation of grazing systems is the development and vegetative vigour of the pasture. Time series of RS indices (Sentinel-2 imagery), such as NDVI and NDWI [35], can address this goal because they are sensitive to changes in the vegetation cover before and after grazing and can be efficient tools to determine the response pattern of pasture [20]. The typical pattern of these indices throughout the vegetative cycle of the pastures (Figure 12) reflects the effect of temperature and precipitation [34]. In this study, a trend of higher vegetative vigour (higher NDVI and higher NDWI) was observed in areas under DG (relative to areas under CG), between the beginning of January and the end of May 2021 (Figure 12). This vegetative response shows that DG livestock systems, with appropriate sheep stocking rates and recovery periods, despite causing small changes to soil penetration resistance (CI), are unlikely to negatively impact plant growth, aspect also highlighted by Mayerfeld et al. [10] and Ma et al. [36].

These results show that soil physical parameters, namely soil compaction, and pasture response relationships are needed to provide improved practical tools for farmers [11]. These tools are particularly important to enhance the ability to make informed and economically viable decisions for management options [11]. An approach that uses monitoring tools to support decisions in complex and dynamic systems exposed to changing conditions, as is the case of the Montado ecosystem, should be used in the future to guide and aid farmers' decision-making process [3]. Although statistically not significant, the systematic tendency observed at all depths evaluated in this study towards greater CI in plots subjected to DG, suggests that future works of longer duration to evaluate compaction/recovery cycles, should also consider the trend towards increased intensification of extensive livestock production, based on electric and mobile fences, with a stocking rates of up to three times higher than in CG systems (approximately 1 UA, per hectare, corresponding to approximately 6–7 sheep.ha^{-1}).

Since sheep exhibit highly selective grazing, CG is said to be responsible for degradation of vegetation and soils and declines in productivity and biodiversity [37,38]. In contrast, DG can be used as a tool to improve pasture resilience, livestock performance, pasture quality and profitability at a farm scale, when considering a typical spring surplus [36,39]. Dynamic grazing systems, that combine DG with flexible stocking rate based on changing rainfall conditions, are fundamental for achieving sustainable outcomes [36,38]. Nevertheless, long term studies are required [37] to quantify responses of different pasture types in variable climatic scenarios and, mainly, whole-farm analysis to integrate the multiple impacts of DG on the farm system, which include the positive impacts on the pasture performance after the deferred period, and the negative impact on pasture growth and nutritive value during the deferred period [39]. These studies should also include the measurement of parameters indicating change in ecosystem function, resilience, and ecological services [36,38].

Recent studies show the potential of the Montado to provide a range of ecosystem services. Guimarães et al. [40] go further and propose a results-based model implemented under Common Agricultural Policy and based on specific environmental results, namely, a healthy and functional soil ecosystem and a biodiverse native Mediterranean pasture. For example, soil degradation is identified as an important problem in the Montado, where animal grazing activity impacts soil health and its productivity through trampling [40]. It is in this framework that expedient technologies such as the electronic cone penetrometer, the soil electrical conductivity meter, satellite imagery and others will become indispensable monitoring tools for the quantification of payments to farmers and for the follow-up by public authorities and policy makers.

5. Conclusions

Compared to continuous grazing (CG), deferred grazing (DG) consists in adapting the number of animals and the number of days grazed to the availability of pasture and represents a more dynamic, intensive, and productive strategy for grazing management. The impact of sheep trampling on soil compaction, associated with different grazing systems, is a complex and little-studied process and could become an important tendency indicator of soil sustainability. This reflects the balance between restorative and compactive mechanisms on grazed and ungrazed areas.

The results of soil resistance measurements (CI) in this study showed no significant differences between CG and DG in all depths evaluated (0–10, 10–20, and 20–30 cm). At the same time, there was no negative impact on vegetative response, measured by vegetation indices obtained by RS (NDVI and NDWI). These findings are encouraging not only from the perspective of sustainability, but also reveal good prospects for the intensification of extensive forage-based livestock systems.

In future works, decision support tools should evaluate the long-term impact on soil compaction of grazing management systems with appropriate sheep stocking rates and recovery periods and should consider at the same time the system's productivity indicators.

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References

1. Psyllos, G.; Hadjigeorgiou, I.; Dimitrakopoulos, P.G.; Kizos, T. Grazing land productivity, floral diversity, and management in a semi-arid Mediterranean landscape. *Sustainability* **2022**, *14*, 4623. [CrossRef]
2. Efe Serrano, J. *Pastures in Alentejo: Technical Basis for Characterization, Grazing and Improvement*; Universidade de Évora—ICAM: Évora, Portugal, 2006; pp. 165–178. (In Portuguese)
3. Jaurena, M.; Durante, M.; Devincenzi, T.; Savian, J.V.; Bendersky, D.; Moojen, F.G.; Pereira, M.; Soca, P.; Quadros, F.L.F.; Pizzio, R.; et al. Native grasslands at the core: A new paradigm of intensification for the campos of Southern South America to increase economic and environmental sustainability. *Front. Sustain. Food Syst.* **2021**, *5*, 547834. [CrossRef]
4. Bégué, A.; Arvor, D.; Bellon, B.; Betbeder, J.; De Abelleyra, D.; Ferraz, R.; Lebourgeois, V.; Lelong, C.; Simões, M.; Verón, S.R. Remote sensing and cropping practices: A review. *Remote Sens.* **2018**, *10*, 99. [CrossRef]
5. Ferreira, P.M.A.; Andrade, B.O.; Podgaiski, L.R.; Dias, A.C.; Pillar, V.D.; Overbeck, G.E.; Mendonça, M.S., Jr.; Boldrini, I.I. Long-term ecological research in southern Brazil grasslands: Effects of grazing exclusion and deferred grazing on plant and arthropod communities. *PLoS ONE* **2020**, *15*, e0227706. [CrossRef]
6. Tozer, K.N.; Muller, K.; Craven, T.; Tarbotton, I.; Coster, A.; Burke, R.; Sherlock, J.; Cameron, C. Effect of deferred grazing during late spring and summer on pasture productivity in Waikato and Bay of Plenty hill country. *J. N. Z. Grassl.* **2020**, *82*, 111–119. [CrossRef]
7. Carreira, E.; Serrano, J.; Gomes, C.J.P.; Shahidian, S.; Paniagua, L.L.; Pilirito, A.; Castro, J.; Carvalho, M.; Pereira, A.F. Effect of sheep grazing, stocking rates and dolomitic limestone application on the floristic composition of a permanent dryland pasture, in the montado agroforestry system of Southern Portugal. *Animals* **2022**, *12*, 2506. [CrossRef]
8. Serrano, J.; Marques, J.; Shahidian, S.; Carreira, E.; Marques da Silva, J.; Paixão, L.; Paniagua, L.L.; Moral, F.; Ferraz de Oliveira, I.; Sales-Baptista, E. Sensing and mapping the effects of cow trampling on the soil compaction of the montado Mediterranean ecosystem. *Sensors* **2023**, *23*, 888. [CrossRef]
9. Reichert, J.M.; Suzuki, L.E.; Reinert, D.J. Compactação do solo em sistemas agropecuários e florestais: Identificação, efeitos, limites críticos e mitigação. *Tópicos Ci. Solo* **2007**, *5*, 49–134. (In Portuguese)
10. Mayerfeld, D.; Kruger, E.; Gildersleeve, R.; Rickenbach, M. Impacts of different grazing approaches on woodland ecosystem properties. *Agrofor. Syst.* **2022**, *96*, 527–540. [CrossRef]
11. Drewry, J.J.; Cameron, K.C.; Buchan, G.D. Pasture yield and soil physical property responses to soil compaction from treading and grazing—A review. *Aust. J. Soil Res.* **2008**, *46*, 237–256. [CrossRef]
12. Sharrow, S. Soil compaction by grazing livestock in silvopastures as evidenced by changes in soil physical properties. *Agrofor. Syst.* **2007**, *71*, 215–223. [CrossRef]
13. Jordon, M.W. Does mixed vs separate sheep and cattle grazing reduce soil compaction? *Soil Use Manag.* **2021**, *37*, 822–831. [CrossRef]
14. Medina, M.C. Effects of soil compaction by trampling of animals in soil productivity. Remediations. *Rev. Colomb. Cienc. Anim.* **2016**, *8*, 88–93. [CrossRef]
15. Teague, R.; Proenza, F.; Norton, B.; Steffens, T.; Barnes, M.; Kothmann, M.; Roath, R. Benefits of multi-paddock grazing management on rangelands: Limitations of experimental grazing research and knowledge gaps. In *Grassland Ecology, Management and Restoration*; Schroder, H.G., Ed.; Nova Science Publishers, Inc.: Hauppauge, NY, USA, 2008; Cap. 1; pp. 41–80.
16. Devantier, B.P.; Stevens, D.R.; Rennie, G.M.; Tozer, K.N. The effect of deferred grazing in spring and early summer pastures on pasture growth rate and feed quality. *J. N. Z. Grassl.* **2017**, *79*, 189–196. [CrossRef]
17. Gao, T.; Yang, X.C.; Jin, Y.X.; Ma, H.L.; Li, J.Y.; Yu, H.D.; Yu, Q.Y.; Xiao, Z.; Xu, B. Spatio-temporal variation in vegetation biomass and its relationships with climate factors in the Xilingol grasslands, Northern China. *PLoS ONE* **2013**, *8*, e83824. [CrossRef]

18. Pentos, K.; Pieczarka, K.; Serwata, K. The relationship between soil electrical parameters and compaction of sandy clay loam soil. *Agriculture* **2021**, *11*, 114. [CrossRef]
19. Serrano, J.; Shahidian, S.; Costa, F.; Carreira, E.; Pereira, A.; Carvalho, M. Can soil pH correction reduce the animal supplementation needs in the critical autumn period in Mediterranean Montado ecosystem? *Agronomy* **2021**, *11*, 514. [CrossRef]
20. Batista, P.; Almeida, G.; Silva, J.; Pandorfi, H.; Silva, M.; Silva, R.; Melo, M.; Lins, F.; Junior, J. Short-term grazing and its impacts on soil and pasture degradation. *Rev. DYNA* **2020**, *87*, 123–128. [CrossRef]
21. FAO. *World Reference Base for Soil Resources; Food and Agriculture Organization of the United Nations, World Soil Resources Reports N 103*; FAO: Rome, Italy, 2006.
22. Serrano, J.; Shahidian, S.; Marques da Silva, J.; Sales-Baptista, E.; Ferraz de Oliveira, I.; Lopes de Castro, J.; Pereira, A.; Cancela de Abreu, M.; Machado, E.; Carvalho, M. Tree influence on soil and pasture: Contribution of proximal sensing to pasture productivity and quality estimation in montado ecosystems. *Int. J. Remote Sens.* **2018**, *39*, 4801–4829. [CrossRef]
23. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* **2007**, *11*, 1633–1644. [CrossRef]
24. Donkor, N.T.; Gedir, J.V.; Hudson, R.J.; Bork, E.W.; Chanasyk, D.S.; Naeth, M.A. Impacts of grazing systems on soil compaction and pasture production in Alberta. *Can. J. Soil Sci.* **2002**, *82*, 1–8. [CrossRef]
25. Roesch, A.; Weisskopf, P.; Oberholzer, H.; Valsangiacomo, A.; Nemecek, T. An approach for describing the effects of grazing on soil quality in life-cycle assessment. *Sustainability* **2019**, *11*, 4870. [CrossRef]
26. Benavides, R.; Douglas, G.B.; Osoro, K. Silvopastoralism in New Zealand: Review of effects of evergreen and deciduous trees on pasture dynamics. *Agrofor. Syst.* **2009**, *76*, 327–350. [CrossRef]
27. McCormick, S.; Jordan, C.; Bailey, J. Within and between-field spatial variation in soil phosphorus in permanent grassland. *Prec. Agric.* **2009**, *10*, 262–276. [CrossRef]
28. Moral, F.J.; Serrano, J.M. Using low-cost geophysical survey to map soil properties and delineate management zones on grazed permanent pastures. *Prec. Agric.* **2019**, *20*, 1000–1014. [CrossRef]
29. Pias, O.H.C.; Cherubin, M.R.; Basso, C.J.; Santi, A.L.; Molin, J.P.; Bayer, C. Soil penetration resistance mapping quality: Effect of the number of subsamples. *Acta Sci.* **2018**, *40*, e34989. [CrossRef]
30. Nawaz, M.F.; Bourrié, G.; Trolard, F. Soil compaction impact and modelling. A review. *Agron. Sustain. Dev.* **2013**, *33*, 291–309. [CrossRef]
31. Debiasi, H.; Franchini, J.C.; Junior, A.A.B.; Oliveira, F.A. Variabilidade espacial e temporal da resistência do solo à penetração após diferentes pressões de pastejo no Norte do Paraná. In *Agricultura de Precisão: Resultados de um Novo Olhar*; Bernardi, A., Naime, J., Resende, Á., Inamasu, R.B.e.R., Eds.; Embrapa: Brasília, Brasil, 2014; Cap. 53; pp. 507–512. (In Portuguese)
32. Moraes, M.T.; Silva, V.; Zwirtes, A.; Carlesso, R. Use of penetrometers in agriculture: A review. *Eng. Agríc.* **2014**, *34*, 179–193. [CrossRef]
33. Duarte, T.F.; Silva, T.J.A.; Bonfim-Silva, E.M.; Fenner, W. Resistance of a Red Latosol to penetration: Comparison of penetrometers, model adjustment, and soil water content correction. *Eng. Agr. Jaboticabal* **2020**, *40*, 462–472. [CrossRef]
34. Kostic, M.; Raijovik, M.; Ljubicic, N.; Ivosevic, M.; Radulovic, M.; Blagojevic, D.; Dedovic, N. Georeferenced tractor wheel slip data for prediction of spatial variability in soil physical properties. *Prec. Agric.* **2021**, *22*, 1659–1684. [CrossRef]
35. Serrano, J.; Shahidian, S.; Marques da Silva, J. Evaluation of normalized difference water index as a tool for monitoring pasture seasonal and inter-annual variability in a Mediterranean agro-silvo-pastoral system. *Water* **2019**, *11*, 62. [CrossRef]
36. Ma, L.; Yuan, F.; Liang, H.; Rong, Y. The effects of grazing management strategies on the vegetation, diet quality, intake and performance of free grazing sheep. *Livest. Sci.* **2014**, *161*, 185–192. [CrossRef]
37. Glindemann, T.; Wang, C.; Tas, B.M.; Schiborra, A.; Gierus, M.; Taube, F.; Susenbeth, A. Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe. *Livest. Sci.* **2009**, *124*, 142–147. [CrossRef]
38. Wang, T.; Teague, W.R.; Park, S.C. Evaluation of continuous and multipaddock grazing on vegetation and livestock performance—A modelling approach. *Rangel. Ecol. Manag.* **2016**, *69*, 457–464. [CrossRef]
39. Tozer, K.N.; Howarth, S.M.; Sherlock, J.; Tarbotto, I.S. Impact of Deferred Grazing on Profitability of a Hill Country Farm in North-western Waikato. In Proceedings of the Resilient Pastures Symposium, Lake Karapiro, New Zealand, 11–12 May 2021; Grassland Research and Practice Series. New Zealand Grassland Association: Dunedin, New Zealand, 2021; Volume 17, pp. 393–400.
40. Guimarães, M.H.; Pinto-Correia, T.; Costa Freitas, M.B.; Ferraz-de-Oliveira, I.; Sales-Baptista, E.; Ferragolo da Veiga, J.F.; Tiago Marques, J.; Pinto-Cruz, C.; Godinho, C.; Belo, A.D.F. Farming for nature in the Montado: The application of ecosystem services in a results-based model. *Ecosyst. Serv.* **2023**, *61*, 101524. [CrossRef]

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CAPÍTULO 9

Discussão geral

O objetivo principal desta tese foi melhorar a compreensão dos fatores que interferem na estabilidade e produtividade do ecossistema Montado, através do estudo das interações entre o clima e as quatro componentes fundamentais: solo, pastagem, árvores e animais. Os artigos que compõem esta tese abordam questões consideradas relevantes para este objetivo, permitindo uma visão mais abrangente e integrada das relações entre fatores abióticos e bióticos.

Um dos problemas da agricultura portuguesa, particularmente dos sistemas extensivos, é a falta de versatilidade funcional dos sistemas de produção, que advém em primeiro lugar, da escassez de estudos de investigação aplicada. Uma forma de alterar este paradigma é a realização de estudos abrangentes, onde se possa por um lado controlar as variáveis e, por outro, ter uma dimensão temporal, que possibilite evidenciar os resultados das interações entre os fatores.

O Montado é um ecossistema de elevada complexidade. As irregularidades climáticas intrínsecas do clima Mediterrânico (Feio, 1991), levam a maiores alterações na germinação, no desenvolvimento e na produção da pastagem, o que condiciona as opções técnicas nos sistemas extensivos de produção de ruminantes.

Assim, a melhor compreensão das inter-relações entre o clima, o solo, a pastagem e o pastoreio, são cruciais a fim de permitir aumentar a eficiência dos sistemas de produção de ruminantes e, concomitantemente, contribuir para a biodiversidade e sustentabilidade ambiental, económica e social.

Os sensores eletrónicos portáteis são ferramentas que permitem mensurações no solo e na pastagem em larga escala, de forma rápida e com elevada fiabilidade (Gebremedhin *et al*., 2019). Os sensores eletrónicos utilizados nos ensaios experimentais, para monitorizar o solo e a pastagem, revelaram-se ferramentas muito promissoras para auxílio na gestão sustentável dos sistemas de produção no Montado. Estas tecnologias revelaram-se fiáveis na caraterização expedita das propriedades físico-químicas do solo e na estimativa da produtividade e da qualidade das pastagens. Destaca-se, nesta tese, a calibração e validação do espetrómetro NIR portátil na estimativa de parâmetros indicadores da qualidade de pastagens no Montado.

A aplicação de calcário dolomítico melhora a fertilidade do solo e, consequentemente, a produtividade e qualidade da pastagem (Carvalho *et al*., 2015). Nos ensaios efetuados ao longo do período experimental, a aplicação de 2000 kg de calcário dolomítico à superfície do solo, por hectare, apenas elevou o valor médio do pH de 5,4 para 5,7. A correção da acidez do solo através da aplicação de calcário dolomítico é um processo lento e gradual (Serrano *et al*., 2020). A ausência de mobilização do solo tende a reduzir a mineralização da matéria orgânica e o impacto negativo sobre a estrutura e o microbioma do solo (Freixial, 2019). A aplicação de calcário dolomítico juntamente com a não mobilização do solo, proporcionam uma forte tendência para o aumento da relação entre o magnésio (Mg) e o manganês (Mn), que contribui para a redução da toxicidade do Mn. Tal pode ser observado ao longo dos anos pela redução gradual da incidência de plantas do género Rumex, normalmente referido como bioindicador da toxicidade por Mn (Carvalho, 2018). De 2018 para 2020, o valor médio do Mg passou de 78,1 mg kg^{-1}, para 94,8 mg kg^{-1}, e o do Mn passou de 50,2 mg kg^{-1} para 40,1 mg kg^{-1}, reduzindo a toxicidade por Mn. A aplicação de calcário dolomítico, teve impacto igualmente positivo na produtividade da pastagem, bem como no seu crescimento outonal e na antecipação da disponibilidade de PB no outono.

A copa das árvores potenciou a aplicação de calcário dolomítico originando, por um lado maiores aumentos no pH do solo e por outro na relação Mg/Mn. Neste sentido, a qualidade da pastagem, ao longo de todo o ciclo vegetativo, beneficiou da presença da copa das árvores, onde os valores de matéria orgânica tendem a ser mais elevados. Este efeito na maior produtividade das pastagens foi mais notório no início do ciclo vegetativo, atenuando-se as diferenças até ao Inverno. As copas das árvores também influenciaram a composição florística da pastagem, identificando-se menos espécies botânicas nas áreas de projeção das copas, relativamente às áreas fora da copa. As espécies botânicas *Avena barbata* L. e *Urtica urens* L. revelaram-se como bioindicadoras da projeção da copa, sendo que a *Urtica urens* L. é pouco palatável no estado verde (Efe Serrano, 2006) e é considerada infestante, tendendo a prejudicar a qualidade da pastagem.

A germinação e desenvolvimento das espécies botânicas da pastagem de sequeiro depende da quantidade das primeiras chuvas outonais. A suplementação é, assim, um fator relevante no funcionamento dos sistemas de produção animal, com base em pastagens de sequeiro. Neste contexto, é requerida suplementação alimentar aos animais: i) no outono, quando a biomassa é escassa, tem excesso de água e carência de energia; ii) no verão, quando a biomassa remanescente está seca e com excesso de fibra e déficit de proteína e de energia. Em termos médios obtiveram-se valores, no outono, para a matéria seca (MS) de 1 ton ha^{-1} e para a PB de 21%. Enquanto no fim da primavera o valor médio de MS foi 3 ton ha^{-1} e de PB foi 11,5%.

A regeneração natural das árvores é uma questão de elevada importância no Montado, uma vez que é notória uma elevada mortalidade destas (Pinto-Correia *et al.*, 2013). Nas áreas de amostragem, apenas foram identificadas jovens plantas *Quercus rotundifólia* Lam. na parcela onde não foi aplicado calcário dolomítico e sujeita a PC.

Ao caracterizar as diferentes comunidades botânicas, nas quatro parcelas dos diferentes tratamentos, foi possível identificar 48 áreas distintas, em que as espécies variaram em diversidade e proporções relativas. Nas diferentes áreas de amostragem foram identificadas 103 espécies, o que revela uma pastagem de elevada biodiversidade. Algumas destas espécies, apresentam, pelo menos em alguma fase do seu ciclo, pouca palatabilidade, razão pela qual são consideradas infestantes. Verificou-se uma relação diferenciada entre o efeito do pastoreio e a PB em algumas fases do ciclo da pastagem. Assim, parece existir uma tendência para que as áreas pastoreadas com elevadas cargas bióticas sujeitas a PD, apresentem teores de PB superiores. Voisin & Lecomte (1968) referem que o PD é eficaz na melhoria das pastagens, sobretudo através do incremento de espécies leguminosas. Nos ensaios realizados, verificou-se nas áreas de PD a eliminação de algumas plantas menos desejáveis. O aumento da carga biótica instantânea pode ajudar na redução da seletividade, o que contribui para a redução gradual de espécies menos palatáveis (Nie *et al*., 1998). As maiores cargas bióticas instantâneas utilizadas nas áreas de PD conduziram a um consumo de pastagem mais homogéneo durante o outono e inverno, constatado pela menor amplitude na altura da pastagem nos diferentes pontos de amostragem, evidenciando uma menor seletividade.

Por outro lado, os menores encabeçamentos associados ao PC, em combinação ou não, com a aplicação de calcário dolomítico, revelaram-se menos interessantes do ponto de vista de aproveitamento da pastagem, possibilitando menor número de animais ao longo do ano, tendo apenas como eventual vantagem, a maior disponibilidade de biomassa seca, passível de ser utilizada pelos animais durante o verão. No entanto são apontadas algumas vantagens ao PC relativamente ao PD, como o retorno dos nutrientes ao solo (Barriga, 2019), diminuição da incidência de arbustos, aumento de espécies botânicas com maior valor nutritivo e melhores desempenhos dos animais, por poderem selecionar a sua dieta (Holechek, 1983; Mendes *et al*., 2015; Santos *et al*., 2019). Nos ensaios realizados, mesmo com encabeçamentos de 1 CN/ha, verificou-se um elevado crescimento de algumas plantas de porte ereto (sobretudo gramíneas) no outono, as quais tendem a limitar o acesso à luz das plantas prostradas (sobretudo leguminosas), refletindo-se posteriormente, num menor desenvolvimento na primavera. As menores cargas bióticas tendem a favorecer maiores alturas da pastagem, com a desvantagem para o desenvolvimento das plantas de porte prostrado, como é o caso das leguminosas (Mendes *et al*., 2015; Ferreira *et al*., 2020). Assim, na parcela onde foi aplicado calcário dolomítico e sujeita a PC verificou-se uma menor biodiversidade da pastagem, ainda que tenham sido identificadas 3 espécies bioindicadoras (*Crassula tillaea* Lest.-Garl., *Poa bulbosa* e *Ranuncullus ollissiponensis* Pers.). No entanto, as espécies botânicas do género Rumex, bioindicadoras de solos ácidos (Eraso, 1991), não se revelaram bioindicadoras, em nenhuma das áreas de ensaios, tendendo mesmo a desaparecer, ao longo do período experimental, permanecendo apenas em áreas muito circunscritas no tratamento sem aplicação de calcário dolomítico ao solo e sujeito a PC.

Para uma gestão mais eficiente das pastagens e do pastoreio, a da altura da pastagem é uma variável muito importante a ter em consideração (Fonseca *et al*., 2012). Neste sentido, nos ensaios realizados, a altura da pastagem mostrou ser, igualmente, uma variável de elevada importância para auxiliar na gestão das pastagens, condicionando os tempos de pastoreio no PD. A altura adotada para remover os animais do PD (cerca 5 cm), não prejudicou a recuperação da pastagem, permitindo um aproveitamento mais racional da biomassa disponível. O sistema de pastoreio interferiu com a altura da pastagem, sendo esta superior nas parcelas em que a carga animal era mais reduzida, mesmo que sujeitas a PC. Contudo, embora os dias efetivos de pastoreio tenham sido menores no PD, que no PC, quando se consideraram, simultaneamente, os dias de pastoreio efetivos e as cargas bióticas, por dia, verificou-se que as parcelas em PD possibilitaram alimentar maior número de unidades animais, evidenciando indiretamente uma maior produção de biomassa. Este efeito foi ainda superior nas condições de aplicação de calcário dolomítico, onde foram registados maior número de dias de utilização de pastagem. A aplicação de calcário dolomítico leva a aumentos de até cinco vezes da produtividade da pastagem (Carvalho *et al*., 2018).

O pastoreio com menores cargas bióticas tende a conduzir a maiores níveis de seletividade na pastagem (Teague & Dowhower, 2003). Embora se tenha verificado pastoreio seletivo com diferentes níveis de intensidade nas quatro parcelas, ocorreram padrões semelhantes nos locais preferidos para pastar, sobretudo a partir do fim do inverno. A ingestão e a seletividade podem ser influenciadas pela altura e pelo valor nutritivo da pastagem (Santos *et al*., 2010; Barriga, 2019). Durante a primavera, em condições que a biomassa da pastagem se apresentava exuberante e sem limitação ao consumo, as ovelhas preferiram pastar em áreas de menor altitude, onde a humidade do solo tende a ser superior. As preferências pelas diferentes áreas de amostragem, não podem ser associadas ao valor nutritivo, uma vez que apenas foram obtidas amostras compósitas de pastagem.

O pastoreio com elevados encabeçamentos, pode levar à degradação do solo e à perda de biodiversidade, devido ao elevado pisoteio (Teague *et al*., 2008; Barcella *et al*., 2016). Assim, o sobrepastoreio é, frequentemente, apontado como o principal responsável pela compactação, devido ao pisoteio dos animais, repercutindo-se em efeitos adversos na produção, qualidade e composição florística da pastagem. No entanto, tendo em conta um limitado horizonte temporal de quatro anos, em que apenas em dois deles, existiram pastoreios diferenciados, os resultados observados mostraram uma ausência de diferenças no índice de compactação entre maior e menor carga animal por hectare. Os resultados parecem indicar que a alternância de períodos de pastoreio, com períodos de ausência de animais, nas parcelas em PD, terá possibilitado a inexistência de um efeito significativo na compactação. Estes resultados podem constituir indicadores para os produtores de ovinos, na perspetiva de intensificação dos sistemas de produção, em pastagens de sequeiro.

Os resultados obtidos tendem a possibilitar uma melhor compreensão das inter-relações entre os componentes do Montado. Esta abordagem contribuiu para melhorar a capacidade de optar por diferentes opções agronómicas, refletindo-se numa eventual maior versatilidade dos sistemas de produção, condição essencial para: i) a intensificação sustentável dos sistemas de produção de ovinos e sua eficiência bio-económica; ii) a conservação, resiliência e biodiversidade; iii) a implementação de sistemas de base tecnológica; iv) o bem-estar animal.

CAPÍTULO 10

Conclusões e perspetivas

Os resultados dos diferentes ensaios, permitem concluir que:

1- As tecnologias utilizadas, mostraram elevado potencial para caraterizar o solo e a pastagem de forma expedita, contribuindo para tomadas de decisão mais informadas;
2- A aplicação de calcário dolomítico reduziu a acidez do solo e a toxicidade do manganês, e melhorou a produção de biomassa da pastagem;
3- O efeito combinado da aplicação de calcário dolomítico e da copa das árvores, proporcionou um efeito positivo na produção de matéria seca e na proteína bruta da pastagem, no outono, reduzindo as necessidades de suplementação dos animais;
4- O pastoreio diferido num limitado horizonte temporal contribuiu para a melhoria da composição florística da pastagem, com a redução de espécies de menor palatabilidade e o incremento de espécies de maior interesse para a produção de ruminantes;
5- Nas parcelas de pastoreio diferido, a aplicação de calcário dolomítico proporcionou maiores taxas de crescimento da pastagem e, consequentemente, mais dias de pastoreio;
6- A implementação de estratégias de pastoreio diferido, com maiores cargas bióticas, não proporcionou impacto negativo na compactação do solo, tornando possível a intensificação sustentável da produção de ovinos no Montado.

Ao longo do período experimental, surgiram algumas questões e ideias que permitem perspetivar os seguintes estudos:

1- Continuar a avaliar o efeito da aplicação de calcário dolomítico em pastagens permanentes de sequeiro num processo de preservação sustentável de médio e longo prazo;
2- Alargar as medições na pastagem com o espetrómetro NIR portátil a todo o ciclo vegetativo para avaliar a evolução da fiabilidade desta ferramenta na estimativa da qualidade da pastagem;
3- Avaliar o efeito do pastoreio de outras espécies ruminantes, nomeadamente bovinos e caprinos, na produção, qualidade e composição florística da pastagem e na regeneração natural do Montado;
4- Avaliar o efeito do pisoteio na compactação do solo em sistemas de pastoreio com elevadas cargas bióticas ao longo de vários anos e com diferentes espécies ruminantes;
5- Avaliar a versatilidade do sistema de produção animal extensivo perante a variabilidade climática, minimizando as necessidades de suplementação dos animais.

CAPÍTULO 11

Bibliografia

Barriga, P.A.B. (2019). *Produção de Novilhos em Pastagem de Inverno Com Diferentes Intensidades de Pastejo e Adubação Nitrogenada em Integração Lavoura-Pecuária*. Tese de Doutoramento. Universidade Tecnológica Federal do Paraná, Campus Pato Branco, Pato Branco, Brasil.

Barcella, M., Filipponi, F., & Assini, S. (2016). A simple model to support grazing management by direct field observation. *Agriculture, Ecosystems and Environment*, *234*, 107–117. https://doi.org/10.1016/j.agee.2016.04.027

Carvalho, M.; Goss, M.J.; Teixeira, D. (2015). Manganese toxicity in Portuguese Cambisols derived from granitic rocks: Causes, limitations of soil analyses and possible solutions. *Revista das Ciências Agrarias*, 38, 518–527. http://dx.doi.org/10.19084/RCA15137

Carvalho, M. *A Seca E a Intensificação Sustentável Dos Sistemas Agro-Pecuários: Desafios E Soluções*. Dossier Secas e Cheias—Como Gerir. 2018, pp. 24–27. http://dspace.uevora.pt/rdpc/bitstream/10174/23541/1/

Efe Serrano, J. (2006). *Pastagens do Alentejo: bases técnicas caracterização, pastoreio e melhoramento*; Universidade de Évora—ICAM, Ed.; Gráfica Eborense: Évora, Portugal, 2006; pp. 165–178.

Eraso, J. R. (1991). *Las plantas de nuestros prados*. Ediciones Mundi-Prensa. ISBN: 84-7114-323-2. Madrid.

Ferreira, P.M.A.; Andrade, B.O.; Podgaiski, L.; Dias, A.C.; Pillar, V.D.; Overbeck, G.E.; Milton, D.S.M.; Boldrini, I.I. (2020). Long-term ecological research in southern Brazil grasslands: Effects of grazing exclusion and deferred grazing on plant and arthropod communities. *PLoS ONE*, 15, e0227706. https://doi.org/10.1371/journal.pone.0227706

Feio, M. *Clima e Agricultura: Exigências Climáticas das Principais Culturas e Potencialidade Agrícolas do Nosso Clima*; Ministério da Agricultura, Pescas e Alimentação: Lisboa, Portugal, 1991; ISBN 972-9175-25-X.

Fonseca, L.; Mezzalira, J.; Bremm, C.; Filho, R.; Gonda, H.; Carvalho, P.C.F. (2012). Management targets for maximising the short-term herbage intake rate of cattle grazing in Sorghum bicolor. *Livestock Science*, 145, 205–211. https://doi:10.1016/j.livsci.2012.02.003

Freixial, R. (2019). *Sementeira direta e agricultura de precisão.* Sílabas & Desafios. ISBN: 978-989-8842-33-6.

Gebremedhin, A.; Badenhorst, P.E.;Wang, J.; Spangenberg, G.C.; Smith, K.F. (2019). Prospects for measurement of dry matter yield in forage breeding programs using sensor technologies. *Agronomy*, 9, 65. https://doi:10.3390/agronomy9020065

Holechek, J. L. (1983). Considerations concerning grazing systems. *Rangelands*, *5*(5), 208–211.

Instituto Português do Mar e da Atmosfera. https://www.ipma.pt (Acedido em 27 de fevereiro de 2023).

Mendes, P., Meireles, C., Vila-Viçosa, C., Musarella, C., & Pinto-Gomes, C. (2015). Best management practices to face degraded territories occupied by Cistus ladanifer shrublands – Portugal case study. *Plant Biosystems*, *149*(3), 494–502. https://doi.org/10.1080/11263504.2015.1040483

Nie, Z.N.; Barker, D.J.; Mackay, A.D.; Valentine, I.; Hodgson, J. (1998). Influence of the timing and duration of pastoral fallowing and nitrogen fertiliser on pasture and white clover (Trifolium repens) growth in hill country. *New Zealand Journal of Agricultural Research*, 41, 19–29. https://doi.org/10.1080/00288233.1998.9513284

Pinto-Correia, T.; Ribeiro, N.; Potes, J. (2013). *Livro Verde dos Montados*; Instituto de Ciências Agrárias e Ambientais Mediterrânicas— Universidade de Évora: Nossa Senhora da Tourega, Portugal.

Santos, B., Voltolini, T., & Salla, L. (2010). Comportamento de Pastoreio - Behavior of grazing. *Revista Electrónica de Veterinária* REDVET, 11(4), 1–33.

Santos, M. E. R., Afonso, L. E., Carvalho, B. H. R., do Rêgo, A. C., Queiroz, G. J. da S., Médica, J. A. de A., de Moraes, L. S., & do Carmo, L. L. S. (2019). Apparent selectivity of sheep in deferred marandu palisadegrass pastures with variable initial heights. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*,71(5), 1727–1734. https://doi.org/10.1590/1678-4162-10750

Serrano, J.; Shahidian, S.; Marques da Silva, J.; Moral, F.; Carvajal-Ramirez, F.; Carreira, E.; Pereira, A.; Carvalho, M. (2020). Evaluation of the effect of dolomitic lime application on pastures—Case study in the Montado Mediterranean ecosystem. *Sustainability*, 12, 3758. https://doi:10.3390/su12093758

Teague, W. R., & Dowhower, S. L. (2003). Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. *Journal of Arid Environments*, *53*(2), 211–229. https://doi.org/10.1006/jare.2002.1036

Teague, R.; Proenza, F.; Norton, B.; Steffens, T.; Barnes, M.; Kothmann, M.; Roath, R. (2008). Benefits of multi-paddock grazing management on rangelands: Limitations of experimental grazing research and knowledge gaps. *In Grassland Ecology, Management and Restoration*; Schroder, H.G., Ed.; Nova Science Publishers, Inc.: Hauppauge, NY, USA; Cap. 1; pp. 41–80.

Voisin, A.; Lecomte, A. (1968). *La Vaca y la Hierba: Cómo Obtener Buenos Rendimientos del Ganado Vacuno*; Tecnos: Madrid, Spain.