applied sciences

MDPI

Review

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

Emanuel Carreira *, João Serrano, José Lopes de Castro, Shakib Shahidian and Alfredo F. Pereira

MED—Mediterranean Institute for Agriculture, Environment and Development, and CHANGE—Global Change and Sustainability Institute, Institute for Advanced Studies and Research, Évora University, Pólo da Mitra, Ap. 94, 7006-554 Évora, Portugal; jmrs@uevora.pt (J.S.); jcastro@uevora.pt (J.L.d.C.); shakib9@gmail.com (S.S.); apereira@uevora.pt (A.F.P.)

* Correspondence: ersc@uevora.pt

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

Citation: Carreira, E.; Serrano, J.; Lopes de Castro, J.; Shahidian, S.; Pereira, A.F. Montado Mediterranean Ecosystem (Soil–Pasture–Tree and Animals): A Review of Monitoring Technologies and Grazing Systems. *Appl. Sci.* **2023**, *13*, 6242. https://doi.org/10.3390/app13106242

Academic Editor: Nathan J Moore

Received: 31 March 2023
Revised: 12 May 2023
Accepted: 13 May 2023
Published: 19 May 2023

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.

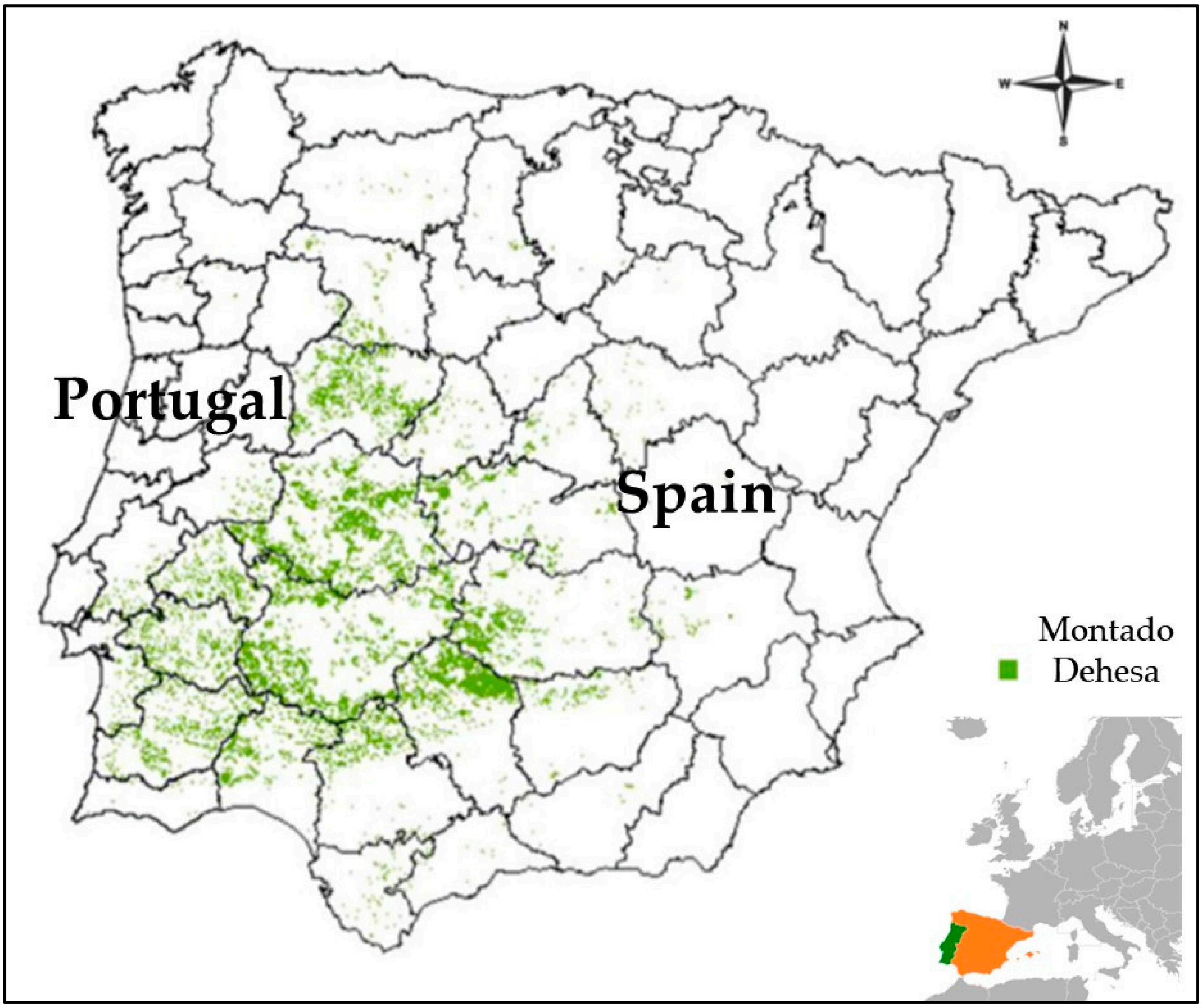

Figure 1. Distribution of Montado and Dehesa in Portugal and Spain. Adapted from [13].

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.

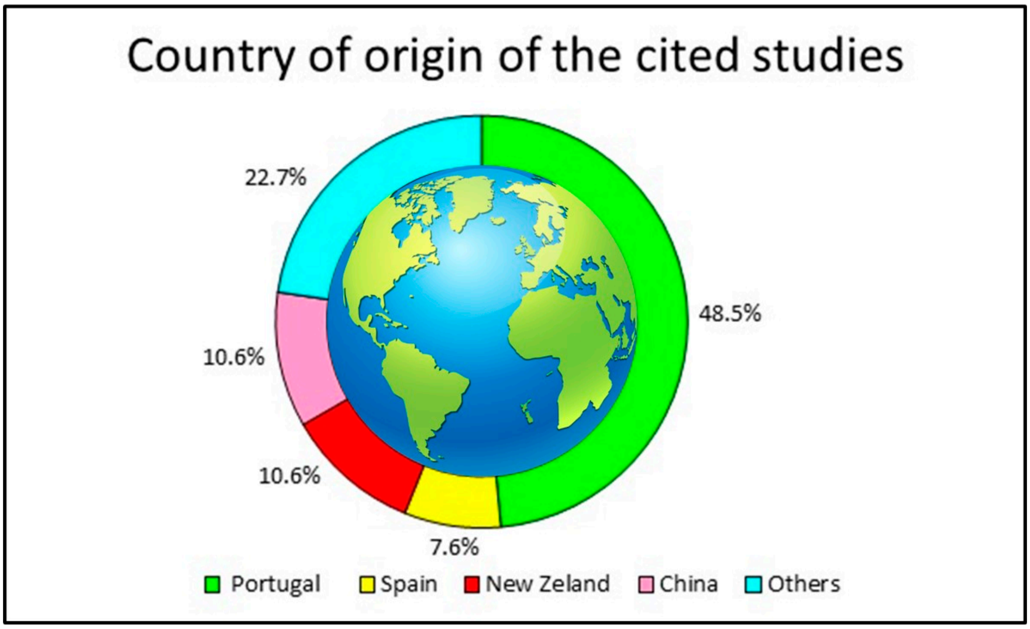

Figure 3. Country of origin of the studies mentioned in Section 2.

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].

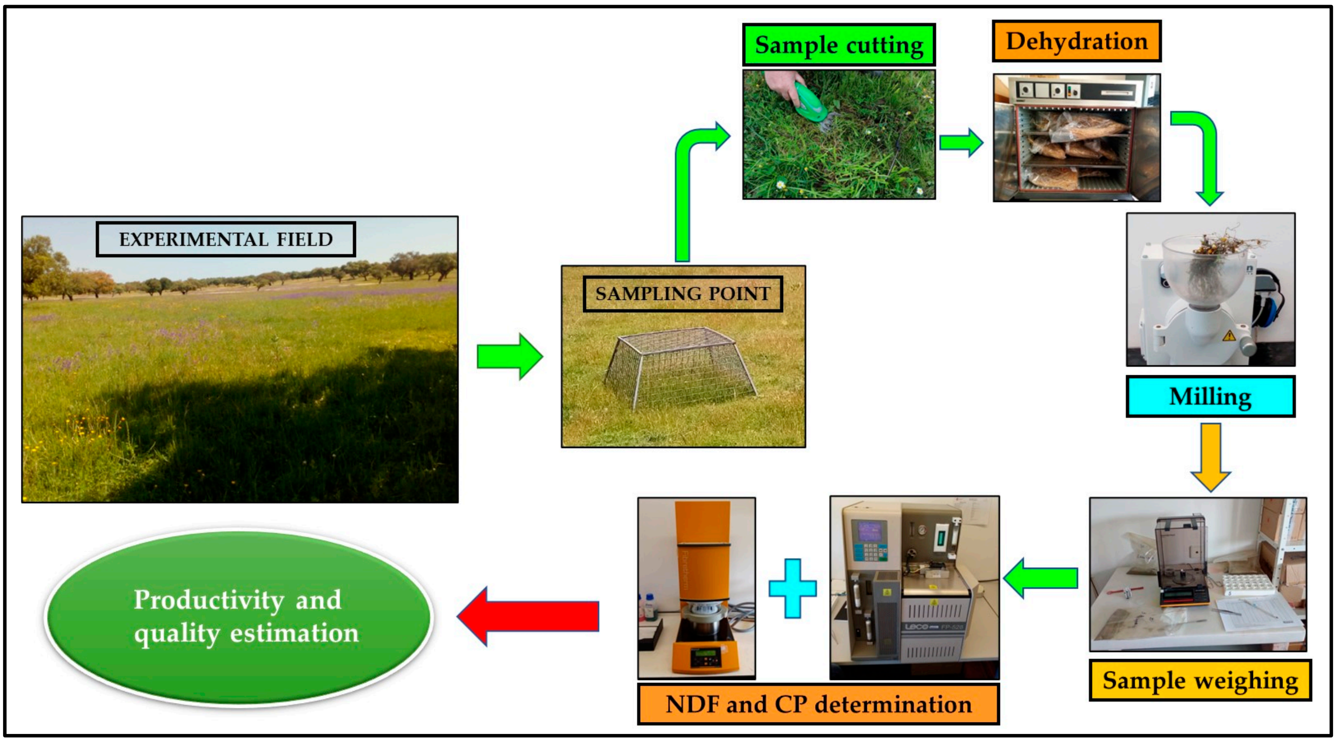

Figure 4. Explanatory diagram of the traditional pasture sampling and laboratory processing process.

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.

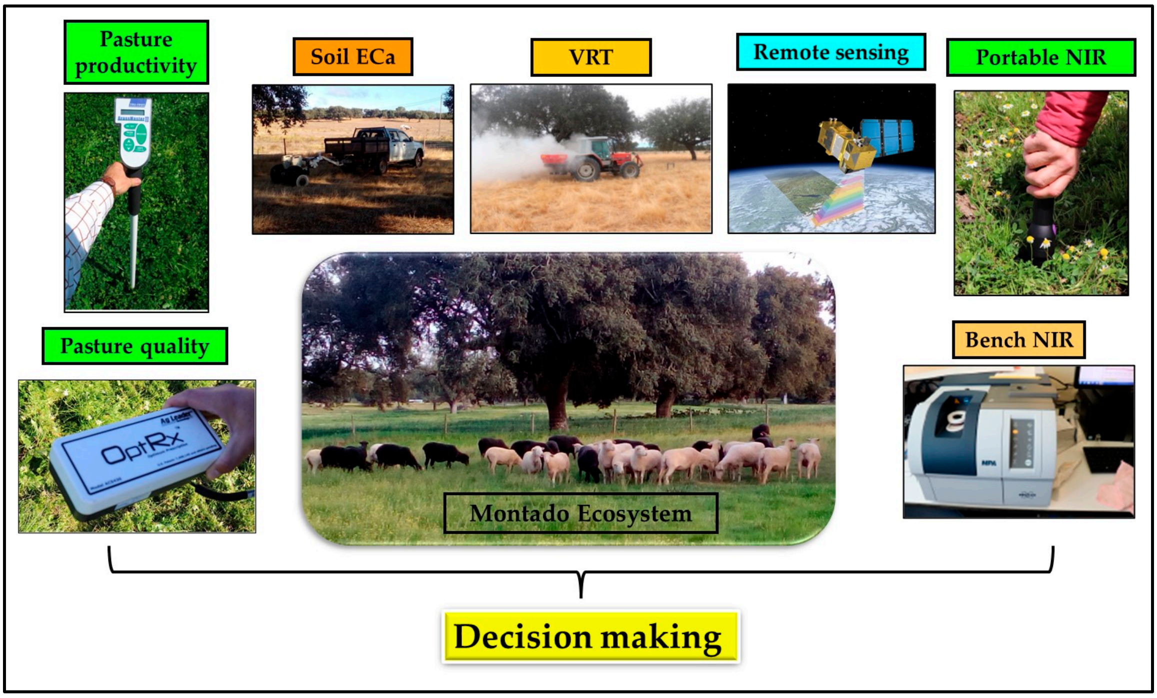

Figure 5. Summary diagram of technologies referred to in this review for soil and rangeland monitoring.

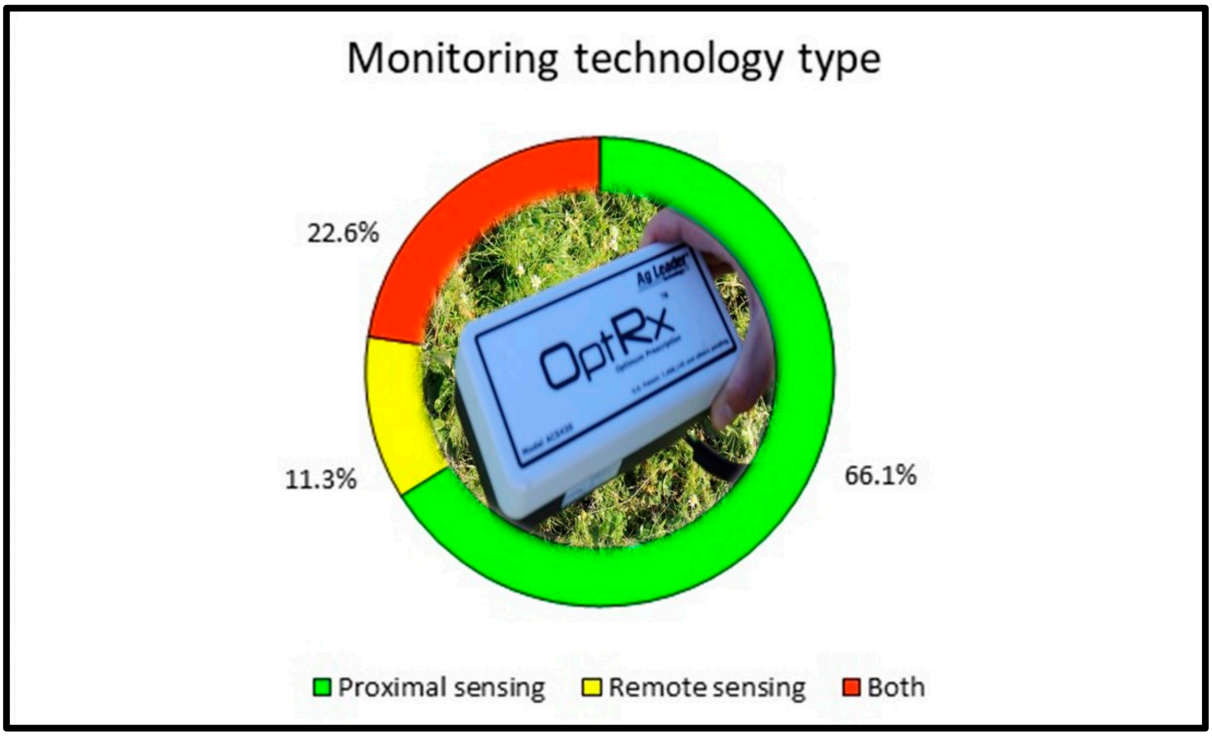

Figure 6. Monitoring technology type.

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.

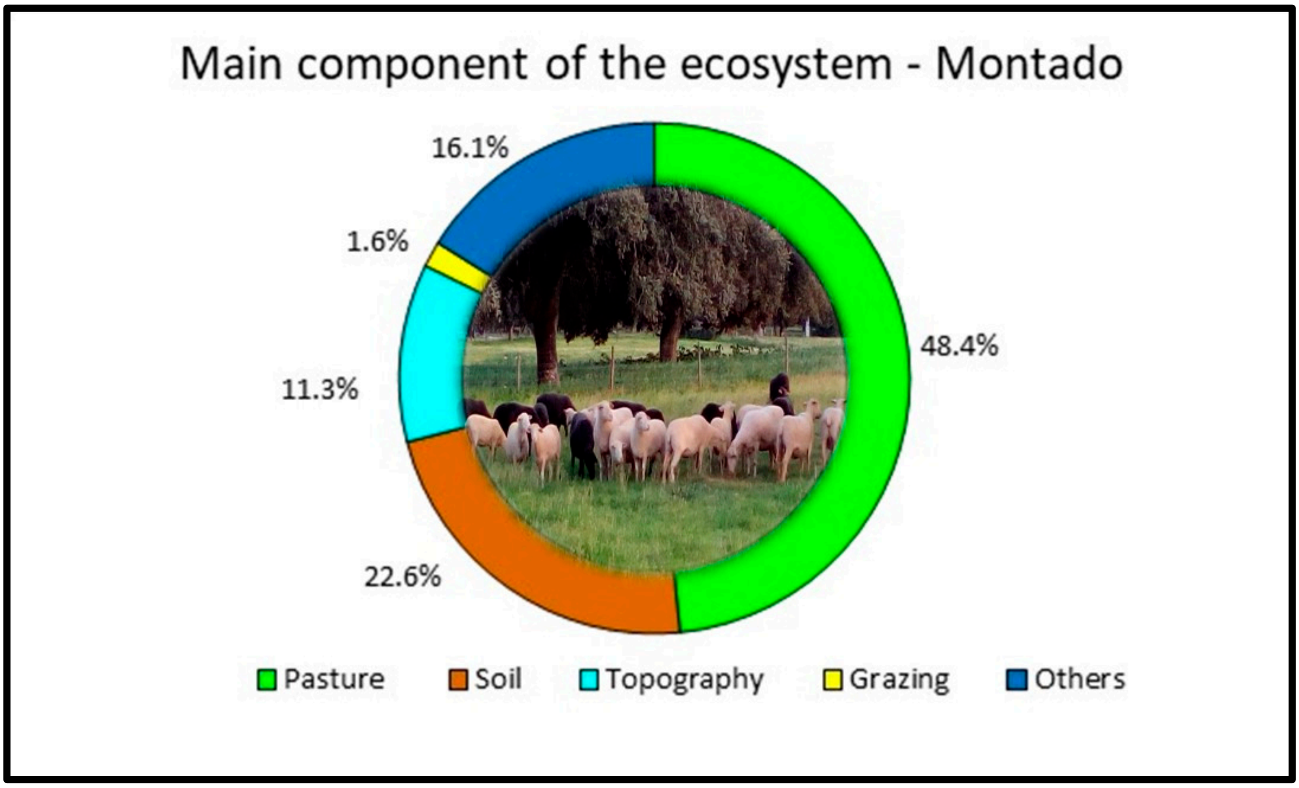

Figure 7. Main component of the ecosystem—Montado.

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.

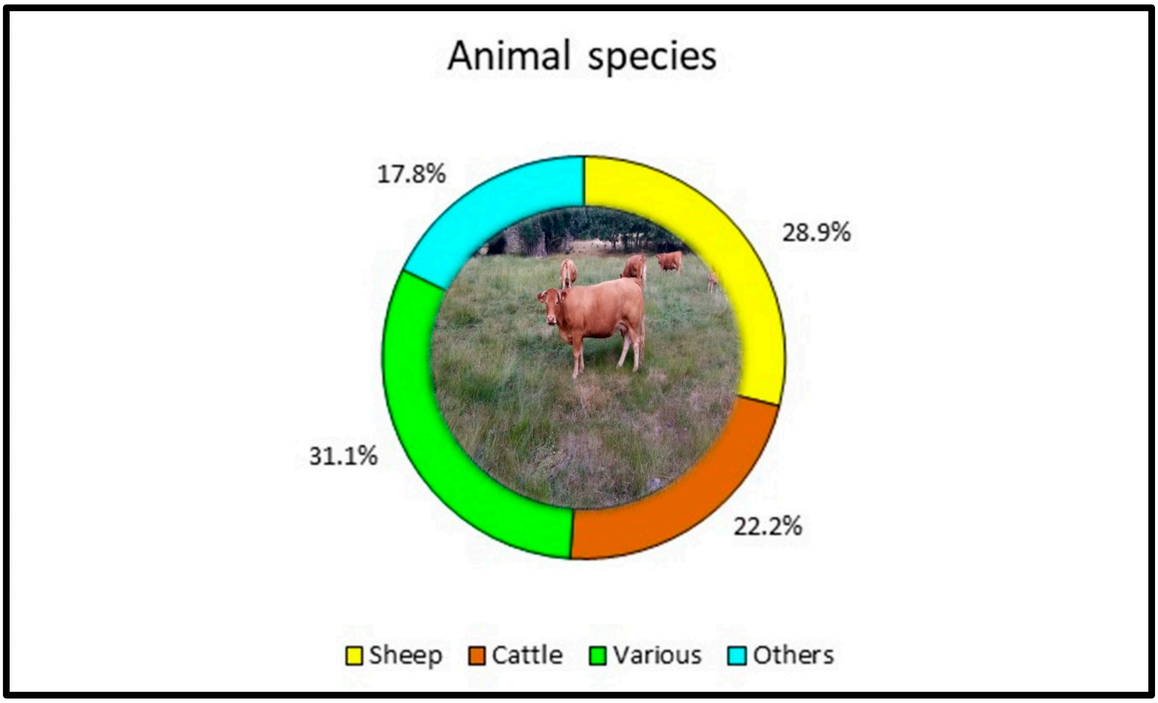

Figure 8. Animal species in studies cited in Section 4.

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.

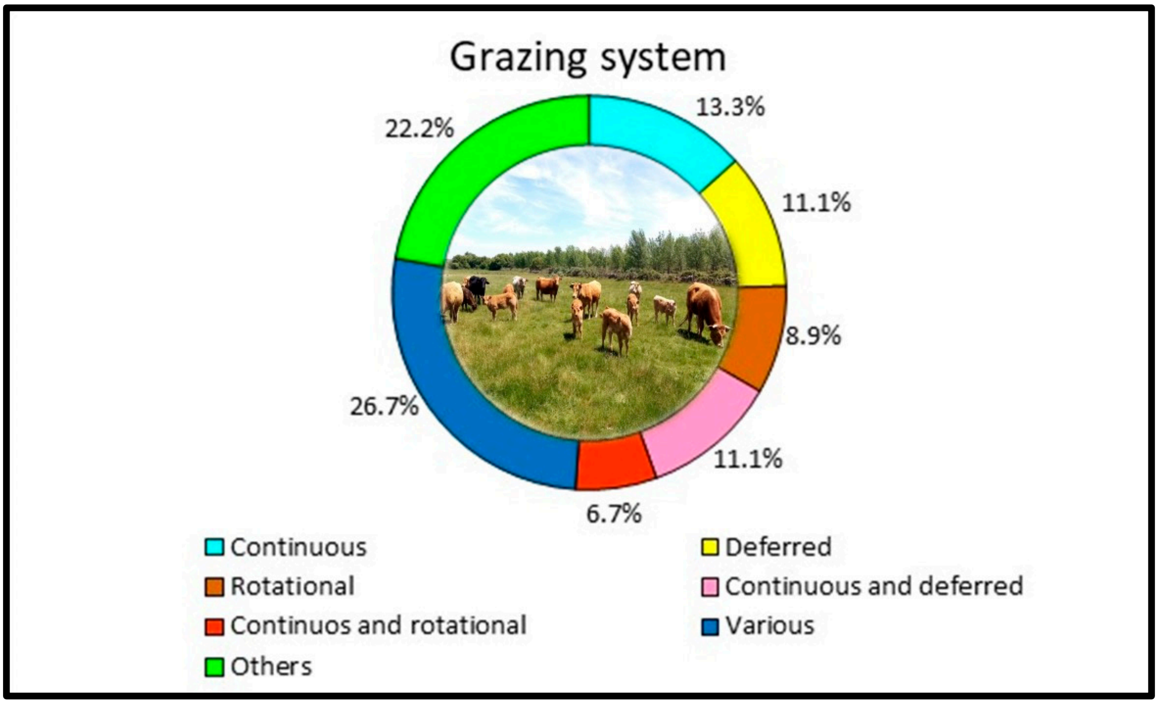

Figure 9. Grazing systems referred to in Section 4.

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.

Author Contributions: Conceptualization, E.C., J.S., J.L.d.C., S.S. and A.F.P.; methodology, E.C.; validation, J.S., J.L.d.C. and A.F.P.; writing—original draft preparation, E.C.; writing—review and editing, J.S., J.L.d.C., S.S. and A.F.P.; supervision, J.S., J.L.d.C., S.S. and A.F.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

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]