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Proximal sensors for monitoring seasonal changes of feeding sites selected by grazing ewes

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Abstract *Montado* is a silvo-pastoral ecosystem of the Mediterranean region, a mixed system of trees and grass, where livestock graze. The information about the spatial and temporal variability of pastures constitutes the basis to estimate available feed, a fundamental decision support tool for the farm manager to define the animal stocking or the rotation of the grazed paddocks. In this study, the intrinsic features of high spatial–temporal variability of Mediterranean grazed pastures were assessed with the objective of evaluating the suitability of two proximal sensing techniques (an active optical sensor, AOS and a capacitance probe) for easily monitoring seasonal variability of pasture productivity and quality linked to animal grazing patterns. The correlation between pasture and sensor parameters was consistent between capacitance and pasture productivity ($r^2 = 0.68$, $P < 0.01$; and $r^2 = 0.87$, $P < 0.01$, respectively for green pasture biomass, PB and pasture moisture content, PMC), between NDVI and pasture productivity ($r^2 = 0.73$, $P < 0.01$; and $r^2 = 0.96$, $P < 0.01$, respectively for PB and PMC) and between NDVI and pasture quality ($r^2 = 0.44$, $P < 0.05$; $r^2 = 0.69$, $P < 0.01$; and $r^2 = 0.78$, $P < 0.01$, respectively for ash, crude protein, CP and neutral detergent fibre, NDF). The approach is a promising methodology for assessing seasonal changes in pasture that have values of biomass that range between 2000 and 85,000 kg ha^{-1} and vegetative sates from de green and leafy to dry. These results can be an important starting point for studies of evaluation and calibration of the optical sensor specifically for pasture quality assessment in different types of biodiverse pastures. This is a key factor for the management of animal grazing intensity and calculation of feed supplementation needs.

Keywords Agro-silvo-pastoral systems · *Montado* · Proximal sensing · Pasture seasonality

Introduction

The southwestern Iberia is characterized by a unique agro-silvo-pastoral ecosystem, named *Montado* in Portugal and *Dehesa* in Spain (de Oliveira et al. 2016). This multi-use system is dominated by oaks (*Quercus* spp.), with an understory vegetation of

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shrubs and pastures which support livestock production, together with cork harvesting and other crops and uses (Pinto-Correia et al. 2011). The system is at risk, evidencing a strong reduction of area in the last decades (Pinto-Correia and Godinho 2013). Recent trends of land management have a focus on production, leading to a progressive increase in cattle stocking numbers (Almeida et al. 2016). The impact of related grazing management decisions, such as pasture allocation, paddock residence time and supplementary feeding, could have consequences on grazing pressure and on overall sustainability of the system (Sales-Baptista et al. 2016a). As such, to maintain the important socio-economic role and the high nature value of these systems in the long term it is essential to understand the components of the system and to understand the interactions between them (David et al. 2013; Peco et al. 2006). Foraging interactions between plants and grazing animals are one of the key driving forces shaping grazing systems, because animals don't graze randomly nor homogeneously, and this behaviour will have consequences. The spatial location of grazing animals will determine the intensity of the impact on pasture (Tomkins and O'Reagain 2007). Consequently, the chances for patches of similar palatability to be ingested depend mainly upon the scale of the herbivore grazing movements. Preferred areas are often over-used resulting in the degradation of soil, which will, in turn, promote the loss of biodiversity and productivity (Bilotta et al. 2007). Relating features of the land cover and of the plant patches to the distribution of grazing animals will improve our ability for sustainable management.

To assess the patterns of pasture utilization, the position of grazing animals can be automatically monitored using GNSS (Global Navigation Satellite System). Combining this information with geographic information systems (GIS) will generate maps depicting the spatial distribution of biomass, which will allow the identification of over-grazed or chronically low yield areas, information essential for a more functional site-specific pasture management decisions (Turner et al. 2000; Flynn et al. 2008). However, the ability to accurately measure aboveground pasture biomass, which is important for calculating forage availability, remains challenging. In Mediterranean pastures even more so, due to the intrinsic spatial and temporal heterogeneity of swards, topped by the generated mosaic of undergrazed and overgrazed patches, a consequence of the selective grazing behaviour.

The most accurate method for estimating biomass is by on-field destructive clipping and dry-weighing sample quadrats of known area (Harmoney et al. 1997). This traditional pasture sampling method is time-consuming, labour intensive and difficult to implement as routine at farm level (Schaefer and Lamb 2016; Louhaichi et al. 2017). To overcome these disadvantages there has been an increased interest in the development of automated monitoring methods (Pullanagari et al. 2013; Handcock et al. 2016). Remote sensing (RS) has been found to be a promising non-destructive tool for estimating nutrient concentrations of vegetation (Zhao et al. 2007). Among the several indexes, the normalized difference vegetation index (NDVI), derived from high-resolution satellite imagery, is the most used to quantitatively predict and map the biomass of annual pastures (Edirisinghe et al. 2011; Cicore et al. 2016; Louhaichi et al. 2017). However, satellite imagery have a limited scope to estimate vegetation cover, mainly due to limited spatial resolutions and to the fact that most algorithms used are site and date specific (Louhaichi et al. 2017). Furthermore, in the *Montado* ecosystem, an additional limitation is presence of tree canopies, turning understory pasture unavailable for detection.

Therefore, simultaneous using RS coupled with proximal sensors at ground level will provide an increase of the accuracy of RS data (Louhaichi et al. 2017). Despite the fact that proximal sensors monitor only a small area or point they have the potential to capture rapid changes in the proportions of photosynthetically active vegetation (Handcock et al. 2016). Active optical sensors (AOS) illuminate the target and measure the reflectance of canopy in the red and near infrared regions reflected in the sensor's integral photo-detector (Schaefer and Lamb 2016) and can be used to track relative growth differences. For example, the NDVI is correlated with vegetative vigour (Gitelson 2004), providing information useful for detailed pastures mapping (Serrano et al. 2016a). However it is important to remember that the spectral reflectance characteristic of pasture canopy is influenced by the several leaf layers (Schaefer and Lamb 2016). As such, vegetation indices are critically dependent on the species, morphology and chlorophyll concentration of the leaves (Schaefer and Lamb 2016). In

Mediterranean pastures, recognised by its multi-diverse botanical composition, this complexity could present a limitation, which could be overcome by combining other ground-level sensor. The Grass-Master II capacitance meter (Novel Ways Electronic, Hamilton, New Zealand) has been used previously (Serrano et al. 2011) in Mediterranean pastures, throughout its vegetative cycle, with variations of floristic composition, phenological stage or pasture moisture content, and the relationship between pasture productivity and corrected meter reading (CMR) of this electronic capacitance probe could justify the interest in performing calibration tests.

The objective of this study was to evaluate two proximal sensing techniques (an optical active sensor and a capacitance probe) for easily monitoring seasonal spatial and temporal variability of pasture productivity and quality linked to animal grazing patterns.

Materials and methods

The study area

The study was conducted on a paddock, with an area of 2.3 ha, located at Mitra farm (coordinates 38°32.2′N; 8°01.1′W), University of Évora, Portugal. The paddock has a low tree density (*Quercus ilex* ssp. *rotundifolia* Lam., 8 trees/ha), and an understory of permanent biodiverse native pasture (legumes and grasses) grazed by ewes in a rotational system. Since March 2014 the pasture has been grazed permanently by 15 adult *Black Merino* ewes. The predominant soil of this field is classified as a Cambisol derived from granite (FAO 2006). Cambisols are characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay, organic matter, aluminium and/or iron compounds. Acid Cambisols are not very fertile and are mainly used for mixed arable farming or as grazing and forest land.

Digital elevation model

In September 2015 a topographic survey of the area was carried out using a real time kinematic (RTK) GPS instrument (Trimble RTK/PP-4700 GPS, manufactured by TRIMBLE Navigation Limited, USA).

The altimetry data were sampled in the field with an all-terrain vehicle on paths approximately 10 m apart. The digital elevation model surface (Fig. 1) was created using the linear interpolation TIN tool from ArcGIS 10.2 (Esri, Redlands, CA, USA) and converted to a grid surface with a 1 m grid resolution.

The map shows that the site has a soft undulating topography, with only about 5 m of difference between the highest and the lowest sampled points.

Climate characterization

The Mediterranean climate is characterized by summer drought, variable rainfall, and mild or moderately cold winters. The monthly average temperature is between 8 and 26 °C; minimum temperatures are close to 0 °C between December and February. The annual rainfall in the region is between 400 and 600 mm; rainfall occurs mainly between October and March and is practically non-existent during the summer.

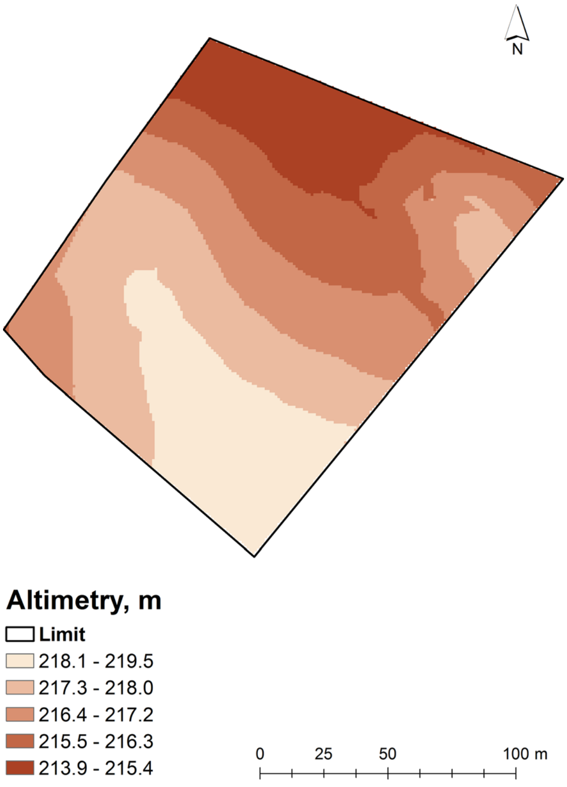


Fig. 1 Altimetry map of the studied field

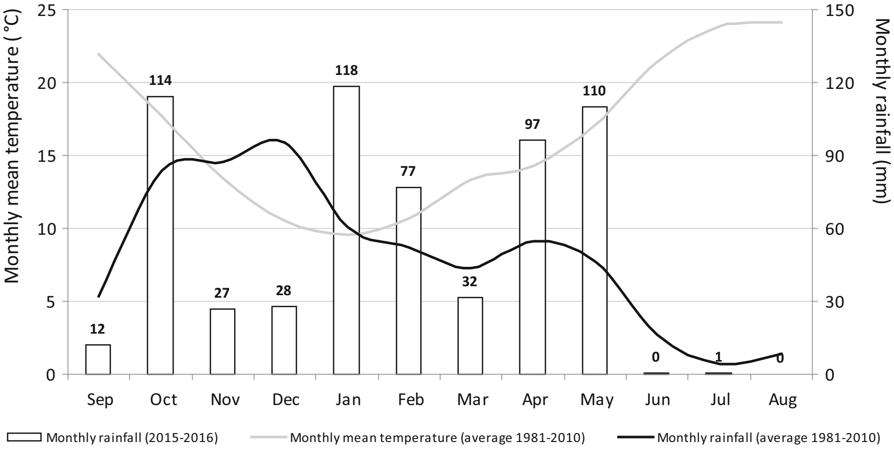


Fig. 2 Thermo-pluviometric diagrams of the Évora meteorological station between 1981 and 2010 (climate normals) and the monthly rainfall between September 2015 and August 2016

Figure 2 illustrates the average thermo-pluviometric diagrams of the Évora meteorological station between 1981 and 2010 (climate normals) and the monthly rainfall between September 2015 and August 2016. This figure shows very significant difference between the agricultural year 2015/2016 and the average historical values in terms of average monthly rainfall, which transformed 2016 into an atypical year, with direct influence on the vegetative cycle of the dryland pastures in Alentejo, Southern region of Portugal. In terms of accumulated rainfall between March and June, the average historical value is 186.4 mm, while in 2016 the rainfall was 238.3 mm. This difference is accentuated when we observe the distribution of the monthly rainfall. Thus, while the average historic values of accumulated rainfall are 83.2, 44.9, 33.5 and 24.8 mm, respectively in March, April, May and June, for the same period of 2016 the following values were observed: 31.6, 96.5, 109.8 and 0.4 mm.

Experimental procedure

Overview

This study aimed at measuring the spatial distribution of nutritive value in the sward using proximal sensors, based on the ewe's foraging decisions. To achieve this, the preferred patches selected by ewes while grazing were sampled using given-up densities technique (Brown 1988).

The overall trial lasted 22 weeks (from 1 April to 25 August 2016). This involved 16 evaluation events (sampling times), of which 14 were performed on a weekly basis (between April and June) and two monthly (one in July and other in August) (Fig. 3). For each sampling week, GNSS loggers were attached to ewes at the beginning of the week. After 48 h of data acquisition the loggers were retrieved and the last 24 h analysed for animal location. These information was used to decide where the sampling patches would be located. The chosen patches were sampled on the next day, using proximity sensors (multispectral and capacitance sensors) followed by sample-clipping of vegetation. On each patch the post-grazed pasture was sampled using three sampling points for biomass assessment. Nutritional value was determined using a composite sample (from the three subsamples). A fourth sampling point of undisturbed pasture, within the same patch, was also collected to assess the pasture on offer.

Tracking animals and selection of sampling patches

Six randomly selected ewes were fitted with GNSS position loggers (CatTrack$^{\mathrm{TM}}$, Perthold Engineering LLC, Anderson, USA; www.mr-lee-catcam.de; Fig. 4a) attached to harnesses. Loggers (previously described by Sales-Baptista et al. 2016b) were programmed to record data every 5 min. In order to prevent the effect of human presence on animal's grazing behaviour, a lag period of 24 h after the start of georreferenced locations were allowed. Data were analysed using Trip@pc software. The three most grazed patches of approximately 400 m^2 within a 24 h grazing path were used for pasture sampling. Foraging

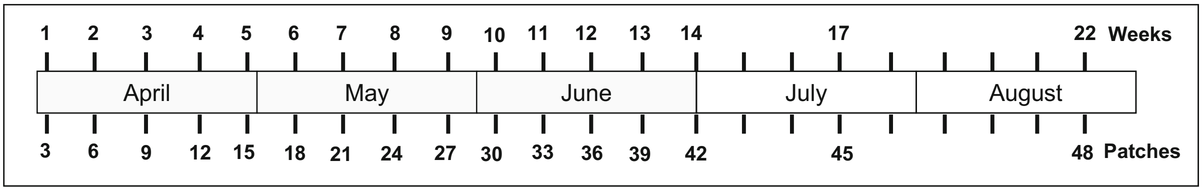


Fig. 3 Schematic diagram of the sampling frequency

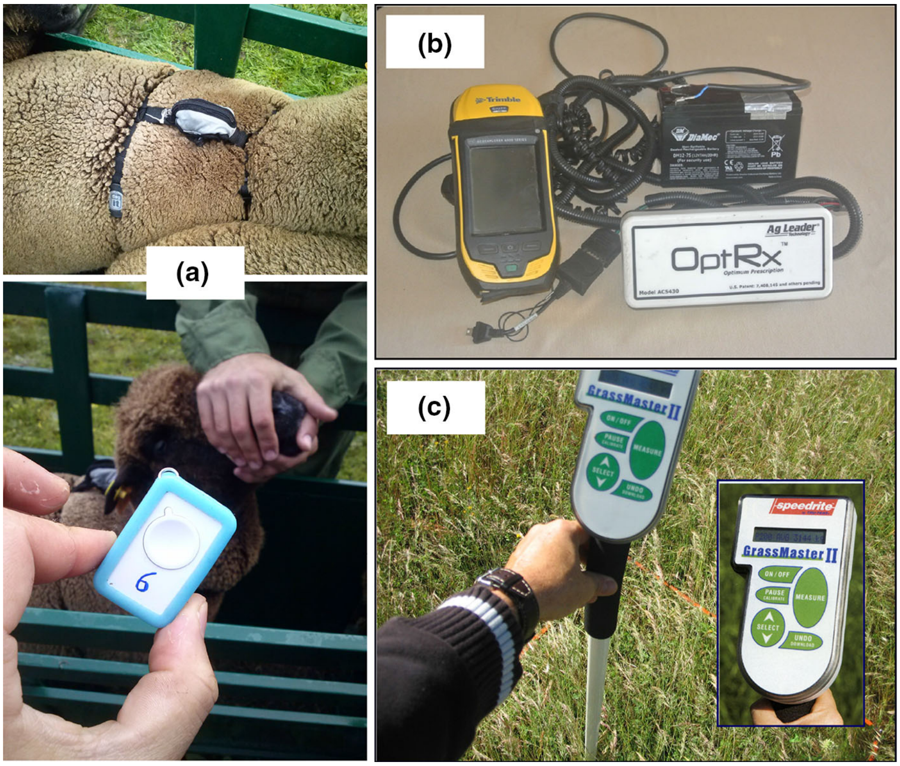


Fig. 4 GNSS position loggers (**a**), optical active sensor (**b**) and capacitance probe (**c**)

use rate (Krebs et al. 1974) was obtained by measuring total time spent in a patch, following the assumptions: (1) major grazing events occur at dawn and dusk; (2) the time spent grazing is a consequence of sward conditions.

Pasture monitoring

In situ measurements with the sensors In each of the three sampling patches, a frame of 0.25 m^2 area (dimensions 0.50 m × 0.50 m) was used to define the data acquisition points. Four subsamples were collected within each patch (see details on the overview section), thus developing a database with 12 sampling points for each sampling week. Throughout the 16 sampling weeks during the study period, a total of 192 sampling points (12 × 16) were established. Each sampling point was geo-referenced.

Vegetation multispectral measurements The multispectral bands were measured with a commercial OptRx® active optical sensor (AOS, Fig. 4b), constructed by Ag Leader (2202 South River Side Drive Ames, IOWA 50010, USA). The optical sensor has a small portable battery as power source and is associated with a Trimble GNSS GeoExplorer 6000 series model 88951 of sub-meter precision (Trimble: GmbH, Am Prime Parc 11, 65479 Raunheim, Germany).

This sensor measures simultaneously three infrared bands: (1) RED (670 nm with a range of 20 nm); (2) RED EDGE (728 nm with a range of 16 nm); and (3) NIR (775 nm with basically everything under 750 nm being filtered). With two of the previous spectral bands NDVI vegetation index was calculated considering the following expression (Eq. 1):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

Before cutting each sample, the operator stood still holding the sensor at 0.75 m above ground and performed measurements for a 2-min period. NDVI data were organized in a spreadsheet and associated with the coordinates of the respective sampling points to calculate the mean and standard deviation of NDVI from about one hundred and twenty readings at each of the four sampling points.

Capacitance measurements Each measurement of capacitance with the "Grassmaster II" probe (Fig. 4c) was preceded by an air humidity level correction. The capacitance readings (corrected meter readings, CMR) were registered after the instrument had been positioned vertically over the vegetation, some 0.2–0.3 m away from the operator's body. In each sampling point, ten readings were carried out with the probe and averaged. Greater detail on the operation of the probe can be found in Serrano et al. (2011, 2016b).

Pasture sample collection and analysis After sensor data acquisition at each sampling point, pasture within the frames was harvested using a portable electric grass shears and stored in coded plastic bags. The 12 pasture samples collected each week were then taken to the Animal Nutrition Laboratory of the University of Évora, where they were weighed, dried (for 72 h at 65 °C), and then weighed again to establish pasture biomass (PB, kg ha^{-1}) and moisture content (PMC, %) according to standard procedures described by Serrano et al. (2011). Overall, throughout the 16 sampling weeks, a total of 192 sampling points (12 × 16) were established for biomass assessment.

Nutritional value was assessed through crude protein (CP), neutral detergent fibre (NDF) and ash content expressed as % of dry matter on a composite sample (from three subsamples) and a further individual sample (see detail on overview section). Conventional methods of wet chemistry (AOAC 2005) were used. Overall, throughout the 16 sampling weeks, a total of 96 data points (3 × 2 × 16) were established.

Statistical analysis

Descriptive statistics analyses, including mean, standard deviation (SD), coefficient of variation (CV), and range, were determined for each dataset of pasture and sensors parameters.

An analysis of correlation between sensor and pasture parameters was performed using "MSTAT-C" software with a significance level of 95% ($P < 0.05$).

The accuracy of regression models obtained between measured PB, PMC, ash, CP or NDF (PB$_m$, PMC$_m$, ash$_m$, CP$_m$ or NDF$_m$) and predicted PB, PMC, ash, CP or NDF (PB$_p$, PMC$_p$, ash$_p$, CP$_p$ or NDF$_p$) was evaluated by the root-mean-squared error (RMSE, Eq. 2) and the respective CV (CV$_{RMSE}$, Eq. 3).

$$RMSE = \sqrt{\frac{\sum_{i-1}^{n}\left(y_p - y_m\right)^2}{n}} \tag{2}$$

where y_p is the predicted PB, PMC, ash, CP or NDF, y_m is the measured PB, PMC, ash, CP or NDF, and n is the number of sampling points; and

$$CV_{RMSE} = \frac{RMSE}{\bar{y}} \times 100 \tag{3}$$

where $\bar{y}$ is the mean measured PB, PMC, ash, CP or NDF.The model was considered excellent, good, acceptable or poor if the CV$_{RMSE}$ were < 10, 10–20, 20–30 or > 30%, respectively (Jamieson et al. 1991).

Results and discussion

Patterns of pasture productivity and quality

The location of grazed patches and corresponding sampling points over the 22 week trial period is showed in Fig. 5. In April (weeks 1–5), grazing occurred essentially at the southern part of the paddock. In May (weeks 6–9) there was a greater dispersion of grazing areas, while in June (weeks 10–14), animals selected mainly two areas (the southern part of the paddock and the flow line). In the summer, July (week 17) and August (week 22), foraging sites were mostly located at the northeast of

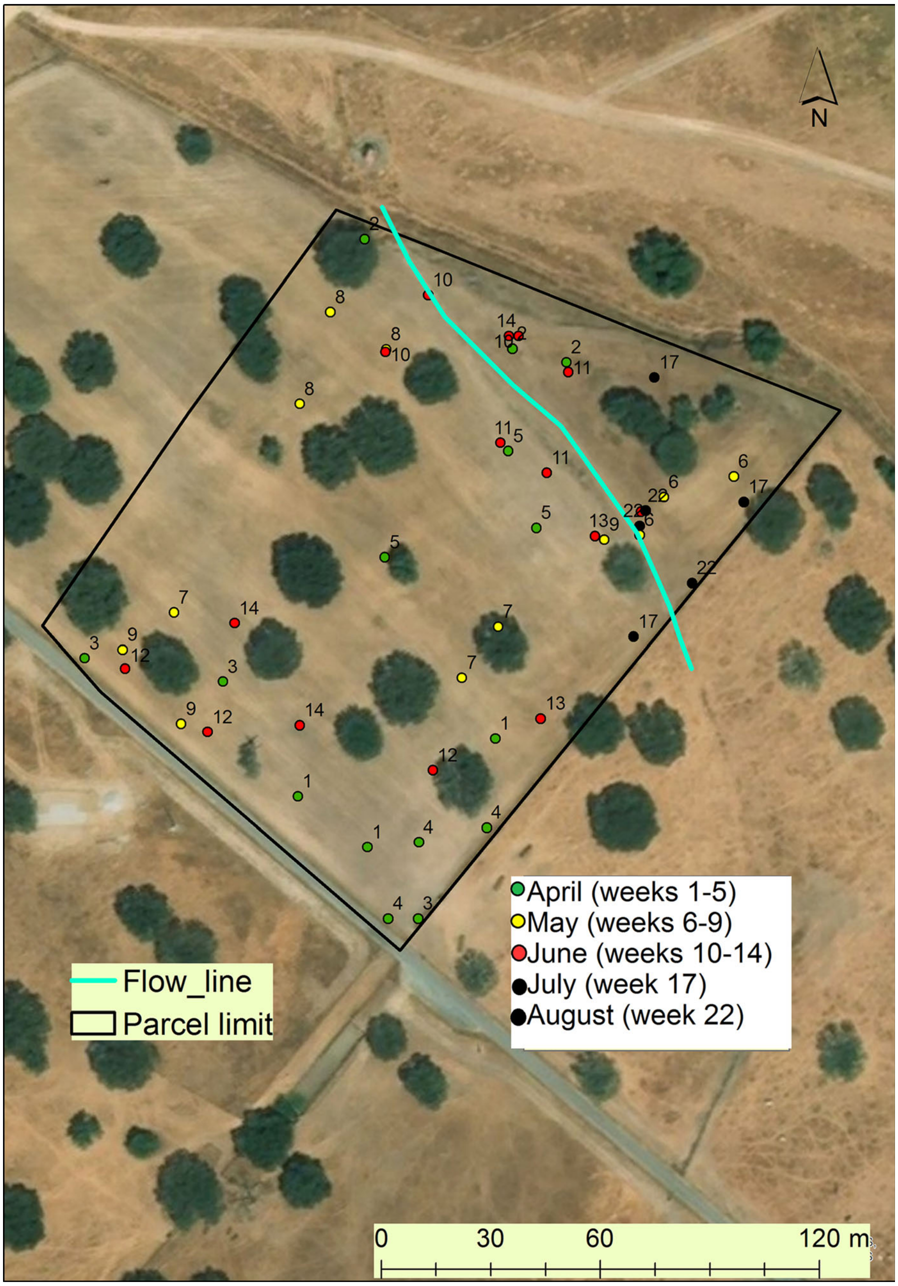


Fig. 5 Location of grazed patches in the studied field and corresponding pasture sampling over the 22 week trial period

the study area, near the flow line possibly due to the higher soil moisture content. In a multi-diverse pasture, different plant species mature at different rates, driving animals to modify their patch location accordingly. Grazing animals typically selected sites were they can maximize the intake rate of energy and protein, which is correlated with biomass and quality (Pinchak et al. 1991). This general trend was supported by our study where the patterns of grazing location were dependent on the pasture biomass and protein content. In the first five weeks ewes select feeding sites with an average crude protein content of 15.5% DM, which is higher than their maintenance requirements (9.4% DM; National Research Council 1985).

Information on pasture production and quality is a useful tool for making timely and effective decisions, allowing for optimum use of forage resources in a pastoral system (Demanet et al. 2015). The results of this study evidence the diversity and variability of natural pastures (in terms of productivity and quality).

Figures 6 and 7 show, respectively, the evolution of the pasture productivity parameters (PB and PMC) and pasture nutritive value parameters (ash, CP and NDF), over the 22-week trial. These results show the typical patterns of productivity and quality parameters of pastures in Mediterranean agro-silvo-pastoral systems throughout their vegetative cycle: yield increase (PB) from winter to late spring (December–May), and an inverse pattern of pasture quality (reduction of nutritional value, PMC, total ash and CP and a continuous increase of NDF with the approach of summer, June to August) (de Oliveira et al. 2013).

High seasonal fluctuations of light, temperature and soil moisture drive plant quality and availability (de Oliveira et al. 2013). The concentration of rainfall in the months of April and May is an important factor for maintaining the growth of the dryland pastures in Southern region of Portugal, with direct influence on the duration of the vegetative cycle. In the present study the high precipitation observed in April and May (Fig. 2) maintained high productivities in these months (weeks 1–9). The extension of pasture monitoring for the months of June, July and August confirmed the extreme effect of the weather conditions (combined influence of low rainfall and high temperatures) on dryland pastures under Mediterranean conditions. From the 10th week on, the decline in pasture productivity is clear, as indicated by the marked decrease in PMC (Fig. 6).

It is accepted that high CP values and low NDF values reflect higher quality pastures (Ren et al. 2015), so the evolution of NDF/CP ratio may reflect the natural degradation of pasture quality throughout its vegetative cycle. Figure 8 shows the pattern of pasture quality degradation index (PQDI = NDF/CP) during the study period. The evaluation of the behaviour of this index may be important to understand the critical moment at which feed supplementation of the animals is justified, until the beginning of the autumnal period with the appearance of the first rains. Ren et al. (2015) have demonstrated that adjusting the NDF/CP ratio

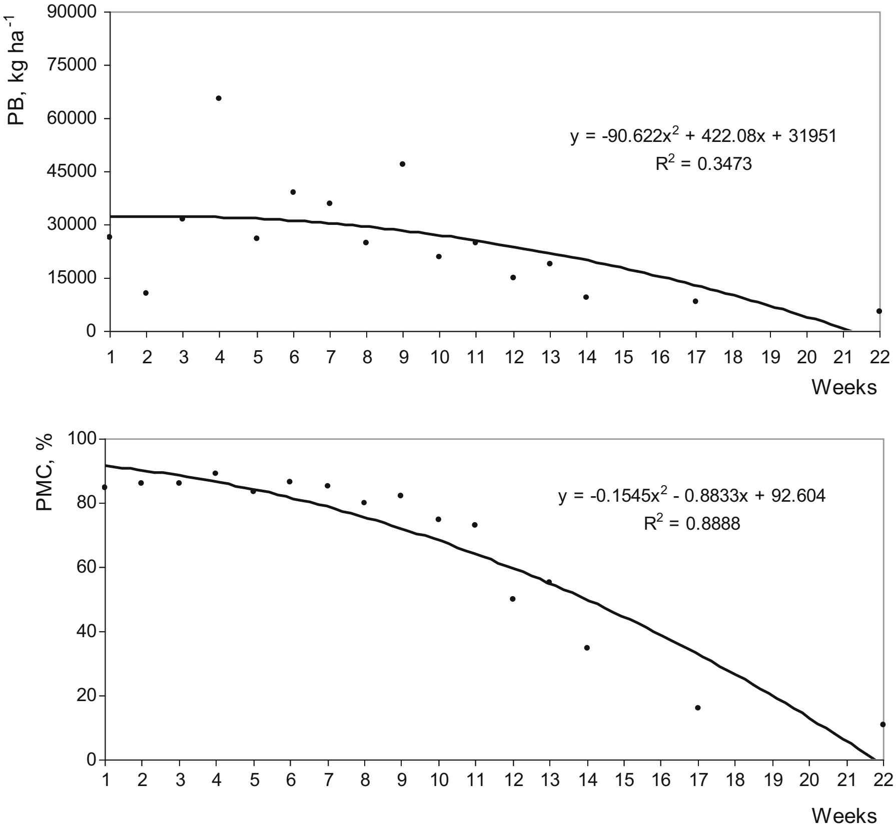


Fig. 6 Evolution between April and August 2016 of the pasture biomass (PB, kg ha^{-1}) and pasture moisture content (PMC, %)

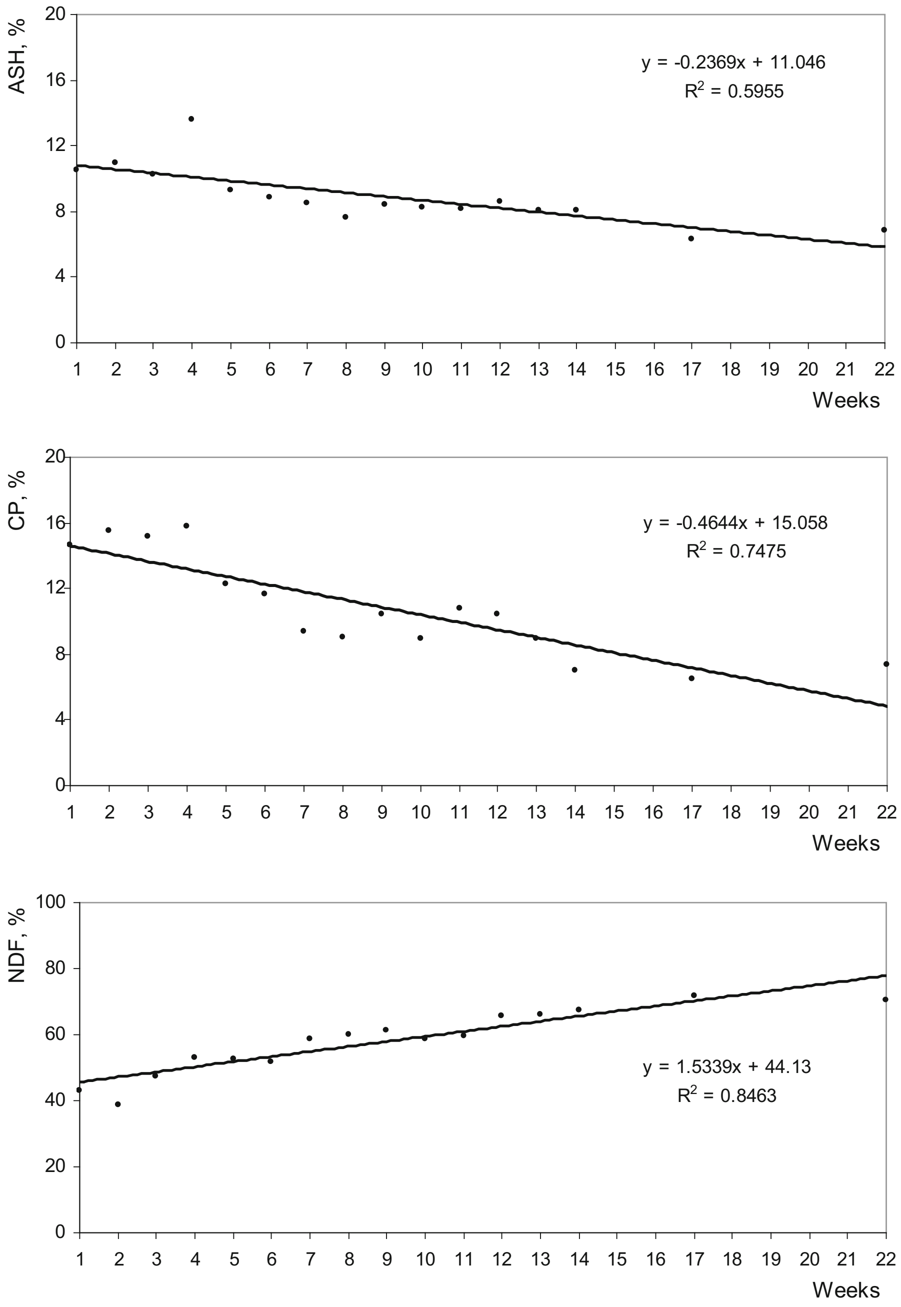


Fig. 7 Evolution between April and August 2016 of the pasture nutritive value parameters (ash, crude protein, CP, and NDF)

through a reduction in the proportion of NDF, is an important strategy for mitigating nitrogen losses in animals.

Figure 9 shows the evolution of NDVI and CMR over the 22-week trial. Higher NDVI's were registered as pasture approached its greatest vegetative vigour (spring), with tendency to decrease continuously and gradually over the study period, when the pasture began to dry due to the combination of higher temperatures and lower rainfall (Gitelson 2004; Serrano et al. 2016a). On the other hand, CMR increased between April and May and decreased significantly from June onwards, a pattern of seasonality similar to the evolution of PB and PMC (Fig. 6).

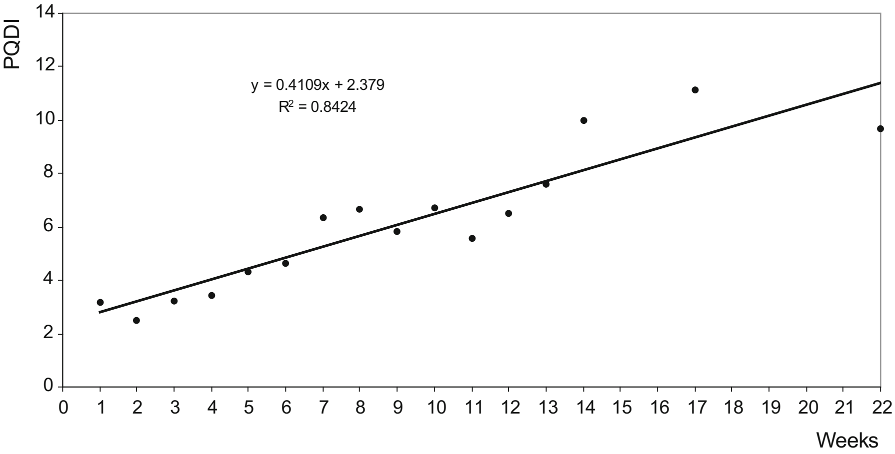


Fig. 8 Evolution of pasture quality degradation index (PQDI) between April and August 2016

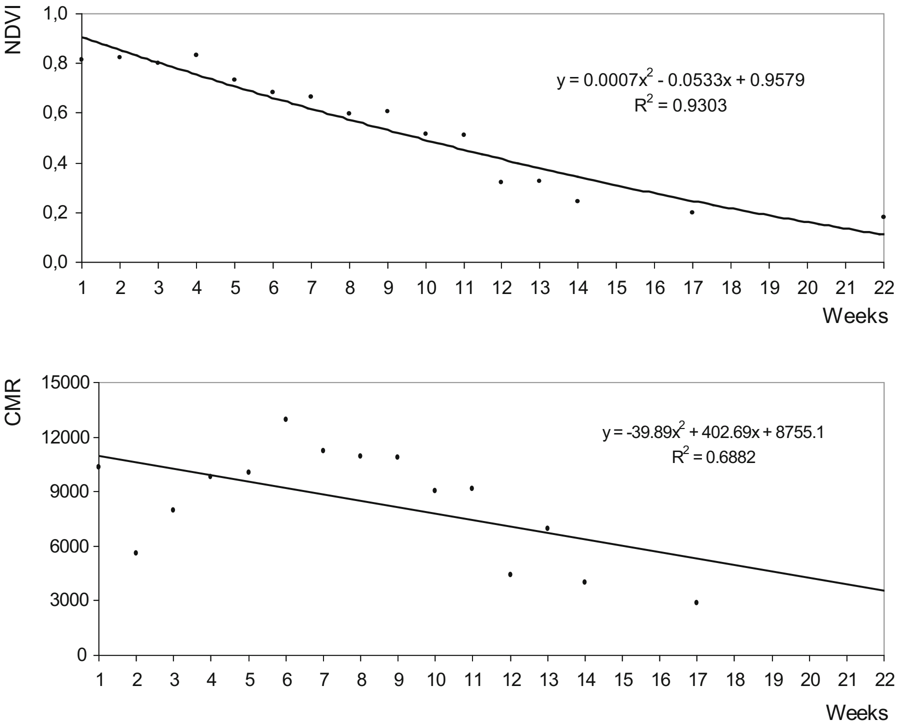
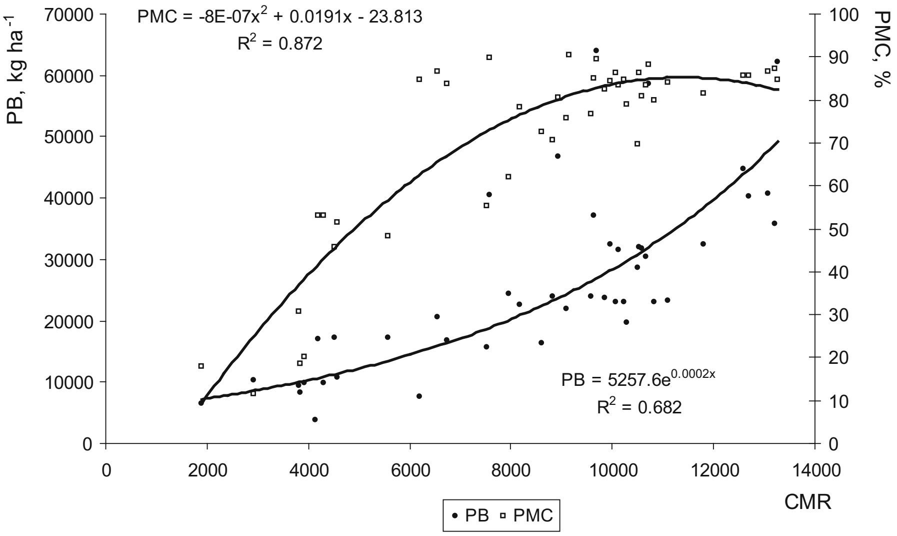


Fig. 9 Evolution of sensor parameters (NDVI and CMR) between April and August 2016

Correlation between pasture and sensors parameters

As might be expected in view of the operating principle of the capacitance probe (sensitivity to PMC), a strong relationship was observed between CMR and PMC (Fig. 10). Essentially, this sensor responds to the wet biomass (Hanna et al. 1999), and according to the manufacturer of the probe, water significantly affects the probe signal. Despite the inclusion of data relating to different plant species and development stages (different sampling dates), coefficients of determination of 0.68 ($P < 0.01$, RMSE = 4735 kg ha^{-1}, CV$_{\mathrm{RMSE}}$ = 18.3%) and 0.87 ($P < 0.01$, RMSE = 8.5%, CV$_{\mathrm{RMSE}}$ = 12.1%), respectively for PB and PMC, were obtained. These results, although site specific, are in accordance with the work of Serrano et al. (2011, 2016a, b) and support

Fig. 10 Relationship between CMR, pasture biomass (PB, kg ha^{-1}) and pasture moisture content (PMC, %)

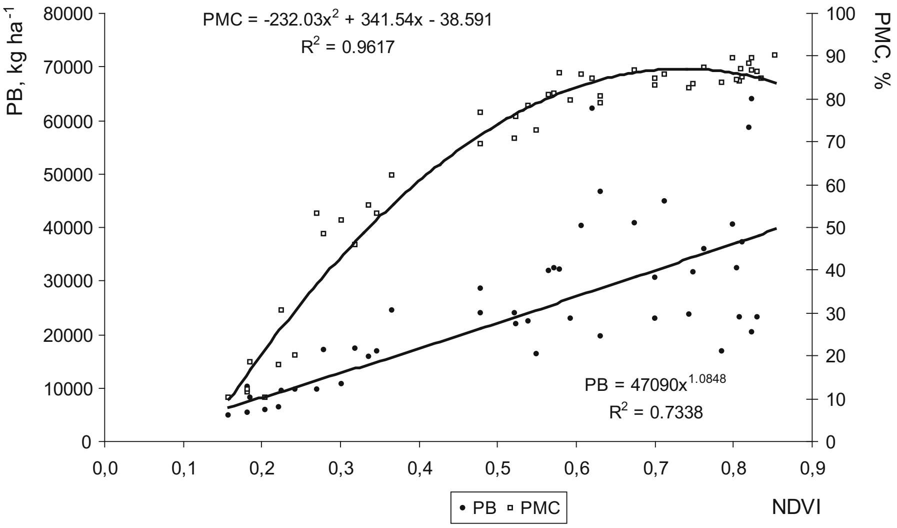


the practical interest of the Grassmaster II probe as a fast method of estimating the productivity of the Mediterranean pastures in Southern Portugal.

Figure 11 shows the correlation between NDVI and pasture productivity in terms of PB and PMC.

The relationship between the NDVI and PMC was nonlinear and strong ($r^2 = 0.96$, $P < 0.01$, RMSE = 5.1%, $CV_{RMSE} = 7.7\%$). Non-linear relationships were also found between NDVI and PB, where NDVI accounted for 73% of the variation in the measured PB ($r^2 = 0.73$, $P < 0.01$, RMSE = 4413 kg ha^{-1}, $CV_{RMSE} = 17.4\%$), which is in agreement with previous studies that showed that commonly the NDVI explains approximately 60–70% of the variance in PB for pastures (Schaefer and Lamb 2016). However, the dispersion of PB greatly increases for NDVI values of 0.6 or higher. According to Schaefer and Lamb (2016), there may be a problem of saturation at top-end biomass levels. Trotter et al. (2010) referenced the saturation of surface reflectance index at around 4000–5000 kg PB ha^{-1} for tall fescue (*Festuca arundinacea* var. Fletcher) pasture. Schaefer and Lamb (2016) also studied the spectral reflectance indices used to infer biomass and sought to address the non-linearity in the optical response of sensors, especially the impending saturation at high leaf area index. Pastures have high diversity as spatial and temporal heterogeneity result from a number of confounding

Fig. 11 Relationship between NDVI, pasture biomass (PB, kg ha^{-1}) and pasture moisture content (PMC, %)



factors, including: diverse species, morphology and interactions between the grazing animals, the natural environmental conditions and management practices (Pullanagari et al. 2013).

In this work, in addition to the interest in estimating pasture productivity using expedited tools (as is the case of the capacitance probe or the AOS), the relationship between NDVI and pasture nutritional quality (ash, CP and NDF) was assessed (Fig. 12). Figure 13 shows the relationship between NDVI and the PQDI.

Correlations of NDVI with pasture quality were relatively strong and significant ($r^2 = 0.44$, $P < 0.05$, RMSE = 1.5%, $CV_{RMSE} = 17.1\%$; $r^2 = 0.69$, $P < 0.01$, RMSE = 1.9%, $CV_{RMSE} = 17.8\%$; and $r^2 = 0.78$, $P < 0.01$, RMSE = 4.3%, $CV_{RMSE} = 7.4\%$, respectively to ash, CP and NDF). The determination coefficients are higher than those obtained by Zhao et al. (2007) (0.61 and 0.58, respectively for CP and NDF) with reflectance data obtained by remote sensing. Correlation of NDVI with PQDI was also strong and significant ($r^2 = 0.78$, $P < 0.01$, RMSE = 1.2%, $CV_{RMSE} = 20.4\%$). These results show the accuracy of the model for estimation of pasture quality based on NDVI measured by proximal AOS. According to the classification proposed by Jamieson et al. (1991) the model is excellent for NDF, good for ash and CP and acceptable for PQDI, which may be justified by the operational principle of the sensor. The OptRx® sensor detects vegetation with high levels of chlorophyll (photosynthetically active vegetation), and this is correlated with CP levels (Reddy et al. 2004). Pullanagari et al. (2013) also found satisfactory relationships between spectral measurements and pasture quality parameters such as CP content, which can be attributed to absorbance of visible radiance by chlorophyll that is abundant in green vegetation. According to Albayrak (2008) canopy reflectance can be used for non-destructive prediction of forage quality variables in pastures.

Naturally changes in species composition in space and time can affect these relationships, requiring further research, therefore the results of this work can be an important starting point for studies that enable the evaluation and calibration of the optical sensor for this specific application of pasture quality assessment in different sites and types of biodiverse pastures. This is a key factor for grazing management and for the calculation of feed supplementation needs throughout the vegetative cycle of the pasture. According to Rascher and Pieruschka (2008), optical sensing techniques have the potential to detect physiological and biochemical changes in plant ecosystems, and non-invasive detection of changes in photosynthetic energy conversion which may be of great potential for managing agricultural production in a future bio-based economy.

Measurement of vegetation indices, such as NDVI, with reflectance sensors is subject to saturation at top-end biomass levels, which has led several research teams to combine spectral reflectance measurements

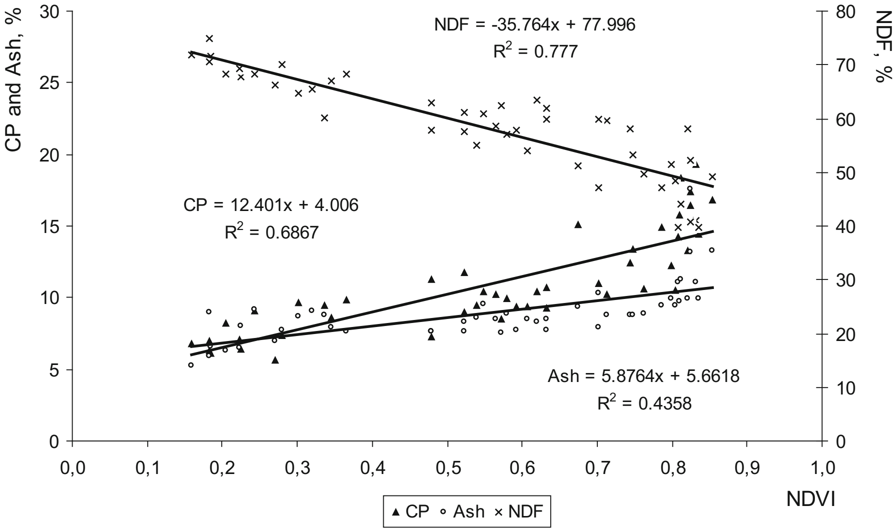


Fig. 12 Relationship between NDVI and pasture quality in terms of ash, crude protein (CP) and NDF

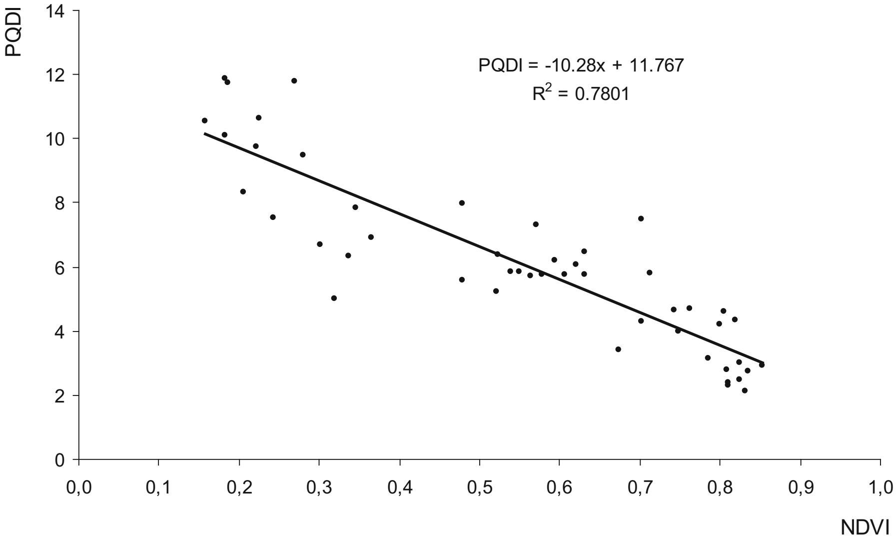


Fig. 13 Relationship between NDVI and pasture quality degradation index (PQDI)

with a physical parameter such as plant height to increase the range over which biomass can be estimated (Freeman et al. 2007; Schaefer and Lamb 2016). It is, therefore, expected that in the coming years new technologies will emerge in response to this challenge, taking into consideration the possibilities offered by remote sensing.

Conclusions

The agriculture sector faces challenges for competitiveness and sustainability which, demand up-to-date knowledge of the options that allow optimization of the productive process. Some of the latest methodologies rely upon the use of sensors that enable the collection of large datasets in real time. However, applying sensors to grazing systems is challenging and may be impaired by the highly spatial and temporal variability of these ecosystems. New technologies for plot-based monitoring are becoming available and affordable. The information created about the spatial and temporal variability of pastures constitutes the basis for the estimate of available feed, a fundamental decision support tool for the farm manager in defining the animal stocking and the rotation of the grazed paddocks. In the present work, the correlation between pasture and proximal sensor parameters was consistent between capacitance and pasture productivity, between NDVI and pasture productivity and between NDVI and pasture quality. Naturally changes in species composition in space and time can affect these relationships, requiring further research under these conditions, in different sites and types of biodiverse pastures. These results highlight the importance of developing an ideal pasture monitoring system that combines data from multiple sources to produce maps with greater detail and accuracy: large-scale satellite remote sensing images, used as reference when a spatial assessment of pastures is required, coupled with fine-scale information provided through high-resolution proximal sensing data, for repeated and continuous monitoring of the pastures. An integrated pasture monitoring system will provide a much better understanding of the livestock system, serving as the basis for the most appropriate management strategies, such as grazing rotations, nutrient management or yield prediction, which are fundamental for ensuring the sustainability of extensive animal production systems.

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