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Monitoring pasture variability: optical OptRx® crop sensor versus Grassmaster II capacitance probe

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Abstract Estimation of pasture productivity is an important step for the farmer in terms of planning animal stocking, organizing animal lots, and determining supplementary feeding needs throughout the year. The main objective of this work was to evaluate technologies which have potential for monitoring aspects related to spatial and temporal variability of pasture green and dry matter yield (respectively, GM and DM, in kg/ha) and support to decision making for the farmer. Two types of sensors were evaluated: an active optical sensor ("OptRx®," which measures the NDVI, "Normalized Difference Vegetation Index") and a capacitance probe ("GrassMaster II" which estimates plant mass). The results showed the potential of NDVI for monitoring the evolution of spatial and temporal patterns of vegetative growth of biodiverse pasture. Higher NDVI values were registered as pasture approached its greatest vegetative vigor, with a significant fall in the measured NDVI at the end of Spring, when the pasture began to dry due to the combination of higher temperatures and lower soil moisture content. This index was also effective for identifying different plant species (grasses/legumes) and variability in pasture yield. Furthermore, it was possible to develop calibration equations between the capacitance and the NDVI ($R^2 = 0.757$; $p < 0.01$), between capacitance and GM ($R^2 = 0.799$; $p < 0.01$), between capacitance and DM ($R^2 = 0.630$; $p < 0.01$), between NDVI and GM ($R^2 = 0.745$; $p < 0.01$), and between capacitance and DM ($R^2 = 0.524$; $p < 0.01$). Finally, a direct relationship was obtained between NDVI and pasture moisture content (PMC, in %) and between capacitance and PMC (respectively, $R^2 = 0.615$; $p < 0.01$ and $R^2 = 0.561$; $p < 0.01$) in Alentejo dryland farming systems.

Keywords Sensors · NDVI · Grassmaster · Pastures · Monitoring

Introduction

Presently, agriculture faces the challenge of increasing food production in response to the growth in world population. An additional challenge is the need to improve the efficiency of the use of production factors, in order to reduce the environmental impact of the farming activity. It is in this context that precision agriculture emerges, making use of sensors, electronic information systems, information management and data analysis tools (geographic information systems, GIS), georeferencing technologies (Global Navigation Satellite System, GNSS), and variable application technologies (Variable Rate Technology, VRT) (Braga and Pinto 2011; Serrano et al. 2014b) in order to optimize the use of resources.

The intensive agro-forestry production system, composed of pastures under tree cover (called "montado" in Portugal and "dehesa" in Spain), covers 3.5–4 million hectares in Portugal and Spain (Seddaiu et al. 2013).

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This type of soil use incorporates biodiverse pastures, different tree types, and grazing animals and accounts for 26 % of the world's agricultural land (Schellberg et al. 2008; Rutledge et al. 2014; Schipper et al. 2014) and 33 % of the total forest area in Portugal (David et al. 2013).

Given the extension of this scenario in the Mediterranean region, the variability of this ecosystem associated with its economic importance demonstrates the potential for differentiated management and use of precision agriculture (PA) (Serrano et al. 2014a). Nonetheless, the diversity of patterns associated with the spatial variability of the soil and the crop dynamics (botanical species and their mixture), with the characteristics of the relief, animal grazing, and climate conditions, can be possible limitations to the application of PA technologies in pastures (Schellberg et al. 2008). The low economic value of grassland products limits the application of expensive hard technologies. However, grassland can benefit from technological developments that have been achieved for arable crops over the past decades (Schellberg et al. 2008). These advances have provided the development of tools that allow for the characterization of the spatial variability of the crops (Cox 2002).

Measurement of plant biomass is the most important procedure in grassland management and field studies of grassland (Tsutsumi and Itano 2005). Pasture management, in terms of grazing and fallow periods in rotational systems, and the estimation of the potential maximum number of animals per unit area are essentially based on estimated herbage mass production and accumulation (Virkajarvi 1999). The methods for evaluating forage mass are mainly grouped in direct and indirect methods. The standard direct method of assessing pasture and forage yield is based on cutting and weighing the forage in a sample area of the pasture (Cauduro et al. 2006). This requires great effort and expense to collect enough samples to accurately represent a pasture (Sharrow 1984; Hanna et al. 1999; Ganguli et al. 2000; Serrano et al. 2011), and it is not cost-effective (Sanderson et al. 2001). Therefore, other techniques, non-destructive and useful over large areas, are required to clarify yield variability and implement more contemporary production strategies such as PA or site-specific management.

Many labor-saving methods for measuring biomass have been proposed (Trotter et al. 2012), such as the electronic capacitance meter (Vickery and Nicol 1982), the rising-plate meter (Scrivner et al. 1986; Laca et al. 1989), or the sward stick (Hutchings 1991). The electronic capacitance meter has been adapted for commercial use, and the interest in its validation remains high, since each pasture is a different ecosystem, with specific characteristics depending on the plant species, their vegetative states, ratio of green to dead material, and the type of grazing management (Reese et al. 1980; Karl and Nicholson 1987; Aiken and Bransby 1992), requiring site-specific calibration. It was shown that this proximal or ground technique requires frequent calibration, with no universal equations for estimating pasture mass.

While the electronic capacitance meter shows relative accuracy (Serrano et al. 2011), this cannot provide estimates across large spatially diverse pastoral landscapes without considerable effort (Trotter et al. 2012). To overcome this problem, several other equipment have been developed that can potentially be mounted on vehicles, including the C-Dax Pasture Meter (Pasture Meter, C-Dax Ltd, Palmerston North, New Zealand) or the Farmworks Ultrasonic Feed Reader (Department of Primary Industries, Australia) (King et al. 2010).

Another very interesting and current approach is the use of remote sensing images (Akiyama and Kawamura 2007). Based on satellite surveillance (e.g., "Pastures from Space," CSIRO, Australia), farmers are provided with estimates of herbage availability over large areas. Donald et al. (2013) used the Landsat satellite imagery data to obtain Normalized Difference Vegetation Index (NDVI) and measure and map pasture biomass. Such applications can assist in decisions relating to pasture renovation, maintenance of pasture composition and soil fertility, and adjusting of stocking rates and grazing management across all paddocks of entire farms (Donald et al. 2013).

With regards to the sensors that can be mounted on vehicles (agricultural tractors, ATVs, etc.), the optical sensors are included in the category of proximal sensors (Trotter 2010). The purpose of these sensors is to overcome some of the limitations, namely, the spatial resolution, of remote detection by satellite imagery (Bausch and Delgado 2003). The dimensions and arrangement of the vegetation units and patterns vary among systems, meaning that no one pixel size fits all precision management requirements (Schellberg et al. 2008).

The optical sensors can be passive (use natural light) or active (have their own light source), with the latter being able to work under all light conditions, such as night. According to Numata et al. (2008), variables such as existing botanical species, density, height, moisture level, percentage of green matter, vegetative condition, or even nutritional state of a crop can translate into different measurements by the optical sensors.

Normally, the measurements of the optical sensors are transformed into vegetation indexes (Qi et al. 1994). For example, NDVI is the best known and most widely used vegetation index and is related to the quantity of photosynthetically active vegetation, that is, to the vegetative vigor of the plants (Morgan and Ess 1997; Broge and Leblanc 2000; Gitelson 2004; Akiyama and Kawamura 2007). Calculation of this index is based on the measurement of two bands: the near infra-red (NIR) and red (RED) (Eq. 1).

$$\mathrm{NDVI} = (\mathrm{NIR}-\mathrm{RED})/(\mathrm{NIR}+\mathrm{RED}) \quad (1)$$

The use of these optical sensors on crops has led to publication of promising results, for example, in measuring cereal water stress (Laliberte et al. 2010) or in identifying areas with weeds (Adamchuk et al. 2004). These two applications are particularly relevant as support for decision making in managing irrigation or application of herbicides, respectively. Another very common application is related to the identification of cereal nitrogen deficiencies, which causes yellowing of the leaves. This principle is used by the "N-sensor" (VRT), which ensures the differential application of nitrogen fertilizer according to the color of leaves (Povh et al. 2008).

Despite some recent studies carried out in Australia and New Zealand (Trotter et al. 2012), there are no published research works focused on the application of optical sensors in monitoring the spatial variability of Mediterranean pastures.

The main objective of this work was to evaluate two technologies which have potential for monitoring pasture variability and support to decision making for the farmer: an active optical sensor ("OptRx®") and a capacitance probe ("Grassmaster II"). Three specific objectives were established: (i) evaluate the active optical sensor OptRx® for surveying the evolution of spatial and temporal patterns of the vegetative state of a pasture; (ii) evaluate the active optical sensor OptRx® for identifying different botanical species in the pasture; and (iii) develop calibration equations for Grassmaster II capacitance probe and for the OptRx® active optical sensor for estimating the productivity of dryland pastures of the Alentejo region.

Material and methods

Experimental sites

The experiments were carried out at two locations in the Évora District: site 1 "Silveira" (coordinates 38° 62.2′ N; 7° 94.8′ W) and site 2 "Mitra" (coordinates 38° 32.2′ N; 8° 01.1′ W).

The field used in site 1 (Fig. 1), with about 7 ha, is located on a slightly sloped area, with elevations of between 273 and 282 m, and sparse trees (olive trees, oak trees, ashes, and mulberries), and is crossed by a torrential water line. It is a natural grazeland composed mainly of grasses, which was not grazed between 2014 and 2015 and thus had a reasonable amount of dry stubble. Forty-seven sampling points were previously geo-referenced with a real-time kinematic (RTK) GNSS instrument (Trimble RTK/PP-4700 GPS, manufactured by Trimble Navigation Limited, USA), each representing a square measuring 34 m on each side (Fig. 1, left). A topographic survey of the area was carried out using the same GNSS receiver. 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, right) was created using the linear interpolation TIN tool from ArcGIS 10.2 (Esri, Redlands, CA, USA) and converted to a grid surface with 1 m grid resolution.

Site 2 had biodiverse forage plants (with a balance of grasses and legumes), which were cut while still green and used as hay or silage.

Characterization of the climate

Figure 2 illustrates the average thermo-pluviometric diagrams of the Évora meteorological station between 1951 and 1980 and in the agricultural year 2014/2015 (in this case only between September 2014 and May 2015, which is the period that influences the productivity of the pasture studied in this experiment).

Comparision of the two diagrams of Fig. 2 shows very significant differences between the agricultural year 2014/2015 and the average historical values in terms of temperature and average monthly precipitation. In terms of temperature, while the spring of 2014/2015 had average values of 14, 17, and 23 °C, respectively, in March, April, and May, the historical averages for the same period were 12, 14, and 17 °C, respectively. In terms of accumulated rainfall between January and May,

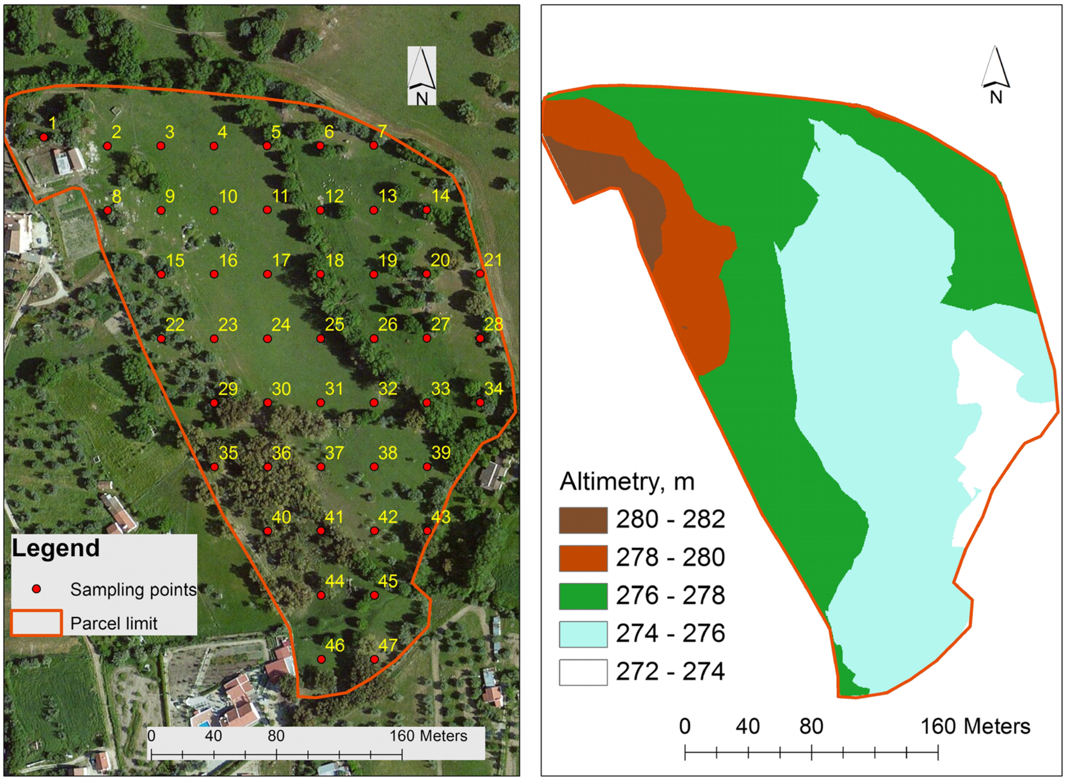


Fig 1 Site 1 ("Silveira"): *left*, aerial photograph (47 sampling points); *right*, altimetry map

the historical average is 350 mm, while in 2015 the rainfall was less than half of this value. The accumulated influence of smaller rainfall and higher temperatures transformed 2015 into an atypical year, with direct influence on the vegetative cycle of the dryland pastures in Alentejo.

Equipments used

The following equipment were used in these experiments:

1. RTK GNSS instrument (Trimble RTK/PP-4700 GPS)
2. Grassmaster II probe (Novel Ways Electronic, Hamilton, New Zealand) (Fig. 3, left)
3. OptRx® active optical sensor (Ag Leader, 2202 South Riverside Drive, Ames, IA 50010, USA) and its power source (small portable battery) (Fig. 3, right)
4. Trimble GNSS, GeoExplorer 6000 series receiver, model 88951, with sub-metric precision (GmbH, Am Prime Parc 11, 65479 Raunheim, Germany) (Fig. 3, right)
5. Material for characterization, cutting, and collecting of the pasture (metallic ruler, metallic ring with an area of 0.1 m^2; portable grass shears; plastic bags with identification of the sampling point)

Methodology of the experiment at site 1 Silveira

At this site, the evolution of the pasture was monitored during the peak spring production season of 2015, with four experiments between March and May (16 March, 14 April, 30 April, and 21 May).

Wooden sticks were used to identify 47 sampling points (see Fig. 1, left). The evolution of the pasture was recorded at each monitoring date, by measuring all 47 sampling points with the OptRx® active optical sensor, associated with the Trimble GNSS receiver. The sensor, placed on a platform standing 0.75 m above the ground (about 0.5 m above the pasture, considering an average pasture height of 0.25 m), registered the value of NDVI obtained from a 2-min sampling of each

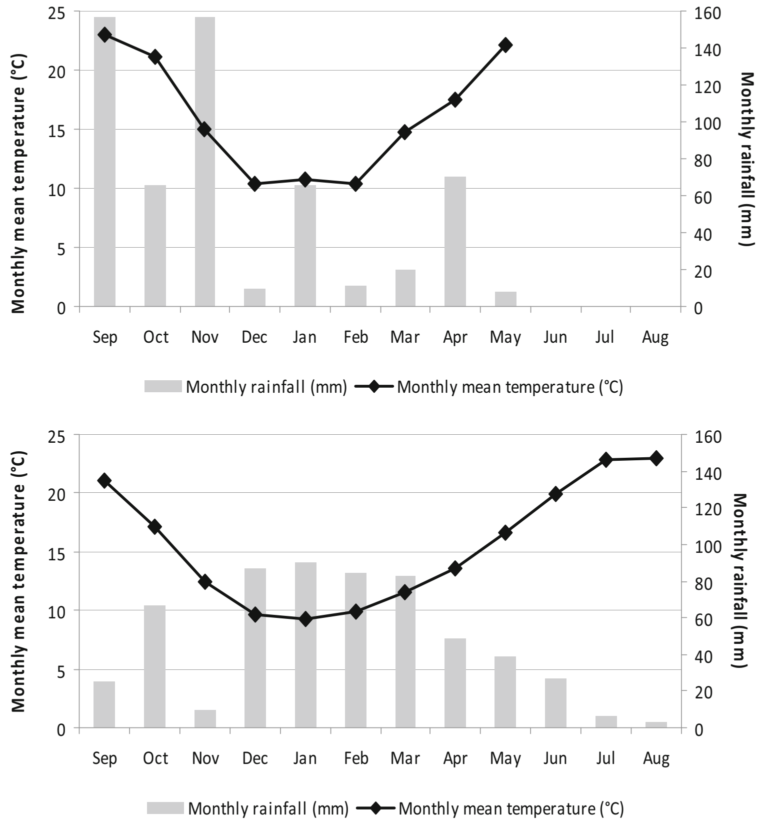


Fig 2 Monthly mean temperature and rainfall for the study area: *top*, average data for the years 1951–1980; *bottom*, data for the year 2014–2015

geo-referenced point. The operator, walking slowly, performed measurements along an imaginary circle with a 3-m radius around the geo-referenced point and then stood still at the area within the circle previously defined as being representative of the vegetation at the geo-referenced point, for the rest of the 2-min period.

In the last experiment carried out at site 1 (21 May), once the optical sensor operator had finished each site, a second operator would measure capacitance with the Grassmaster II probe, followed by a third operator who would cut and collect the green matter contained in the metallic circle (with a 0.1 m^2 area). Each measurement by the Grassmaster probe was preceded by an air humidity level correction. The capacitance 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 measuring area, 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). Following the readings, the metallic rim was placed and the pasture inside each sampling point was cut with a portable

Fig 3 *Left*, console of the Grassmaster II capacitance probe; *right*, optical sensor ("OptRx®"), GPS receiver ("Trimble"), and portable battery used in field trials

electric grass shears at 1–2 cm above ground level and stored in marked plastic bags.

The collected pasture samples were then taken to the Pasture and Forage Technology Laboratory of the University of Évora, where they were weighed, dehydrated (for 72 h at 65 °C), and then weighed again to establish pasture productivity in terms of green matter (kg GM/ha) and dry matter (kg DM/ha) according to standard procedures (Serrano et al. 2009).

The NDVI index and the measurements related to pasture productivity were organized in a spreadsheet and associated with the coordinates of the respective sampling points.

Also in 21 May, 47 geo-referenced soil samples were taken in site 1 using a gouge auger and a hammer, from the 0–0.30-m soil layer. The soil was characterized in terms of soil moisture content (SMC), organic matter, P_2O_5, and K_2O.

Experimental methodology at site 2 Mitra

The aim of this experiment, carried out at the peak of flowering (first week of April 2015), was to evaluate the consistency of the measurements by the vegetation sensor and, at the same time, the sensitivity of the sensor to different botanical species and different productivities. Three experiments were carried out, which correspond to the different paths taken by the operator with the OptRx® sensor at a height of 0.75 m from the ground.

Experiment 2.1—Five repetitions were carried out on a path composed of three zones: a zone of bare soil, a zone of grasses, and a zone of legumes. In the two pasture areas, this was followed by the measurement of the capacitance with the Grassmaster II probe and cutting of the vegetative material (in an area of 0.1 m^2) for direct measurement of productivity.

Experiment 2.2—Five repetitions were carried out on a path composed of six zones: bare soil, high grasses (0.50 m height), legumes, dry grasses, low grasses (0.15 m height), and bare soil. In the four pasture zones, this was followed by the measurement of the capacitance with the Grassmaster II probe and cutting of the vegetative material (in an area of 0.1 m^2) for direct measurement of productivity.

Experiment 2.3—Two zones of the pasture were selected, one with only legumes and the other with only grasses. In each of these, three sampling points were referenced with short pasture (<0.30 m high) and three sampling points with tall pasture (0.60–0.70 m high). At each one of these locations, NDVI and capacitance were measured, followed by cutting of the vegetative material (in an area of 0.1 m^2) for direct measurement of productivity.

Statistical treatment of the data

Descriptive statistical analysis (average, interval of variation, standard deviation, and coefficient of variation) was calculated for the various data sets obtained from the field (NDVI, capacitance, and forage productivity).

The data obtained in the experiments carried out at site 1 were analyzed with ArcGIS 10.2 (Esri, Redlands, CA, USA) software to produce the corresponding maps. All surfaces (NDVI, capacitance, pasture productivity, soil moisture content, organic matter, phosphorus, and potassium) were interpoled on a 5-m grid, using an ordinary kriging method and a spherical semivariogram model with a 30-m lag size. Table 1 shows the best variogram models obtained with the ordinary kriking interpolator for soil and pasture parameters.

The data obtained in all the experiments (both sites 1 and 2) were aggregated, and correlations were established between the parameters with a level of statistical significance of 95 % ($p < 0.05$).

The Pearson correlation coefficient, the most common statistical technique used in analytical studies of the relative consistency (Atkinson and Nevill 1998), was used to evaluate the relationship between the pasture and soil parameters in site 1 and the repeatability between the measurements carried out in site 2.

Results and discussion

Experiments at site 1 Silveira

Table 2 shows the descriptive statistics of NDVI at different dates and of pasture and soil parameters on 21 May 2015, using the set of 47 sampling points of the pasture at site 1.

The vegetation indexes indicate the condition of vegetation at a particular field: values of NDVI close to 1 mean higher soil coverage by photosynthetically active vegetation; at the other extreme, values of NDVI close

Table 1 Best variogram models obtained with the ordinary kriging interpolator for soil and plant parameters (spherical model and lag size of 30.0 m)

Parameter	Nugget effect	Partial sill	Range (m)	RMSSE
Pasture				
$NDVI_{16/03}$	0.00	0.02	102.43	1.01
$NDVI_{14/04}$	0.00	0.01	34.51	1.03
$NDVI_{30/04}$	0.00	0.01	10.10	1.01
$NDVI_{21/05}$	0.00	0.01	29.73	1.06
$GM_{21/05}$ (kg/ha)	9970713.25	8839686.77	360.00	0.99
$DM_{21/05}$ (kg/ha)	561105.64	0.00	434.56	0.98
$CMR^2{}_{1/05}$	1725447.04	1597309.54	64.84	0.99
$PMC_{21/05}$ (%)	63.67	2.99	360.00	0.99
Soil				
SMC (%)	13.52	12.62	64.84	1.06
OM (%)	0.18	0.61	360.00	1.17
P_2O_5 (mg/kg)	131.42	1322.76	360.00	0.99
K_2O (mg/kg)	526.91	1754.32	360.00	1.05

GM green matter, *DM* dry matter, *CMR* capacitance, *PMC* pasture moisture content, *OM* soil organic matter, *SMC* soil moisture content, *RMSSE* root mean squared standardized error

to 0 indicate areas of bare soil (Dusseux et al. 2015). Through descriptive statistical analysis, it is possible to carry out a first evaluation of the spatial and temporal variability of pasture at site 1. At all the measurement dates, the values of NDVI for the 47 sampled points show great consistency in terms of interval of variation, average, and coefficient of variation (CV). The latter varied between 13 and 16 % at the four sampling dates.

Figure 4 shows the maps of spatial variability of NDVI and evolution of its patterns during the growing season, between March and May 2015. In average terms (see Table 2), the value of NDVI increased progressively between mid March and the end of April ($NDVI_{méd} = 0.521 \pm 0.073$ on 16 March; $NDVI_{méd} = 0.569 \pm 0.074$ on 14 April; and $NDVI_{méd} = 0.586 \pm 0.080$ on 30 April) and then decreased significantly on 21 May ($NDVI_{méd} = 0.468 \pm 0.073$). The positive evolution of this index at the beginning of spring reflects the evolution of the meteorological conditions in the region (see Fig. 2), when the average temperatures reached 15–20 °C and monthly rainfall was around 70 mm. The combination of these two conditions resulted in rapid growth of pasture after a characteristic

Table 2 Descriptive statistics of Normalized Difference Vegetation Index (NDVI) at different dates and of pasture and soil parameters on 21 May 2015, using the set of 47 sampling points of the pasture at site 1

Parameters	Pasture								Soil			
	NDVI				GM (kg/ha)	DM (kg/ha)	CMR	PMC (%)	SMC (%)	OM (%)	P_2O5 (mg/kg)	K_2O (mg/kg)
Date (2015)	16/03	14/04	30/04	21/05	21/05	21/05	21/05	21/05	21/05	21/05	21/05	21/05
Mínimum	0.329	0.344	0.391	0.310	2198	608	3134	43.8	5.8	0.7	8.0	48.0
Maximum	0.814	0.786	0.795	0.759	22330	4450	9631	89.2	27.5	4.5	1648.0	930.0
Mean	0.521	0.569	0.586	0.468	6373	1916	5321	66.9	13.4	1.6	64.0	118.0
SD	0.116	0.103	0.097	0.110	4360	922	1997	9.7	6.0	0.8	237.8	126.9
CV (%)	22.3	18.1	16.5	23.5	68.4	48.1	37.5	43.8	45.0	47.8	371.6	107.6

GM green matter, *DM* dry matter, *PMC* pasture moisture content, *CMR* capacitance, *SMC* soil moisture content, *OM* soil organic matter, *SD* standard deviation, *CV* coefficient of variation

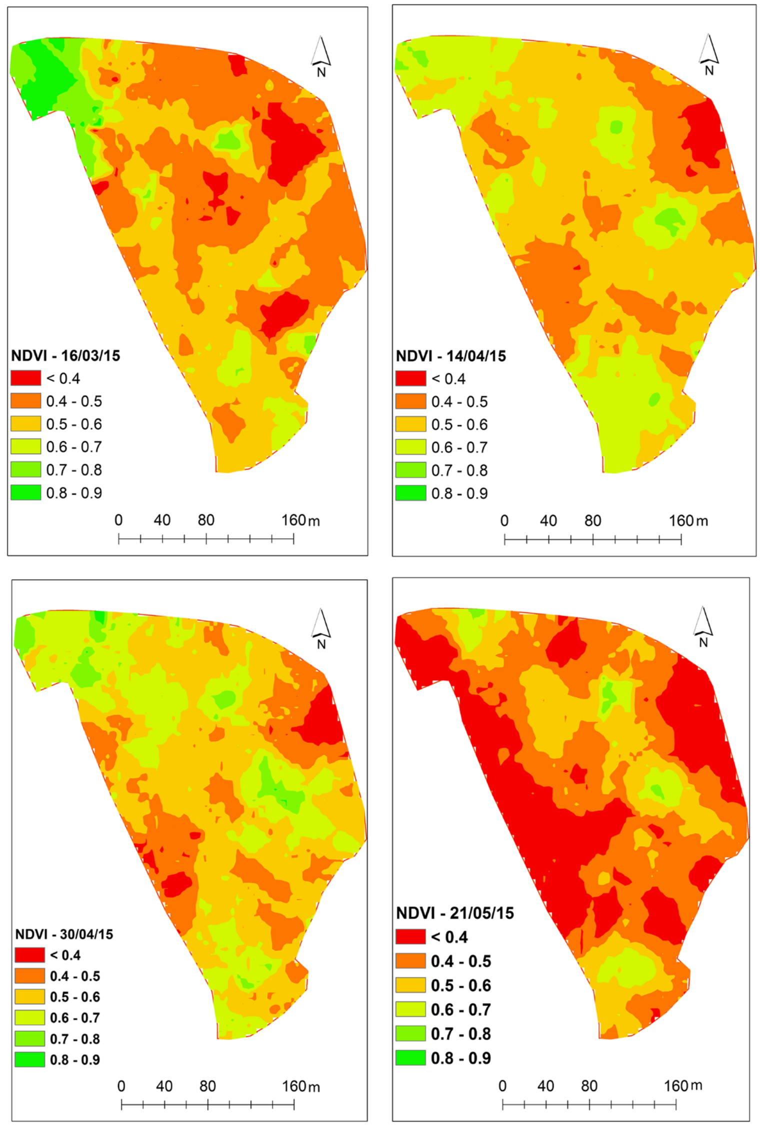


Fig 4 NDVI maps of site 1 ("Silveira"), between March and May of 2015

winter with low temperatures that slowed the vegetative growth. The results also indicate a decrease in the values of pasture NDVI on 21 May, after a few days of exceptionally high temperatures for the season, which, associated with a dry spell, accelerated the vegetative cycle of these dryland plants, resulting in many areas of dry vegetation. This pattern, strongly dependent on the conjugation of the temperature/rainfall binomium, is characteristic of Mediterranean dryland pastures (Marques da Silva et al. 2008). Many studies recognize the role of water in vegetative development of pastures. Kumhálová et al. (2011) confirmed that the availability of water is one of the main productivity factors for pastures, especially in dry years. Starting at the end of spring, the ground is covered with dry vegetation until the beginning of the first rains, normally between September and October, when a new growth cycle begins.

Unlike NDVI, the productivity of the pasture showed high values of CV, ranging between 50 % (in the case of DM) and 70 % (in the case of GM), which shows the extraordinary heterogenity of the parcel, namely, in terms of soil drainage, with impact on the plant growth cycle. An extensive area of the valley remained waterlogged during all the winter and part of the spring. On the other hand, the absence of animal grazing in the year 2014 led to the accumulation of dry grasses from the previous year in all the low areas and thus resulted in relatively low average productivity (less than 2000 kg of DM/ha) which reflect an inadequate management of the animal grazing, associated with the Mediterranean climate conditions with poor soils and irregular distribution of the rainfall (Efe Serrano 2006). Additionally, an extensive area of pasture with low productivity was visible under the dense tree cover, where the shade promotes mainly the development of shrubs.

Figure 5 presents the maps showing the spatial patterns of pasture productivity (in terms of GM and DM) of PMC and CMR on 21 May. The highest values of PMC (higher than 70 %) are observed at the opposite ends of the field (Northwest and Southeast), corresponding also to higher pasture productivity and higher measured values of capacitance by the Grassmaster II probe.

Table 2 shows the high variability of soil parameters, with the moisture and organic matter presenting a CV value close to 50 % and the main macronutrients phosphorus and potassium presenting a CV value of more than 100 %. This spatial variation is represented in the form of maps in Fig. 6. It is possible to perceive similarity of patterns between SMC (Fig. 6), NDVI (Fig. 4), GM, and CMR (Fig. 5). Moreover, similarity between the patterns of soil organic matter, phosphorus (P_2O_5), and potassium (K_2O) (Fig. 6) is clear; aspects confirmed in Table 3 through high correlation coefficients.

In summary, the evaluation of the pasture at Silveira site reveals essentially three zones (Table 4):

1. Some pockets of legumes (mainly *Trifolium subterraneum*) which cover only about 10 % of the area of the field (5 out of the 47 sampling squares); in

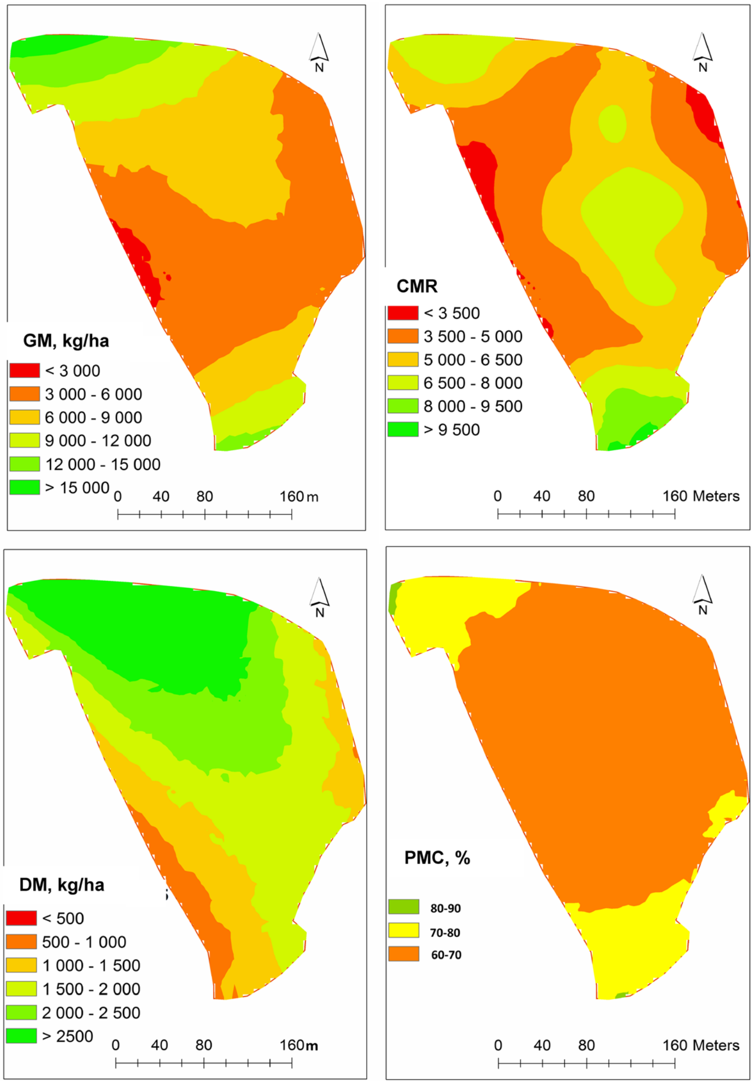
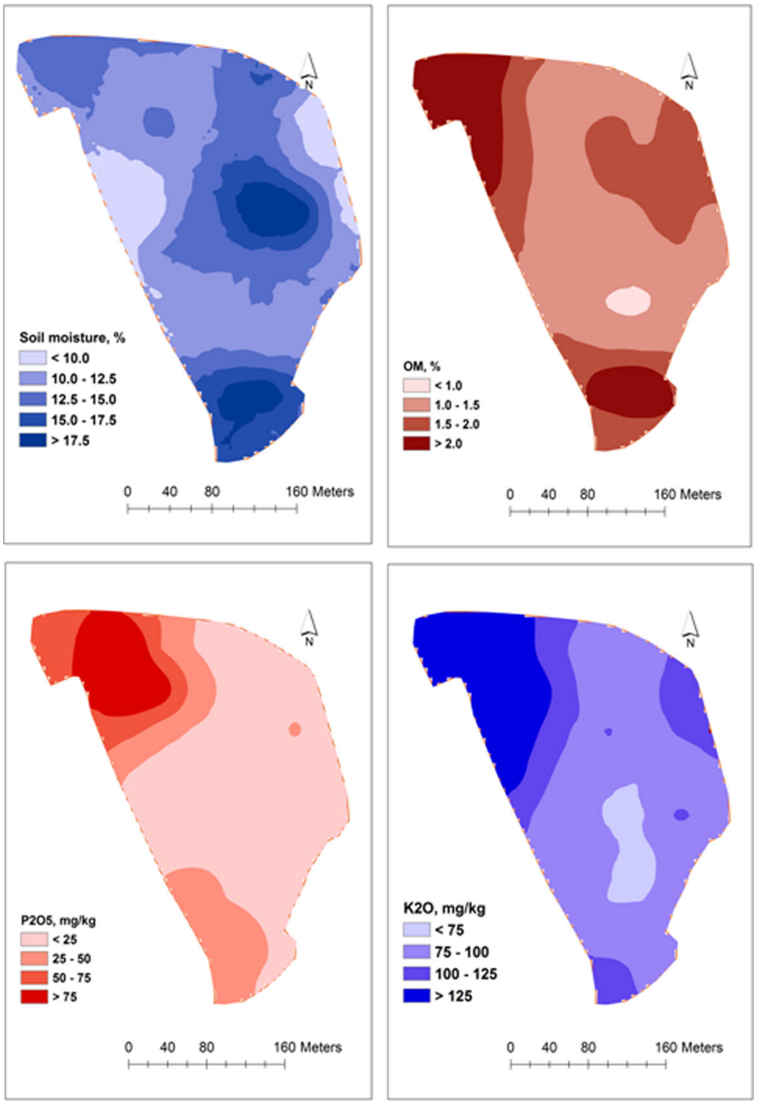


Fig 5 Capacitance (CMR), pasture green (GM), and dry matter (DM) and pasture moisture content (PMC) maps of site 1 ("Silveira"), of 21 May 2015

Fig 6 Soil moisture content, organic matter (OM), phosphorus (P_2O_5), and potassium (K_2O) maps of site 1 ("Silveira")



well-drained shade areas, with higher productivity of GM and higher PMC, corresponding to relatively high vegetation indexes and capacitance values ($NDVI_{méd}=0.563\pm0.176$; $CMR=7158\pm2103$)

2. Predominance of grasses (mainly *Lolium rigidum*) at around half of the area of the field (22 of the 47 sampling squares), in the flat areas with a tendency for waterlogging during the winter, with dry stubble from the previous year limiting the vegetative development; intermediate values of vegetation index and of capacitance ($NDVI_{méd}=0.490\pm0.095$; $CMR=5749\pm2070$)
3. Tree cover zone which occupies around 40 % of the field area (20 of the 47 sampling squares), with a reduced solar exposition, where other short botanical species predominate (mainly *Anagalis arvensis*) with low productivity (mostly less than 1000 kg of DM/ha); the low vegetative cover originates low indexes of vegetation and capacitance ($NDVI_{méd}=0.421\pm0.086$; $CMR=4344\pm1350$).

In practice, this information can be made available to the farmer to make management decisions. Despite this pasture having an ecosystem with a high potential due to water availability and the tree cover, its present state justifies an intervention as to promote a better biodiverse equilibrium, which could be achieved through corrections of the soil drainage, phosphate fertilization, and differential

Table 3 Correlation coefficients (*r*) between pasture and soil parameters at site 1

Parameters	Pasture					Soil			
	GM	DM	CMR	PMC	NDVI	SMC	OM	P_2O_5	K_2O
Pasture									
GM	1	0.638**	0.664**	0.449*	0.678**	0.485*	0.324*	ns	ns
DM	–	1	0.284*	ns	0.405*	0.321*	ns	ns	ns
CMR	–	–	1	0.671**	0.700**	0.775**	ns	ns	ns
PMC	–	–	–	1	0.457*	0.351*	ns	ns	ns
NDVI	–	–	–	–	1	0.709**	ns	ns	ns
Soil									
SMC	–	–	–	–	–	1	0.275*	ns	ns
OM	–	–	–	–	–	–	1	0.577**	0.645**
P_2O_5	–	–	–	–	–	–	–	1	0.969**
K_2O	–	–	–	–	–	–	–	–	1

GM green matter, kg/ha, *DM* dry matter, kg/ha, *CMR* capacitance, *PMC* pasture moisture content, %, *NDVI* normalized difference vegetation index, *SMC* soil moisture content, %, *OM* soil organic matter, %, P_2O_5 and K_2O, mg/kg, *ns* correlation not significant

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

planting of legumes and by the re-establishment of regular grazing.

Experiments at site 2 Mitra

Table 5 presents the average values of the main characteristics of the pasture zones considered in the experiment at site 2.

In experiment 2.1, consisting of two pasture zones (grasses and legumes), the zone covered by legumes (dominating species, *Trifolium resupinatum*) clearly presents higher productivity of green matter and higher PMC than the grass area (predominant species, *Holcus lanatus*), indicating a less advanced state of vegetative development, corresponding to higher values of NDVI and capacitance.

In experiment 2.2, consisting of four pasture zones (tall grasses, legumes, dry grasses, and low grasses), the highest values of NDVI and capacitance were obtained in the case of legumes (predominant species, *Medicago polymorpha* and *Medicago rugosa*) and grasses (predominant species, *Avena sterilis* and *Hordeum murinum*), tall and green—zones which have higher green matter production (GM) and higher PMC values (>80 %). The lowest values of NDVI and capacitance were observed in the areas with dry grasses and lower productivity. The short grasses presented intermediate values of NDVI and capacitance.

In experiment 2.3, two productivity zones were identified in each botanical species: short and tall grasses, respectively with 0.3 and 0.7 m height (predominant species, *Chamaemelum fuscatum* and *Avena sativa*), and short and tall legumes, respectively with 0.3 and 0.6 m height (predominant species, *Trifolium michelianum*). The highest values of NDVI (and of capacitance) were observed simultaneously in the zone

Table 4 Characteristics of the different areas of the pasture at site 1 on 21 May 2015

Zone	NDVI	GM (kg/ha)	DM (kg/ha)	CMR	PMC (%)
(I) Legumes (*n* = 5)	0.563 ± 0.176	12098 ± 6380	2248 ± 583	7158 ± 2103	77.8 ± 11.0
(II) Grasses (*n* = 22)	0.490 ± 0.095	7235 ± 2467	2439 ± 806	5749 ± 2070	65.4 ± 6.6
(III) Other species (*n* = 20)	0.421 ± 0.086	3995 ± 3911	1225 ± 652	4344 ± 1350	65.8 ± 8.6

NDVI normalized difference vegetation index, *GM* green matter, *DM* dry matter, *CMR* capacitance, *PMC* pasture moisture content, *n* number of sampling points

Table 5 Average values of the main characteristics of the pasture zones considered in experiment at site 2

Site	Botanical species	NDVI	GM (kg/ha)	DM (kg/ha)	CMR	PMC (%)
2.1	Grasses (h = 20 cm)	0.600 ± 0.078	9700	2803	6081 ± 1263	71.1
2.1	Legumes (h = 30 cm)	0.784 ± 0.050	18700	2599	7957 ± 782	86.1
2.2	Tall grasses (h = 50 cm)	0.741 ± 0.023	17900	3401	5666 ± 253	81.0
2.2	Legumes (h = 25 cm)	0.857 ± 0.008	20100	1602	5680 ± 214	87.1
2.2	Dry grasses (h = 10 cm)	0.282 ± 0.012	3900	1275	3878 ± 172	67.3
2.2	Short grasses (h = 15 cm)	0.576 ± 0.030	4900	1509	4911 ± 188	69.2
2.3	Short grasses (rep. I)	0.638 ± 0.038	16100	2000	7488 ± 1211	87.6
2.3	Short grasses (rep. II)	0.542 ± 0.023	8300	1200	6334 ± 1034	85.5
2.3	Short grasses (rep. III)	0.688 ± 0.033	11300	1800	7296 ± 879	84.1
2.3	Tall grasses (rep. I)	0.778 ± 0.033	24300	4830	9384 ± 1605	80.1
2.3	Tall grasses (rep. II)	0.832 ± 0.023	28700	4470	12575 ± 2210	84.4
2.3	Tall grasses (rep. III)	0.795 ± 0.043	20900	3290	11301 ± 2517	84.3
2.3	Short legumes (rep. I)	0.737 ± 0.025	46100	7610	11953 ± 3816	83.5
2.3	Short legumes (rep. II)	0.705 ± 0.021	27700	4370	7192 ± 3325	83.2
2.3	Short legumes (rep. III)	0.746 ± 0.027	33900	5590	6435 ± 978	83.5
2.3	Tall legumes (rep. I)	0.909 ± 0.018	63500	7950	16864 ± 2176	87.5
2.3	Tall legumes (rep. II)	0.877 ± 0.069	73500	9550	14406 ± 2854	87.0
2.3	Tall legumes (rep. III)	0.899 ± 0.028	71900	8590	15536 ± 2176	88.1

NDVI normalized difference vegetation index, *GM* green matter, *DM* dry matter, *CMR* capacitance, *PMC* pasture moisture content, *h* height, *rep.* repetition

of high legumes (zone of highest productivity in terms of GM), and the lowest values of NDVI (and of capacitance) were observed simultaneously in the zone of short grasses (zone of lowest productivity in terms of GM).

Table 6 summarizes the values of NDVI measured in five repetitions, at the three zones considered in experiment 2.1 (bare soil, grasses, and legumes) and at the six zones considered in experiment 2.2 (two with bare soil and four with the above-mentioned pasture conditions). The results clearly indicate the stability of NDVI values in the various repetitions in any of these zones of the experiments 2.1 (0.14–0.16 for bare soil; 0.59–0.63 in the case of grasses; and 0.78–0.79 in the case of legumes) and 2.2 (0.10–0.13 for initial bare soil; 0.70–0.77 in the case of tall grasses; 0.85–0.87 in the case of legumes; 0.27–0.30 in the case of dry grasses; 0.55–0.63 in short grasses; and 0.09 in the final bare soil), which

Table 6 Normalized Difference Vegetation Index (NDVI) values measured at the five repetitions (I–V), at the zones considered in experiments 2.1 and 2.2

Experiment	Zone	I	II	III	IV	V
2.1	Bare soil	0.154 ± 0.023	0.143 ± 0.003	0.161 ± 0.024	0.160 ± 0.018	0.157 ± 0.006
2.1	Grasses (height = 20 cm)	0.611 ± 0.054	0.585 ± 0.070	0.589 ± 0.099	0.586 ± 0.060	0.631 ± 0.092
2.1	Legumes (height = 30 cm)	0.786 ± 0.042	0.783 ± 0.048	0.788 ± 0.059	0.777 ± 0.050	0.788 ± 0.049
2.2	Bare soil	0.104 ± 0.008	0.122 ± 0.005	0.122 ± 0.004	0.126 ± 0.006	0.126 ± 0.005
2.2	Tall grasses (height = 50 cm)	0.765 ± 0.016	0.704 ± 0.037	0.740 ± 0.017	0.744 ± 0.027	0.751 ± 0.014
2.2	Legumes (height = 25 cm)	0.852 ± 0.004	0.863 ± 0.007	0.851 ± 0.008	0.850 ± 0.005	0.867 ± 0.004
2.2	Dry grasses (height = 10 cm)	0.282 ± 0.006	0.280 ± 0.007	0.303 ± 0.007	0.275 ± 0.004	0.272 ± 0.003
2.2	Short grasses (height = 15 cm)	0.628 ± 0.006	0.568 ± 0.011	0.561 ± 0.006	0.554 ± 0.013	0.567 ± 0.004
2.2	Bare soil	0.086 ± 0.014	0.089 ± 0.004	0.084 ± 0.005	0.091 ± 0.004	0.089 ± 0.004

demonstrates the consistency of the sensor in identifying the different botanical species and, in the particular case of experiment 2.2, the different heights and vegetative states of the plants. This consistency of measurements at the same location was confirmed by the high correlation coefficients (Atkinson and Nevill 1998; Hopkins 2000) obtained between repetitions (range of 0.84 to 0.97).

This set of results of the experiments carried out at site 2 demonstrates the capacity of the OptRx® active optical sensor to identify different botanical species (grasses/legumes), diverse development stages, and different productivity zones within the same botanical species. In an analogy to the use of NDVI in cereals, for the identification of zones with nitrogen deficiency, this sensor can identify imbalances in the characteristics of the vegetation (botanical species), for example, due to water stress or deficient soil drainage. The information regarding the reduced presence or even extinction of a given botanical species in a certain zone of the field can be used in preparing differential application maps for fertilizers or seeds, which is the basis for using VRT.

Agregate data of sites 1 and 2

Correlation between parameters

The interest in evaluating fast tools for monitoring pastures has led various research teams to study these new technologies in various parts of the world. Nonetheless, there are no published works that provide a direct comparison of the capacitance probe and optical sensor in the monitoring of pasture productivity, which makes it difficult to provide background literature for this discussion, but which provides greater relevance to this study. It was based on these considerations that this study evaluated the correlation between the parameters measured by the sensors (capacitance and NDVI) as well as the correlation between these and the pasture characteristics (GM, DM, and PMC). To this end, the values of the data (NDVI, capacitance, GM, DM, and PMC) from the experiments carried out on 21 May at site 1 (47 samples) were aggregated with the data from the experiments carried out at site 2 (two samples from experiment 2.1; four samples from experiment 2.2; 12 samples from experiment 2.3).

Figure 7 shows the correlations between capacitance and NDVI using the aggregate of 65 samples. The resulting coefficient of determination ($R^2 = 0.757$) reveals a close relation between these two parameters, which is justified by the underlying operating principles of the two technologies and in their relation to the pasture productivity: (i) on the one hand, the capacitance probe is sensitive to pasture humidity (PMC) and thus tends to present higher values in pastures with higher GM content (Serrano et al. 2011); (ii) the OptRx® sensor, on the other hand, measures higher values of NDVI in areas with higher density of photosynthetically active vegetation (Dusseux et al. 2015), which also correspondes to higher concentration of GM.

Figures 8 and 9 show the best correlation equations (and their coefficients of determination) between productivity (GM and DM) or pasture humidity (PMC) and

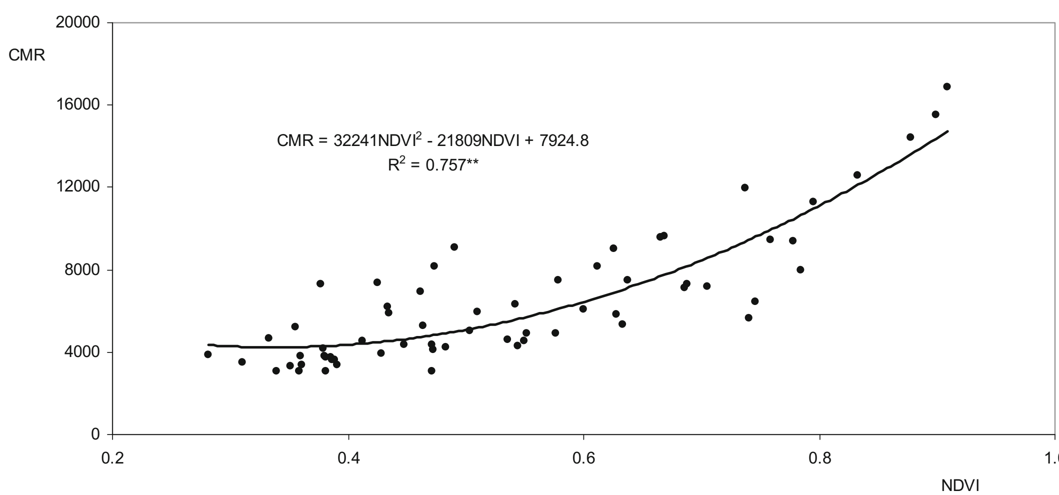


Fig 7 Correlation between the capacitance (CMR) and NDVI, using the set of all sampled points (experiment of 21 May at site 1 and experiment of site 2)

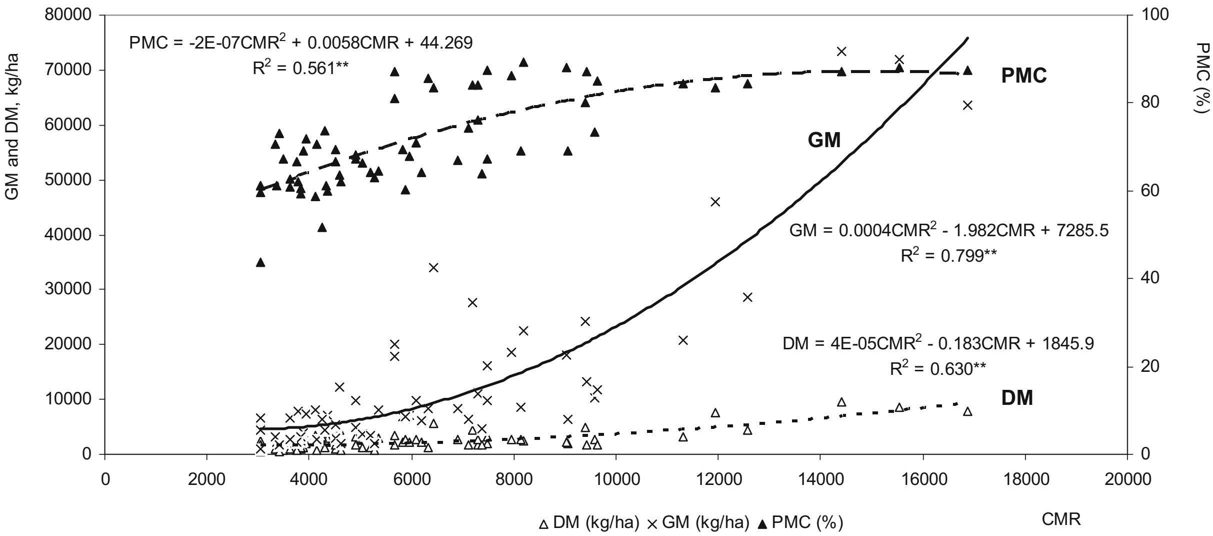


Fig 8 Correlation between pasture productivity (GM and DM) and capacitance (CMR) and between pasture moisture content (PMC) and capacitance (CMR) using the set of sampled points (experiment of 21 May at site 1 and experiment of site 2)

the measurements carried out by the sensors (capacitance and NDVI, respectively)

It is possible to observe a direct relation between all the parameters involved: greater values of capacitance and NDVI are related to higher pasture productivity (GM and DM) and to higher humidity rates in the pasture (PMC). In both cases (capacitance and NDVI), the best coefficients of determination were obtained in the correlation with GM ($R^2 = 0.799$ in the case of capacitance; $R^2 = 0.745$ in the case of NDVI). Despite being significant ($p < 0.05$), the correlations of capacitance and NDVI were weaker with DM and PMC (R^2 between 0.524 and 0.630), which certainly indicated the heterogenity of the vegetative state of the plants (varying for each botanical species) and the consequent variability of PMC, but which can also be a reflection of the above-mentioned interference of the senescent vegetation material which remained in the pasture at site 1, due to absence of animal grazing, a fact also observed by Barnes et al. (2010) and Trotter et al. (2012).

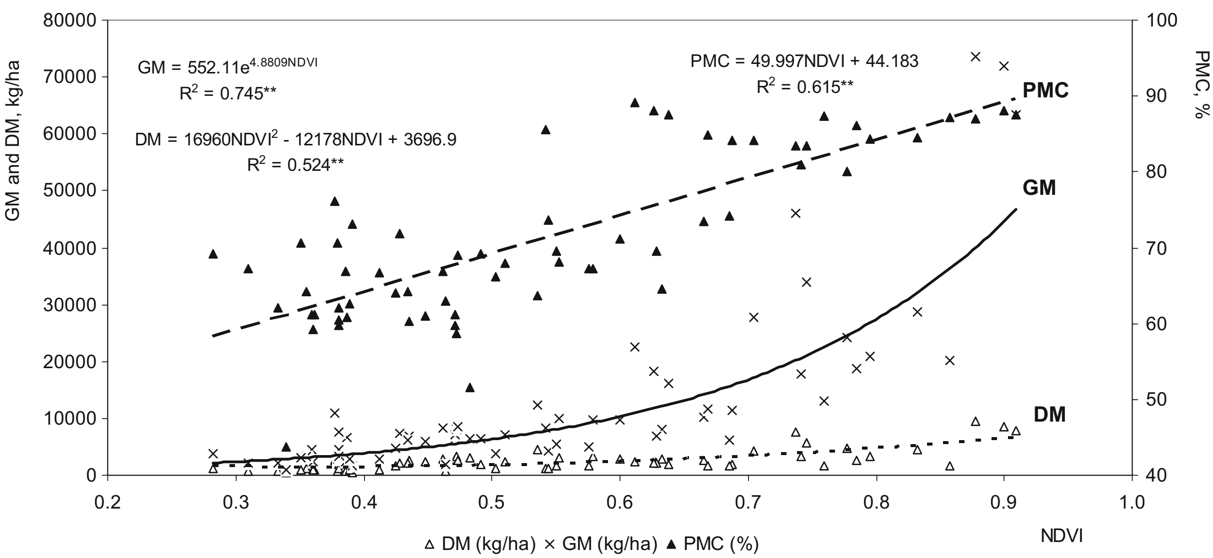


Fig 9 Correlation between pasture productivity (GM and DM) and NDVI and between pasture moisture content (PMC) and NDVI, using the set of sampled points (experiment of 21 May at site 1 and experiment of site 2)

Since these two tools present very similar and acceptable results for the characterization of the pasture productivity (areas with higher production and green matter present higher values of capacitance and NDVI), it is understandable that the active optical sensor should gradually replace the capacitance probe, since it has the advantage of monitoring an extensive area of the pasture in a continuous manner (for example, assembled on a motorized vehicle), in an expeditious way, without the need for the direct and manual intervention of the operator at each point, which is the case of the capacitance probe.

There are also good perspectives for using both in a complementary manner: on the one hand, the capacitance probe is more appropriate for the point estimate of productivity in certain areas of the pasture; on the other hand, the active optical sensor, since it does not need direct and manual intervention of the operator at each point and with the possibility of being assembled on a vehicle, has higher potential for fast, efficient, and continuous monitoring of extensive pasture areas, of their temporal evolution in terms of spatial variation of productivity and floral composition.

The significant correlation obtained between these parameters, for biodiverse pastures (grasses, legumes, and other species) representative of the region and with different states of vegetative growth (PMC of between 40 and 90 %), justifies the interest in development and extension of these studies to other pastures that are characteristic of the Mediterranean region. It can also be interesting to evaluate the capacity of the optical sensor at different times of the year, namely, at the peak of autumn production. Trotter et al. (2012) registered significant differences in the correlations obtained between pasture productivity and NDVI measured by active optical sensors in function of the proportion of vegetative and senescent material that existed at the pasture at different stages of its development.

Sensing and measurement of properties of crops provides high quantities of on-farm data which, if properly collected, stored, and interpreted, can provide excellent means for improving the knowledge on factors determining the production process (Schellberg et al. 2008). The use of fast and efficient tools associated with georeferenced systems can simplify the pasture monitoring process. 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 parcels (Serrano et al. 2014b).

Conclusions

Today, agriculture faces challenges related to competitivity and sustainability which demand by the farm manager up-to-date knowledge of the existing options for optimizing the productive process. Technologies are available for all the different stages of the process of PA, but, generally, the sellers do not provide comprehensive technical support which would allow the users to make the maximum use of them. The continuous evolution of the technological tools justifies, thus, the interest in experimentation, calibration, and sharing of the results.

The management of pastures and the planning and management of their respective animal production systems are essentially based on estimates of productivity. Thus, the evaluation of the technologies with potential for fast, efficient, and continuous monitoring of aspects related to the variability of the pasture that can help the decision-making process by the farm manager is a fundamental element for the economical success in a strategic sector such as extensive animal production.

In this work, two types of sensors for monitoring the spatial and temporal variability of the pasture were evaluated: an optical sensor and a capacitance probe. The results demonstrate the potential of OptRx® active sensor for monitoring the evolution of spatial and temporal patterns of vegetative growth in biodiverse pastures through the NDVI index. Higher indexes were registered as the pasture approached its full vegetative growth, with a pronounced fall in these indexes at the end of spring, when the pasture started to dry up due to the higher temperatures and a reduction in the soil moisture content. This index was also effective in the identification of different botanical species (grasses/legumes) and, within these, of the different development stages.

Significant and very strong correlations were obtained between capacitance (measured with Grassmaster II probe) and NDVI ($R^2 = 0.757$) and between any of these parameters and the pasture productivity in terms of kilogram of GM per hectare ($R^2 = 0.799$ and $R^2 = 0.745$, respectively). The correlations of these parameters with the pasture productivity in terms of kilogram of DM/ha and with the PMC showed weaker coefficients of determination (R^2 between 0.524 and 0.630), which might have been influenced by the pasture in site 1, which, because of lack of grazing, contained dry material from the previous year, which interfered with the measurements of the sensors.

The results open new perspectives for other works that would allow the testing, calibration, and validation of the active optical sensor in a wider range of pasture production conditions, namely, the extraordinary diversity of botanical species that are characteristic of the Mediterranean region at the different periods of the year (autumn and spring), but also in irrigated pastures and forages, under intensive production systems, where technological advantages are progressively more important.

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