Method Article

Classification of Mediterranean hedgerows: A methodological approximation

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A B S T R A C T

The present paper addresses the methodology carried out to obtain a new classification of hedgerow networks in the Mediterranean region using GIS and Remote Sensing. A new methodology has been developed due to the need to establish a typification of the hedgerows in this sector of southern Europe, where the variable conditioning the localization, area and type of these landscapes is degree of surface soil moisture. In the continental Mediterranean context, this age-old agricultural system is closely linked to access to, and management of, water resources, which are vital in the dry season. For this reason, we mapped the hedgerow network of a continental Mediterranean mountain, establishing different levels of surface soil moisture provided by images from the satellite *Sentinel-2.* The results render three types of hedgerows: moist, semi-moist and dry, each one presenting clearly differentiated localizations and characteristics. To this can be added the analysis of the evolution of their area from 1956 to the present time from aerial pictures and satellite images and their correlation with surface soil moisture and slope. We present results on this tested method from the central sector of the Iberian Peninsula, Spain.

- The presented procedure focuses on a new classification of hedgerow networks in the Mediterranean region based on the degree of surface soil moisture.
- The method stablishes different levels of surface soil moisture provided by images from the satellite Sentinel-2.
- The procedure allows us to analyze and correlate the evolution of Mediterranean hedgerows with surface soil moisture.

Specifications table

Subject Area:	Environmental Science
More specific subject area:	Geography of rural landscape; Biogeography
Method name:	*Remote sensing and GIS applicated to hedgerows classification*
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Method details

Some research in the study area has focused upon the different environmental variables influencing the localization of the hedgerows, among these, soil water content [1,2]. No studies, however, address the relationship between surface soil moisture and the localization of these landscapes. For the reason we attempt to establish a new classification of this agricultural landscape in the Mediterranean region, proposing a typology based upon the parameter conditioning its existence in this sector of southern Europe: degree of surface soil moisture. The next step is to analyze the change of the hedgerow landscape from 1956 to the present time from aerial pictures and satellite images and their correlation with surface soil moisture and slope. The methodology is validated by the study of the central sector of the Guadarrama Mountains and its piedmont, one of southern Europe's most significant areas of continental Mediterranean hedgerows (Fig. 1).
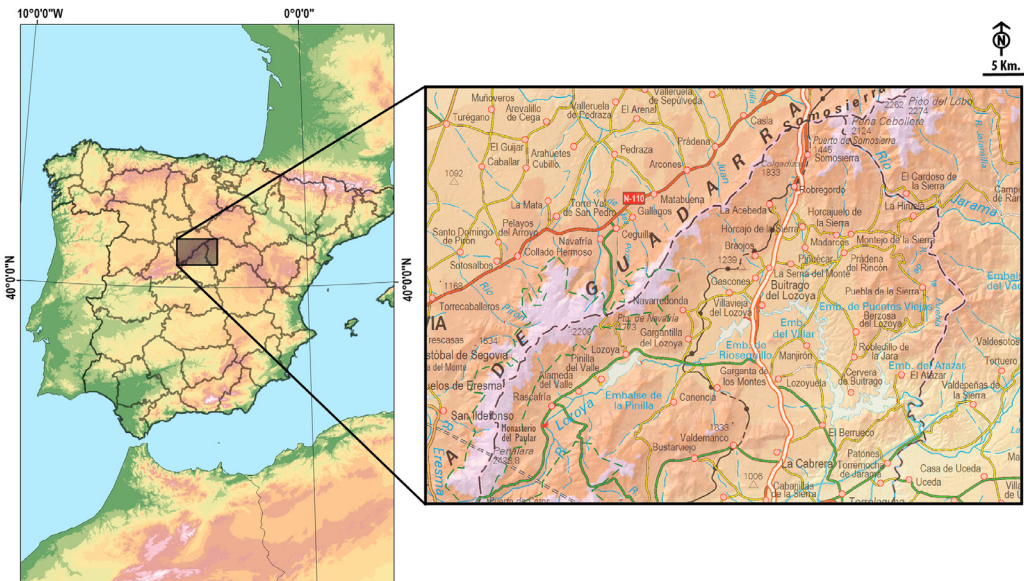

Fig. 1. Study area (Map base source: Spain MDE from USGS Shuttle Radar Topography, 2004 [3]: Topographic information from Spanish National Geographic Institute 1:200,000 [4]).
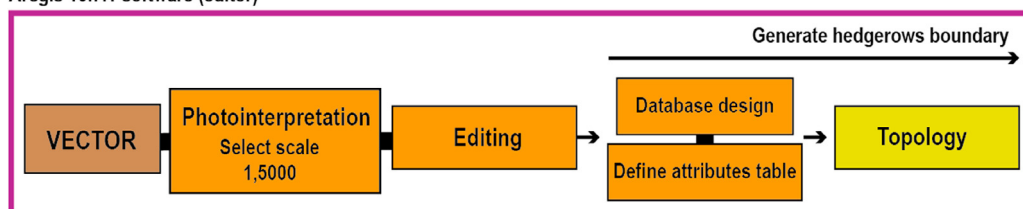
Arcgis 10.7.1 software (editor)

Fig. 2. Define hedgerow area (initial phase).

The methodology was developed in three phases: demarcation and quantification of the area occupied by hedges and urban land in 1956 and at the present time, estimation of the variables most influencing their localization (surface soil moisture and slope) and, lastly, typification thereof. Vector info was processed within Arcgis 10.7.1 software (editor module). For raster Spatial Analyst and Image Analyst modules (Arcgis) were used. Finally, we have analyzed SENTINEL 2 images [5] with ERDAS IMAGINE.

In the initial phase (Fig. 2 y 3) we digitized in shape file format the areas considered to constitute hedgerow networks and urban land at the present time and in 1956. For this, images info was interpreted considering technical features [6–8], interface urban-rural in the mediterranean mountains [9–15] and landscape patterns in Spain [16–18]. This information was photointerpreted at a scale of 1:5000 considering any possible modifications or rectifications of the existing information or any incorporation of new polygons. Finally, all the information was topologically validated. We delimited the hedgerows following a series of criteria among which we considered to be fundamental to include plots presenting a division (hedgerows, hedgerows with trees, trees, or stone walls with hedges and trees, dry stone walls etc.) or those presenting an internal limit without a physical boundary but with a visible external one.

For the urban land we considered the continuity of the built-up area on both dates. We subsequently conducted a verification in the field on predesigned tracks on the LIDAR layer (0.5 m.), available at the National Geographic Institute [19]; on these itineraries we represented the hedgerows presenting different typologies and altitudinal levels. The vectorial information was processed by means of Arcgis 10.7.1 software and the raster with Imagine Analysis by Arcgis. (Fig. 2). As reference digital sources we employed: the *Mapa Forestal de la Comunidad de Madrid (*Forestry Map of the Madrid Regional Autonomy) in *.shp* format (*Consejería de Medio Ambiente de la CAM*- Madrid Regional Autonomy Dept. of the Environment) [20], the Rural Cadastral Registry cartography at a scale of 1:5000 by means of the WMS system (*Dirección General del Catastro- General* Land Registry) [21], the orthoimage of the Madrid Regional Autonomy from the year 2014 at a scale of 1:5000 (*Geoportal de la Infraestructura de Datos Espaciales de la CAM*-the Madrid Regional Autonomy Infrastructure Geoportal for Spatial Data) [22], the Madrid Regional Autonomy's Map of spatial occupation at a scale of 1:5000 (Madrid Regional Autonomy) [23] and Series A (1945–1946) and B (1956–1957) from the USAF (United States Air Force) [24], previously georeferenced and mosaicked.

Using the cartography of hedgerow networks and of urbanised land for the two dates, we performed a comparative analysis in which we considered the most representative changes with regard to size, shape and use. This enabled us to quantify the principal change processes (loss or stability in the case of the hedgerows, and increase or stability in the case of the urbanised environments) (Fig. 3).

In the second phase we classified the hedgerows according to surface soil moisture with the use of *Sentinel-2* images. In this phase ERDAS IMAGINE and Image Analyst Module (Argis 10.7.1) were used (Fig. 4). To this end we previously selected images available from 2008 to 2015 for the two periods, spring and summer; the final third of spring (May) and the first two thirds of summer (June–July) are of particular relevance. In this seasonal selection we preferentially considered the irrigation needs of the delimited areas, mostly comprising meadows, which enables clearer discrimination. In the case
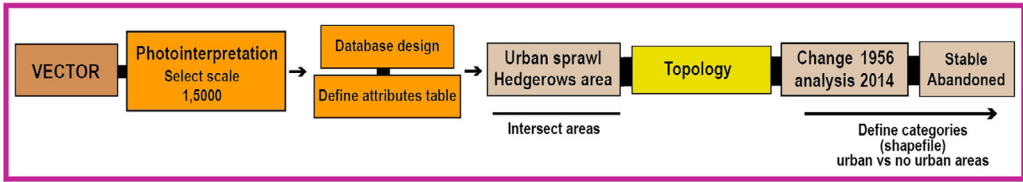
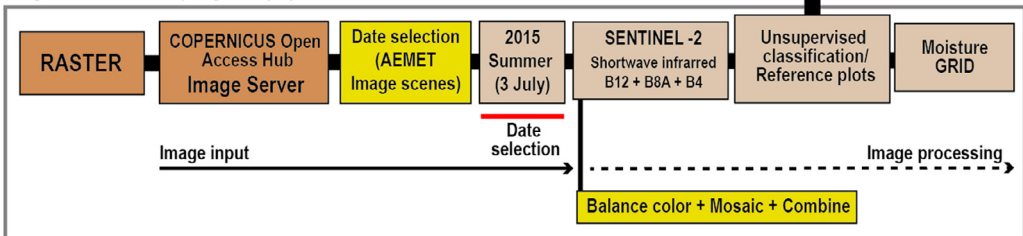**Fig. 3.** Define urban sprawl and change categories (initial phase).

Fig. 4. Image processing (second phase).

of the abandoned zones or the sectors at higher altitudes, the references were surface runoffs or old channels that were partially functional as a result of overflow.

Having defined the reference periods, we eliminated any flyovers with dense cloud cover, deficiencies in data collection or difficult-to-balance chromatic values. The "valid" images were compared with the seasonal summaries of the AEMET (2015) involving the search for years classified as "normal". In this appraisal we considered the possible dryness resulting from an excessively dry spring or from a very wet summer. The Navacerrada meteorological station was used to characterize the climatic year, since it was the only one that had comparable data for both dates. Precipitation at the Navacerrada station was lower in both years, than the average from historical records (1349.8 mm): 1071 mm (1956), and 1153.14 (2019) [25]. The climatic year accumulated a rainfall deficit, especially in spring, with average rainfall between 288 mm and 203 mm compared to the average of 362.1 mm.

Finally, the only image that complied with a series of characteristics enabling a certain degree of reliability was the one from July 3rd 2015 in a summer considered by the AEMET [25] to be normal-wet (W =Wet: 20% $\leq$f<40%. N =Normal: 40% $\leq$ 60%) and in which recorded precipitation was around the median. *Sentinel-2* enabled a combination of bands (EOS DATA ANALYTICS, 2017) at different resolutions (10 .m - Near-Infrared bands- and 20 m, Red Edge and shortwave infrared bands), which facilitated discrimination of the different levels of surface soil moisture (near-infrared -12-; Red Edge 8 -8A- and Red -4-) applied to agriculture [26–30], to irrigated fields [31–33] and, more precisely, to pasture [34,35]. The scenes (a total of four) were mosaicked and contrasted with the use of the nearest neighbour method to obtain a final image in GRID format. Due to the volume of resulting information we performed a clip of the image on the area defined as hedgerows for easier handling. Subsequently, to eliminate errors we conducted a test using the *shape file* layer of hedgerows as a reference. On the tracks designed in the initial phase we performed systematic sampling of the sectors in which we had previously ascertained the seasonal variability of the levels of surface soil moisture. We then obtained an unsupervised classification in 6 categories which were simplified in three: moist, semi-moist and dry. We had previously evaluated the inclusion of further categories or reducing them to just these three. In the first case an excessive number of values made no contribution and in the second case, a loss of nuances was generated in the transition between categories, particularly in those exhibiting a greater degree of variability due to the loss of homogeneity on the surface: semi-moist and dry.
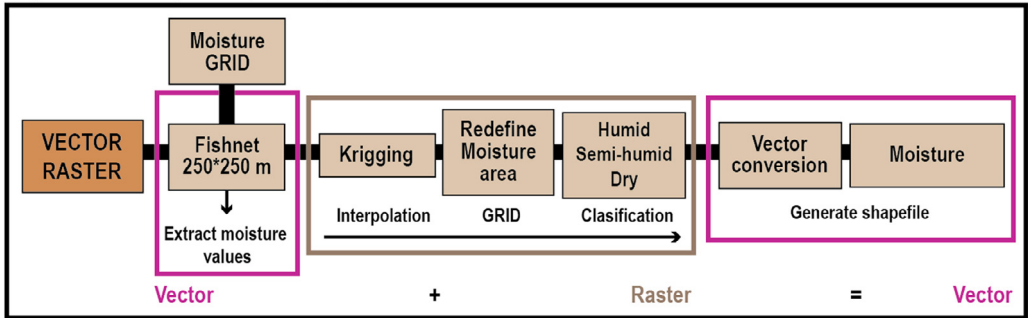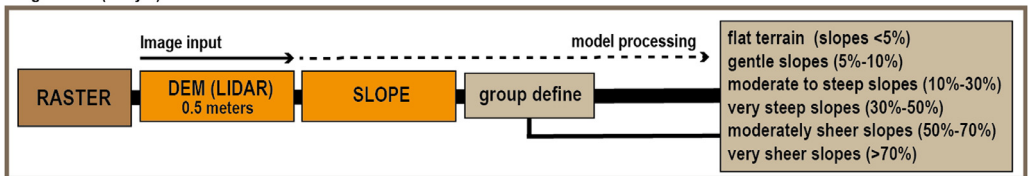
Fig. 5. Image processing (third phase).

Fig. 6. Slope processing (third phase).

Finally, *in the third phase* we designed a mesh measuring 250*250 metres covering the whole study area, obtaining the centroids which were subsequently crossed with the categories of moisture (Fig. 5). These centroids were interpolated by means of krigging normally used in GIS studies and applied to estimate soil moisture [36–38], an interpolation system that proves valid when the sample is well distributed [39–41]; this provided cartography of surface soil moisture and an initial classification of the hedgerow networks from SENTINEL-2 [42–45]. In this phase, slopes were calculated and incorporated as the determinant variable in the processes of abandonment or stability in the hedgerow networks (Fig. 6). Some authors consider this factor to be vital for the maintenance or abandonment of agriculture or livestock farming [46–49]. In the calculation we used the slopes calculated in percentages with the LIDAR (0.5 m.) model [50–53], which were grouped into 6 intervals [54]: 1) flat terrain (slopes <5%); 2) gentle slopes (5%–10%); 3) moderate to steep slopes (10%–30%); 4) very steep slopes (30%–50%); 5) moderately sheer slopes (50%–70%); 6) very sheer slopes (>70%).

Method validation

The proposed area for validating the methodology is situated at the southern piedmont of the Guadarrama Mountains, within the central sector of the Iberian Peninsula. The mountain range, running in a northwest-southeast direction, is articulated in a series of raised (2400 m) and sunken (900 - 1000 m) morphostructural blocks presenting intense altitudinal gradients. The relief is generally arranged following a tectonic system of post-alpine reactivation faults, the direction of which conditions the existence of a series of intramontane and longitudinal depressions on the periphery of the dominant reliefs. Running along the foot of the main reliefs are gentle ramps that form a piedmont, which progressively loses height. We divided the area into six groups (49 municipalities), considering its agrological and physiographic characteristics. In this sector, piedmonts alternate with depressions and slopes on granites, upon metamorphic materials and on mixed materials. The climate is of the continental Mediterranean type with hot dry summers, average precipitation slightly higher than 650 mm per year and average temperatures ranging from 12 to 14°C. The strong altitudinal and climatic gradient generated by the mountain range favours the existence of a high degree of bio-
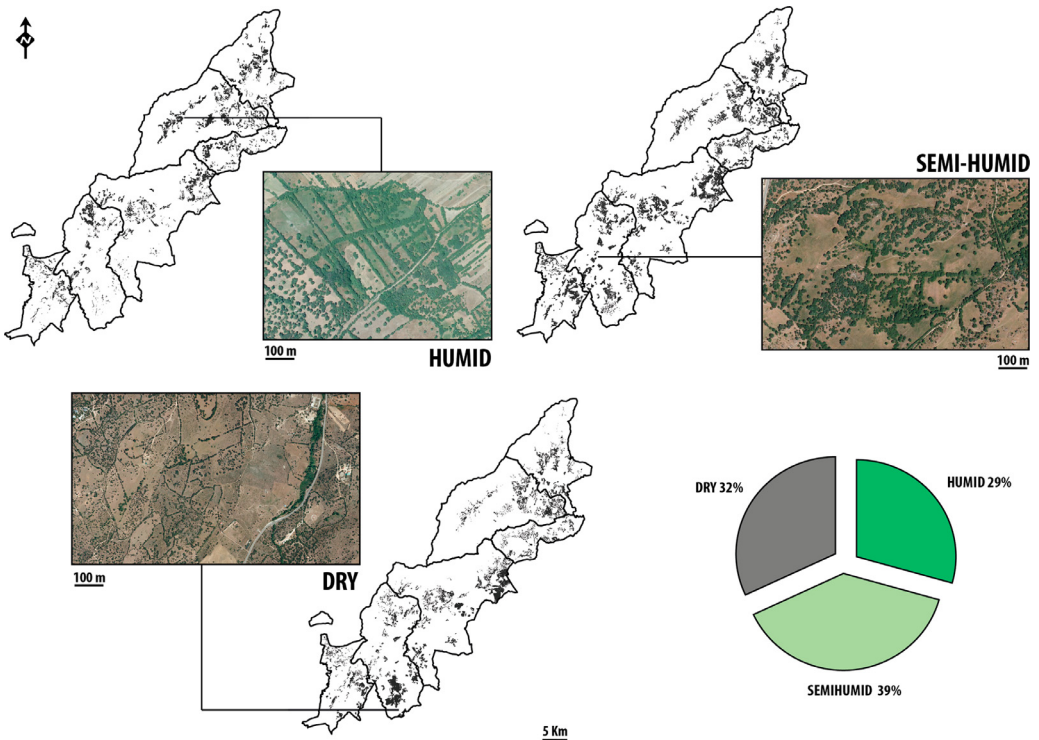
Fig. 7. Distribution and area occupied according to degree of surface soil moisture.

and agro-diversity, with different types of pastures. A long period of summer drought, along with seasonal water resources, are characteristics determining the uniqueness of these hedgerow networks in relation to the Atlantic ones in the north of the peninsula and central Europe, and it is precisely the hydro-climatic conditions that make Guadarrama's hedgerows heterogeneous.

Dependence on water resources: definition of typologies according to surface soil moisture.

As has been pointed out, access to, and management of, water resources is fundamental in the localisation of hedgerows. In the continental Mediterranean context, this agrosystem is associated with the accumulation of water resources in the mountain headwaters and with the proper channelling thereof in the dry season (June-September). In the study area the hedgerow network occupies a total area of 24,400 ha. The results of the analysis of the *Sentinel-2* images provided three categories: moist (7169.12 ha), semi-moist (9428.23 ha) and dry (7803.53 ha) hedgerows (Fig. 7).

The moist hedgerows cover 29.38% of the total and constitute the most productive irrigated agrosystems. The highest concentrations of this category are reached in a specific meadow silvosystem (Lozoya Valley), with 43.98% of hedgerows and a high degree of surface soil moisture. In this sector the waters of the Montes Carpetanos and the Cuerda Larga sub-ranges, concentrated in the river Lozoya and its headwaters, contribute to maintaining water resources in the most unfavourable season. However this situation is replicated in some municipalities of other sector (La Cabrera) (44.12% of the hedgerows are moist), where the irrigated zones are displaced in the search for abundant headwaters. The absolute minimum values (2.23%) coincide with environments containing no abundant headwaters, and which mostly lie upon a granitic rocky piedmont with therophytic pastures.

The semi-moist category are the ones occupying the biggest area (38.64%). They constitute mixed agrosilvosystems with temporary irrigation, associated with the continuity of runoffs from the
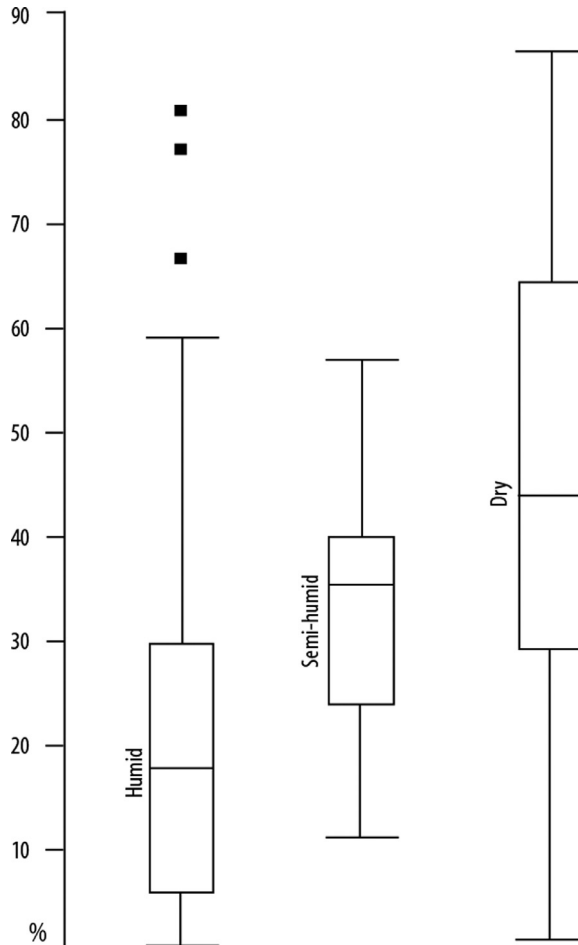
Fig. 8. Area of abandoned hedgerows in relation to the degree of surface soil moisture.

southern slopes of the Central System or with occasional water surpluses from temporary streams and depressions. The highest values (49.08 and 42.61%) are reached in sectors where some medium- and large-sized hedgerows maintain suitable moisture conditions until the start of the summer. The maxima are also high on the granitic piedmont in highly fragmented plots in which the capacity for water retention of small depressions and flat zones plays a vital role. Dry hedgerows occupy 31.48% of the area. Maximum values (1397.50 ha and 748.90 ha) are reached in some parts of Lozoya lacking abundant headwaters or concentrated on dry slopes and in small valleys (Fig. 8).

Regarding the change over time of these rural systems, in 1956 this area was 58,065 ha, whereas in 2014 only 24,400 ha were mapped. These data reflect the generalised abandonment of traditional activities in the rural environment. Nowadays it is possible to distinguish between hedgerows still used up to the present time (42.41%), abandoned ones (48.26%) and urbanised ones (9.33%).

One of the variables influencing the abandonment of the hedgerows is surface soil moisture; 16.65% of the abandoned ones present a high degree of soil moisture, 31.73% pertain to the intermediate category and 51.62% are dry. Falling within the latter category are over half the hedgerows that have been abandoned, and in some sectors they represent over 60%. These figures are repeated in 14 of the 49 municipalities, dry hedgerows being the ones most abandoned in 27 of

Table 1
Area of hedgerows in relation to slope (slope intervals according to Martín Serrano et al., [54]).

	1: <5%	**2**: 5–10%	**3**: 10–30%	**4**: 30–50%	**5**: 50–70%	**6**: >70%
	Ha					
Hedgerows 1956	30,839,16	16,139,27	11,852,60	86,81	1,76	0,00
Hedgerows stable in 2017	15,410,25	6349,03	2855,02	9,95	0,03	0,00
Abandoned hedgerows	10,921,42	8566,24	8466,48	68,00	1,01	0,00
	%					
Hedgerows 1956	52,34	27,39	20,12	0,15	0,00	0,00
Hedgerows stable in 2017	62,58	25,78	11,59	0,04	0,00	0,00
Abandoned hedgerows	38,97	30,57	30,21	0,24	0,00	0,00

them. The moist hedgerows, much more fertile and productive and in most cases, more accessible and enduring throughout time, are the least abandoned category (16%). A total of 25% of the municipalities reveal a rate of abandonment of the moist hedgerows of less than 7%, and with the exception of three extreme values, where hardly any other kind of hedgerow exists, the abandonment figures do not exceed 60% in any case.

As we can see in the Table 1, another variable conditioning the stability or abandonment of the hedgerow networks is slope. In 1956, 99.85 % of the hedgerows were situated on slopes of between 0% and 30%. At the present time, they are situated on flat terrain (62.58%) and the ones on slopes greater than 5% (60.78%) are abandoned.

We can conclude that this methodology enables us to typify hedgerow landscape in the continental Mediterranean mountains of the Iberian Peninsula according to the degree of surface soil moisture, and that three types of hedgerows can be established: moist, semi-moist and dry. This classification is innovative, because within the Atlantic environment [55,56], the variable degree of surface soil moisture does not constitute a differentiating element of the landscape. Surface soil moisture was shown to constitute a factor conditioning the type of hedgerow abandoned, over half of which were dry hedges.

The other variable in the maintenance or abandonment of hedgerows is slope. Within the traditional model pertaining to the mid-1900s, the hedgerow landscape was concentrated on flat land or on terrain with moderate slopes. In 1956 the hedgerows delimiting rye fields and dry farming pastures, currently abandoned, were situated on less productive land presenting slopes greater than 10%. This type of hedgerow landscape can also be recognised in other sectors [57–59]. On the contrary, the more gently sloping land (< 10%) currently remains functional and fundamentally comprises meadows with easy access to irrigation. Arable land on steeper slopes is also maintained, although to a lesser degree; this land presents surface soil moisture associated with springs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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