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Research Paper

A comparison of microclimate and environmental modification produced by hedgerows and dehesa in the Mediterranean region: A study in the Guadarrama region, Spain

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HIGHLIGHTS

- Temperature profiles were similar in hedgerows and dehesa.
- Hedgerows had higher soil water content, lower wind speeds, and higher total soil organic carbon.
- Conditions under woody vegetation in both systems extended out to the adjacent open fields.
- Hedged fields have advantages over dehesa for shelter, production and natural capital.

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ABSTRACT

Two common forms of traditional land use systems in Mediterranean landscapes are dehesa and hedged fields. Both are agroforestry systems in which domestic stock are pastured: amongst parklike trees in dehesa, and in enclosures surrounded by stone walls and woody vegetation in hedged fields. The latter are now tending to be replaced by dehesa due to labour costs. Here, we investigate the boundary layer microclimate and environmental characteristics of these two land uses in order to evaluate the respective differences in relation to climate modification, soil organic carbon, and soil water content. *Fraxinus angustifolia*-dominated sites were investigated in the Guadarrama mountains, Spain, in high summer with simultaneous sampling under trees in both dehesa and hedgerows and in adjacent open fields. Whilst temperature profiles were similar in both systems, hedgerows had higher soil water content, lower wind speeds, and higher total soil organic carbon compared to dehesa, and moreover these trends also applied to open fields of the respective systems. We conclude that not only do hedged fields have advantages over dehesa for shelter and production, but that the climatic modifications of hedged field systems potentially modify boundary layer climates on a broader scale than both individual fields and dehesa. Thus, the conservation of hedged field systems provides natural capital and broad environmental gains.

1. Introduction

Agriculture is the dominant landuse of western Europe comprising half the land surface area (measured as arable land, permanent crops, pastures and mixed mosaics) (Meiner, Georgi, Petersen, & Uhel, 2010). In the Mediterranean Basin a long history of human presence have fashioned cultural landscapes that intermingle natural vegetation with fields for crops or grass in the form of savanna-like 'dehesas' (Antrop, 1997; Bunce et al., 2001; Schmitz, De Aranzabal, Aguilera, Rescia, & Pineda, 2003). These comprise multi-purpose agroforestry systems with a mosaic of widely spaced trees combined with crops, pasture or shrubs (Grove & Rackham, 2001). Many such traditional European agroforestry systems have declined sharply over the last century and in the Iberian peninsular the pace of change has accelerated greatly since the 1950s with significant depopulation of many rural areas (Comins, Sendra, & Sanz, 1993; Díaz, Campos, & Pulido, 1997; Eichhorn et al., 2006; Pinto-Correia, 1993).

Notwithstanding these declines, agricultural-dominated landscapes still often contain natural capital in the form of woody vegetation that provide ecosystem services such as provisioning

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(e.g., wood for fuel, timber), regulating (carbon sequestration, purification of air and water), and cultural services (e.g., cultural and aesthetic) (Hassan, Scholes, & Ash, 2005; Höchtl, Born, & Plieninger, 2010). Woody vegetation in dehesas have been reported to improve soil fertility, microclimate, soil water-holding capacity and have beneficial effects both in terms of moderating the environmental conditions of adjacent crop fields and on overall species diversity (Bergmeier, Petermann, & Schroder, 2010; Gea-Izquierdo, Allen-Díaz, San Miguel, & Cañellas, 2010; Joffre & Rambal, 1988; Jose, Gillespie, & Pallardy, 2004; Moreno, Obrador, & Garcia, 2007; Moreno Marcos et al., 2007; Sánchez, Lassaletta, McCollin, & Bunce, 2010).

Another multi-purpose agroforestry system of the Mediterranean region is the mosaic of fields bounded by stone walls, often naturally colonized by woody vegetation (Sánchez et al., 2010). (We refer to the latter as 'hedgerows' – see Section 2.) Like dehesas, hedgerows in the Mediterranean are capable of reducing soil erosion (Donjadee, Clemente, Tingsanchali, & Chinnarasri, 2010), modifying the microclimate (Casa, Valentini, Scarascia, & Mugnozza, 1994; Sánchez et al., 2010), maintaining soil water content, protecting orchards (Gomez-del-Campo, 2010), as well as providing habitat for woodland (Sitzia, 2007) and other plant species (Bassa, Chamorro, José-María, Blanco-Moreno, & Sans, 2012) whilst at the same time serving their primary function of enclosing pastures. The microclimate of such hedgerows have been shown to be a factor governing the occurrence of certain insects on farmland (Gardiner & Dover, 2008; Ricci, Franck, Bouvier, Casado, & Lavigne, 2011; Scalercio, Iannotta, & Brandmayr, 2007) and in the Mediterranean region hedgerows have also been shown to aid the survival of forest carnivores in agricultural landscapes (Pereira & Rodriguez, 2010).

Rural landuse in Europe is currently undergoing polarization – with intensification on the one hand and extensification/marginalization and abandonment on the other – with implications for changing socioeconomic, cultural and biodiversity values of landscapes (Plieninger & Schaar, 2008; Schmitz et al., 2003). Such processes result in structural changes to these traditional landscapes that may have as yet unknown consequences for the landscape values and resources (Plieninger, Höchtl, & Spek, 2006) as well as the natural services they provide. In our study area traditional pasture systems with hedgerow dominated by *F. angustifolia* are being transformed into dehesa systems, thus maintaining land as pasture but potentially with a lower demand for labour. When neglected, fields suffer encroachment by woody vegetation with deterioration of pastures (Mairota, Leronni, Xi, Mladenoff, & Nagendra, 2014). Thus, we are particularly interested in comparing and evaluating the modifying effects on the environment of the pastures brought about by the transformation of hedgerow into dehesa systems.

The change and decline of *Quercus* dehesa has been well documented (e.g., Eichhorn et al., 2006) but little comparable information exists for dehesas dominated by other species such as *F. angustifolia* as in our study area (Madera & Uradnicek, 2001; Sánchez et al., 2010). These *F. angustifolia*-dominated hedgerow and dehesa landscapes differ substantially from those of *Quercus*-dominated dehesas in (amongst other environmental factors) the higher water table requirements of the soil (Jaeger, Gessler, Biller, Rennenberg, & Kreuzwieser, 2009) that, with the characteristic structure of the vegetation, contribute to form multipurpose cultural landscapes. We hypothesize that the vertical structures of both systems bring about modifications in microclimate and soil conditions but the extent to which the systems differ is unknown. The findings will have possible implications for ecology, production, and management. Our study focuses on high summer since this dry period produces a strong climatic constraint (Joffre & Rambal, 1993) when a soil water deficit is a key factor affecting productivity (Ibañez, Lledó, Sánchez, & Rodá, 1999).

2. Methods

2.1. The study area

The study was carried out in three sites situated on the gently sloping (10°–20°) south-facing pediment of the Central Mountain Range (Guadarrama) in the Madrid region (40°40′ to 40°46′ N and 4°02′ to 3°34′ W). The substrate of the study fields is formed by granite and gneiss rocks and arkoses. The flora of hedgerow and dehesa systems comprise natural vegetation although the species composition may have been influenced by deliberate selection and by browsing. *F. angustifolia* is the most frequent tree species forming the dehesas and hedgerows in this region in contrast to other dehesas in Spain which are dominated by oaks *Quercus* spp. Other common woody species in this study area include *Quercus rotundifolia*, *Quercus pyrenaica*, *Salix* spp., *Euonymus europaeus*, *Prunus spinosa*, *Acer monspessulanum*, *P. spinosa*, *Rosa micrantha*, *R. corymbifera*, *R. canina*, *R. squamosa*, *Frangula alnus*, *Crataegus monogyna*, *Osiris alba*, *Rubus ulmifolius*, *Lonicera etrusca*, *L. periclymenum* and *Rhamnus cathartica*. Common species in the herbaceous layer under the woody vegetation include *Aristolochia paucinervis*, *Centaurea nigra*, *Primula veris*, *Viola riviniana*, *Agrimonia eupatoria* and *Alliaria petiolata*. In the fields the most common herbaceous plants are *Arrhenatherum elatius*, *Dactylis glomerata*, *Festuca ampla*, *Holcus lanatus*, *Agrostis castellana*, *Anthyllis vulneraria*, *Briza media*, *Trifolium* spp., *Rumex acetosa*, *Plantago lanceolata*, *P. media*, *Lotus corniculatus* and *Hypochoeris radicata*.

The hedgerows in this study comprise field margins which originated as stone walls built as a defence by farmers and landowners against the rights of Mesta transhumance sheep (Grove & Rackham, 2001; Klein, 1920). These *c.* 1 m high stone walls are an integral part of the field margins that surround dehesas and are still useful to keep cattle in fields. We refer to these structures as 'hedges' or 'hedgerows' although they comprise a mix of stone wall and woody vegetation. Maintenance includes repair of stone walls and pollarding of *F. angustifolia* to provide browse for cattle during the summer period (although cattle also eat other hedgerow plants) (Sánchez, 2001). During the winter months hedgerows and the woody vegetation in the dehesa serve as a refuge for stock against cold winds.

2.2. Site selection

Three sites were selected on the southern side of the Central Mountain Range (Guadarrama). All sites had a common land use – cattle ranging – the most widespread use of such land throughout the study area. Grazing in each field is controlled by shepherds who move cattle between fields to control for over-grazing. Initial site selection was made using aerial photographs and cartography to control for vegetation structure and relief. Hedgerow networks were chosen to be close to dehesa fields with both systems having similar characteristics in terms of size, vegetation cover, species composition, horizontal structure and aspect. The selection process involved fieldwork to measure hedgerow and dehesa vegetation so that they could have similar characteristics in terms of mean woody vegetation cover for each field. Hedgerow homogeneity was measured using a standardized procedure (Bickmore, 2002). Though uncommon, hedgerows having barbed-wire to protect the hedgerows from browsing were excluded in the selection process to enable a more uniform sample.

The three most similar study sites were selected, namely: Collado Mediano (hereafter referred to as Coll-Med), El Vellón-Lozoya valley (Vell-Loz) and Cerceda-Manzanares (Cer-Man) and to control for altitudinal differences, all were located between a narrow altitude band from 974 to 1040 m above sea level. All three sites showed little difference in climatic variability, being classified in the Mediterranean region (Lionello, Boscoso, & Malanotte-Rizzoli, 2006) with Coll-Med and Cer-Man in the Mediterranean Mountain 5 (MM5) at the limit of MM6 – in which Vell-Loz was located – in the European strata described by Metzger, Bunce, Jongman, Mucher, & Watkins (2005). All fields were planar with no significant obstacles to wind circulation apart from the vegetation and stone walls. From within the sites, fields were randomly selected from suitable fields for each one of the three study sites; however hedgerows surrounding the fields could not have gaps greater than two-thirds of their total length and 80% of the trees had to be *F. angustifolia*. Inevitably, the study sites differed slightly in soil conditions, precipitation and other climatic and meteorological conditions, several of them expressed in the CLIMOAL analysis (Manrique, 1993) of Table 1. In each of the sites, four dehesa and hedgerow fields were selected for sampling, each one with two sampling points, one corresponding to the middle of the field (without woody vegetation in the proximity) and the other placed under the woody vegetation of the dehesa or the hedgerow vegetation (Fig. 1; Table 1).

2.3. Experimental layout and data collection

The main aim of comparing the microclimate and soil conditions of two different structures of the vegetation was achieved through the measurement of temperature, wind, soil, total water content and organic carbon during the summer dry period. Temperature is a key parameter for climate change estimations, especially underground temperatures (Verdoya, Chiozzi, & Pasquale, 2007), and can be considered relevant during the summer in Mediterranean landscapes for species' habitat. Soil water content and total organic carbon were chosen since differences in carbon storage in the soil and in water availability are especially relevant to evaluate the productive and ecological differences in which we were interested.

Table 1
Summary characteristics for study sites. *mm/year* mean yearly precipitation in mm (20 years mean), *T* mean yearly temperature in C, *GXP* Gaussian Xerothermic Period time in months in which the mean monthly temperatures curve is over the monthly precipitation curve (based on Gaussen, 1954, Gaussen, 1955), *Annual PET* yearly potential evapotranspiration (based on Thornthwaive, 1948), T_1–T_4: mean weekly temperature from week 1 (just before the sampling period) to week 4 (*c.* 1 month before the sampling period), PET_1–PET_4 weekly potential evapotranspiration from week 1 to week 4.

Variables	Site		
	Coll-Med	Cer-Man	Vell-Loz
mm/year	641	654	670
T (°C)	14.1	14.0	13.9
GXP	4.2	4.0	3.8
Annual PET	690.6	683.0	677.4
T_1	30.2	30.2	29.8
T_2	30.3	30.2	29.9
T_3	30.7	30.6	30.1
T_4	30.9	30.8	30.3
PET_1	32.1	32.1	31.9
PET_2	32.2	32.1	32.0
PET_3	32.6	32.5	32.3
PET_4	33.2	33.0	32.8

All the measurements were taken during the last five days of July and the first five days of August 2009, being the warmest period of the year and all were taken under similar weather conditions, so that evapotranspiration (ET) was mainly due to woody vegetation uptake. In each of the three study sites eight sampling areas were selected with two sampling stations: one in the middle of a field, and the other under the woody vegetation of hedgerow or dehesa trees. Therefore the total number of sampling stations was $3 \times 8 \times 2 = 48$. Twelve replicates were taken corresponding to each of the four different sampling areas: under woody vegetation of hedgerows (labelled as H or UH in the following figures) or dehesa (D or UD), and in corresponding hedgerow fields (HF or F), or dehesa fields (UF or F). Table 1 shows a summary of these conditions.

Daily temperature cycles were measured at two hourly intervals at each sampling point at four vertical heights above ground

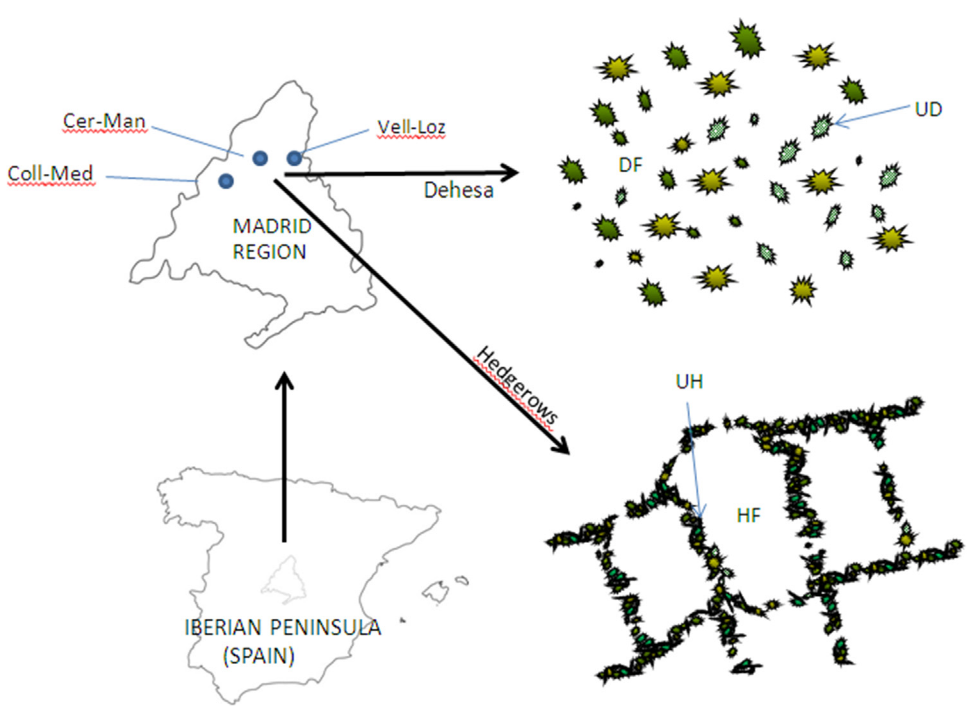

Fig. 1. Location of the study region, showing location of study sites and design. For each study site (Coll-Med, Cer-Man, Vell-Loz) measurements were taken in hedgerow and dehesa systems in the shelter of trees (UD, UH) and in adjacent control plots in fields (HF, DF).

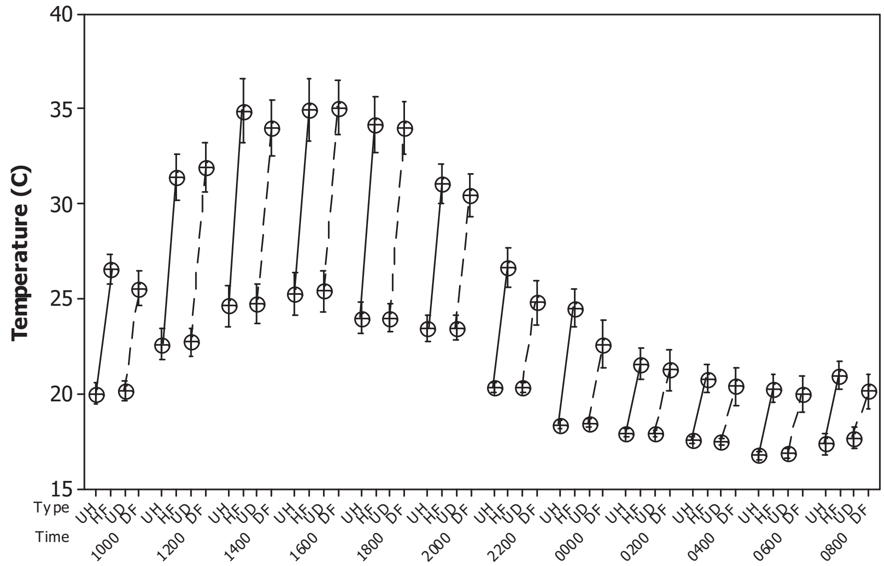

Fig. 2. Overall diurnal temperature differences between hedge (UH) and adjacent open field areas (HF) (solid lines) and dehesa (UD) and adjacent field areas (DF) (dashed lines). All data pooled.

(300, 100, 30, 15 cm), at ground level (0 cm), and at two depths underground (−10 and −30 cm) (336 in total). Data were averaged by height layers according to theoretical differences in heat transfer: S, the underground layer where convection is dominant (means of −10 and −30 cm data); 0, the laminar sub-layer (where molecular heat transfer is dominant); L, the transitional layer between molecular and turbulent heat transfer (15 and 30 cm); and H, where turbulent heat transfer is dominant (100 and 300 cm) (Elías & Castellvi, 1996; Oke, 1987; Sánchez et al., 2010). Thermographs were cross-checked with Digitermo® and StopAway® thermometers and the error was ±0.1 °C for the temperature range of this investigation.

To compare wind speed between hedgerow and dehesa fields a Lutron AM-4221 digital cup anemometer was used and the average of four measurements was taken every 2 h at 1 m above ground at each point to complete a 24-h cycle. The Walkely–Black method was used to estimate the soil total organic carbon, taking nine samples in a 6 m^2 area around each point (Walkely, 1935). Soil water content was determined through gravimetric measurements, taking nine samples at a fixed time of the day (0900) around the same point where temperatures were taken.

2.4. Data analysis

Variables were inspected for normality. Variables which would not readily transform to obtain normal distributions were inspected for any large deviations from normality and analyses were carried out if the deviations were not great (McDonald, 2009). There were no significant differences between replicates so these are not reported. Since we were primarily interested in comparisons between hedgerows and dehesa, the differences between paired samples of variables Temperature, Soil water content, Wind speed, and Total organic carbon were tested for using matched pairs *t*-tests. All analyses were carried out using Minitab-16 (Minitab, 2010).

3. Results

3.1. Temperature

The overall trends for diurnal temperature variation between dehesa and hedgerows and adjacent open fields, respectively, were very similar (Fig. 2). Hedgerows produced a similar overall modification to temperature as dehesa with no significant difference in mean temperatures beneath dehesa and hedges during the day (*t*-test for matched pairs: $t = 0.96$, $p = 0.34$). On average, temperature differences between dehesa and hedges and adjacent fields were 9.1 and 9.4 °C lower during the day and 3.1 higher and 4.1 °C lower at night, respectively. The overall difference between mean temperatures of dehesa, hedges, and adjacent open fields were on average 7.8 and 9.4 °C during the day, and −3.1 and 4.1 °C at night, respectively.

3.2. Soil water content, wind speed, and organic carbon

Overall, comparing both treatments and controls separately, there were consistent trends for all three sites with soil water content being higher under hedgerows and in adjacent open fields compared to those for dehesa and adjacent open fields (Fig. 3a), wind speed was lower under hedgerows compared to dehesa and correspondingly for controls (Fig. 3b), and organic carbon was higher under hedgerows compared to dehesa (Fig. 3c).

There was a very highly significant difference in soil water content between matched samples for hedges (*t*-test for matched pairs (all sites), $t = 17.96$, $p < 0.001$) and dehesa ($t = 16.09$, $p < 0.001$), with soil water levels being on average 25.1% higher under hedgerows compared to dehesas. Further, soil water content reductions in fields adjacent to hedgerows were consistently less than the corresponding differences between dehesa and adjacent fields, showing reductions of 89.5, 96.4 and 37.8% compared to 112.6, 103.5, and 20.8% in Coll-Med, Cer-Man, and Vell-Loz, respectively (Fig. 3a).

Wind speed was reduced under dehesa and hedges compared to open fields with very highly significant differences (*t*-test for matched pairs, dehesa $t = -11.3$, $p < 0.001$; hedge, $t = -15.46$, $p < 0.001$). Although there were greater reductions in dehesa (57.9, 52.8, and 36.8%) compared to hedgerows (30.1, 50.4, and 22.8%) versus adjacent open fields in the aforementioned sites it should be stressed that all wind speeds were considerably lower in the hedged landscape compared to the dehesa landscape (Fig. 3b).

There were very highly significant differences in organic carbon between dehesa, hedges and their respective adjacent open fields (*t*-test for matched pairs (all sites), dehesa $t = 21.0$, $p < 0.001$; hedge, $t = 23.08$, $p < 0.001$). Organic carbon levels under hedgerows were

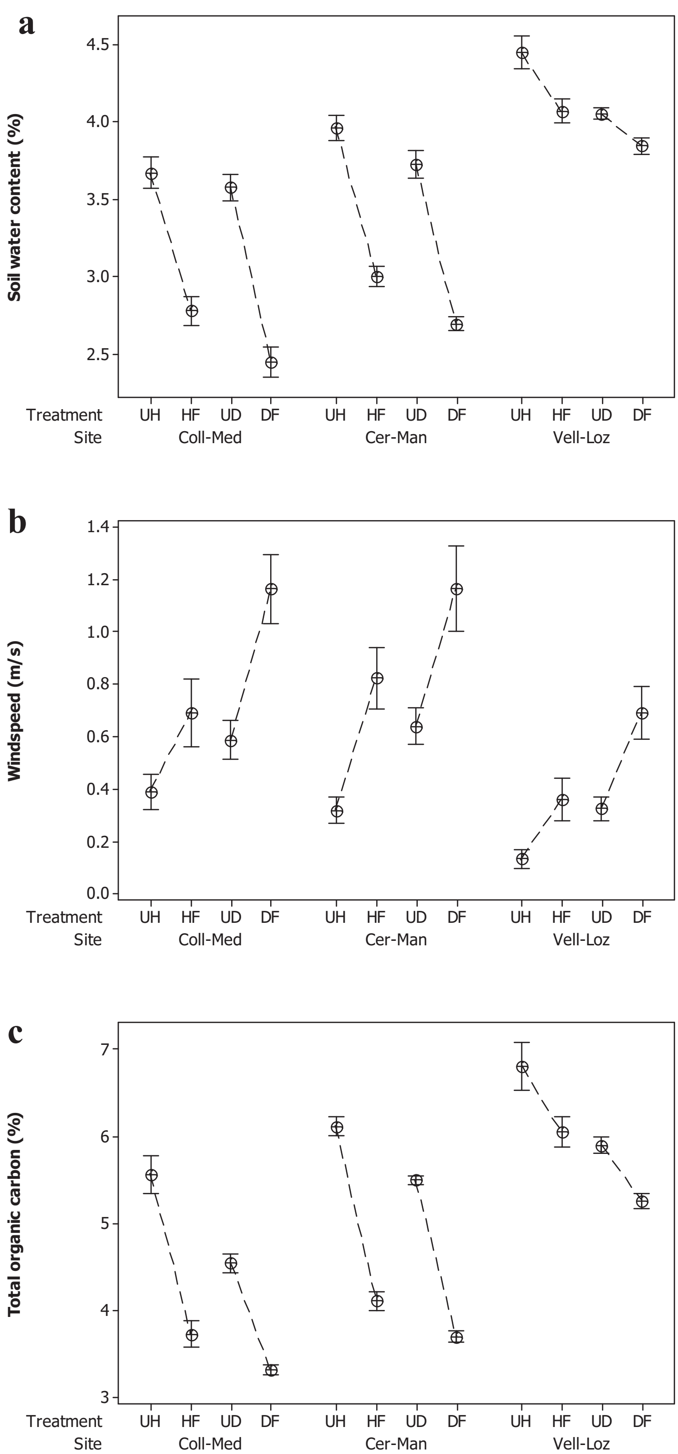

Fig. 3. Differences between environmental and microclimate measures for under hedgerow (UH) and adjacent field (HF), and under dehesa (UD) and adjacent field (DF) in the three study sites for (a) soil water content, (b) wind speed, and (c) soil total organic carbon. All data pooled.

higher than corresponding measures under dehesa compared to open fields, with differences of 183.3, 200.7 and 76.0% versus 122.8, 179.7 and 64.1%, in Coll-Med, Cer-Man, and Vell-Loz, respectively (Fig. 3c). Finally, there was a very highly statistically significant difference between organic carbon levels under hedgerows compared to those under dehesa (*t*-test for matched pairs, $t = 13.3$, $p < 0.001$) with levels being, on average, 16.6% higher under hedgerows.

4. Discussion

The study plots for hedgerows and dehesa were selected so that they were similar in terms of tree height, field size, and approximate dimensions of the study area and they were sufficiently close (maximum distance between dehesa and hedged fields 735 m) so that they experienced similar climatic conditions (Appendix A). Accordingly, any differences in microclimate and environmental modification are likely to arise from the spatial arrangement of the vegetation rather than any of the aforementioned variables. The linear arrangements of trees in hedgerows make them functionally equivalent to windbreaks. Thus, hedgerows form barriers that modify air flow passing over them with significant wind flow reduction on the leeward side. The high wind speed reduction in hedged fields found here is probably due to the *quiet zone* effect just behind the hedgerow where wind speed is reduced greatly over a distance five to 10 times the height of the trees (Brandle, Hodges, & Zhou, 2004; Helfer, Zhang, & Lemckert, 2009) or even more than 12 times the hedgerow height when the wind blows in the most effective direction (Campi, Palumbo, & Mastrorilli, 2009). Given the small average size of fields in our study area (all ≤102 m width, Appendix A) this implies a potentially relatively large shelter effect in fields behind hedges compared to dehesa. However, an unknown is whether wind velocities are reduced below limits to produce a reduction in evaporation due to the volume of hot air passing over the ground surface (Helfer et al., 2009) with implications for soil water content, a key factor which increases the pasture yield into the summer period in Mediterranean agroecosystems (Ben Salah, Beji, & Salah, 1989; Campi et al., 2009; Kuemmel, 2003; Sánchez et al., 2010).

In Mediterranean ecosystems most herbaceous species cease active growth by mid-June (Joffre, Leiva Morales, Rambal, & Fernandez Ales, 1987). Therefore ET during the driest part of the summer periods is mainly due to woody vegetation uptake and is almost equal to loss by transpiration. Any differences in ET between hedgerow and dehesa systems may result from the different degree of control of the stomata, since the more isolated or discontinuous the woody vegetation is the more the stomata play a role in the control of upward water flux, and the aerodynamic conductance is higher and the transpiration is more influenced by the rate and pattern of air stream over the canopy (Joffre & Rambal, 1988; Landsberg & McMurtrie, 1984). At the same time, and probably as a consequence of the described environmental factors (but possibly also due to the effect of woody vegetation of the hedgerow in combination with the stone wall), air, sediment, leaves and other types of organic matter become trapped, thus leading to hedged fields to have a significantly higher soil organic carbon content compared to dehesa fields (as shown here). Such differences can have significant benefits in terms of reducing moisture stress as has been reported for other types of sheltered fields in the Mediterranean (Campi et al., 2009; Gomez-del-Campo, 2013; Rosenberg, 1979). Part of the difference probably comes from the observed higher reduction of wind speed in hedged fields, since water evaporation from the soil greatly depends on wind speed and, depending on the shelter characteristics, can be reduced by up to 35% (Messing, Afors, Radkvist, & Lewan, 1998).

Soil moisture content under hedges was on average 25% higher than under dehesa. The moist soil layer acts to further decrease evaporation by reducing the humidity gradient between the water surface and the overlying air (Elías & Castellvi, 1996). Additionally, woody vegetation of both dehesa and hedges can contribute to reduced evaporation by humidifying the air passing through the trees due to transpiration (Herbst, Roberts, Rosier, & Gowing, 2007) (although for equivalent amounts of biomass this effect can be considered to be similar for both systems). As shown in our results, temperatures under hedge (UH) and under dehesa (UD) were quite similar, therefore the observed higher soil water content under hedges could potentially lead to better connectance (e.g., conductivity of heat) with consequences such as a decrease of high temperature spots and milder day temperatures, as described by Sánchez et al. (2010).

Thus, the microclimate created by hedgerows and dehesa systems must be understood within the paradigm that involves the integration of the biological processes that drive soil–plant systems and that can serve to optimize nutrient cycling, minimize external inputs and maximize the efficiency of their use (Fernandes, 2006; Gama-Rodrigues, 2011). ET is particularly important in environments with long hot, arid periods, such as the Mediterranean region, where a lack of water resources is the main factor limiting agricultural development (Campi, Palumbo, & Mastrorilli, 2012). From the results obtained both hedgerow and dehesa systems appear to potentially reduce ET in pastures by modifying the aerodynamic component of the energy balance (see Burke, 1991; Campos, Villodre, Carrara, & Calera, 2013). However, these systems potentially reduce ET to different extents with important implications for the ecosystem services that these systems provide in Mediterranean ecosystems (Nieto-Romero, Oteros-Rozas, González, & Martín-López, 2014).

Agri-environment schemes usually include the restoration of woody cover in different horizontal structures in farmland, hence this research provides evidence for assessing the potential of silvopastoral systems as a conservation option (Kleijn & Sutherland, 2003). In certain parts of Europe microclimate considerations are important for shelterbelt planting (Kristensen & Caspersen, 2002). The changes in exposure due to changes in land use and land cover can influence regional climates (Hanjie & Hao, 2003), and since forecasts for climate change provided by circulation models indicate an increased water deficit for the Mediterranean region (IPCC, 2007; Jin, Kitoh, & Alpert, 2010), the promotion of one or other system of horizontal structure of the vegetation should be taken into account. Hedgerow systems are able to reduce the impact of the wind on ET (Brandle, Hintz, & Sturrock, 1988; Sudmeyer, Crawford, Meinke, Poulton, & Robertson, 2002; Van Eimern, Karschon, Razumova, & Robertson, 1964) and although the woody vegetation of dehesa systems is also able to reduce wind speed (Kainkwa & Stigter, 1994; Stigter, Kainkwa, Eltayeb Mohamed, & Onyewotu, 1997) and modify the ET balance (Joffre & Rambal, 1993) the differences should be taken into account in land use planning.

Given the aforementioned distinctiveness of *F. angustifolia*-dominated systems our results may not be directly transferable to silvoagrosystems dominated by other tree species. However, the approach we have taken provides the basis for research of other Mediterranean systems, ultimately, to inform the land planning process in order to promote optimal horizontal structures of vegetation to better provide natural services and improve productivity. Further work is also needed on the role of ET in hedge and dehesa systems in order to evaluate the consequences for the potential differences inferred in this study.

5. Conclusions

The results here highlight that the traditional hedgerow system in areas dominated by *F. angustifolia* under Mediterranean climate conditions is potentially more effective than dehesa systems in providing natural services and, potentially, pasture yield. This is reflected in a higher reduction of wind speed, improved conservation of soil moisture, and higher organic carbon content despite similar temperatures in both systems. Therefore the hedgerow system is potentially a more effective system that can provide better natural services and conservation of water resources – critical for ameliorating the effects of climate change – and is in sharp contrast with the current tendency towards changes towards dehesa systems. We recognize these results are only valid for habitats similar to those in our study area with the key characteristic of having a high water table most of the year. Accordingly, similar studies that analyze the horizontal structure of vegetation to achieve the best natural services and yields are recommended in other Mediterranean environments so that they can provide evidence for effective planning and management.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2015.07.002

References

Antrop, M. (1997). The concept of traditional landscapes as a base for landscape evaluation and planning: The example of Flanders region. *Landscape and Urban Planning*, *38*, 105–117. http://dx.doi.org/10.1016/S0169-2046(97)00027-3

Bassa, M., Chamorro, L., José-María, L., Blanco-Moreno, J. M., & Sans, F. X. (2012). Factors affecting plant species richness in field boundaries in the Mediterranean region. *Biodiversity and Conservation*, *21*, 1101–1114. http://dx.doi.org/10.1007/s10531-012-0245-y

Ben Salah, H., Beji, M. A., & Salah, H. B. (1989). Effects of windbreak protection on faba bean production. *Annales de l'Institut National de la Recherche Agronomique de Tunisie*, 125–137.

Bergmeier, E., Petermann, J., & Schroder, E. (2010). Geobotanical survey of wood-pasture habitats in Europe: Diversity, threats and conservation. *Biodiversity and Conservation*, *19*, 2995–3014. http://dx.doi.org/10.1007/s10531-010-9872-3

Bickmore, J. C. (2002). *Hedgerow survey handbook: A standard procedure for local surveys in the UK*. Bangor: Countryside Council for Wales.

Brandle, J. R., Hintz, D. L., & Sturrock, J. W. (1988). *Windbreak technology*. Amsterdam: Elsevier.

Brandle, J. R., Hodges, L., & Zhou, X. H. (2004). Windbreaks in North American agricultural systems. *Agroforestry Systems*, *61*, 65–78. http://dx.doi.org/10.1023/B:AGFO.0000028990.31801.62

Bunce, R. G. H., Pérez, M., Elbersen, B. S., Prados, M. J., Andersen, E., Bell, M., et al. (2001). *Examples of agri-environment schemes and livestock systems and their influence on Spanish cultural landscapes*. Alterra: Wageningen.

Burke, S. (1991). The effect of shelterbelts on crop yields at Rutherglen, Victoria. In *Proceedings from a National Australian Conference on the Role of Trees in Sustainable Agriculture* Albury, Victoria, Australia, (pp. 89–99).

Campi, P., Palumbo, A. D., & Mastrorilli, M. (2009). Effects of tree windbreak on microclimate and wheat productivity in a Mediterranean environment. *European Journal of Agronomy*, *30*, 220–227. http://dx.doi.org/10.1016/j.eja.2008.10.004

Campi, P., Palumbo, A. D., & Mastrorilli, M. (2012). Evapotranspiration estimation of crops protected by windbreak in a Mediterranean region. *Agricultural Water Management*, *104*, 153–162. http://dx.doi.org/10.1016/j.agwat.2011.12.010

Campos, I., Villodre, J., Carrara, A., & Calera, A. (2013). Remote sensing-based soil water balance to estimate Mediterranean holm oak savanna (dehesa) evapotranspiration under water stress conditions. *Journal of Hydrology*, *494*, 1–9. http://dx.doi.org/10.1016/j.jhydrol.2013.04.033

Casa, R., Valentini, R., Scarascia, M., & Mugnozza, G. (1994). Influenza di barriere arboree frangivento sul microclima e sul bilancio energetico di colture retrostanti in ambiente mediterraneo. *Monti e Boschi*, *5*, 41–47.

Comins, J. S., Sendra, J. B., & Sanz, F. M. (1993). Crisis and permanence of the traditional Mediterranean landscape in the central region of Spain. *Landscape and Urban Planning*, *23*, 155–166. http://dx.doi.org/10.1016/0169-2046(93)90065-L

Díaz, M., Campos, P., & Pulido, F. J. (1997). The Spanish *dehesas*: A diversity in land-use and wildlife. In D. J. Pain, & M. W. Pienkowski (Eds.), *Farming and birds in Europe; the Common Agricultural Policy and its implications for bird conservation* (pp. 178–209). London: Academic Press.

Donjadee, S., Clemente, R. S., Tingsanchali, T., & Chinnarasri, C. (2010). Effects of vertical hedge interval of vetiver grass on erosion on steep agricultural lands. *Land Degradation and Development*, *21*, 219–227. http://dx.doi.org/10.1002/ldr.900

Eichhorn, M. P., Paris, P., Herzog, F., Incoll, L. D., Liagre, F., Mantzanas, K., et al. (2006). Silvoarable systems in Europe – Past, present and future prospects. *Agroforestry Systems*, *67*, 29–50. http://dx.doi.org/10.1007/s10457-005-1111-7

Elías, F., & Castellvi, F. (1996). *Agrometeorología*. Madrid: Ministerio de Agricultura, Pesca y Alimentación and Ediciones Mundi-Prensa.

Fernandes, E. C. M. (2006). Agroforestry for productive and sustainable landscapes in the face of global change. In A. C. da Gama-Rodrigues, N. F. de Barros, E. F. da Gama-Rodrigues, M. S. M. Freitas, A. P. Viana, J. M. Jasmin, C. R. Marciano, & J. G. A. Carneiro (Eds.), *Sistemas agroflorestais: bases científicas para o desenvolvimento sustentável* (pp. 15–31). UENF: Campos dos Goytacazes.

Gama-Rodrigues, A. C. (2011). Soil organic matter, nutrient cycling and biological dinitrogen-fixation in agroforestry systems. *Agroforestry Systems*, *81*, 191–193. http://dx.doi.org/10.1007/s10457-011-9372-9

Gardiner, T., & Dover, J. (2008). Is microclimate important for Orthoptera in open landscapes? *Journal of Insect Conservation*, *12*, 705–709. http://dx.doi.org/10.1007/s10841-007-9104-7

Gaussen, H. (1954). Théories et classification des climats et microclimats. In *VII Congrés Int CNRS Bot Act 7 and 3* (pp. 125–130).

Gaussen, H. (1955). Expression des milieux par des formules écologiques. *Annales de Biologie*, *31*, 257–269.

Gea-Izquierdo, G., Allen-Díaz, B., San Miguel, A., & Cañellas, I. (2010). How do trees affect spatio-temporal heterogeneity of nutrient cycling in Mediterranean annual grasslands? *Annals of Forest Science*, *67*, 112. http://dx.doi.org/10.1051/forest/2009091

Gomez-del-Campo, M. (2010). Physiological and growth responses to irrigation of a newly established hedgerow olive orchard. *HortScience*, *45*, 809–814.

Gomez-del-Campo, M. (2013). Summer deficit-irrigation strategies in a hedgerow olive orchard cv. 'Arbequina': Effect on fruit characteristics and yield. *Irrigation Science*, *31*, 259–269. http://dx.doi.org/10.1007/s00271-011-0299-8

Grove, A. T., & Rackham, O. (2001). *The nature of Mediterranean Europe. An ecological history*. London: Yale University Press.

Hanjie, W., & Hao, Z. (2003). A simulation study on the eco-environmental effects of 3N Shelterbelt in North China. *Global Planetary Change*, *37*, 231–246. http://dx.doi.org/10.1016/S0921-8181(02)00208-4

Hassan, R., Scholes, R., & Ash, N. (Eds.). (2005). *Millennium ecosystem assessment*. Washington: Island Press.

Helfer, F., Zhang, H., & Lemckert, C. J. (2009). *Evaporation reduction by windbreaks: Overview, modelling and efficiency. Urban Water Security Research Alliance Technical Report No. 16.*

Herbst, M., Roberts, J. M., Rosier, P. T. W., & Gowing, D. J. (2007). Seasonal and interannual variability of canopy transpiration of a hedgerow in southern England. *Tree Physiology*, *27*, 321–333. http://dx.doi.org/10.1093/treephys/27.3.321

Höchtl, F., Born, K. M., & Plieninger, T. (2010). Landscape change and regional identity: Introduction to the special section. *Landscape Research*, *35*, 427–430.

Ibañez, J. J., Lledó, M. J., Sánchez, R. J., & Rodá, F. (1999). Stand structure, aboveground biomass and production. In F. Rodá, J. Retama, C. Gracia, & J. Bellot (Eds.), *Ecology of Mediterranean evergreen oak forests* (pp. 31–43). Berlin: Springer.

IPCC. (2007). *The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge: University Press.

Jaeger, C., Gessler, A., Biller, S., Rennenberg, H., & Kreuzwieser, J. (2009). Differences in C metabolism of ash species and provenances as a consequence of root oxygen deprivation by waterlogging. *Journal of Experimental Botany*, *60*, 4335–4345. http://dx.doi.org/10.1093/jxb/erp268

Jin, F. J., Kitoh, A., & Alpert, P. (2010). Water cycle changes over the Mediterranean: A comparison study of a super-high-resolution global model with CMIP3. *Philosophical Transactions of the Royal Society A*, *368*, 5137–5149.

Joffre, R., Leiva Morales, M. J., Rambal, S., & Fernandez Ales, R. (1987). Dynamique racinaire et extraction de l'eau du sol par des graminees perennes et annuelles mediterraneennes. *Acta Œcologica Œcologia Plantarum*, *8*, 181–194.

Joffre, R., & Rambal, S. (1988). Soil water improvement by trees in the rangelands of Southern Spain. *Acta Œcologica Œcologia Plantarum*, *9*, 405–422.

Joffre, R., & Rambal, S. (1993). How tree cover influences the water balance of Mediterranean rangelands. *Ecology*, *74*, 570–582. http://dx.doi.org/10.2307/1939317

Jose, S., Gillespie, A. R., & Pallardy, S. G. (2004). Interspecific interactions in temperate agroforestry. *Agroforestry Systems*, *61*, 237–255. http://dx.doi.org/10.1023/B:AGFO.0000029002.85273.9b

Kainkwa, R. M. R., & Stigter, C. J. (1994). Wind reduction downwind from a savanna woodland edge. *Netherlands Journal of Agricultural Science*, *42*, 145–157.

Kleijn, D., & Sutherland, W. J. (2003). How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology*, *40*, 947–969. http://dx.doi.org/10.1111/j.1365-2664.2003.00868.x

Klein, J. (1920). *The mesta: A study in Spanish economic history 1272–1836*. Harvard: Harvard University Press.

Kristensen, S. P., & Caspersen, O. H. (2002). Analysis of changes in a shelterbelt network landscape in central Jutland, Denmark. *Journal of Environmental Management*, *66*, 171–183. http://dx.doi.org/10.1006/jema.2002.0582

Kuemmel, B. (2003). Theoretical investigation of the effects of field margin and hedges on crop yields. *Agriculture, Ecosystems and Environment*, *95*, 387–392. http://dx.doi.org/10.1016/S0167-8809(02)00086-5

Landsberg, J. J., & McMurtrie, R. (1984). Water use by isolated trees. *Agricultural Water Management*, *8*, 223–242.

Lionello, P., Boscoso, R., & Malanotte-Rizzoli, P. E. (Eds.). (2006). *Mediterranean climate variability*. Amsterdam: Elsevier.

Madera, P., & Uradnicek, L. (2001). Growth response of oak (*Quercus robur* L.) and ash (*Fraxinus angustifolia* Vahl.) on changed conditions of the floodplain forest geobiocoene hydrological regime. *Ekologica (Bratislava)*, *20*(Suppl. 1), 130–142.

Mairota, P., Leronni, V., Xi, W., Mladenoff, D. J., & Nagendra, H. (2014). Using spatial simulations of habitat modification for adaptive management of protected areas: Mediterranean grassland modification by woody plant encroachment. *Environmental Conservation*, *41*, 144–156. http://dx.doi.org/10.1017/S037689291300043X

Manrique, E. (1993). *Informatizaciones "CLIMOAL"*. Madrid: Escuela Universitaria de Ingenieria Técnica Forestal. Fundación Conde del Valle de Salazar.

McDonald, J. H. (2009). *Handbook of biological statistics* (2nd ed.). Baltimore: Sparky House Publishing.

Meiner, A., Georgi, B., Petersen, J.-E., & Uhel, R. (Eds.). (2010). *The European environment state and outlook: Land use*. European Environment Agency. http://www.eea.europa.eu/soer/europe/land-use

Messing, I., Afors, M., Radkvist, K., & Lewan, E. (1998). Influence of shelterbelt type on potential evaporation in an arid environment. *Arid Soil Research and Rehabilitation*, *12*, 123–138. http://dx.doi.org/10.1080/15324989809381503

Metzger, M. J., Bunce, R. G. H., Jongman, R. H. G., Mucher, C. A., & Watkins, J. W. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, *14*, 549–563. http://dx.doi.org/10.1111/j.1466-822X.2005.00190.x

Minitab. (2010). *Minitab 16 statistical software*. State College, PA: Minitab Inc.

Moreno, G., Obrador, J. J., & Garcia, A. (2007). Impact of evergreen oaks on soil fertility and crop production in intercropped dehesas. *Agriculture, Ecosystems and Environment*, *119*, 270–280. http://dx.doi.org/10.1016/j.agee.2006.07.013

Moreno Marcos, G., Obrador, J. J., García, E., Cubera, E., Montero, M. J., Pulido, F., et al. (2007). Driving competitive and facilitative interactions in oak dehesas through management practices. *Agroforestry Systems*, *70*, 25–40. http://dx.doi.org/10.1007/s10457-007-9036-y

Nieto-Romero, M., Oteros-Rozas, E., González, J. A., & Martín-López, B. (2014). Exploring the knowledge landscape of ecosystem services assessments in Mediterranean agroecosystems: Insights for future research. *Environmental Science and Policy*, *37*, 121–133. http://dx.doi.org/10.1016/j.envsci.2013.09.003

Oke, T. R. (1987). *Boundary layer microclimates*. London: Routledge.

Pereira, M., & Rodriguez, A. (2010). Conservation value of linear woody remnants for two forest carnivores in a Mediterranean agricultural landscape. *Journal of Applied Ecology*, *47*, 611–620. http://dx.doi.org/10.1111/j.1365-2664.2010.01804.x

Pinto-Correia, T. (1993). Threatened landscape in Alentejo, Portugal: The Montado and other agro-silvo-pastoral systems. *Landscape and Urban Planning*, *24*, 43–48. http://dx.doi.org/10.1016/0169-2046(93)90081-N

Plieninger, T., Höchtl, F., & Spek, T. (2006). Traditional land-use and nature conservation in European rural landscapes. *Environmental Science and Policy*, *9*, 317–321.

Plieninger, T., & Schaar, M. (2008). Modification of land cover in a traditional agroforestry system in Spain: Processes of tree expansion and regression. *Ecology and Society*, *13*, 25. http://dx.doi.org/10.1016/j.envsci.2006.03.001

Ricci, B., Franck, P., Bouvier, J. C., Casado, D., & Lavigne, C. (2011). Effects of hedgerow characteristics on intra-orchard distribution of larval codling moth. *Agriculture, Ecosystems and Environment*, *140*, 395–400. http://dx.doi.org/10.1016/j.agee.2011.01.001

Rosenberg, N. J. (1979). Windbreak for reducing moisture stress. In B. J. Barfield, & J. F. Gerber (Eds.), *Modification of the aerial environment of plants* (pp. 397–408). St. Joseph: ASAE.

Sánchez, I. A. (2001). *Adaptación al cambio climático mediante la configuración espacial de la vegetación: los setos* (Ph.D. thesis). Madrid: Universidad Autónoma de Madrid.

Sánchez, I. A., Lassaletta, L., McCollin, D., & Bunce, R. G. H. (2010). The effect of hedgerow loss on microclimate in the Mediterranean region: An investigation in Central Spain. *Agroforestry Systems*, *78*, 13–25. http://dx.doi.org/10.1007/s10457-009-9224-z

Scalercio, S., Iannotta, N., & Brandmayr, P. (2007). The role of semi-natural and abandoned vegetation patches in sustaining lepidopteran diversity in an organic olive orchard. *Bulletin of Insectology*, *60*, 13–22.

Schmitz, M. F., De Aranzabal, I., Aguilera, P., Rescia, A., & Pineda, F. D. (2003). Relationship between landscape typology and socioeconomic structure. Scenarios of change in Spanish cultural landscapes. *Ecological Modelling*, *168*, 343–356. http://dx.doi.org/10.1016/S0304-3800(03)00145-5

Sitzia, T. (2007). Hedgerows as corridors for woodland plants: A test on the Po Plain, northern Italy. *Plant Ecology*, *188*, 235–252. http://dx.doi.org/10.1007/s11258-006-9159-7

Stigter, C. J., Kainkwa, R. M. R., Eltayeb Mohamed, A., & Onyewotu, L. O. Z. (1997). Essentials and cases of wind protection from scattered trees and shelterbelts. In E. G. Bonkoungou, E. T. Ayuk, & I. Zoungrana (Eds.), *Les parcs agroforestiers des zones semi-arides d'Afrique de l'ouest [Parkland Agroforestry of the semi-arid areas of West Africa]* (pp. 75–93). Nairobi: SALWA-Network, Ouagadougou, and ICRAF.

Sudmeyer, R. A., Crawford, M. C., Meinke, H., Poulton, P. L., & Robertson, M. J. (2002). Effect of artificial wind shelters on the growth and yield of rainfed crops. *Australian Journal of Experimental Agriculture*, *42*, 841–858, doi:procite:29feaace-4c08-4676-a829-12f592fa4eb5.

Thornthwaive, C. W. (1948). An approach toward a rational classification of climate. *Geographical Review*, *38*, 55–94.

Van Eimern, J., Karschon, R., Razumova, L. A., & Robertson, G. W. (1964). *Windbreaks and shelterbelts. Technical note No 59*. Geneva: WMO.

Verdoya, M., Chiozzi, P., & Pasquale, V. (2007). Thermal log analysis for recognition of ground surface temperature change and water movements. *Climate of the Past Discussions, European Geosciences Union*, *3*, 315–324, <hal-00298169>.

Walkely, A. (1935). An examination of methods for determining organic carbon and nitrogen soils. *Journal of Agricultural Science*, *25*, 598–609. http://dx.doi.org/10.1017/S0021859600019687