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The effect of hedgerow loss on microclimate in the Mediterranean region: an investigation in Central Spain

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Abstract In Central Spain hedgerows are an important component of the landscape although many have been lost due to landscape planning and reallotment programmes. Loss of hedgerows can produce changes in environmental conditions that can be especially critical in summer, corresponding with the dry period in Mediterranean ecosystems. In order to show the effects of hedgerow removal on summer Mediterranean environmental conditions in rural landscapes, this paper describes a comparison of some key environmental conditions between areas where hedgerows are still present, compared to areas where they have been removed. Through a two-way ANOVA, it was found that temperatures in the hedgerows were significantly different from those in the fields, whilst air temperatures beneath the hedgerows were lower, and steadier, than those of surrounding areas. When temperatures of the fields were compared to those sites where hedgerows had been removed, significant differences in temperatures were detected belowground and sometimes at soil surface level but not at higher levels. The levels of soil water content and organic carbon were higher where hedgerows were still in place. These differences indicate potentially negative environmental impacts due to hedgerow removal. The implications of hedgerow conservation for environmental protection and for cropland productivity are discussed.

Keywords Mediterranean hedgerows · Hedgerow removal · Summer temperature · Soil water content · Soil carbon · Ecological stability

Introduction

Hedgerows have been lost throughout Western Europe due to the progressive modernisation of agricultural practices since the 1940s (O'Connor and Shrubb 1986; Meeus 1993). In Spain, landscape change after the Civil War was driven first by the colonising orientation of rural politics, and second by agronomic policies of the Franco regime involving large-scale

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planning and land reallotment programmes (*concentración parcelaria*; Gomez and Mata 1993). As a result of these pressures, hedgerow loss in parts of Spain came about as shifts in land use favoured extensive cattle ranching over more traditional practices with their emphasis on hay production (Apilañez and Mortera 1997; Sánchez 2001). During recent decades, further landscape change has come about due to more locally oriented land planning at the level of autonomous regions and the municipalities.

Hedgerows are a common feature of many agricultural landscapes throughout Europe and concerns over their loss have covered a broad range of environmental issues including microclimate modification, radiation interception, wind erosion, and loss of visual amenity (Pollard et al. 1974; Forman 1995; McCollin 2000; Oyarzun et al. 2007) although perhaps the greatest volume of literature concerns losses of biodiversity, e.g. birds (O'Connor and Shrubb 1986; Krebs et al. 1999), carabid beetles (Aviron et al. 2005), butterflies (Dover and Sparks 2000) beneficial arthropods (Maudsley 2000; Marshall et al. 2006) and crop or pasture response (Brandle et al. 1988; Bird et al. 2002). Other functions lost include cultural associations such as fuelwood production and a supplementary source of resources such as wild fruits and berries (Baudry and Bunce 2001).

Land use and land cover influence regional climates (Hanjie and Hao 2003), and the removal of vegetation cover potentially leads to increases in air and soil temperatures (Majorowicz 1996; Lewis and Wang 1998; Nitoiu and Beltrami 2005). Hedgerow removal affects a range of factors including water loss (Kinama et al. 2005), precipitation, and light interception (McIntyre et al. 1996; Herbst et al. 2006), and therefore is likely to affect local microclimates especially in regions that have high ambient temperatures. The characteristics of hedgerows are often very different in southern Europe compared to the north and there is a restricted literature on Mediterranean hedgerows (but see Paoletti et al. 2001; Padoa-Schioppa et al. 2001; Sánchez et al. 2005; Schmitz et al. 2007; Sitzia 2007; Llausàs et al. 2009). The Mediterranean continental climate of central Spain is characterized by extremes of temperature and a deficiency of soil water availability during the summer period (Izco 1984) that affects biomass, production and stand structure (Ibañez et al. 1999). The effect of hedgerows mitigating this effect is not well known though one investigation with windbreaks point towards a significant effect (Cleugh et al. 2002). Accordingly, this paper seeks to address this gap in the literature by presenting the first analyses of the role of hedgerows in microclimate modification in the Mediterranean region.

Methods

Definition

Here we define hedgerows to be a more or less continuous lines of woody vegetation made of trees and/or shrubs subject to direct or indirect management. In the case of *Fraxinus angustifolia* hedgerows of central Spain dealt with in this paper (Fig. 1), direct management involves pollarding of trees, while indirect management might involve, for example, the effect of cattle browsing and grazing on the hedgerows (Barr and Gillespie 2000; Barr and Petit 2001; Sánchez 2001; Schmitz et al. 2007).

Study area and selection of study sites

The study region is located in the Segovia and Madrid regions (41°05′, 3°44′) of Central Spain (Fig. 2). Yearly mean temperatures range from 11.0 to 14.1°C and mean highest monthly temperature varies from 29.0 to 31.1°C (measurements from data stations in the study region). *F. angustifolia* is the most frequent woody species in hedgerows with *Quercus rotundifolia*, *Q. pyrenaica*, *Salix salvifolia*, and *S. atrocinerea* also present. The management that includes pollarding and pruning for firewood collection, maintains hedgerow trees between c. 4 and 8 m in height on average though exceptionally trees may reach 12 m. The shrub layer is mainly composed of *Prunus spinosa, Rosa* spp., *Rubus ulmifolius, Osiris alba, Lonicera etrusca, L. periclymenum, Crataegus monogyna, Rhamnus cathartica* and *Euonymus europaeus* and the average optical porosity (ϕ) of the hedgerows, measured by photographic techniques (Brown 1969), is 0.31.

Hedgerows often lie adjacent to stonewalls which range in height from 0.85 to 1.15 m. The probable origins of these hedgerows is in plant establishment by the stonewalls that formerly protected the fields from grazing stock. Field systems in the southern zones (to the south of the Sistema Central mountain

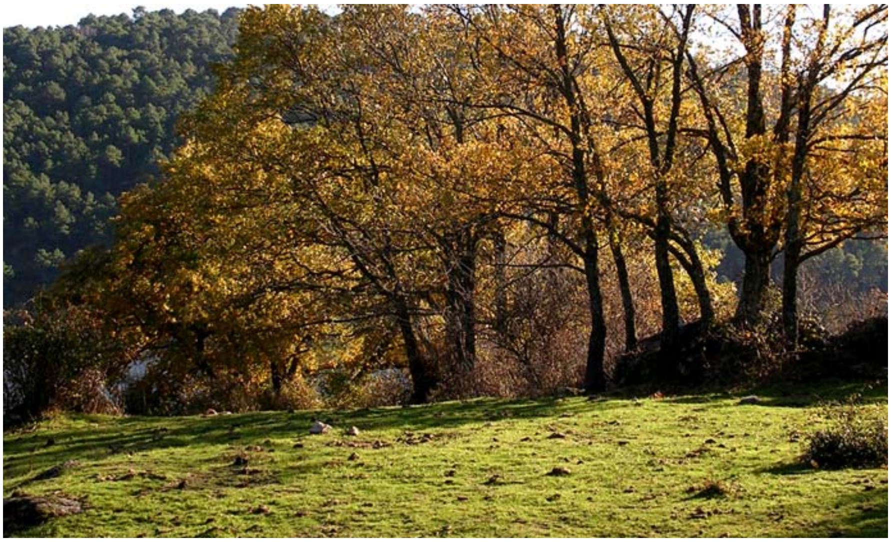

Fig. 1 The photograph shows the characteristics of the hedgerows in the study area. Whilst in Britain such a feature would be considered as a line of trees, in Spain and other European countries such as Austria, they are considered as hedgerows

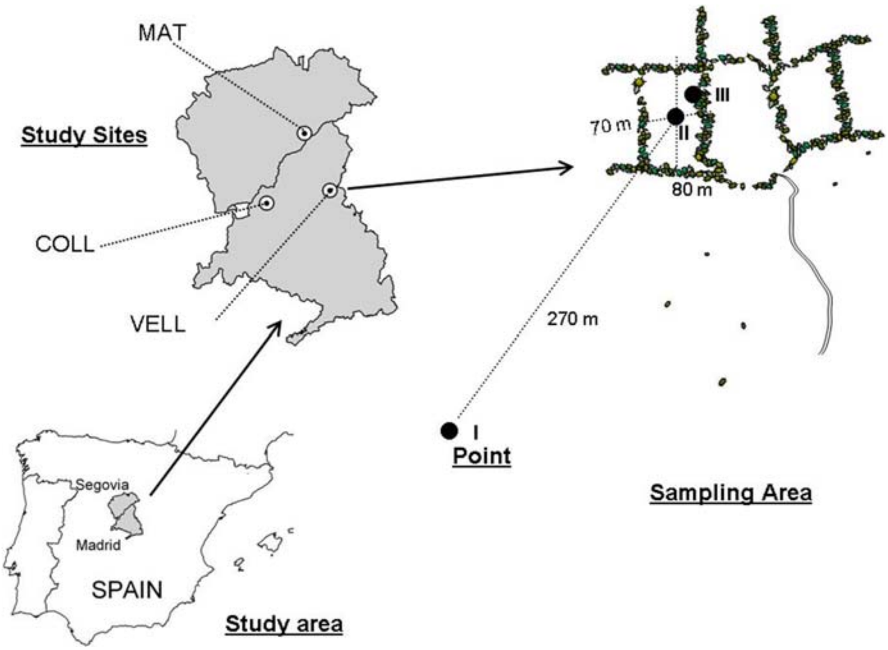

Fig. 2 Location of the study sites within Spain and a generalised example of a sampling area. *Point I* corresponds with fields where hedgerows have been removed; *point II* with fields surrounded by hedgerows; and *point III* inside the hedgerow

range) are more often used for cattle grazing and the northern zones (to the north of the Sistema Central) for hay and various traditional crops.

The present study reports on the microclimate variation between areas where hedgerows are still an integral component of the cultural landscape and those where hedgerows have been removed. We hypothesise that hedgerow removal might produce variations in soil water content, soil organic carbon (C) and temperature, all of which could have implications for agricultural production.

In order to avoid bias, field, soil (type and texture) and hedgerow characteristics with close similarity were selected. Despite land use differences between the regions, we controlled for this factor by selecting a single use: moderate density cattle grazing that produced a surface cover of short grasses. Through cartography and aerial photographs eight sites were found where parts of the hedgerows had been removed and the rest formed a hedgerow network covering at least 10 ha. Each sampling area constituted an independent hedgerow network separated from other networks by at least 10 km inside the study area. In order to find three similar and standard sites, field (size, distances between fields with hedgerows and removed hedgerows, suitable sampling points) and hedgerow characteristics (structure, species content, cover, gap size) were measured based on a standardised procedure (after Baudry and Bunce 2001; Bickmore 2002). After comparison, we chose three study sites based on the similarity of these characteristics, namely: Collado Mediano (Coll), El Vellón (Vell) and Matabuena (Mat) at 994, 974 and 1,156 m above sea level, respectively. For each of these, four sampling areas were selected based on the closest central values of the standard ranges (Table 1). The rest were discarded due to atypical characteristics such as the presence of a slope, significant obstacles to wind circulation other than hedgerows, degraded hedgerow systems (more than half of randomly chosen 30 m hedgerows with gaps greater than 2/3 of their total length), the presence of uncommon woody species, idiosyncratic structure or dimensions, differing land use, or the lack of presence of appropriate standard sampling areas according with the criteria). There was no precipitation during the sampling period nor the month before. Table 2 provides additional meteorological data of the study sites based on a CLIMOAL analysis (Manrique 1993).

In order to set these sites into a wider context, a subsequent comparison was made by fitting the sites into European strata described by Metzger et al. (2005). The site Mat fell directly into the Mediterranean Mountain 5 category (MM5), and whilst Coll also fell into MM5 it was very close to Mediterranean North 6 (MN6)—in which Vell was also present. The latter are both on the edge of the boundaries of the strata and reflect the variation in local conditions from the core values at a European level. Whilst all three sites fall into the Mediterranean region, local factors such as soil, slope and other aspects differentiate between them at the site scale.

Data collection

In order to address the environmental changes produced by hedgerow removal, summer conditions were studied because these were likely to have higher temperatures and water shortages. Although radiation and reflectance are also likely to be key factors, air temperature is the parameter most directly relevant to climate and climatic change literature, and ground-surface temperature is one of several parameters

Table 1 Main standard and sampling areas characteristics

Sampling areas	FSD (m)	FLD (m)	D I–II (m)	MAH (m)	MTC (%)	ASC (%)	WS (m)	WC (m)
Coll 1	79	97	275	5.4	92	81	2.6	6.2
Coll 2	74	82	255	5.0	61	74	2.9	6.6
Coll 3	67	79	283	5.9	65	71	2.1	5.2
Coll 4	82	83	294	6.2	86	79	3.3	6.3
Vell 1	88	83	258	6.0	90	84	3.5	6.4
Vell 2	64	91	290	5.3	72	80	2.0	5.8
Vell 3	72	76	284	5.5	71	70	3.1	7.0
Vell 4	77	83	272	5.1	66	75	2.5	6.1
Mat 1	71	88	253	5.8	69	82	2.7	6.6
Mat 2	82	91	288	6.3	82	86	2.4	7.1
Mat 3	75	80	266	5.1	93	72	3.4	6.2
Mat 4	79	85	293	5.2	75	72	3.0	6.3
Mean ± SE	76 ± 1.9	85 ± 1.7	276 ± 4.3	5.6 ± 0.1	77 ± 3.2	77 ± 1.6	2.8 ± 0.1	6.3 ± 0.1
Standard	60–100	70–110	250–300	5–6.5	60–100	60–100	1.5–3.5	4–8

FSD field short distance in m, *FLD* field long distance in m, *D I–II* distance between points I and II in m (Fig. 2), *MAH* mean maximum height in m (averaged over eight samples for each sampling area), *MTC* mean tree cover in %, *MSC* mean shrub cover in %, *WS* mean width of the shrubs (averaged over eight samples for each sampling area), *WC* mean width of the canopy (averaged over eight samples for each sampling area), *Standard* required range of values of the fields selected as a sampling area

Table 2 Study sites key characteristics

	Sites		
	Coll	Vell	Mat
mm/year	641	670	820
T (°C)	14.1	13.9	11.0
GXP	4.2	3.8	2.2
Annual PET	690.6	677.4	552.0
T_1	30.4	30.1	28.8
T_2	30.2	30.0	28.4
T_3	30.8	30.3	29.0
T_4	31.1	30.7	29.3
PET_1	32.3	32.1	26.1
PET_2	32.1	31.7	25.7
PET_3	32.6	32.3	26.3
PET_4	33.5	33.0	26.6

mm/y mean yearly precipitation in mm (20 years mean), *T* mean yearly temperature in °C, *Gaussian Xerothermic period* time in months in which the mean monthly temperatures curve is over the monthly precipitation curve (based on Gaussen (1954, 1955) and in the variables proposed by Allué-Andrade (1990) such as CLIMOAL represents it), *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 (circa 1 month before the sampling period), PET_1–PET_4 weekly potential evapotranspiration from week 1 to week 4

controlled by air temperature (Lewis and Wang 1992). Because of the greater heat storage capacity underground, temperatures are likely to be important, especially when we consider potential alterations in spatial configuration of vegetation arising from climatic changes. Large contrasts in annual average ground surface temperatures between closely located sites with and without trees have been directly observed previously (Lewis 1998). Good data on fluxes from individual ecosystems or land mosaics and the contrasts between them are essential both to understanding the functioning of the boundary layer and energy/mass accounting (Miller 1984), although such factors are not well understood (Sellers et al. 1997; Beltrami and Harris 2001).

Data were collected during the warmest period of the year between the last 5 days of July and the first 5 days of August of 2004, all with similar weather conditions so that the data could be comparable. At each site, the four sampling areas were composed of a field completely surrounded by hedgerows and a nearby field where hedgerows had been removed (Fig. 2). In total, three sites and four sampling areas per site were sampled.

In each sampling area three measurement points were chosen in order to compare the environmental conditions between them. Point I corresponds with an open field where hedgerows had been removed, point II was in a nearby field afforded some protection by hedgerows, and point III a measurement point placed under the hedgerow surrounding point II (Fig. 2). Thus, having three points for each of the 12 sampling areas, the total number of measurement points was 36. For each of the 12 point III's, five typically structured points under the hedge were selected and from which one was picked at random. In our study sites, a typical hedge structure means a hedge having *F. angustifolia* tree cover and a shrub cover of any of the common species with the standard conditions indicated in Table 1. To maintain similar ground conditions, the three points in each sampling area were located no less than 200 m and no more than 300 m apart to avoid the hedgerow influence at point I's; the average short and long distance from side to side of rectangular fields surrounded by hedgerows was 76 and 85 m, respectively. A total of 252 temperature daily cycles were measured at 2 h intervals at points I, II and III at seven fixed vertical heights (300, 100, 30, 15, 0 cm above ground and 10 and 30 cm underground). Day and night periods were defined through the natural sharp changes in temperature existing at after dawn and dusk. Thermographs were cross-checked with Digitermo® and StopAway® thermometers and, in the temperature range of the investigation, the error was ±0.1°C.

Gravimetric measurements of the soil water content were carried out with samples taken at the same time of the day (09:00) at the same points where the temperatures were being taken thus obtaining four samples and averaging them to obtain the water percentage of the soil at each sampling point. Measurements of soil total organic C were carried out using the Walkely–Black method (Walkely 1935). Four samples were taken and averaged in a 4 m^2 area around each point. Wind speed was measured with a Lutron AM-4221 digital cup anemometer calculating the average of four measurements taken every 2 h at 1 m above ground again at each point to complete a 24 h cycle.

Data management and analysis

To analyse the effect of variables point and height on the daily summer temperature behaviour and detect possible interactions between variables a two-way ANOVA (SPSS 12.0) was performed for each site, differentiating day (D) and night (N). The temperature in °C (*T*; dependent variable) was contrasted with the categorical independent variables points (I, II and III levels) and height (four levels, S: 30 and 15 cm under ground level; 0: at ground level; L: 30 and 15 cm above ground; and H: 100 and 300 cm above ground). The selection of the four height levels was based on theoretical differences of heat transfer at different heights layers (Elías and Castellvi 1996) that differentiate the S underground level, the 0 level in the laminar sub-layer (where molecular heat transfer is dominant), the L corresponding with the intermediate layer (representing a transition between molecular and turbulent heat transfer) and the H (where turbulent heat transfer is dominant). Before doing the analysis of the levels S, L and H the temperature of the two heights for each level was averaged. The variable *T* was logarithmically transformed to obtain a normal distribution for each group. Games-Howell post-hoc tests by pairs for each separate height were applied to detect significant differences between mean values of *T* between points I, II and III.

Results

Temperature results

There were significant interactions ($P < 0.001$) for the three sites between variables point and height for both day and night (Table 3). This implies that *T* differences between the three points were not always similar at the four studied (grouped) heights which therefore show an absence of parallelism (Figs. 3, 4).

During the day (Fig. 3), averaged median temperature varied between 18.2–44.3°C, 18.3–39.4°C and 17.8–37.1°C for Coll, Vell and Mat, respectively. For the three sites the highest *T* was at point I height 0, and the lowest at point III height S. Across all points the lowest *T* was registered at the S height. For the three sites, points III surface data (0, S, H) were similar with a range of 27–28°C for Coll and 23–24°C for Vell and Mat. Point I and II surface *T* were more dissimilar; at Coll, at height 0 in both points the highest *T* were reached, although height L and H showed similar *T*. Vell showed a similar pattern, although L temperatures were lower than S temperatures. In Mat H temperature was lower than in L, but at 0 height there was an important decrease between point I and II.

Table 3 Results of two-way ANOVA performed to analyse the effect of variables point (I, II and III) and height (S, O, L and H levels) and their interactions (point × height) on the daily summer temperature behaviour for each site differentiating day and night

			F (6, 564)	*P*
Day	Coll	Height	149.8	$<0.1 \times 10^{-11}$
		Point	208.9	$<0.1 \times 10^{-11}$
		Height × point	10.3	0.7×10^{-11}
	Vell	Height	131.9	$<0.1 \times 10^{-11}$
		Point	193.1	$<0.1 \times 10^{-11}$
		Height × point	5.8	0.5×10^{-6}
	Mat	Height	155.2	$<0.1 \times 10^{-11}$
		Point	308.1	$<0.1 \times 10^{-11}$
		Height × point	11.0	0.1×10^{-10}
Night	Coll	Height	175.3	$<0.1 \times 10^{-11}$
		Point	5.2	0.006
		Height × point	27.1	$<0.1 \times 10^{-11}$
	Vell	Height	29.7	$<0.1 \times 10^{-11}$
		Point	26.9	0.7×10^{-11}
		Height × point	6.8	0.6×10^{-6}
	Mat	Height	54.2	$<0.1 \times 10^{-11}$
		Point	55.5	$<0.1 \times 10^{-11}$
		Height × point	9.8	0.3×10^{-9}

At all the heights and sites (with the exception of Mat at height H) there were significant differences between point III and points I and II, with point III always cooler and more stable (Table 4). Temperature differences reached 12°C in Coll and Vell at height 0; 5°C higher than in Coll at all heights, in Vell at heights S, 0 and H, and in Mat at heights 0 and L. Between points I and II there were only significant differences at height S (always with a greater soil water content and total soil organic C at point II) and at height 0 in Mat. Averaged *T* differences at height S of both points were 5, 3 and 2°C for Coll, Vell and Mat, respectively. For points I and II the average difference at Mat was higher than 6°C. During day time, at heights 0 and L in Coll and Vell, high

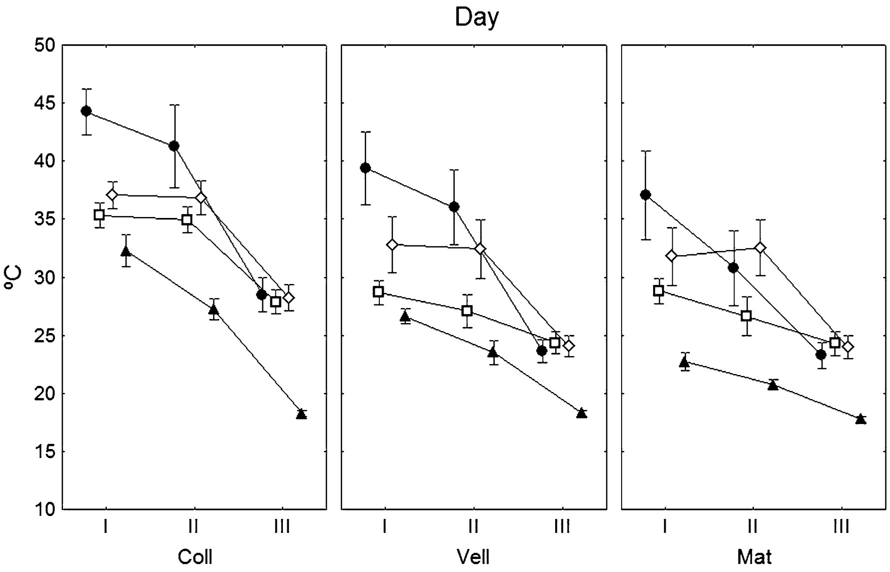

Fig. 3 Variation of average day temperatures (non-transformed data) for each point (I, II and III), height (S, O, L and H levels) and site ($n = 24$). *Vertical bars* denote 95% confidence intervals. Height symbols: S (▲); O (●); L (◇); H (□). See text for further explanation

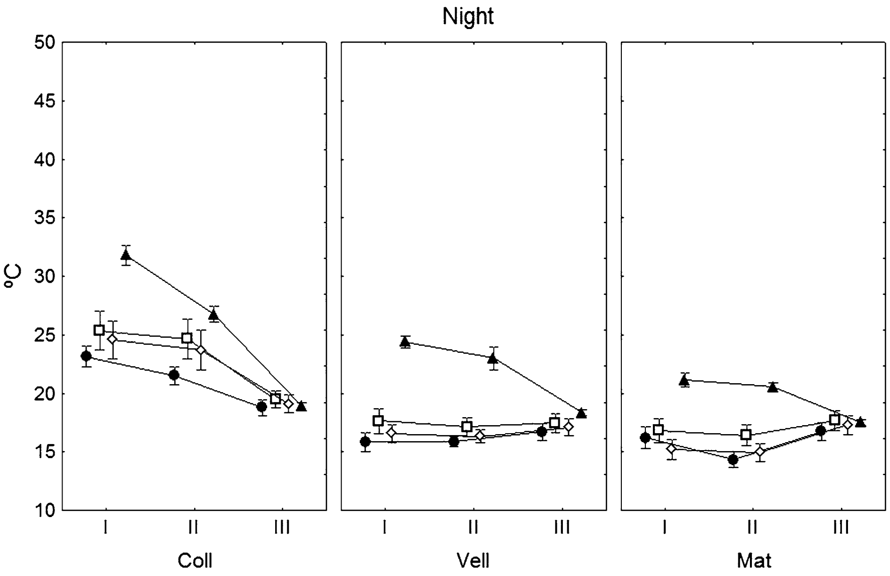

Fig. 4 Variation of average night temperatures (non-transformed data) for each point (I, II and III), height (S, O, L and H levels) and site (Coll, Vell and Mat) ($n = 24$). *Vertical bars* denote 95% confidence intervals. Height symbols: S (▲); 0 (●); L (◇); H (□). See text for further explanation

temperature spots (HTS) were present as shown in Fig. 3.

At night, in spite of there being a significant interaction between the three sites, there was greater correspondence than during the day (Fig. 4). For all three sites, there was a consistent reduction of maximum and minimum *T* and the range was 18–31, 16–26 and 14–21°C for Coll, Vell and Mat, respectively. At height S, average *T* and change patterns were similar to those of the daytime. However, since air *T* for all the points and sites showed a significant decrease, average below ground *T* were therefore higher than surface *T*. The highest *T* was that registered at point I at height S for the three sites. The lowest *T* varied between sites: for Coll it was at the four heights of point III and for Vell and Mat at the heights 0 and L of points I and II. In the point III of the three sites *T* were similar at the four heights. Similar *T*-values were recorded for points I and II of the three sites (data not shown). Notwithstanding that, in Coll, *T* at height 0 was slightly lower that at height S and H.

Significant differences at night, between point III and the other points were found at Coll for all heights but only at height S at Vell (Table 4). In Mat a

Table 4 Significance in the temperature means comparison (Games Howell post hoc test; $P < 0.05$; $n = 24$) between points I, II and II for each height (S, O, L and H), site (Coll, Vell and Mat) and period (day and night)

			I	II	III
Day	Coll	H	a	a	b
		L	a	a	b
		O	a	a	b
		S	a	b	c
	Vell	H	a	a	b
		L	a	a	b
		O	a	a	b
		S	a	b	c
	Mat	H	a	ab	b
		L	a	a	b
		O	a	b	c
		S	a	b	c
Night	Coll	H	a	a	b
		L	a	a	b
		O	a	b	c
		S	a	b	c
	Vell	H	a	a	a
		L	a	a	a
		O	a	a	a
		S	a	b	c
	Mat	H	a	a	a
		L	b	b	a
		O	b	a	b
		S	a	a	b

For each row equal letters means absence of significance. Highest values are represented by the a, middle with b and lowest with c

particular situation occurred; there were differences between point III with a lower *T* and points I and II, however, at height 0, *T* is significantly lower in II and similar between points II and III, and also at height L the *T* of point III was significantly higher than the measured in points I and II. Between points I and II, there were significant differences at height S and 0 in Coll, at height S in Vell and at height 0 in Mat. Despite this significant difference, the average difference in height *T* was lower than that recorded during the day. There was an average difference of 8°C between points II and III, and 5°C between points I and II in Coll at height S. For the other cases the range variation was lower.

Soil water content and total organic carbon

Soil organic C and soil water content are strongly correlated ($r = 0.86$; $P < 0.05$). Figures 5 and 6 show a general increase in both total soil organic carbon and soil water content, from Coll with the lowest amount, to Mat with the highest. Soil organic C was always lower at point I and higher at points II and III. Only in Mat was soil organic C similar between points II and III. On the other hand, the soil water content difference was greater between Vell and Mat than between Coll and Vell. At point I the soil water content percentages were always lower than points II and III. Points II were similar to points III with the exception of Coll.

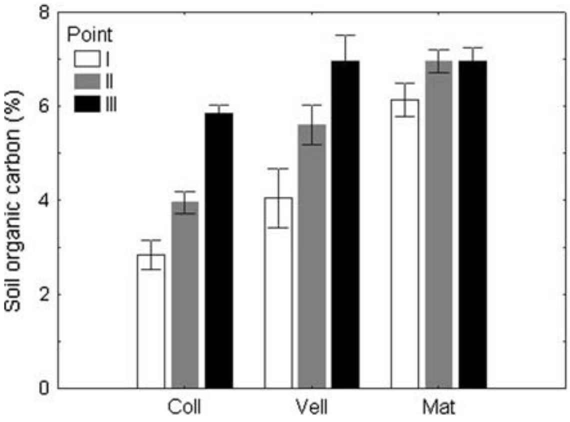

Fig. 5 Soil organic carbon (%) at the sampling points (I, II and III) and sites (Coll, Vell and Mat)

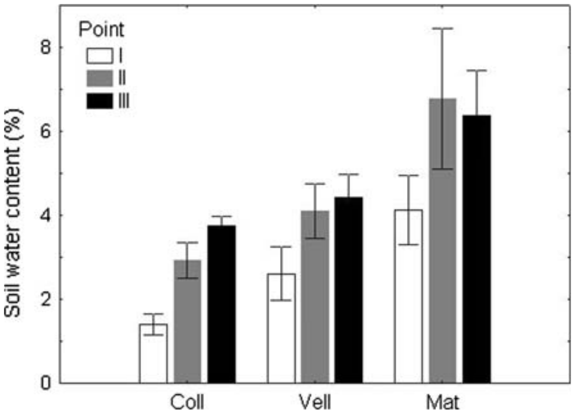

Fig. 6 Soil water content (%) at the different points (I, II and III) and sites (Coll, Vell and Mat)

Wind reduction

There was no significant difference in wind reduction between the three study sites (data not shown). The average wind reduction of the three sites for points II and III in relation to point I was 69.5 and 93.4%, respectively. This result therefore shows the expected effect of hedges on wind reduction.

Discussion

When considering the energy balance of a field the steady state conditions can be described by:

$$R_n + H_\mathrm{L} + H_\mathrm{s} + G = 0$$

where R_n is the net radiation, H_L the latent heat flux, H_s the sensible heat flux, and G the soil heat flux. Our results suggest that the removal of hedgerows leads to changes in all the components of this equation: R_n for the forage will increase in response to removing hedgerows (although it is unclear from our data whether R_n increases at the field scale); G increases because R_n increases, and evaporation and transpiration will decrease as soil water becomes limiting—which can also contribute further to increasing G (however, drier soil has a much lower thermal conductivity and heat capacity than moist soil so this may not be by a large amount); soil temperature may increase much more than G especially during daytime; and H_L will be lower while H_s will be increased. However, the effects of other components, e.g. differential plant growth, advection or moisture relations, may also influence the effect of evaporation and transpiration in sheltered areas (Rosenberg 1979).

The HTS at heights 0 and L in points II, can be partly attributed to the reduction of turbulent mixing and therefore to the lower vertical transport of H_s, but this could partly (or wholly, as in Mat at height 0) be compensated by the higher water content of the soil. At points I a higher proportion of the high temperatures reached in the HTS could be attributed to the lower soil water content. Contrary to the observations of Hagen and Skidmore (1971) at points II of our sites of Coll and Mat, under summer Mediterranean conditions, the greater evapotranspiration due to the higher soil water content in protected fields is not sufficient to reduce H_s and, hence, to lower air temperature. Our results also show how HTS are only reduced at heights 0 and L and therefore include neither the night nor the upper parts (H) where turbulent mixing is easier. Only in the case of Mat, where the amount of soil water for points II was higher, and above the normal level for Mediterranean fields in summer (Padilla and Pugnaire 2007), was the effect of soil water sufficient to reduce H_s and air temperatures to a lower level than those in the open. *Fraxinus angustifolia* hedgerows may be able to grow in zones with a high percentage of soil water (López 2001) and from our results we suggest that these hedgerows contribute to maintaining a higher soil water content. The higher water content of points II and III may also have a direct effect on soil temperature and therefore there may be a threshold in soil water content in relation to the formation of the HTS that for the Mediterranean ecosystems of central Spain might be above, approximately, 3.5% (this data was obtained comparing HTS formation and soil water content). Therefore, the contribution of hedgerows to soil water conservation may ameliorate the effects of the lack of water during the summer, which could result in a longer productive period for the fields.

Because of the greater heat storage capacity in the soil, underground temperatures are significant due to changes in the spatial configuration of the vegetation. Major contrasts in the annual average ground surface temperatures between closely located sites with and without trees have been observed (Lewis 1998). As other authors have found (Van Eimern et al. 1964; Skidmore et al. 1972; McNaughton 1988; Cleugh et al. 1998), plant roots growing (below ground) in protected fields (II and III) have less extreme soil temperatures, lower variability, and higher water content. This might be related to the effect on edaphic processes and the build-up of organic C in the soils of fields with hedgerows. In contrast when hedgerows are removed, there may be consequences, e.g. a lower grass productivity or soil erosion.

The effectiveness of hedgerows in the protection of the fields does not depend so much on the percentage of wind velocity reduction but on how the velocity is reduced below limits which affect different factors (Kuemmel 2003) such as soil erosion, the inhibition of plant growth (Woodruff et al. 1959) or water content in the soil (Brown and Rosenberg 1972; Miller et al. 1973). In addition, mechanical protection may also be important as has been reported for sheltered Citrus on the Mediterranean coast (Rosenberg 1979).

Points III showed significantly steadier microclimatic conditions at all heights and can be considered as a reference in the continuum to points II, in representing hedged mosaic landscapes.

The reduction of wind speed at the measurement points is a surrogate for shelter although this probably fails to give a full characterisation of the shelter effects at the field scale (Nelmes et al. 2001; Dierickx 2003). The relatively homogeneous wind velocity reduction recorded between sites and the protection that the hedgerows provide to the fields indicate similar consequences to the main shelter effect (Rosenberg 1979). The shadowing effect over points II can be considered negligible due to the brief shadowing period that also corresponds when the sun is at its lowest.

From field interviews, it was found that when hedges are too dense local farmers make gaps so that the air can move through the fields in summer (Sánchez 2001). This practice indicates that farmers perceive the lack of air movement in the fields as a problem for grass production for cattle in the fields (point II), or animal comfort, and they therefore create strategic openings. This may explain the few significant differences between points I and II in air temperature.

As in any other habitat, the environmental conditions within the vicinity of hedgerows potentially influences species colonisation and survival (de Blois et al. 2002; Deckers et al. 2004; Harvey et al. 2005), thus the microclimatic conditions associated with hedgerows might be important in their ecological function in providing suitable habitat for certain species in Mediterranean systems, especially those that require more temperate conditions. However, it is unknown the degree to which temperatures of point III's are similar to the equivalent forest in Mediterranean conditions. The possible function of hedgerows as habitat or corridors for forest species has been studied in temperate climates (e.g. Le Coeur et al. 1997; McCollin et al. 2000) and in the temperate-Mediterranean boundary (Sitzia 2007). However, Mediterranean forests tend to be more open that those in temperate climates, although many Mediterranean hedgerow woody species are formed with species and vegetation densities also commonly found in temperate climates (Sitzia 2007). The presence of such species might have the effect in creating more humid and mesic habitats more similar to forest conditions like riverine forests (Sterling 1996), and could be considered as temperate enclaves within Mediterranean climate and during the summer. Therefore, some species such as woodland birds could move through the hedgerows that have a more moderate temperature than the fields.

Because little research is being done on Spanish Mediterranean hedgerows (Santos Perez and Remmers 1997), the results are relevant when considering the value of hedgerow landscapes as habitats, especially during the summer when temperature conditions are extreme and so dissimilar to those of temperate climates. The observed effects on temperature at soil and soil sub-surface levels, soil organic C and soil water content probably make landscapes where hedgerows have been removed less resilient to potential human induced climatic changes.

Conclusions

When comparing fields where hedgerows had been removed with others where hedgerows were still in place we found significantly milder summer day soil temperatures, sometimes at the soil surface level, and also higher soil organic carbon and water content. We also found significantly milder day temperatures at all heights, and higher soil organic C and water content between the fields and the hedgerows. Hedgerow removal in Mediterranean ecosystems can have important consequences especially during the summer since hedgerows potentially function as refuge habitat and/or corridors due to their capacity to provide milder temperature conditions and a higher soil water content, not only for the hedgerow itself but also for parts of the surrounding fields that therefore could achieve a higher productivity. When reallotment programmes in hedged Mediterranean landscapes are devised or funded it is therefore essential that policy makers should take into account the broader environmental value of hedgerows.

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