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Soil fertility evolution and landscape dynamics in a Mediterranean area: a case study in the Sant Llorenç Natural Park (Barcelona, NE Spain)

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The cartography of land covers was used to study fertility and soil evolution in a mountainous Mediterranean area during the anthropocene period (Crutzen P J 2002 Geology of mankind Nature 415 23). The aim was to determine changes in fertility as agricultural lands were abandoned in the 14 000 hectare area that constitutes Sant Llorenç del Munt Natural Park in a pre-coastal Catalan mountain range (north-eastern Iberian Peninsula). The analysis of land covers using vegetation maps, orthorectified images and aerial photography has allowed us to differentiate six vegetation groups: holm-oak wood, pine grove, oak wood, scrub, active agricultural fields and abandoned agricultural fields. The anthropic covers over the past 100 years were subdivided into five categories: active fields and those abandoned over four time periods. Study variables include field shape (concave, convex, flat), orientation (north, south) and slope (ranging from 12° to 24°). The parameters used for the physical-chemical soil analysis included organic material, phosphorous and potassium; fertility was classified based on groups, types and classes. The results indicate that even when the visual appearance of certain landscapes is similar, the edaphic characteristics may be very different. Changes induced by human disturbance share this phenomenon. Therefore, land management should be considered globally, taking into account vegetation, soils and water as interdependent factors, since it is their interaction that produces landscape and most affects its evolution over time.

Key words: *landscape dynamic, human disturbance, abandoned and active agricultural fields, soil alterations, Mediterranean areas, last century scale processes*

Introduction

It is accepted that the impact of human activities has affected all parts of the Mediterranean area and there are no unaltered environments. The mid-mountain Mediterranean is no exception. To understand the evolution of these landscapes it is important to describe how changes in land use have affected the environment (García-Ruiz and Lasanta 1993; García-Ruiz *et al.* 1998; Li *et al.* 2006). For more than a millennium, the quantity of agricultural land has expanded and contracted in terms of demographic pressures and the requirements of the local inhabitants, undergoing slow but important changes. These changes have been especially drastic in the past few decades, when large sections of land have been completely abandoned (Gallart and Lorens 1994).

The process of change has been significant in the Mediterranean mountains as active cereal crop and sheep farming have ceased, economic activity has come to a standstill and the local population has declined to a historic low (Rommens *et al.* 2005). This has produced a landscape of abandoned terraces covered by reforested woods (Schmitt *et al.* 2003) or afforestation by conifers, especially Aleppo pine (*Pinus halepensis*) and Stone pine (*Pinus sylvestris*). However, the process of re-growth does not always follow the theoretical sequence of grassland–scrub–forest. This is largely due to the type of management after the fields have been abandoned, the complex history of disturbance, including fires (Kalabokidis *et al.* 2007), and the heterogeneous topography and soil (Bertran 2004), with intermediate states of plant colonisation that can last for decades (Sjögren 2006; Soriano 1994).

These changes are well described for plant cover, including implications such as infiltration rates, superficial runoff, interception of rainfall, erosion and sediment production (Lasanta *et al.* 2001). In general, more studies have been performed on the hydrological and geomorphological consequences (Ruiz Flaño *et al.* 1992) than on associated soil alterations (Brierley *et al.* 2006); therefore, more in-depth analyses are needed in this field of study.

One of the lines of research of the Mountain Areas and Landscape Research Group at the Autonomous University of Barcelona (GRAMP-UAB) is the evolution of mountain soils with respect to changes in land use. Since 1994 we have performed fertility analyses of the soils (Soriano 1994), followed the evolution of soils and erosion (Molina 2000; Nadal 1997 2002), and analysed fossil and carbon remains (Pèlachs 2004).

The present middle scale study of fertility and soil evolution is based on the cartography of land covers in Sant Llorenç del Munt and Obac Sierra Natural Park in Catalonia (north-eastern Iberian Peninsula), describing soil characteristics of this area in the Mediterranean mountains in terms of several geo-ecological variables that underlie the problems associated with land abandonment and its persistence over time. The study divides the research region into homogeneous areas, based on natural vegetation (holm-oak wood, pine grove, oak wood and scrub), abandoned or active agricultural fields, shape and orientation. It presents a comparative analysis of soil fertility in terms of historical uses, analysing organic material, phosphorus, potassium, and a fertility index. The goal is to show how the consequences of changing land use involve more than just changes in landscape (Miles *et al.* 2001), suggesting that land management should be considered in a global manner, including vegetation, soils and water in a comprehensive analysis.

Study area

Sant Llorenç del Munt and Obac Sierra Natural Park is located in the pre-coastal Catalan mountain range, north-eastern Iberian Peninsula (surface area 14 000 hectares; Figure 1). This range is mostly made up of conglomerates and intercalations of sandstone and lutites of continental origin deposited during the Eocene by an important alluvial system from the old Catalan-Balear massif (Maestro 1987). The conglomerates reach a thickness of 1200 m maximum, with different compositions depending on the source area (Palaeozoic, Triassic and calcareous clasts from the Cretaceous). The quaternary sediments, always quite modest in size, are limited to the valleys and are found from 350 m in the main valley to a maximum altitude of 1100 m.

Rainfall is around 600 mm per year, decreasing towards the northwest as the humid winds from the coast run into the orographic barrier along the Obac and Sant Llorenç range (Pintó 1993). Precipitation is irregular throughout the year and inter-annually, with heavy rainstorms in spring and autumn (Figure 2). Almost all rainfall is concentrated in approximately 10 per cent of the days of the year, with intensities over 100 mm in 24 hours.

The average annual temperature ranges between 10.2ºC at the Mola station (1100 m asl) and 14.6ºC at the Terrassa station (280 m asl) (Nadal 2002), with an altitudinal thermal gradient (Figure 3). The climate is defined as xeroteric, with a marked sub-winter period, except for the Mola station, which has a more humid trend (Nadal 2002).

Holm oak is the potential vegetation (Panareda *et al.* 1993), even though human activities have helped to eliminate much of the original forest. Current plant cover is typically composed of communities of holm-oak wood, *garrigas* (*Quercetum cocciferae* community), and scrub, and other plant formations include the substitution of pine groves with Aleppo pine, although this has not helped to modify the environmental drought conditions because its crowns are relatively small. Finally, there are some deciduous trees such as durmast oak (*Quercus petraea*) and hazelnut, as well as communities of rupiculous plants on lithological outcrops.

Due to the abandonment of agricultural land, the current landscape is perhaps the least anthropised in

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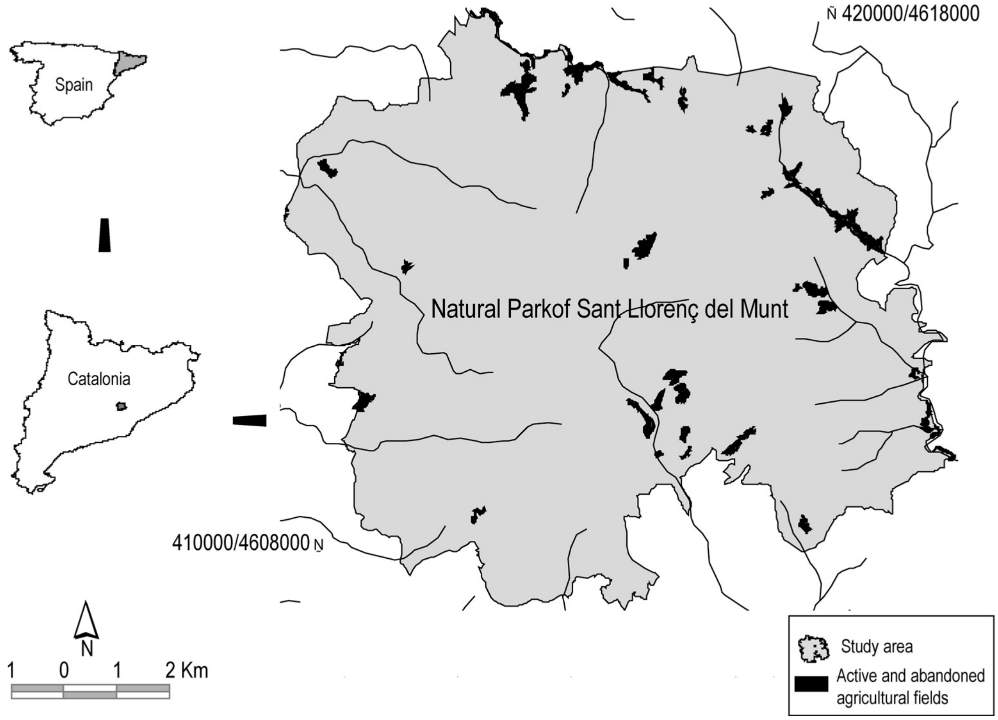

Figure 1 Location of the study area

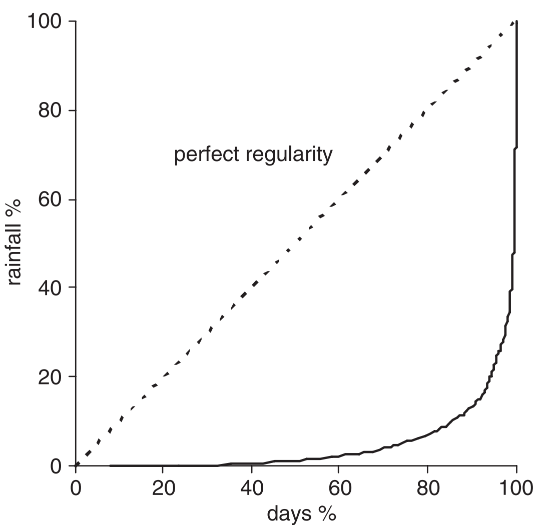

Figure 2 The degree of irregularity in rainfall in the study area based on data from the Castellar del Vallès weather station (Nadal 2002)

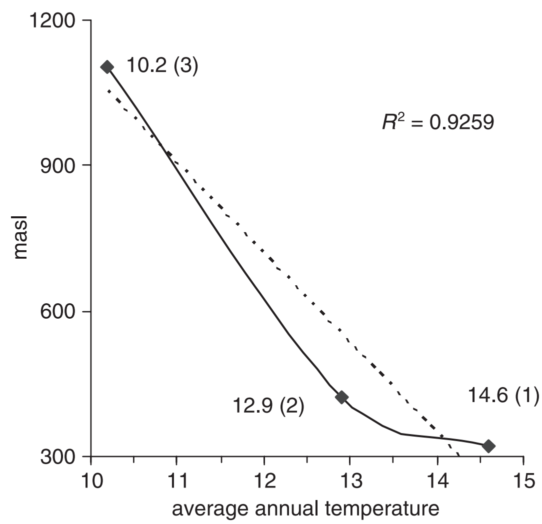

Figure 3 Relationship between height and temperature between the Terrassa (1), Matadepera (2) and la Mola (3) stations (Nadal 2002)

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the study area's recent history. For many centuries, the most extensive agricultural uses were vineyards, olive groves and cereal crops, and the areas with low density arboreal or bushy vegetation were used for goat and sheep pastures. The gentler slopes were cultivated and the forest, primarily oak and holm-oak, was limited to land that was unproductive or very difficult to access.

During the second half of the twentieth century, agricultural abandonment resulted in the return of secondary forests of Aleppo and Stone pine and holm oak. In the last phase of abandonment, the cereal crops and olive groves disappeared, with the exception of some residual areas, along with forest products. The spontaneous reforestation resulting from the abandonment of this territory has had the effect of producing an apparently natural landscape, even though in the midst of the vegetative growth there are innumerable remnants of the intensive anthropic occupation over the past centuries, such as the walls of former terraced fields, remains of coal bunkers, old roads or trails that have been lost.

Methods

Land covers were grouped as holm-oak wood (ho), pine grove (pg), oak wood (oa), scrub (sc), active fields and abandoned fields, based on the cartography of land covers in the Natural Park. These categories were subdivided into fields abandoned before 1956, active in 1956, active in 1972 and active in 1994. Other variables included field shape (concave, convex, flat) and orientation (north, south). A detailed map was made with SIG ArcView using these variables. Lithology was not considered since all sampling areas were located on Eocene conglomerates. We developed an accurate sampling of the fields and an analysis of the most important parameters related to fertility and soil evolution. To reduce some of the variation between plots, we considered slopes in the range of 12º–24º.

Although the published definitions may vary slightly, soil fertility is understood to refer to the capacity to nourish the soil with essential elements. Therefore, the evolution of this fertility gives us a clear idea of the dynamic as land progresses through the cycle of cultivation/abandonment/afforestation.

For fertility analysis we sampled 108 homogeneous areas with 25 subsamples each, with equidistant distribution across the area sampled, to obtain one general sample per area (average surface = 1 ha) (Cobertera 1993) using an Edelman-type probe. The parameters used for the physical-chemical soil analysis included organic material, phosphorous and potassium.

Fertility was classified based on groups, types and classes (Cobertera 1993). We found four types of relationship between phosphorous and assimilable potassium, grouped by the quantitative concentration of phosphorous and potassium, from which 16 variants are obtained, representing differing concentrations of the two elements. On the basis of the concentration of organic material (classified into two groups), we obtain 32 fertility variations, scored from 100 points for high fertility to 5 points for lowest fertility (Table 1).

A series of statistical tests was carried out on the soil sample data. Following normal statistical procedures (Pett 1997; Sierra 1994), we tested the normality and homogeneity of the data with the Kolmogorov-Smirnov (Table 2) and the Leveen statistical

Table 1 Fertility index

Classification	Description	Fertility index
Group A	Organic material >2%	
Group B	Organic material <2%	
Type a	Balanced phosphorous and potassium	
Type b	Rich in phosphorous	
Type c	Deficient in potassium	
Type d	Rich in potassium	
Class I	Very good fertility	100–85
Class II	Good fertility	80–65
Class III	Moderate fertility	60–45
Class IV	Low fertility	40–25
Class V	Very low fertility	20–5

Source: Cobertera (1993, 142–5)

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test, respectively ($P < 0.05$). The data distribution was not normal so we used the non-parametric Kruskal-Wallis test, which considers the range of values observed for each variable for all the areas and evaluates the distribution of the ranges (Table 3).

Results

The most important differences found between wooded areas and abandoned and actively cultivated fields were obtained from four indices: organic material, phosphorous, potassium and fertility index. These permit an explanation of the territorial evolution that is based on land use, detailed below.

Organic material

Despite the fact that this parameter has great spatial variability, Saña's regional study of Catalonia reported values ranging from 0.7 per cent to 8.66 per cent, with an average of 2.8 per cent (Saña 1996). In the study area, the range of values is from 2.2 per cent in cultivated fields to 3.9 per cent in holm-oak wooded areas.

The quantity of organic material varied by the time since abandonment: active fields scored 2.23 per cent compared to fields abandoned before 1956 with 3.33 per cent (Table 4 and Figure 4). Organic material was slightly higher in shady than in sunny areas in most cases, due to the difference in temperature. This observation was true for all cases except fields ab56.

In the wooded samplings, values were similar in holm-oak woods (3.73) and pine groves (4.21), although an oak wood was always poor in organic material (2.05) due to its very low pH (Porta *et al.* 2003). The value in the holm-oak woods was very similar on the north and south slopes. In the pine groves there were strong contrasts due to the difference in growth and exposure to the sun (5% organic material and less than 4% in the shade).

Phosphorous

In the abandoned fields, phosphorous levels were quite homogeneous (range 2.5–8.7 ppm, with some exceptions at 22 ppm). Average values were highest in the active fields, where the need for phosphorous was greater and was added through fertilisers, and decreased with time of abandonment.

In the forest areas the coefficient of variation (CV) was much lower than in the farmed fields. It is interesting to compare the pine forest values (4.29 ppm) with those of fields abandoned prior to 1956 (4.42 ppm); this reinforces the idea of 'naturalisation' of abandoned spaces and their progressive conversion to pine forest.

The holm-oak woods had low CV with uniform values compared to other areas. Values were slightly higher in the south-facing slopes in holm-oak wood (ho) and in oak wood (oa), but not in the pine groves (pg). This is explained by the lack of cover; the shaded parts were so exposed that the soil did not accumulate much humus (Table 5).

Table 2 Normality test. Level of significance (Kolmogorov-Smirnov test)

	Organic material	Phosphorous	Potassium
ho	0.2	0.123	0.2
oa	0	0	0
pg	0.036	0.074	0.2
ab56	0.173	0.2	0.192
ac56	0.2	0	0.074
ac72	0.07	0	0.2
ac94	0.024	0.163	0.2

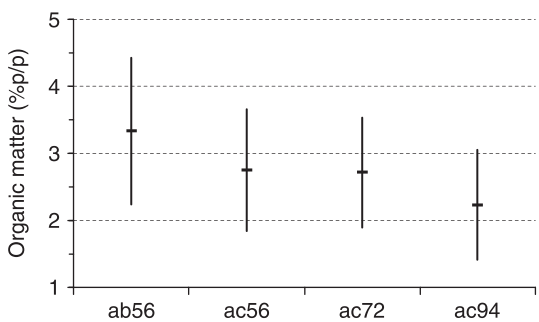

Figure 4 Organic material content in the farmed fields

Table 3 Levels of significance

Analysis	Test	Organic material	Phosphorous	Potassium
Homogeneity of variance	Leveen	0.027	0.002	0.001
Contrast statistics (non-parametric statistics)	Kruskal-Wallis	0	0	0.024

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Potassium

Potassium levels were quite similar among plots, except for fields active in 1994, due to artificial fertilisation (Porta *et al.* 2003). As shown in Table 6, the extreme values were between 60 ppm (fields abandoned before 1956) and 368 ppm (fields active in 1994), with very low CV for natural uses (around 20%) and a bit higher for abandoned fields (less than 40%). These differences were due to the heterogeneous character of the areas disturbed by humans, compared with the homogeneity of natural areas (García-Ruiz *et al.* 1996).

Fertility index

Fertility in the active fields is classified as 'very good'; it falls considerably when fields are abandoned (Table 7). Thus, values over 80 in active fields decreased to 70 or less in recently abandoned fields. However, they recovered for fields abandoned before 1956, in which fertility was similar to active fields. Thus, the order was as follows:

> active in 1994 > abandoned before 1956 > active in 1956 > active in 1972

The CV of the series was less than 25 per cent (except in fields active in 1972, with 32%), so that the consistency of the data is quite high, and demonstrates how an abrupt decline in fertility upon abandonment of a field can be recuperated gradually over time.

The levels of fertility in forested areas (holm-oak, pine grove and oak woods) are higher than active or abandoned fields. The level in pine groves (75.71) was between that of fields abandoned before 1956 (79.64) and those still active in that year (70.29). A similar pattern was found for other parameters.

In holm-oak woods, fertility levels could be considered optimal (87.92) as a result of the forested area and minimal human intervention, including lack of forest management in recent decades. The pine groves, on the other hand, were a product of intense deforestation in the past that substituted holm-oak wood (*Quercetum ilicis galloprovinciale*) for Aleppo pine. Levels in these forests are often similar to the fields abandoned before 1956, which, despite a variety of uses, underwent a total deforestation.

The CV for the forest data series is slightly more homogeneous than for agricultural use. The plots with less human intervention were less altered and those with an internal dynamic are more mature and uniform. All of these findings are trends, and should not be considered absolute.

Statistical analysis

None of the areas analysed showed a normal distribution or homogenic variation; therefore, we used non-parametric statistical analysis. A Dunn test was carried out to compare the average ranges observed for each area with the T statistic that follows an approximately normal distribution (Table 8).

A factorial analysis was also carried out to describe how the study variables were grouped. There was only one group for potassium (no statistical differences). Organic material had two groups: active fields and uses that were less anthropomorphic. Phosphorous

Table 4 Average values of organic material in the farmed fields (%p/p)

	Average	SD	%CV
ab56	3.33	1.09	32.83
ac56	2.75	0.91	33.05
ac72	2.71	0.82	30.25
ac94	2.23	0.81	36.48
ho	3.87	0.81	20.89
pg	3.86	0.71	18.42
oa	2.43	0.46	18.86

Table 5 Average values of phosphorus (ppm) and values in terms of orientation

	Average	SD	%CV	Range (max–min)	North	South
ho	5.42	1.18	21.84	(7.4–2.1)	5.03 (±1.18)	5.80 (±1.16)
pg	4.29	1.08	25.16	(6.8–1.9)	4.49 (±0.79)	4.09 (±1.38)
oa	4.55	1.47	31.23	(6.0–2.7)	3.40 (±0.99)	5.70 (±0.42)
ab56	4.42	1.24	28.03	(6.5–2.5)		
ac56	4.23	1.71	40.38	(8.7–2.6)		
ac72	6.77	5.27	77.74	(22.0–3.1)		
ac94	74.24	60.70	81.76	(228.0–2.5)		

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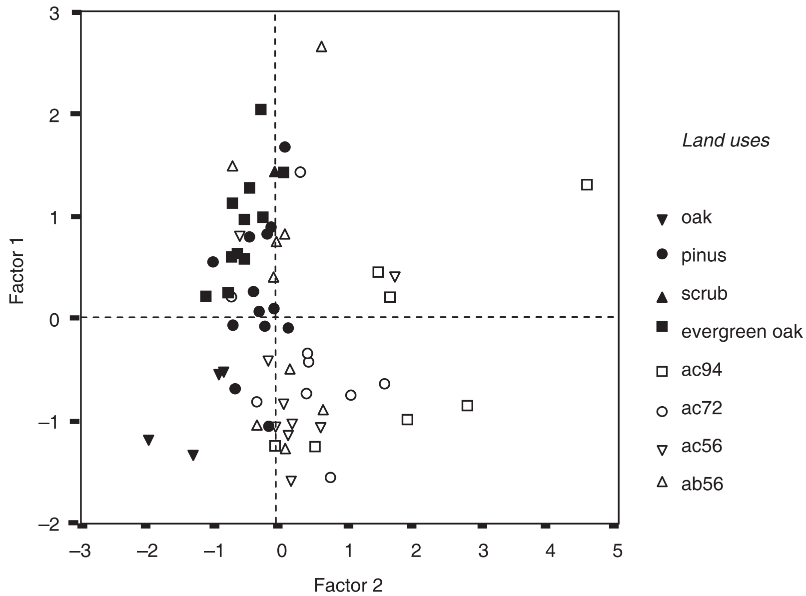

Figure 5 Factorial analysis (factors 1 and 2)

Table 6 Average values of potassium (ppm)

	Average	SD	%CV	Range (max–min)
ho	137.58	25.14	18.27	(172–82)
pg	123.15	21.75	17.66	(156–63)
oa	118.75	13.77	11.59	(138–107)
ab56	108.71	32.28	29.69	(163–60)
ac56	119.06	32.54	27.33	(179–67)
ac72	115.18	37.36	32.43	(203–71)
ac94	210.63	98.20	46.62	(368–73)

Table 7 Average values of fertility in the study areas

	Value	SD	%CV
ho	87.92	12.01	13.66
oa	81.25	19.31	23.77
pg	75.71	21.11	27.89
sc	82.50	18.48	22.41
ab56	79.64	19.16	24.06
ac56	70.29	16.05	22.84
ac72	67.08	21.36	31.85
ac94	83.33	17.90	21.47

also had two groups. One group had two more natural uses (holm-oak wood and oak wood) along with active fields. The second phosphorous group included abandoned fields and pine groves, which were relatively similar.

In the factorial analysis (Table 9), the first three components explained almost 80 per cent of the variance but the weights were similar (35% for the first, 24% for the second and 20% for the third).

The analysis reflects what happens when a territory is abandoned. The soil characteristics of the abandoned fields were not very similar to the soils from holm-oak and oak woods, even though the process of naturalisation often lasted for more than 50 years.

In Figure 5 (factors 1 and 2), the most disturbed areas in the present and past (unshaded symbols) are mostly in the lower right quadrant, and the least disturbed areas (black symbols) in the upper left.

Discussion and conclusions

The parameters we analysed (organic material, phosphorus and potassium) provide the optimum indicators (fertility index) to contrast soils that have experienced heavy anthropic pressures in the recent past and those that have not and to illustrate the landscape dynamic results from these differences in the Mediterranean context.

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A large number of what we currently call natural spaces were, until the past few decades, part of the agricultural land that has seen a reduction in intensity of use and evolved toward a near total abandonment of fields, giving way to a majority presence of natural elements to the detriment of anthropic ones.

In the mountain areas studied, the presence of organic material in the soil is lower in areas of human disturbance (Porta *et al*. 2003) and improved substantially when fields were not cultivated. However, it decreased again with time, and recovered slightly as the forest began to appear. Despite this, the evolution is not completely linear and there are often small variations, so the organic material content in holm-oak woods and pine groves was almost the same as in fields abandoned in the intermediate time period (active in 1956 and active in 1972).

Given the inverse relationship between organic material and temperature (Molina 2000), the former is higher in shaded areas than in sunny areas in all cases and the series of data are less dispersed. Likewise, the values for exposed holm-oak woods to the north and south are very similar due to their large cover, which minimises the differences between slopes. The opposite was observed for pine groves, where the soil cover was much lower, so there were greater differences between slopes (Rommens *et al*. 2005).

The evolution of soil fertility was not linear but tended to increase in accordance with the naturalisation process. Abandoned fields lose their chemical fertility, from an average value above 80 to less than 70. After more than 50 years of abandonment, fertility recovers slowly to more than 80, after which there is no further increase and values may even decrease considerably in pine groves, to equal the highest values in holm-oak woods – the most mature state observed (Figure 6).

In general, the values from the forest were higher than the abandoned fields and fertility was higher on the north slopes where the soil was more humid. Furthermore, the fertility of the more mature soil uses was more homogeneous and did not vary significantly by orientation.

Potassium content was very similar for all uses (human disturbed or natural). Only the active fields had much higher values. Orientation and the geoshape did not influence potassium content. With respect to phosphorous, the data series of natural uses are more homogeneous than the abandoned fields. Phosphorous decreases drastically in the first period of abandonment, but recovers with time as the plots turn into pine groves. Thus, the statistical analyses suggest that soil evolves differently under natural uses than after human disturbance.

From these results, it appeared that, even though the visual appearance of the landscape may be similar,

Table 8 Dunn test. Homogeneous subgroups (a, b)

OM		P		K
a	b	a	b	
ac72	pg	ac94	pg	oa
ac56	oa	ho	ab56	ab56
ac94	ho	oa	ac72	pg
ab56			ac56	ac72
				ac56
				ho
				ac94

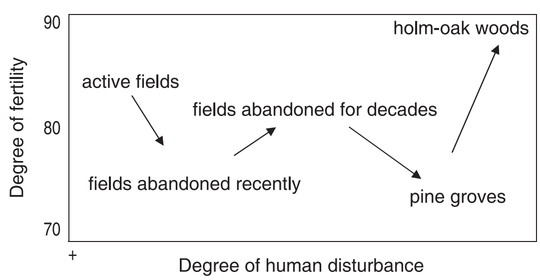

Figure 6 Evolution of soil fertility in terms of time that has passed since abandonment (according to their fertility level)

Table 9 Factor matrix

First factor	Second factor	Third factor
Organic material	Phosphorous	pH
Nitrogen	Potassium	Calcium carbonate equivalent
Electrical conductivity	Carbon/nitrogen	
Magnesium		

the edaphic characteristics are very different. When agricultural fields are abandoned followed by a spontaneous reforestation, the soil evolution is more similar to that of cultivated land. Therefore, the difference between the visual landscape and the soil characteristics can last for decades, especially in terms of organic material and fertility.

The results confirm that the transformations of the countryside have a temporal dynamic with a very large inertia (Thomas 2001). These changes are reflected in the vegetation and in the physical and chemical characteristics of the soil (Lasanta *et al.* 2000).

One of the aspects of the land use/abandonment dichotomy not addressed in this study is that of soil carbon pools (Lanz *et al.* 2001) and carbon release into the atmosphere with the conversion of agricultural land to wooded area.

Human disturbance results in a variety of transformations. Since these changes are a consequence of the same phenomena, land management should be considered globally, including vegetation, soils and water in the same inertia. Their joint interaction produces landscape and its evolution over time, or the landscape dynamic.

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