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The effects of farmland abandonment and plant succession on soil properties and erosion processes: a study case in centre of Portugal

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Abstract

The aim of this research was to assess changes in the physical and chemical properties of soil and the rate of erosion under traditional land use and during the natural

vegetation succession following land abandonment, in a marginal area of Portugal. A chronosequence was used, which included soils cultivated with cereal crops (the traditional land use in the territory), the typical stages in vegetation succession following land abandonment (herbaceous, shrub and wood), and native forest (used as a reference ecosystem).The results indicated that the differences in both soil properties and soil erosion were related to land management and the different stages in plant succession, highlighting that continuous cropping is primarily responsible for depleting soil nutrients and intensifying the degradation processes.

Keywords: Land abandonment, plant succession, soil quality, soil erosion, Portugal central

Resumo

O presente trabalho tem como objetivo a avaliação das alterações nas propriedades físicas, químicas e na taxa de erosão do solo sob uso o tradicional e em várias etapas de sucessão da vegetação após o abandono agrícola, numa área marginal de Portugal. Para o efeito, usou-se uma crono-sequência que incluiu solos com a cultura de cereais (o uso tradicional do território), etapas típicas de sucessão da vegetação após o abandono das terras (herbácea, arbustiva e arbóreo) e vegetação autóctone (como ecossistema de referência). Os resultados mostram diferenças significativas tanto nas componentes físicas e químicas dos solos como nas taxas de erosão, as quais se relacionam com a gestão da solo e com os diferentes etapas de sucessão vegetação, destacando-se o cultivo contínuo de cereais como o principal responsável pelo depleção dos nutrientes e a intensificação dos processos de degradação do solo.

Palavras-Chave: Abandono agrícola, sucessão de vegetação, qualidade do solo, erosão do solo, Portugal central

1. Introduction

In recent decades the greatest large-scale change occurring in southern European countries has been land abandonment (Van Camp et al., 2004). This has been particularly marked in marginal mountainous or semi-mountainous areas which are difficult to access and where a traditional or semi-traditional form of agriculture was practised until some years ago, involving low inputs and intensive human labour (Loumou & Giourga, 2002).

Changing land use patterns can have major environmental impacts on soil and water quality (Gebhart et al., 1994; Post & Kwon, 2000; Doran, 2002), biodiversity and the global climatic systems they interact with (Houghton, 1994; Chen et al., 2001). In general, farmland abandonment has resulted in very significant transformations to landscape heterogeneity, characterised by the spread of natural vegetation including both forest and bush land (Ubalde et al., 1999; Gallart & Llorens, 2003; Poyatos et al., 2003), an increasing wildfire hazard (Lasanta & Cerdà, 2005) and changes in soil and water quality (Pardini et al., 2002). Field experiments on the influence of land use and land abandonment have been carried out in several parts of Europe (Martinez-Fernandez et al., 1996; Ruecker et al., 1998; Bochet et al., 1998; Pardini et al., 2002), with the aim of understanding the mechanisms involved in the natural regeneration or degradation of abandoned land. Knowledge of soil evolution following the abandonment of farmland is of particular interest in the Mediterranean region, where processes of desertification have been reported (Puigdefabregas, 1995). In addition, the analysis of changes in soil properties due to changing land use can support decisions and policy-making processes at regional and national levels (Gong et al., 2006).

In the Mediterranean region abandoned fields evolve quite differently depending on the environment and land use features. Some of these features, in particular soil type, water availability and the type of pre- and post-abandonment land use influence the dynamic system following abandonment, which is highly dependent on the local area. Land abandonment may have positive or negative effects on land quality (Kosmas et

al., 2000) and may lead to a phase of deterioration or improvement in the soils depending on the particular land and climate conditions in the area. Under favourable climate conditions that can support sufficient plant cover, the soil may improve over time in terms of organic matter, floral and faunal activity, soil structure, and infiltration capacity, and will therefore be less at risk of erosion (Kosmas et al., 1999). When the plant cover is poor, the erosion may be very active and the regeneration of the land may prove impossible. In other situations involving land partly covered by annual or perennial vegetation, the remaining bare land with low permeability soils (e.g. clays) creates favourable conditions for overland flow, soil erosion and land degradation (Kosmas et al., 1999).

It is therefore important to analyse soil quality and any trends indicating change over time (Herrick 2000). These changes may be assessed by measuring and comparing the current values against: 1) values at the beginning of the monitoring period (Arshad & Martin, 2002); 2) historical data for values when available (Hartemink, 1998), using values measured at different time intervals (Lemenih et al., 2005); 3) analysis of the soil properties in reference ecosystems (Feigl et al., 1995). Soils developed under mature ecosystems (climax vegetation) are active systems in equilibrium with their environmental conditions. High environmental quality has been ascribed to such mature ecosystems and they are therefore used as a reference to evaluate soil quality in certain ecological settings (Doran & Jones, 1996; Rodríguez-Rodríguez et al., 2002). The quality of the soil in these sites is an important determiner of the resulting environmental quality.

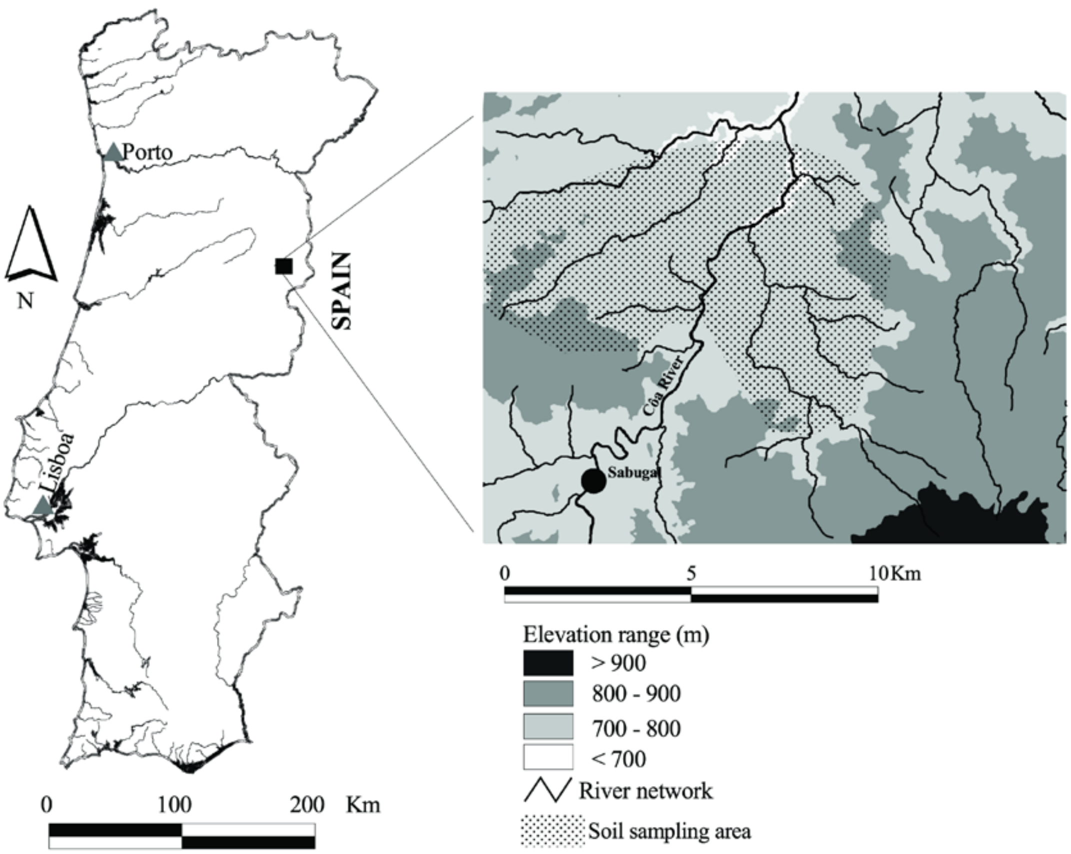
The key issues in this study were an assessment of the influence of traditional land use on soil properties and soil quality, and the responses of the soil in terms of physicochemical properties and sensitivity to erosion following land abandonment and subsequent plant recovery, using a chronosequence of plots which corresponded to the different stages of vegetation succession. Changes in the direction and magnitude of the physical and chemical properties of soils subject to agricultural use were compared with autochthonous forest plots.

2. Material and methods

2.1. Description of the area

The study took place in the upper Côa catchment, in the central inland region of Portugal near the Spanish border (between 40°40' N and 40°15' N and 7º15' W and 6°45' W) (Figure 1). The area has a typical subhumid Mediterranean climate with generally hot dry summers and cold wet winters. The mean annual precipitation at the Guarda-Gare station is about 800 mm and the mean annual temperature is 11º C. July and August are the driest and hottest months, with only 20 mm of rainfall and an average temperature of over 20º C. Approximately 70% of the precipitation occurs during autumn and winter, between October and March. The topography is relatively flat, with an average elevation of around 700-800 a.s.l. The lithology consists mainly of granite and the soils are classified as associations of humic and district cambisols.

Figure 1. Location of the study area



In this area, as in many other parts of Portugal and the Mediterranean region, traditional land use has been abandoned on a significant scale. This was first noted in

marginal mountainous or semi-mountainous areas with difficult access where the agriculture was traditional or semi-traditional, involving low inputs and intensive human labour. Following the intensification and industrialisation of agriculture in the 1950s and 60s, the mass abandonment of non-mechanisable and marginal areas began, together with mass migration to the main cities or to other European countries. From the 1990s onwards, the European Union (EU) Common Agrarian Policy recognised the natural and human handicaps in most of the rural areas in Portugal, associated with physical and structural constraints, depopulation and land abandonment.

Over eighty per cent of Portuguese territory falls within the definition of 'Less-Favoured Areas' (Regulation 950/97). Dry cereal cultivation was the traditional extensive crop in marginal areas of Portugal. EU agricultural policy has encouraged a reduction in cultivated land, especially cereal crops, and farmers receive subsides if they set aside part of their property. According to *Eurostat* data (2005) for Portugal, arable land was reduced by about 1,300,000 hectares and cereal crops by around 1,000,000 hectares between 1973 and 2003/04, representing 46% and 69% of the total area respectively.

When cultivation stops and no other disturbance such as fire or grazing follows, a process of plant succession takes place (Grime 2001). The dynamics of the vegetation in these recently abandoned fields begins with a herbaceous stage in the form of a low-cover therophytic community that provides little protection for the soil. This is due to the existence of significant gaps in the cover and the fact that it is completely dry at the end of the summer when the first episodes of intense rainfall occur. However, the protection increases as the annual graminae are replaced by perennial varieties at the end of this stage (*Agrostis castellana*, *Dactylis* sp.).

The onset of the next stage is marked by the slow emergence of shrubs, mainly *Lavandula stoechas* and *Cytisus multiflorus* in areas with poor soils, and the rapid appearance of *Cytisus striatus* in deeper soils, sharing the space with *Cistus psilosepalus*. Although there are differences in the cover (with variations of between 70 and 100 percent), both communities offer good protection for the soil.

These shrub communities decline following the establishment of a tree stand dominated by *Quercus pyrenaica* Willd., initiating a process of forest recovery leading to the climax association of the *Holco mollis-Querceto pyrenaicae* sigmetum. This represents the early stage in the establishment of the oak forest, with major variations in cover in the tree layer. This process of natural succession leading to the development of woodland requires a very long period of abandonment with no significant disturbance. Small areas are covered by recovering *Quercus pyrenaica* stands, due to a dramatic increase in the forest fire regime and burnt areas.

The oak communities assumed as the mature version and used as a reference are dense stands dominated by *Quercus pyrenaica* at tree layer, offering full protection for the soil. On the basis of their floristic composition, these communities can be interpreted as the driest version of the *Holco mollis-Quercetum pyrenaicae*, sometimes individualised as *Genisto falcatae-Quercetum pyrenaicae* (Costa el al., 2000), despite similarities in floristic composition (Figueiredo, 2005). Some of these stands are episodically subject to disturbance, usually related to the collection of litter.

2.2. Experimental design

The purpose of the experiment was to compare five different land uses/covers usually found in the central inland region of Portugal, including the traditional land use in the territory and the different stages of plant succession following land abandonment, namely:

- Cereal crop (CC) or traditional land use: dry farming systems (alternating between one year of cereal cultivation, mainly rye, and two or more fallow years) was the dominant land use in the territory for many decades. Nowadays, due to land abandonment only a small percentage of the study area is occupied by this land use.
- Herbaceous cover (HC) or the early stage of abandonment (after 3-7 years): the first stage in land abandonment, characterised by a sparse herbaceous cover of annual plants.
- Shrub cover (SC) or the intermediate stage of abandonment (after 8-15 years): considered the second stage of plant succession in the study area. It is

associated with perennial shrub communities, chiefly dominated by *nanophanerophytes* such as *Cytisus multiflorus* and *Lavandula sampaioana*, and is the most common form of land cover in the landscape affected by farmland abandonment.

- Recovering *Quercus pyrenaica* (QR) or the advanced stage of abandonment (after 16-40 years): a stage of variable cover among plots at tree layer, with a tendency to increase over time. The *Quercus pyrenaica* adult stage (QA) represents the climax vegetation stage in the study area. As soils of mature ecosystems are in dynamic equilibrium with their environmental conditions, they have high environmental quality and were used as a reference to evaluate and compare the properties of the sites monitored.

As they have very similar characteristics in terms of the dominant factors involved in soil formation (lithology, climate and topography), it can be assumed that the changes after abandonment can mainly be attributed to the effects of changes in land use and cover, whilst interference from other factors is relatively unimportant.

Vegetation cover, soil sampling and analysis

Twenty-two plots in the study area were selected from a previous soil survey to represent different land uses/covers with similar parent material, soils, relief, and climate. Four plots were located for each land use/cover, with the exception of shrub communities, where six plots were selected. The main reason for this was the fact that, as already mentioned, this is the predominant land cover type in the study area.

The sampling sites had specific physical characteristics, thus enabling the results to be compared. All the sites were located between 700 and 800 m a.s.l., and slope variations were minimised (<10%). Four 1 m^2 areas were selected in each plot and the surface cover and vegetation type (lichens+mosses, herbaceous, shrub and litter) were estimated as percentages. Within each site, soil samples from 0-10 cm and 10-20 cm layers were collected from two points. These depths were chosen because they are the layers which are most sensitive to human activity. Vegetation cover and soil samples were collected in April 2006. The following soil properties were determined for all samples: texture, bulk density, porosity, penetration resistance, pH, organic matter

content, available potassium (K) and phosphorus (P), nitrogen (N), exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}).

A Coulter LS Particle Size Analyzer was used for particle size analysis of the fraction < 2 mm. Dry bulk density and porosity were measured using a cylindrical core of a known volume. Soil resistance was assessed with a pocket penetrometer. The organic matter content was determined by the Tinsley method (1950) and nitrogen was extracted using the Kjeldahl method (Bremner, 1965). pH was measured in a 1/2.5 soil/water ratio (Black, 1965). The available K and available P were determined by the Égner-Riehm method and the exchangeable bases by the ammonium saturation method (NH_4OAc, 1*N*, at pH 7.0) (Chapman, 1965).

Soil erosion

A portable rainfall simulator based on the design produced by Cerdá *et al.* (1997) was used to compare the erosion response under cereal crops and the different land cover types. The rainfall simulator consisted of a springlink device placed 2 m above the soil, which was able to provide a spatially homogeneous rainfall intensity of 53-55 mm h^{-1}. A small 0.24 m^2 round plot was inserted carefully into the soil. The rainfall simulations lasted 60 minutes. Tests were carried out over two years (2005 and 2006), after a very intense period of natural rainfall (in April and November 2006) and a long, dry season (August 2005 and 2006). The tests therefore took place under different plant cover and soil moisture conditions. The overland flow and sediment transport were collected and laboratory analyses were carried out in order to determine the sediment concentration.

2.3. Statistical Analysis

All the data was analysed using SPSS 19 for Windows. One-way analysis of variance (ANOVA) and the Tukey multiple comparison procedure were performed on each soil property layer to test whether the changes in the soil properties investigated were statistically significant ($P<0.05$). A correlation matrix was calculated which included vegetal cover, soil properties and soil erosion. All the correlation coefficients were reported at 5% of probability.

3. Results and Discussion

3.1. The effects of farmland abandonment and plant succession on vegetation cover

Significant statistical differences were found amongst the different types of land-use/cover in the study area (Table I). A significant trend can be identified for soil cover, ranging from low values for plots with cereal crops to very high values for plots occupied by mature oak forest. This trend is reflected in the lower variations in plots with the same land-use/cover. The largest standard deviation, revealing great variability amongst plots, is mainly a consequence of the traditional cereal crop system, in which the soil is usually ploughed between March and April and remains without vegetation until sowing, which takes place October or November. The purpose of this is to increase top layer fertility and soil productivity. Despite an increase in the soil cover during the earliest stage of succession, associated with an increase in annual plants, it remains very discontinuous and the differences between plots remain significant. The main change occurs with the establishment of a shrub land stage, dominated by *Cytisus* sp. After one decade of abandonment, the vegetation cover extends to around 90% of the area in plots associated with both recovering and adult oak stands, the soils are completely covered with vegetation and the differences between the plots are slight. The ground is almost entirely covered with litter. Successional changes in plant species composition, nutrient accumulation and retention capabilities can cause substantial changes in soil resource patterns (Aber *et al.*, 1998).

Table I: Percentages of soil cover for cereal crops and the different stages of vegetation succession (mean and ± standard deviation).

	CC	HC	SC	QR	QA	ANOVA
Soil cover (%)	43.81±38.98^{A}	62.81±11.29^{B}	89.70±6.62^{C}	98.38±2.13^{C}	100.00±0.00^{C}	**
Lichens & Mosses	5.00±5.97	7.81±2.81	8.20±3.82	5.06±6.71	3.44±3.99	n.s
Herbs and shrubs	38.81±4.17^{B}	53.44±7.67^{C}	75.50±11.14^{D}	5.13±2.86^{A}	1.94±1.86^{A}	**
Litter	0.00±0.00^{A}	1.88±2.21^{A}	5.54±2.45^{A}	88.00±7.56^{B}	94.62±4.96^{B}	**

Notes: ** $P < 0.01$; n.s.= not significant. For each property, values followed by different capital letters are significantly different ($P < 0.05$) according to Tukey multiple comparison. CC= Cereal Crop; HC= Herbaceous Cover; SC= Scrub Cover; QR= *Quercus pyrenaica* Willd. - in recuperation; QA= *Quercus pyrenaica* Willd. - adult stage.

3.2. The effects of farmland abandonment and plant succession on the physical properties of the soil

The particle size distribution for the top 20 cm layer shows significant differences between land cover types (Table II). In this layer, the soils associated with natural forest land (QA) showed the lowest values for sand and the highest values for silt and clay fractions, in comparison with the soils associated with cereal crops (CC) and herbaceous cover (HC), which had the highest values for sand fractions (with values of 74.16±4.17 per cent and 76.70±1.95 per cent, respectively).

These results may be attributed to the erosion of the finer soil particles during the final decades of cultivation. Several studies have reported drastic alterations in particle size distribution after deforestation and subsequent cultivation (Wielemaker and Lansu, 1991; Johnson-Maynard *et al.*, 1997). Thus, the changes in soil properties observed in farmed fields compared with the soil conditions in natural forest land may be interpreted as the effects of deforestation and subsequent cultivation.

Table II: Physical properties of the soil for cereal crops and the different stages of vegetation succession (mean and ± standard deviation).

	CC	HC	SC	QR	QA	ANOVA
Texture (0-20cm) (%)						
0,063-2mm	$74.16±4.17^{BC}$	$76.70±1.95^{C}$	$71.95±5.31^{BC}$	$69.17±5.49^{B}$	$60.35±6.38^{A}$	**
0,002-0.063mm	$20.91±3.14^{A}$	$19.01±1.47^{A}$	$22.49±4.90^{AB}$	$25.35±4.22^{B}$	$33.00±5.03^{C}$	**
<0,002	$4.92±1.09^{A}$	$4.30±0.65^{A}$	$5.46±0.75^{A}$	$5.48±1.56^{AB}$	$6.65±1.57^{B}$	**
Bulk density (g cm^{-3})						
0-10cm	$0.87±0.15^{A}$	$1.23±0.11^{B}$	$1.04±0.16^{AB}$	$0.93±0.16^{A}$	$0.91±0.15^{A}$	**
10-20cm	$1.01±0.10^{A}$	$1.29±0.09^{B}$	$1.14±0.13^{AB}$	$1.04±0.08^{A}$	$1.03±0.15^{A}$	**
Porosity (%)						
0-10cm	$67.31±5.50^{B}$	$53.38±4.13^{A}$	$60.78±5.94^{AB}$	$65.14±5.98^{B}$	$65.65±5.45^{B}$	**
10-20cm	$60.51±3.18^{B}$	$51.41±3.60^{A}$	$56.90±4.98^{AB}$	$60.70±3.16^{B}$	$60.85±6.73^{B}$	**
Resistance to penetration (kg cm^{-2})						
Surface	$0.82±0.29^{A}$	$2.87±1.12^{C}$	$2.26±1,15^{BC}$	$2.19±1.13^{B}$	$1.53±0.56^{AB}$	**

Notes: ** P < 0.01; * P < 0.05. For each property, values followed by different capital letters are significantly different (P < 0.05) according to Tukey multiple comparison. CC= Cereal Crop; HC= Herbaceous Cover; SC= Scrub Cover; QR= *Quercus pyrenaica* Willd.- in recuperation; QA= *Quercus pyrenaica* Willd.- adult stage.

Bulk density (g cm^{-3}) also revealed important differences between the stages of vegetation succession in both layers analysed. In the top layer, bulk density increased significantly in the first stage after abandonment, involving a predominantly herbaceous cover (from 0.87±0.15 to 1.22±0.11 g cm^{-3}) (Table II). Even in the 10–20 cm soil layer, bulk density increased significantly in the first stage of succession, although at a lower rate than in the top layer. Nevertheless, as the succession period continued, the development of shrub and wood communities led to a decrease in bulk density in both the 0-10 and 10-20 cm layers. Similarly, porosity in the 0–10 cm and 10-20 cm layers decreased when the herbaceous cover was dominant and increased when shrubs and trees became established (Table II). Soil resistance to penetration follows a similar pattern to bulk density; the highest values were registered under the herbaceous and shrub cover and the lowest under cereal crops, as a consequence of disturbing the soil due to cultivation (Table II).

3.3. The effects of farmland abandonment and plant succession on the chemical properties of the soil

The soil was very acid in all stages of the succession (Table III). In the upper (0-10 cm) layer there was no difference between the various types of soil cover. This means that the soil pH does not depend on the stage of plant recovery but is likely to be related to the parent material, which is mainly composed of acid rocks, namely granite with microcline and quartz. A significant variation was observed in the 10-20 cm layer, mainly related to the differences between the CC and QR fields. No marked difference was found between HC, SC and QA.

Organic matter content can be used as an indicator of soil resilience (Mendoza-Vega & Messing, 2005). It is considered the single most important indicator of soil quality and an indicator of the sustainability of ecogeomorphic systems (Sparling, 1991; Swift & Woomer, 1993; Imeson, 1995). Different stages of abandonment have different effects on soil organic matter (SOM) and consequently significant differences were found in the various stages of succession, which were much more pronounced in the top 10 cm layer (Table III). The SOM for the different land cover types declined with increased soil depth. Soils associated with crop production and herbaceous cover had the lowest

SOM in both layers, with averages of around 0.5 per cent, and there were no significant differences between them. A loss of organic matter was observed following abandonment, mainly due to mineralisation and erosion. In fact, the soil is unprotected in the first fallow years and inputs of organic manure end when the fields are no longer cultivated (Ruecker et al., 1999). The decline in SOM and loss of soil structure contribute significantly to erosion.

Table III: Chemical properties of the soil for cereal crops and the different stages of vegetation succession (mean and ± standard deviation)

	CC	HC	SC	QR	QA	ANOVA
pH (em H_2O)						
0-10cm	4.89±0.09	4.81±0.14	4.78±0.31	4.66±0.37	4.93±0.16	n.s
10-20cm	4.95±0.37^{C}	4.80±0.10^{AB}	4.70±0.21^{AB}	4.60±0.19^{A}	4.86±0.16^{BC}	*
Organic matter (%)						
0-10cm	0.55±0.27^{A}	0.53 ±0.31^{A}	1.38±0.71^{B}	1.46±0.23^{B}	3.19±0.82^{C}	**
10-20cm	0.41±0.19^{A}	0.36±0.26^{A}	0.61±0.48^{A}	0.40±0.14^{A}	1.78±0.66^{B}	**
Total N (%)						
0-10cm	0.04	0.03	0.05	0.08	0.12	nt
C/N						
0-10cm	4.78	3.67	6.15	8.70	15.08	nt
Available K (mg kg^{-1})						
0-10cm	71.38±36.90^{A}	77.50±36.75^{A}	102.04±36.70^{AB}	122.00±14.00^{B}	186.13±27.53^{C}	**
10-20cm	53.50±31.98^{A}	78.88±42.65^{A}	84.83±28.02^{A}	65.62±31.99^{A}	167.13±22.48^{B}	**
Available P (mg kg^{-1})						
0-10cm	41.00±14.19^{A}	61.19±17.20^{A}	32.70±23.78^{A}	36.00±42.13^{A}	129.19±62.74^{B}	**
10-20cm	26.81±18.51^{A}	92.31±52.79^{B}	53.54±56.86^{A}	31.83±34.54^{A}	105.00±81.21^{B}	*
Ca^{2+} (mmolc kg^{-1})						
0-10cm	13.3± 4.7^{B}	10.6±4.7^{AB}	7.7±3.1^{AB}	9.0±0.60^{AB}	4.7±2.1^{A}	**
10-20cm	13.6± 4.4^{C}	8.3±3.3^{B}	4.3±1.7^{A}	3.9±4.7^{A}	14±0.8^{A}	**
Mg^{2+} (mmolc kg^{-1})						
0-10cm	8.1±3.4^{A}	4.3±2.6^{A}	4.6±2.6^{A}	6.3±3.0^{A}	7.4±2.3^{A}	*
10-20cm	7.9±3.5^{B}	3.5±1.5^{A}	3.3±2.2^{A}	4.7±3.1^{A}	3.7±0.8^{A}	**

Notes: ** $P < 0.01$; * $P < 0.05$; n.s.= not significant.; n.t.= not tested (only two available); For each property, values followed by different capital letters are significantly different ($P < 0.05$) according to Tukey multiple comparison. CC= Cereal Crop; HC= Herbaceous Cover; SC= Scrub Cover; QR= *Quercus pyrenaica* Willd. - in recuperation; QA= *Quercus pyrenaica* Willd.- adult stage.

Later on, the vegetation dynamics leading to shrub and tree cover are responsible for an increase in organic matter content in the upper 10 cm. No significant differences in SOM were found between SC and QR in the top soil layer and the averages obtained were around 1.5 per cent. The soil organic matter content in the top layer (0-10 cm) of CC and HC was only about 15 per cent of the amount found under autochthonous vegetation. Under SC and QR the proportion increased to 43 per cent. This increase in organic matter after an extended period of abandonment is confirmed by studies performed in Mediterranean conditions (Martinez-Fernandez et al., 1996; Dunjó et al., 2003). Research by Martinez-Fernandez et al. (1996) into the effects of a 1-30 year period of land abandonment in south-eastern Spain, for example, showed that the soil property most closely related to both vegetation dynamics and length of abandonment was the total organic carbon content. These results suggest that the abandonment of agricultural practices and the development of native species may improve soil fertility and offer great potential for restoring degraded ecosystems.

Concerning the C/N ratios, the autochthonous vegetation presented the highest value, of around 15. In contrast, the lowest values were registered in the CC and HC plots (4.78 and 3.67 respectively). The highest C/N ratio observed in QA could be due to the input of relatively recent plant or microorganism residues. As organic carbon and nitrogen represent quantity and quality in organic matter, it can be concluded that there is an evident regeneration process in the degraded soils after lengthy farmland abandonment, but there are still major discrepancies when compared with adult *Quercus pyrenaica* stands.

As far as the available K contents are concerned, all the samples present reasonable parallels to the results for organic matter. The available K associated with the different land cover types declined as the depth increased (Table III). The main significant differences in the upper layer were found between CC and HC (group I), QR (group II) and the autochthonous vegetation (group III). With regard to SOM, QA had the highest available K (186.13±27.53 mg kg^{-1}). At a depth of 10 to 20 cm there was no difference between CC, HC, SC and QR. These results indicate that cropland abandonment and the restoration of vegetation as shrub and woodland increase the accumulation of K in the soil, since the nutrient-rich branches and coarse litter fraction are important

nutrient sources (Gong et al., 2006). The loss of K from litter was relatively rapid in the initial decomposition stage, when more than 60 per cent of K was released from litter within six months and > 75 per cent by the end of 12 months (Gong et al., 2006).

Concerning the available phosphorus content (P), the highest values were also detected under adult *Quercus pyrenaica* (129.19±62.74 mg kg^{-1}) (Table III). Nutrients, including P, are sequestered in biomass (Vitousek & Reiners, 1975). As a result of conservative nutrient cycling in the forest ecosystem, P largely remains bound in biomass (Yanai, 1992; Joergensen et al., 1995). Consequently, in the top layer statistically significant differences were observed between QA and the other land covers. Among CC, HC, SC and QR no significant differences were registered, although a remarkable decrease in this macronutrient could be observed after a lengthy period of abandonment and plant recovery. The appearance of a higher available P content in the CC soil, and especially in HC, can be attributed to the input of P fertilizer by farmers in order to improve cereal productivity (Ruecker et al., 1999; Gong et al., 2006). The higher available phosphorus content in plots with herbaceous cover (HC) may also be related to fallow land and its traditional use as grassland pasture. The faster rate of cycling in the most intensively grazed plots must be related to the phosphorus excreted by cattle mainly as bicalciumphosphate (Barrow, 1987), which is readily available to plants. Continuous grazing and the subsequent return of phosphorous in faeces means that the availability of this element in herbaceous cover remains higher than in shrub land, which has a lower turnover rate (Ruecker et al., 1999).

The distribution of Ca^{2+} ($mmol_c$ kg^{-1}) also changes with the succession stage (Table III), more significantly in 10-20 cm layer. All the samples revealed a very low Ca^{2+} content of less than 20 $mmol_c$ kg^{-1}. At plot scale, the highest values were found for cereal cultivation (CC), as a consequence of the input of Ca fertilizer by farmers to mitigate high soil acidity. In fact, severe problems are normally encountered when the pH is below 5.5 (Norton *et al.*, 1999). Under acid conditions, Al^{3+} and H^+ ions displace Ca^{2+} and Mg^{2+} from the exchange complex, leading to leaching and a reduction in the availability of some essential plant nutrients, as well as altering many of the soil's chemical, physical and biological processes (Camberato & Pan, 2000). The decrease in Ca^{2+} following land abandonment is associated with ending applications of organic

manure. The lowest Ca^{2+} values, representing only one third of those found in cultivated land, were obtained for adult *Quercus pyrenaica* stands. No marked differences in Mg were found, but the values were low (below 10 $mmol_c\ kg^{-1}$) in all samples. The highest values were found for cereal crops, due to fertilizer inputs (Table III).

3.4. The effects of farmland abandonment and plant succession on soil erosion

The results obtained for soil erosion losses (Table IV) show a statistically significant difference between types of land use/cover. The highest recorded values were found for cereal crops, with an average of 34.29±23.63 g $m^{-2}\ h^{-1}$, which can be ascribed both to changes in soil structure and the disappearance of any vegetation or litter cover, associated with deep ploughing and weak resistance to erosion. Ploughing completely destroys the vegetation and litter layer and the soil structure; consequently the top layer is highly erodible and easily removed by rainfall. Many studies have reported the detrimental effects of soil erosion on agricultural productivity.

Table IV: Soil erosion (g $m^{-2}\ h^{-1}$) for cereal crops and the different stages of vegetation succession (mean and ± standard deviation).

	CC	HC	SC	QR	QA	ANOVA(t.f)
Soil erosion	34.29±23.63^{B}	15.26±20.08^{A}	0.23±0,31^{A}	0,01±0,03^{A}	n.a.	**

Notes: ** $P < 0.01$; n.a.= not available; t.f.= Only tested for four land covers; For each property, values followed by different capital letters are significantly different ($P < 0.05$) according to Tukey multiple comparison. CC= Cereal Crop; HC= Herbaceous Cover; SC= Scrub Cover; QR= *Quercus pyrenaica* Willd.- in recuperation; QA= *Quercus pyrenaica* Willd.- adult stage.

Although the differences in magnitude recorded between fields in the early (HC), intermediate and advanced (SC and QR) stages of succession were notable, they are not statistically significant. Herbaceous cover with an average value of 15.26±20.08 g $m^{-2}\ h^{-1}$ registered a marked drop in sediment loss when compared to cereal crops, although the observed sediment yield rates were very high in comparison with the results for shrub and tree cover. This decrease in soil loss can mainly be attributed to both the lower soil erodibility (since the upper soil layer is not longer disturbed) and the rapid establishment of a herbaceous cover, with ±60-70 per cent of the vegetation cover in contact with the ground, thus favouring infiltration and hindering water

erosion. Recovering *Quercus pyrenaica* and shrub land presented the lowest soil erosion losses (< 1 g m^{-2} h^{-1}) due to the denser vegetation cover, with ±90-100 per cent of the total cover in contact with the ground, which always efficiently protects soil from raindrop impact, improves infiltration and reduces the rate of erosion.

3.5. Correlations between plant cover and soil properties

Table V shows the different correlations between plant cover, the components of physical and chemical properties, and soil erosion. In both the 0-10 cm and 10-20 cm layer, the soil organic matter and available K show significant positive correlations with the total plant cover (p <0.000), notably with litter cover more than herbaceous or shrub cover. The silt and clay portions reveal a similar trend, whereas the sand fraction and Ca^{2+} and Mg^{2+} exchangeable bases confirm a significant negative correlation with plant cover.

Sediment transport showed a clear negative correlation with soil covered by vegetation, which was almost significant at p< 0.001. Litter cover offers more protection against water erosion, since it absorbs some of the raindrop energy and leads to an exponential decrease in splash erosion.

Figure 2 presents trends for plant cover and other variables relating to soil properties and sediment yield. The results obtained for trends in plant cover and other variables relating to soil properties and sediment yield confirm that cereal crops create greater susceptibility to land degradation and erosion. The risk of soil erosion in land abandoned after agricultural activity can be reduced by the natural and progressive growth of annual herbs and perennial shrubs in the cleared site to maintain a stable and suitable plant cover. Durán *et al.* (2010, 2011), for example, reported that soil erosion was significantly lower in shrub land as a result of the high infiltration rate created by the increase in organic matter deposited on the soil. Our findings confirmed that these characteristics of shrub land could have led to a lower risk of soil erosion by influencing surface hydrological processes. In addition, in shrub land dominated by a variety of plants, the organic matter, potassium, and clay content were high, mainly due to the incorporation of decomposing plant litter (Rodríguez et al., 2003 Durán et al, 2011). Soils with *Quercus pyrenaica* improved the soil by increasing the organic C,

total N, and soil-available P, and facilitating the colonisation and development of understory vegetation. The lower average erosion under this type of plant cover can clearly be attributed to the dense canopy structure and litterfall, which more provides a more effective shield against rainfall erosivity. The rain water that reaches the soil infiltrates the soil profile and percolates to the groundwater or flows downhill as runoff.

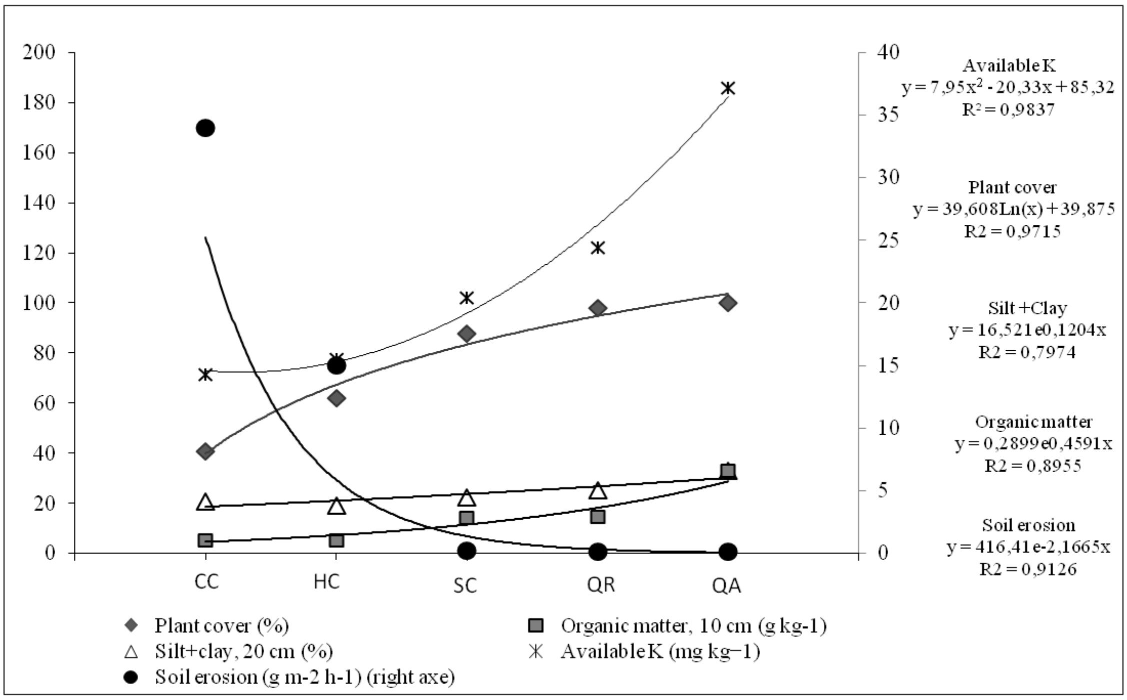
The results obtained concur with those of other studies in showing the importance of vegetation, and especially the litter cover, in improving certain physical and chemical components of the soil and reducing soil erosion (Trimble 1990; Kosmas et al. 2000; Fu et al, 2004; Nunes et al., 2010, 2011; Durán-Zuazo et al., 2012).

Table V: Correlation matrix for plant cover, physicochemical soil components and soil erosion

	Total plant cover	Lichens + Mosses	Herbaceous+ shrubs	Litter cover
Sand fraction (0-20 cm)	-0,487**	0,286	0,485**	-0,642**
Silt fraction (0-20 cm)	0,487**	-0,275	-0,515**	0,664**
Clay fraction (0-20 cm)	0,384*	-0,279	-0,279	0,430**
Bulk density (0-10 cm)	-0,006	0,165	0,387*	-0,314*
Bulk density (10-20 cm)	-0,064	0,257	0,374*	-0,341*
Resistance to penetration	0,227	0,140	0,279	-0,114
Soil organic matter (0-10 cm)	0,647**	-0,240	-0,421**	0,670**
Soil organic matter (10-20 cm)	0,393**	-0,207	-0,345*	0,481**
pH (0-10 cm)	-0,160	-0,171	-0,042	-0,043
pH (10-20 cm)	-0,389**	-0,190	-0,038	-0,159
Available P (0-10 cm)	0,150	-0,098	-0,408**	0,389**
Available P (10-20 cm)	0,059	0,022	-0,082	0,080
Available K (0-10 cm)	0,580**	-0,312*	-0,465**	0,676**
Available K (10-20 cm)	0,399**	-0,154	-0,299*	0,437**
Ca^{2+}(0-10 cm)	-0,500**	-0,018	0,100	-0,340*
Ca^{2+} (10-20 cm)	-0,789**	0,041	0,193	-0,550**
Mg^{2+} (0-10 cm)	-0,126	-0,165	-0,344*	0,204
Mg^{2+}(10-20 cm)	-0,417**	0,014	-0,135	-0,104
Soil erosion	-0,753**	-0.272	-0.346	-0.440*

** $P < 0.01$; * $P < 0.05$

Figure 2: Trend for plant cover and other variables relating to soil properties and sediment yield, under different land use/cover



4. Conclusion

Agricultural land use and natural succession associated with land abandonment has a strong impact on the physicochemical properties of soil and the soil erosion response. This study suggests that continuous cropping is primarily responsible for depleting soil nutrients and reducing fertility. This trend is easily identified in the soil organic matter, C/N ratios and available K and is mainly associated with the soil's vulnerability to erosion. The cultivated soils in the study area are very poor from a chemical point of view, mainly due to the low organic matter content and C/N ratio. Our results are similar to those found in other research in which cultivated land showed the highest erosion yield and the lowest soil quality (Ruecker et al., 1998; Dunjó et al., 2003). Recently abandoned plots with a predominantly herbaceous cover do not seem to enhance soil fertility after crop cycle cessation, but positively influence soil erosion.

Plant succession implies positive changes in soil properties and suggests the improvement and recovery of the system. The intermediate stages of vegetation succession following farmland abandonment are largely responsible for an increase in soil porosity, organic content and nutrient concentration (available P and nitrogen),

whereas bulk density and soil erosion clearly decrease. Trees and shrubs function as natural barriers to reduce erosion. Soil nutrient enrichment under these cover types might be due to the accumulation of a litter layer, which enhances meso and micro fauna and flora that alter the chemical, biological and physical properties of the soil. Native plant communities seem to offer a high potential for restoring degraded ecosystems. However, significant differences were detected between soil properties in the different seral stages, even between recovering adult *Quercus pyrenaica* and *Quercus pyrenaica*, especially when the chemical properties were compared. Our study indicates that soils under recovering *Quercus pyrenaica* only have about 46 per cent organic matter content, 28 per cent available P and 65 per cent available K, which are lower values in comparison with the mature *Quercus pyrenaica* stands. On the basis of these results it may be suggested that recovering native forests on previously abandoned cropland represents one feasible option for ecological recovery that will increase soil quality, combat soil erosion, increase carbon dioxide sequestration, improve environmental sustainability and, at least partially, restore control over the processes of desertification. In fact, forest cover is one of the most common methods for restoring degraded land and minimising the risk of soil erosion (FAO, 1989).

However, land abandonment and the cessation of traditional management practices leads to the rapid invasion and homogenisation of the landscape by generalist species (e.g. *Cytisus multiflorus*). The creation of large homogeneous patches of vegetation and the accumulation of fuel due to fire exclusion policies are cited as the major causes of changes in the forest fire regime in Mediterranean Europe. In fact, Portugal's burnt area has increased mainly during the last three decades. This rising trend distinguishes Portugal from the other southern Member States with the highest burnt areas, particularly in the central and northern regions. Thus, forest fires constitute one of the most significant environmental problems and are frequently considered the major cause of soil degradation and desertification.

Given this context, a set of measures should be put in place to reduce the amount of fuels in marginal areas, in order to reduce the spread and intensity of fires. Shrub and forest fuel management is one of the cornerstones of successful fire management and

may include the use of silvicultural practices, such as grazing and localised mechanical interventions, as well as prescribed fires.

5. References

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