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Soil Erosion Under Different Land Use and Cover Types in a Marginal Area of Portugal

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1. Introduction

According to the CORINE programme, Spain and Portugal are the Mediterranean countries in the European Union facing the greatest risk of erosion (Desir & Marín, 2007). In Portugal, areas at high risk of erosion cover almost one third of the country (Grimm et al., 2002). The main causes of soil erosion are inappropriate agricultural practices, land abandonment, deforestation, overgrazing, forest fires and construction activities (Grimm et al., 2002; Yassoglou et al., 1998). Several studies in the Mediterranean region have addressed the present-day hydrological response and erosion rates for arable and marginal land affected by land abandonment (Casermeiro et al., 2004; García-Ruiz et al., 1995, 1996; Nunes et al., 2010, 2011; Nunes, 2007; Pardini et al., 2002, 2003; Romero-Díaz, 2003; Ruiz-Flaño et al., 1992), forest fires (Cammeraat & Imeson, 1999; Coelho et al., 2002, 2004; Doerr et al., 2000; Ferreira et al., 2005; Ferreira, 1990; Ferreira, 1996; Imeson et al., 1992; Shakesby et al., 1993, 1996) and afforestation (Ferreira, 1996; Ternan et al., 1997; Thomas et al., 2000; Shakesby et al., 2002). The results show wide variations in runoff generation and sediment yield, mainly depending on environmental conditions, vegetation cover, changes in previous land use, the period of soil abandonment, etc.

In Portugal, as well as in many other Mediterranean countries, the main type of land use was rainfed cereal crops until the middle of the twentieth century. After the introduction of modern agriculture, the opening up of the international markets and the lowering of crop prices, market-oriented cultivation of cereals became unprofitable in most marginal areas in Portugal. In addition, socio-economic and political changes in Portugal in the 1970s led to higher agricultural wages and migration from the countryside (Pinto-Correia & Mascarenhas, 1999). Thus, abandoned farmlands became evident, very often in marginal, mountainous or semi-mountainous areas and areas that were difficult to access, in which traditional or semi-traditional agriculture was practised until recent decades, involving low input and intensive human labour. Abandonment implied the extensive decline of arable land and resulted in very important transformations to the landscape, characterised by the spread of natural vegetation, including both shrub land and forest.

Additionally, the EU's Common Agricultural Policy recognises the natural handicaps of such areas and their association with depopulation and land abandonment through its structural support for 'Less-Favoured Areas' (Regulation 950/97). Around eighty per cent of the Portuguese Utilised Agricultural Area (UAA) falls within the definition of Less Favoured Areas (LFAs), and a substantial amount of this is classified as mountain area. Much of this mountain zone is designated Objective 1.

In 1992, measures accompanying the reform of the Common Agricultural Policy (CAP) were adopted to benefit the environment, early retirement and forestry. These measures aimed to support the envisaged processes of change, and to mitigate some of the effects deemed to be disadvantageous to farmers (Van-Camp et al., 2004). European Economic Commission (EEC) Regulation 1765/92 (EEC, 1992) led to a substantial increase in set-aside land in the European cereal-growing regions (Crabb et al., 1998; Van Rompaey et al., 2001). Agricultural land afforestation (Regulation 2080/92), which established an aid programme for the afforestation of former agricultural lands, also aimed to enhance long-term forest resources and combat soil erosion and desertification by promoting forestry as an alternative form of land use. However, the overall effectiveness of afforestation in reducing soil erosion remains uncertain, due to the poor development of the forest cover in some areas leading to significant areas with sparse tree cover, and the erosional impact of forest harvesting, which usually involves clearcutting (Porto et al., 2009). In fact, little data is available. The extent to which these measures are applied in areas under medium/high risk of soil erosion needs to be assessed (Van-Camp et al., 2004).

According to Caraveli (2000), the implementation of CAP measures in Mediterranean countries has reinforced *intensification* processes in productive practices in the more fertile areas of the lowlands and *extensification* (i.e. abandonment or marginalisation and the collapse of traditional farming systems) in the LFAs, which has been going on for decades. Land use changes characteristic of extensification include fewer cultivated fields, more shrub patches, larger areas of natural pastures, and abandonment of some patches, followed by the development of stratified bush communities. The CAP agreement requires Member States to maintain a permanent pasture area, which should prevent the wide-scale ploughing up of land for arable cultivation and potential problems with soil degradation often associated with arable farming in some areas (Van-Camp et al., 2004). Nevertheless, the influence of grazing on vegetation development and soil erosion processes is rarely quantified in literature on the subject (Ries, 2010).

The specific objectives of the current research were: (i) to evaluate and compare the hydrological and erosional response of soils under different land uses and vegetation types in central inland Portugal, (ii) to identify and describe the main factors that control their hydrogeomorphic response and (iii) to assess the efficiency of alternative land uses proposed by the CAP for soil erosion control. The six land uses and vegetation types studied (cereal crop, fallow land or short-term abandonment, shrub land or long-term abandonment, recovering autochthonous vegetation or very long-term abandonment, arable land afforested with *Pinus pinaster* and arable land transformed into pastureland) are representative of situations frequently found throughout central and northern Portugal, and also in other Mediterranean systems. The main aim was to obtain consistent conclusions for ecosystem management in marginal areas of Portugal. This information on the hydrogeomorphic response could be useful in the future as a guide for regional soil conservation planning.

2. Study area

The study was carried out in the high Côa river catchment, in a peripheral area of Portugal close to the Spanish border (Fig. 1). The substratum comprises mainly granites with poor, shallow soils, classified as distric cambisols (FAO-UNESCO, 1974), and an undulating relief with elevation ranges from 700 to 900 m a.s.l. The area has a sub-humid Mediterranean climate, characterised by wet, cool winters (5.8 ºC average temperature) and hot, dry summers (25.8 ºC average temperature). The mean annual precipitation of 800 mm has a high inter- annual variable distribution and seasonal concentration. The wettest periods of the year are concentrated in the autumn and winter months, between October and February, and the driest in summer, between June and September.

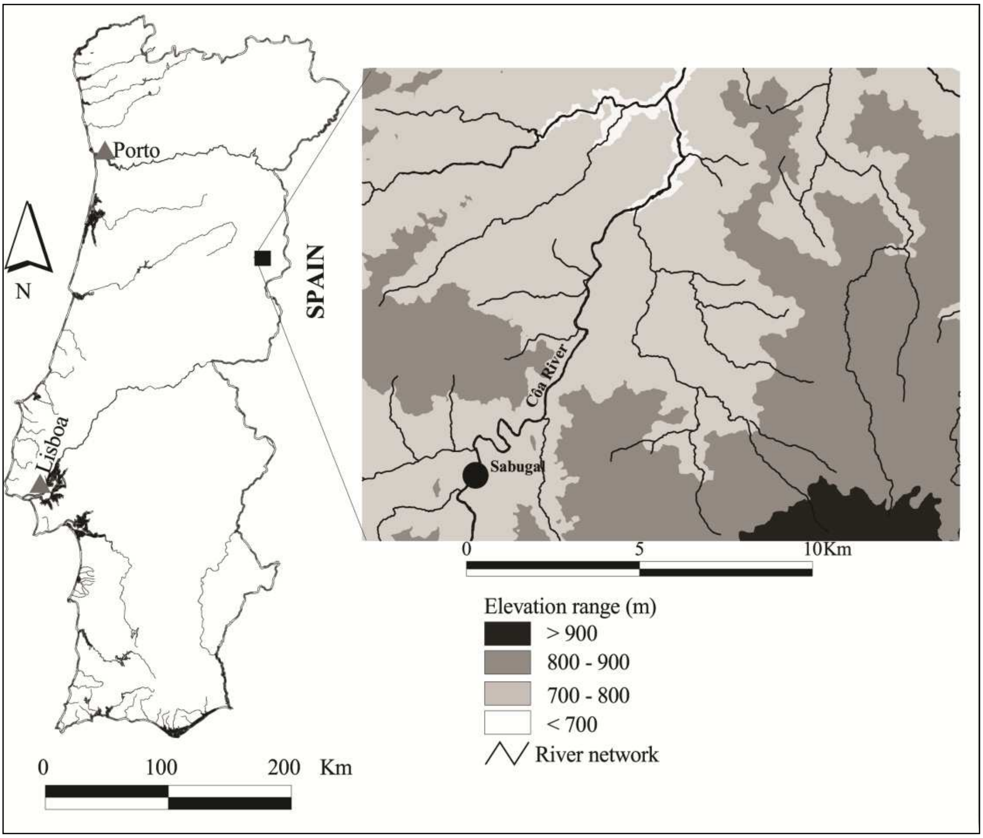

Fig. 1. Location of the study area

Agricultural activities dominated land use in marginal areas of Portugal for many decades. In the 1960s, approximately over half the utilized agricultural area was divided between non-irrigated cereals (the dry system) and unseeded fallow rotations. Cereal crops were sown from October to mid November to make use of autumn precipitation for germination. Spring was the main growing season and mature cereals were harvested in June to early July before the onset of the hot, dry months. Cereal fields were rotated with unseeded fallow in order to regenerate soil moisture and nitrogen levels for the following year's cereal rotation.

Agricultural activities have become less important since the mid-20th century, coincided with the widespread migration of the population to certain European countries (France, Germany, Luxembourg, etc.) and to urban centres (Nunes, 2007). This exodus and subsequent abandonment of cultivated land was associated with the low rate of return from traditional crops, a result of the low productivity of dry farming systems (a Mediterranean climate, undulating relief, and poor, shallow soils), uncompetitive farm structures (with small, scattered plots), the peripheral location of the area, the lack of alternative employment sectors and the extensive presence of elderly farm owners. Furthermore, the socio-economic and political changes in Portugal in the 1970s that led to higher agricultural wages and migration from the countryside, made it difficult to maintain traditional management and manual shrub clearing, which was essentially based on low labour costs. During the period 1960-2001, the study area lost about 60% of its total population and more than 90% of its farmers.

According to SROA (Service of Agrarian Recognition and Management, 1951-56) statistics, in the middle of the last century cereal cultivation occupied about 55% of the total area of the Guarda district. Five decades later, the same crop only represented 10% of the total surface (CORINE Land Cover, 2000), meaning that approximately 80% of the cereal crop area had been abandoned.

Complete farm abandonment has resulted in enhanced natural secondary succession and the spread of shrub and woodland (Lasanta et al., 2009). In the first stage of land abandonment, after 4-5 years the dominant vegetation belongs mainly to the *Gramineae* family and forms a sparse herbaceous cover (Fig. 2). Perennial shrub communities, mainly dominated by nanophanerophytes such *Cytisus multiflorus* and *Lavandula sampaioana*, follow after two decades of farmland abandonment. As a result of the abandonment of cultivated land and the decline in forest land, shrub plant communities have become one of the most important vegetation types in the Iberian Peninsula (Casermeiro et al., 2004). Negligible areas are covered by recovering *Quercus pyrenaica*, indicating a lengthy period of abandonment of approximately 30-40 years. The *Quercus pyrenaica Willd*. wood is the characteristic autochthonous vegetation in the study area. The unmanaged accumulation of large quantities of fuel has led to a dramatic increase in forest fires and burnt areas (Carvalho et al. 2002), and therefore to difficulties with *Quercus* regeneration.

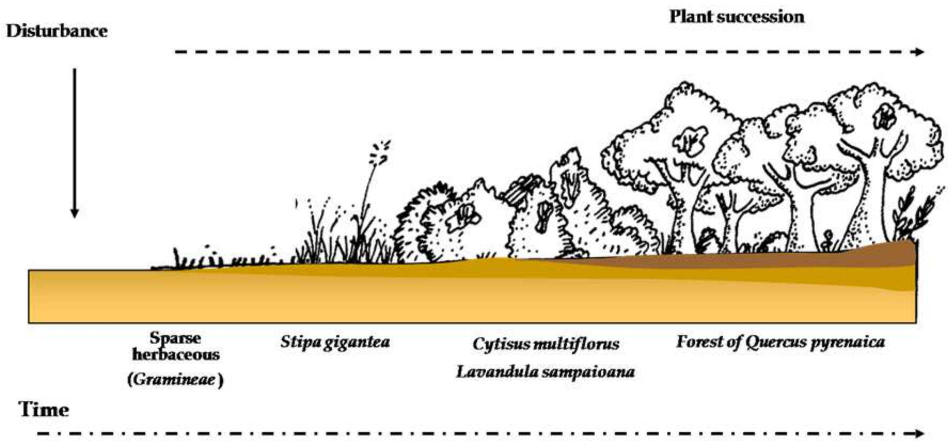

Fig. 2. Dynamic evolution of vegetation in the study area following land abandonment (adapted from Capelo, in Costa et al., 1998)

The 1992 MacSharry reforms to the European Union Common Agricultural Policy have reinforced the falling rates of cereal production. The reforms included a set-aside program requiring farmers to take certain percentages of their arable land out of production. With the opening up of international markets and the lowering of crop prices, the market-oriented cultivation of cereals became unprofitable in most of Portugal. Farmers receive more in the form of direct payments per hectare under the set-aside regime in comparison with arable crop production. Consequently, they put greater percentages of their farms into set-aside. As an example, in the Guarda district early retirement has affected about 10 000 farmers and an area between 60 000 ha and 90 000 ha, since 1996. This represents about 40% of the total number of farmers and 30%-45% of the utilised agricultural area.

In contrast, pastureland has increased by over 25%, in the last two decades (INE, 2000). In fact, recent EU agri-environmental measures support the maintenance of natural pastures or the extensive cultivation of fodder crops (without deep ploughing and the use of fertilisers) and the livestock unit subsidy supports maintenance of livestock (Borges et al., 1997). The current CAP measures for Portugal also promote forest development measures (EU Regulation 2080) by supporting new plantations and shrub clearance.

3. Methodology

Six types of land use associated with traditional land use, land abandonment and subsequent plant recovery, and alternative land uses proposed by the CAP for marginal areas (extensification of land use and conversion of arable land to forest) were selected for the study.

1. Cereal crops (traditional land use)

In dry cereal systems with Mediterranean marginal soils, during March/April the 20-30 cm of top soil is turned over and remains without vegetation until sowing. This process is called laying fallow. The cereals are planted from October to mid November to make use of autumn precipitation for germination. Spring is the main growing season and mature cereals are harvested from June to early July before the onset of the hot, dry months.

2. Fallow land (traditional land use or short-term abandonment)

In a rainfed cereal system, fallow land is a traditional part of the cereal rotation system. During fallow cycles, land remains unseeded for 2, 3 or more years to enhance soil fertility and soil moisture availability for subsequent crops. No chemical fertilizers or manures are used, and the plant residue is kept in the fields. Fallow lands are usually used as grazing land in traditional land use agropastoral herding practices in the territory.

3. Shrub land (long-term abandonment)

When arable land is abandoned, a process of plant colonisation begins. This is a very complex process in which ecological conditions (both physical and biotic factors), human activity (the agricultural history of the fields' as well subsequent management, namely grazing, fire, clearing, etc.) and time interact. Before shrubby species, mainly *Cytisus spp.*, proliferate, abandoned fields in central inland Portugal are invaded by herbaceous plants during the first years of abandonment. It can take more than 15-20 years for shrub land with a high percentage of ground cover to develop. Due to the accumulation of biomass in abandoned fields after recolonisation, there has been an increase in forest fires.

4. Recovering oak (very long-term abandonment)

The Pyrenean oak (*Quercus pyrenaica* willd.) is the autochthonous species in this area. Human activities over the centuries have led to considerable deterioration of the native arboreal vegetation characteristic of the region. The restoration of native vegetation is a very long process, disturbed by the regular occurrence of forest fires.

5. Afforested land (conversion of arable land to forest)

The main aim of Afforestation Regulation 2080/92 (Community Aid Scheme for Forestry Measures in Agriculture) was to reduce agricultural surpluses, but the EU also hoped that it would 'enhance forest resources'; 'provide greater ecological balance in countryside management'; and 'combat the greenhouse effect". The CAP measures for afforestation of marginal fields promote the use of a wide range of native species; however the main species selected in the area studied was *Pinus pinaster*. In Portugal, soil preparation before planting, often carried out by public works companies, involves the use of heavy machinery and deep ploughing techniques.

6. Pastureland (conversion of arable land into pasture - extensification of land use)

Recent EU agri-environmental measures support the maintenance of natural pastures or extensive cultivation of fodder crops (without deep ploughing and the use of fertilisers) and the livestock unit subsidy supports the maintenance of livestock. The study area was used for grazing cattle and the unit head per hectare was lower than 1. This value has been classified as light to moderate grazing (Rauzi & Smith, 1973; Van Haveren, 1983).

A total of 26 x 50m^2 plots were created. In each plot, the percentage of plant cover (lichens + mosses, herbaceous + shrub canopy, litter cover and bare soil) were estimated at the end of the dry and wet seasons. The height of the vegetation was also determined (in cm). Two soil samples (0-10 cm) were collected and certain characteristics (grain size distribution, bulk density, soil organic matter, etc.) were determined. A Coulter LS Particle Size Analyzer was used for grain size analysis for fractions of < 2 mm. Dry bulk density and porosity were measured using the cylinder method. Soil resistance was assessed through the use of a pocket penetrometer. Soil moisture was determined by the gravimetric method. Organic matter content was determined by the Tinsley method (1950). Soil water repellency was measured using the Ethanol Method (MED), at the suggestion of Doerr et al. (1998). The ethanol concentrations used in this study area were 0, 1, 3, 5, 8.5, 13, 18, 24 and 36%, representing liquid surface tension intervals of approximately 5 dynes/cm (Coelho et al., 2005). A zero value corresponds to hydrophilic (or wettable) soil and 36% to extremely water repellent soils. These tests were carried out before the rainfall simulations.

A rainfall simulator similar to the one described and tested by Cerdà et al. (1997) was used to evaluate the main hydrological and erosional characteristics of the soil[1]. It consists of a springlink device placed 2 m above the soil. A small 0.24 m^2 round plot is inserted carefully into the soil (Fig. 3). Rainfall simulations have a duration of 60 minutes and intensities of around 53-55 mm h^{-1}. Tests were carried out over two years (2005 and 2006) under different plant cover and soil moisture conditions. Tests were carried out in August of 2005 and 2006, when there was a severe drought due to very low precipitation in the preceding three months (10 mm and 45 mm, respectively) and in April and November of 2006 after a very intense period of natural rainfall (160 mm and 300 mm, respectively, during the preceding months). The average monthly temperatures also differed, ranging

[1] It is important to note that although rainfall simulation tests on small surfaces are used worldwide, their results should only be considered for comparative purposes, especially in the case of sediment concentration (Lasanta et al., 2000; Pardini et al., 2002). In fact, measurements on experimental plots are acceptable only for comparative purposes, that is, to assess the amount of overland flow and erosion in different environments and land use types. They cannot be accepted as absolute coefficients or rates.

from 10ºC and 13ºC during the wet season experiments to 21ºC and 22.5ºC in the dry season. The slope gradient varied from 0 to 20%. The number of simulations for each land use type varied from 4 to 10. Time to runoff (number of minutes between the beginning of simulated rainfall and runoff), runoff coefficient (rates for the relationship between rainfall intensity and runoff, in %) and total soil loss (in g m^{-2}) were the evaluated parameters. Water and sediment samples were taken continuously (every 2 minutes) from the beginning of runoff.

Fig. 3. Example of the plot used in the rainfall simulations (shrub and pastureland)

To understand the factors influencing runoff generation, the detachment of sediments from the plot and their removal to the outlet, explorative data analysis, correlation analysis and Principal Component Analyses (PCA) were performed using the SPSS 17.0 statistical package. One-way analysis of variance (ANOVA) and the Waller-Duncan multiple comparison procedure were performed on each soil property layer and for runoff and soil erosion to test whether the changes in land use and cover were statistically significant (p-value <0.05). The *Spearman-Rho* correlation coefficient (Rs) was selected to estimate the correlation between the quantitative attributes of the soil surface and runoff and sediment production. This rank-correlation method is considered robust against outliers and non-normal distribution of data.

Principal components analysis is an ordination method, used to simplify data by reducing the number of variables. The PCA procedure generates indices called principal components, which are linear combinations of the original variables. The most efficient data description and reduction are obtained when the variables are highly correlated.

4. Results

4.1 Soil cover

Results for plant cover for the different types of land use and vegetal covers are summarised in Table 1. The percentage of plant cover is clearly related to seasonal changes in vegetation. The lowest soil cover percentages were recorded in late summer. Conversely, the highest values were registered for the soils with the highest moisture content, peaking in the autumn and spring. These differences were mainly due to the variations registered for the density of grass cover, lichens and mosses, which dry up in the summer season and grow in the winter and spring. The existence of a marked seasonal dynamic due to the predominance of annual vegetation generated significant cycles and temporal differences, both for the protection of the soil against erosion and evapotranspiration, and for the incorporation of organic matter and, obviously, primary production.

Land use types/covers	Lichens & mosses	Herbs & shrubs	Litter cover	Total vegetation cover
Dry, hot season				
Ploughed land	2.0	3.0	0.0	5.0
Cereal crop	a	a	a	a
Fallow land	3.0	20.0	10.0	33.0
Shrub land	4.0	60.0	20.0	84.0
Recovering oak	1.5	2.5	90.0	94.0
Afforested land	0	3.0	2.0	5.0
Pastureland	2.5	2.5	65.0	70.0
Mean	2.7	15.2	31.2	41.6
Wet, cold season				
Ploughed land	9.5	2.0	0.0	11.5
Cereal crop	15.0	56.0	0.0	71.0
Fallow land	32.5	30.0	5.0	67.5
Shrub land	14.0	68.0	10.5	92.5
Recovering oak	3.5	3.0	92.0	98.5
Afforested land	13.5	1.5	0.0	15.0
Pastureland	22.5	69.0	5.0	96.5
Mean	15.8	32.8	16.1	64.6

a. Not available in this season of the year.

Table 1. Plant cover (%) per season for the different land use types/cover monitored

The results demonstrate that the highest surface cover was recorded in wood plots, with figures exceeding 90%. Old abandoned fields with recovering oaks showed a very homogeneous yearly soil cover related, in particular, to the predominance of litter cover. In the shrubland, the soil cover of grass, lichens and mosses explained the differences observed between the dry and wet seasons, with values between 84 and more than 92%. In fact, during the different stages of vegetation succession, the development of soil cover, mainly the herbaceous, shrub and litter cover, depends on the length of time the land has been abandoned and the activities developed after cropland abandonment.

The soil cover of recently abandoned fields increased around 30%between the dry and wet periods, mainly due to the development of lichens, mosses and grass. The pastureland shows a similar behaviour, with an increase by more than 20% between dry, hot and wet, cold season.

In contrast, the ploughed and afforested land revealed average annual values of less than 15%. As the cereal (mainly rye) is planted in the end of September or beginning of October, the crop is covering the ground before winter and continues to grow in the spring. Therefore the percentage of soil cover during the monitored wet season was high.

4.2 Soil characteristics

Table 2 summarizes the physico-chemical properties of soils for the different types of land use and vegetal covers. There were no significant differences in particle size distribution for the top 10 cm layer among the land cover types. A sandy loam texture was found in all the soils studied, in line with the same parent material on which they lie. In this layer, the soils revealed a very high percentage of sand fractions, over 70% of the total, and a low silt and clay fraction. In general, a sandy, coarse-textured soil drains easily and quickly after rain but has a lower moisture-retention capacity and a lower nutrient-retention capacity. Unlike texture, there was a significant difference in bulk density (g cm^{-3}) among land covers (p-value <0.001). The lowest values were recorded for the cereal crop and arable land afforested with *Pinus pinaster*, as a consequence of ploughing up the top layer for cereal cultivation, tree planting and the removal of ground cover to avoid forest fires.

Conversely, the highest values for bulk density, which correspond to the lowest porosity percentages, were registered in grazing plots and fallow land or short-term abandoned land. Soil bulk density is a more direct measure of soil compaction (Roberson, 1996) and perhaps the greatest impact of grazing consists of changes to the soil structure due to compaction (Roberson, 1996; Wood, 2001). In fact, the intense and continual pressure from moving livestock easily compacts soils, particularly when they are wet and more susceptible to compaction (Brady, 1984; Warren et al., 1986). Firestone (1995), for example, observed a 13% increase in the bulk density of grazed soils under oaks in California. Orr (1960) measured an increase of up to 20% in bulk density in the top 4 inches of grazed South Dakota steam bottom soil when compared with exclosures. Compaction is a strong direct effect of force which leads to the indirect effect of reduced infiltration and the resulting force of increased overland flow, which in turn leads to increased erosion (Trimble & Mendel, 1995). Extension of the abandonment stage and the expansion of shrub and wood communities tend to reduce soil bulk density.

All the soils were very low in organic matter. In the soils with cereal crops and in fallow land the organic matter content was around 0.50%. Despite the higher organic matter obtained for afforested and grazed land, there were still no significant differences between these four land uses. Soil erodibility in all land use types was expected to be high because of the sandy soil texture and low organic matter content. Vegetation restoration after abandonment, involving the development of shrub and tree cover, seems to enhance the organic matter within the upper layer of the soil. These changes in soil surface conditions are related to the greater contribution to organic matter provided by the leaves and roots of both the annual and perennial species of these vegetal communities.

	Cereal crop	Fallow land	Shrub land	Recovering oak	Afforested land	Pasture land	ANOVA
Texture, % (0-20 cm)							
Sand	74.18±4.17	76.70±1.95	71.96±5.32	69.67±4.18	71.11±3.34	72.04±3.34	ns
Silt	20.99±3.14	19.01±1.47	22.50±4.88	25.35±4.22	24.02±33.15	22.77±4.39	ns
Clay	4.92±1.09	4.30±0.65	5.48±1.56	6.48±1.45	4.88±0.49	5.19±1.43	ns
Soil bulk density, g cm-3 (0-10 cm)	0.85±0.13[a]	1.23±0.11[c]	1.04±0.16[b]	0.91±0.16[ab]	0.81±0.06[a]	1.22±0.07[c]	**
Soil resistance to penetration, g cm-2	0.77±0.30[a]	2.86±1.11[b]	2.22±1.24[b]	1.88±0.99[b]	0.60±0.22[a]	3.98±0.59[c]	**
Organic matter, % (0-10 cm)	0.55±0.27[a]	0.53 ±0.31[a]	1.38±0.71[b]	1.46±0.23[b]	0.84±0.22[a]	0.73±0.26[a]	**
Soil moisture content, % (0-10cm)							
Dry season	2.18±1.32[ab]	1.20±0.98[a]	0.80±0.22[a]	3.63±1.10[bc]	3.70±1.20[bc]	4.00±1.83[c]	**
Wet season	11.1±1.81[a]	14.53±3.79[ab]	13.84±3.08[ab]	18.13±5.48[b]	13.64±1.25[ab]	18.00±3.91[b]	*
Water repellency, %	0.65±0.27[a]	2.65±1.98[a]	13.25±3.45[c]	19.75±2.36[d]	1.04±1.18[a]	6.24±0.91[b]	**

Significance level notations are: ** p<0.01, * p<0.05 level (1-tailed), ns: not significant; Means within a column followed by different letters differ at the 0.05 probability level according to Waller-Duncan test; a: not available in this season.

Degree of hydrophobocity (% of ethanol): 0- hydrofilic; ≤5- slightly hydrophobic; ≤13- strongly hydrophobic; ≤ 24- severely hydrophobic

Table 2. Physical and chemical properties of soils (mean and ± standard deviation) in different land use types/covers

The amount of water in the soil changed significantly from one season to another. On average, the soil water content in the upper 10 cm rose from 0.8% during the dry period to 18.1 % during the wet period. The highest values were detected in the top layer of the recovering oak and pasture land plots. Under very wet conditions, all the soils were hydrophilic, which agrees with the finding of Coelho et al. (2005). Under dry conditions, the shrubland and *Quercus pyrenaica* woods showed water repellency, which was more pronounced in the tree formation. This may be due to the higher levels of litter cover and organic matter in the soil that were recorded. The results for soil water repellency show a spatial discontinuity in shrubland, linked to the spatial variability of the land cover. The substances responsible for the soil's ability to repel water are related to the organic compounds derived from living or decomposing plants (Doerr et al., 2000). In fact, the relationship between these two variables and water repellency are very high (Rs= 0.782 for the percentage of soil cover with litter and Rs= 0. 674 for the percentage of organic matter content). These results are similar to those referred to in literature on the subject, which considers that there is a strong correlation between soil water repellency and organic matter and litter cover (Coelho et al., 2005; Doerr and Moody, 2004).

4.3 Hydrogeomorphic response

Table 3 summarizes the statistical analysis for the hydrological and sedimentological parameters in the different types of land use during the dry and wet periods. The results from the preceding ANOVA demonstrate significant statistical differences (P <0.000) for land use and soil covers, which means that variables have an important effect on runoff and soil loss amounts regardless of the season.

With high intensity rainfall, the afforested and laying fallow land produce the highest runoff and sediment yield coefficient, with an annual average of 64% and 45% of the rainfall and 75 g m^{-2} h^{-1} and 43 g m^{-2} h^{-1}, respectively. These results show that the soil in these plots, which has very poor plant cover and low infiltration, encourages overland flow and soil erosion. Ploughing soils for cereal crop or soil operations for forestation procedures (that involve the use of heavy machinery and deep ploughing techniques) have a direct and influential effect on soil losses, essentially increasing them. Even in the first years of tree development, especially when it is necessary to control vegetation cover to prevent forest fires and competition from other species, the soil surface remains unprotected for extended periods of the year, thus accelerating water and sediment flows. In fact, ploughing completely destroys the vegetation and litter cover, breaks up the soil structure and reduces the number of obstacles to overland flow, leading to a more efficient transport of sediments. This hydrological response is also affected by the lack of macroporosities, meaning that only a little water infiltrates into the soil matrix. The soils also offered weak resistance to penetration (Nunes et al., 2010).

The growth of cereals results in increased soil cover, which explains the higher runoff time and lower overland flow and sediment yields. Crops protect the soil surface from splash and surface sealing. In the initial growth stage, the area covered with plants is small but as the crop matures at the end of winter and early spring it plays an increasing role in protecting the soil surface (Nunes & Coelho, 2007). The average recorded values during the wet period were twice lower than the values recorded for ploughed land without cereal crops. In fact, the effectiveness of any crop, management system or protective cover depends in particular on how much protection may be available at different times of the year.

Recently abandoned fields or fallow land present the highest variation in overland flow response, with values ranging from 74% to 12% of the total rainfall. The soil erosion rate varies between 68 g m^{-2} h^{-1} and 3 g m^{-2} h^{-1}. A detailed analysis shows that rainfall simulations performed during the dry period present overland flow and sediment yields that are significantly higher than those which occur during the wet season. The reason for the high overland flow and therefore the effect on erosion yields may be ascribed to the low plant cover density after a long, hot, dry season, and the presence of a microcrust (2-3 mm deep) in most of the plots (Nunes, 2007). This crust considerably reduces the infiltration capacity of the topsoil and its hydraulic conductivity also tends to decrease over time (Seeger & Ries, 2001), even in sandy soils (Kidron & Yair, 2001). The increased vegetation cover and destruction of the microcrust layer in wet periods reduces the runoff percentage and enhances infiltration capacity. At the same time, it also reduces splash and sediment detachment, and therefore the erosion rates. A similar intra-annual behaviour was observed under grazing plots, however a delay in runoff, an increase in soil infiltration capacity and a reduction in soil erodibility were recorded. Soil loss from the pasture plots was lower, approximately 4 times less than that of the fallow land or recently abandoned fields.

	Time to runoff		Runoff (%)			Erosion (g m-2 h-1)		
Land use/ plant cover		(min.)*	Dry season	Wet season	Aver age	Dry season	Wet season	Aver age
Ploughed land n=5+4 (100%)	Max. Med. Min. S.D	34.00 9.30 5.15 9.36	49.00 30.30 8.00 14.25	67.70 59.83 54.00 5.30	45.07	56.36 28.55 3.40 18.20	84.86 57.66 43.68 16.32	43.10
Cereal crop n=4 (100%)	Max. Med. Min. S.D	24.30 16.37 9.20 6.57	a. a. a.	41.00 20.33 8.00 12.35	20.33	a. a. a.	34.70 18.13 4.20 12.01	18.13
Fallow land n=6+4 (100%)	Max. Med. Min. S.D	23.05 9.55 1.00 8.23	74.00 43.83 14.00 22.54	24,00 16.90 12.10 4.53	30.34	67.56 21.48 2.96 22.46	9.13 5.92 2.90 2.28	13.70
Shrub land n=4+4 (62.5%)	Max. Med. Min. S.D	20.00 11.23 4.30 6.00	14.00 7.83 0.00 5.02	3.70 1.80 0.00 1.78	4.80	0.90 0.38 0.00 0.33	0.24 0.06 0.00 0.10	0.22
Recovering oak n=4+4 (12.5%)	Max. Med. Min. S.D	38.00 . . .	2.00 0.50 0.00 0.87	0.00 0.00 0.00 0.00	0.25	0.10 0.03 0.00 0.04	0.00 0.00 0.00 0.00	0.01
Afforested land n=5+4 (100%)	Max. Med. Min. S.D	5.00 3.58 2.10 1.31	71.00 61.00 47.60 8.57	70.00 66.20 63.20 3.49	63.60	145.50 97.40 65.80 33.10	87.00 52.20 36.80 21.82	74.80
Pastureland n=4+4 (87.5%)	Max. Med. Min. S.D	23.00 11.00 3.50 7.00	41.80 32.50 21.80 8.96	25.90 14.50 0.00 12.15	23.50	8.10 4.10 1.30 2.82	4.80 2.40 0.00 1.98	3.25
Med. S. D. ANOVA (*p-value)*		11.40 9.10 0.000	29.33 24.15 0.000	25.65 41.44 0.000	26.84 23.50 0.000	25.32 26.08 0.000	19.48 27.11 0.000	21.89 33.77 0.000

n*:* number of rainfalls simulations performed under dry and wet season. *(100%)*: Percentage of rainfall simulations with runoff. *: Calculated values based on rainfall simulations with runoff. a: Not available in this season of the year.

Table 3. Overland flow and erosion yields measured during rainfall experiments

Measurements performed on recovering *Quercus pyrenaica* revealed very low or no overland flow in both dry and wet seasons. In these plots, the infiltration capacity exceeds the intensity and quantity of rainfall simulations; both soil erosion and surface runoff are very well controlled, ensuring soil conservation and even improving some of the soil characteristics (organic matter content, porosity, exchange capacity and nitrogen content). These results also suggest that water repellency does not play an important role in overland flow generation, mainly due to the high litter cover, but additionally as a result of the patchy and discontinuous nature of soil water repellency at plot level, as suggested by Ferreira et al. (2005). In fact, since water repellency is a patchy soil surface phenomenon, the existence of hydrophilic patches and macropores that allow water to infiltrate the soil will considerably reduce superficial water transport. Moreover, macroporosities created by roots and soil animals allow for infiltration into the deeper layer, despite the existence of strong water repellency in the top layer of the soils. Deep and interconnected macropores may cause rapid flow to the soil without significant water recharge into the matrix (Seeger & Ries, 2001).

Shrubland presents significantly higher overland flow and erosion rates during the dry summer period than in the wet season. These results can be related to an increase in soil water repellency after a long period without rainfall. In fact, a dual trend can be described (Fig. 4): first, runoff increases slightly from the beginning and a runoff discharge peak was detected between 15-20 minutes of the experiment. This behaviour could be due to the hydrophobic character of the soil surface. After that, infiltration increases, due to a decrease in soil water repellency after wetting. The hydrophobic substances act as a cement that binds the soil mineral particles together (Coelho et al., 2005) but has a tendency to attenuate in contact with water. Similar results, with a progressive decrease in runoff, have been observed, for example by Contreras López and Solé-Benet (2003), in semi-arid Mediterranean soil (SE Spain). Jordán et al. (2008) also detected a runoff rate peak after 20 minutes in dry conditions in a Mediterranean climate. Subsequently, the overland flow declined slightly. Another reason which explains why the highest runoff and erosion amounts occur during the dry season is associated with the disappearance of the herbaceous cover, which implies a higher percentage of bare soil and an increase in soil compaction.

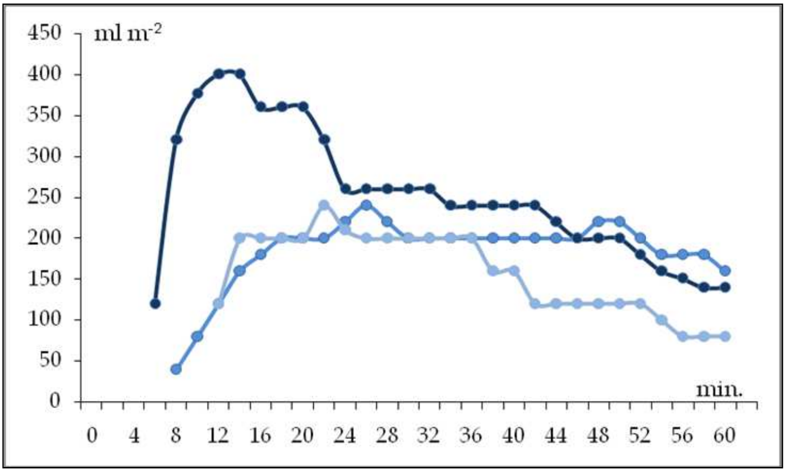

Fig. 4. Shrubland runoff curves in the dry period.

4.4 Relationship between variables (statistical analysis)

To determine which variables have more influence on runoff and sediment loss, Spearman correlations and principal components analysis were carried out. Analysing the relationship between all the data (Table 4), significant correlation coefficients between the characteristics of the plot and runoff and sediment production were found, in both the wet and dry period. The results obtained show that, annually, total plant cover is the main factor which explains runoff generation (Rs= -0.824) and the movement of sediments (Rs= -0.913). This concords with other studies (Grove & Rackham, 2001; Kosmas et al., 2000; Lattanzi & Meyer, 1974; Trimble, 1990) which found a (negative) linear relationship between the total volume of overland flow and the mass per unit of plant cover. In fact, plant cover decreases the kinetic energy of the rain that is released and dissipated to the soil surface, reducing the amount of detachment and, hence, the erosion that can occur (Greene & Hairsine, 2004). As a result, the increase in soil cover corresponds to an increase in the range of conditions under which the soil surface is stable and therefore less exposed to crust or seal. Consequently, an increase in plant cover during a wet season decreases splash and sediment detachment and improves the negative correlation coefficients (Rs: -0.836 for overland flow and Rs= -0.940 for erosion rates).

Vegetation type is also important, with litter cover offering more protection against overland flow and water erosion, especially under dry conditions. Several studies have analysed the influence of various forms of cover on the formation of crust and seal (Greene & Hairsine, 2004). This cover can be a canopy cover of vegetation or contact covers, such as litter cover, mulch or cryptogams (mosses, lichens, etc.), which form in close association with the soil surface. Vegetal litter cover absorbs some of the energy of raindrops and leads to an exponential decrease in splash erosion (Casermeiro et al., 2004).

	Year (dry + wet period) n= 56		Dry period n= 28		Wet period n= 28	
	Runoff (%)	Erosion (g m^{-2} h^{-1})	Runoff (%)	Erosion (g m^{-2} h^{-1})	Runoff (%)	Erosion (g m^{-2} h^{-1})
Slope (%)	ns	-0.280*	ns	ns	ns	ns
Total plant cover (%)	-0.824**	-0.913**	-0.726**	-0.882**	-0.836**	-0.940**
Lichens + Mosses (%)	ns	ns	ns	ns	ns	ns
Herbs+ shrubs (%)	ns	ns	ns	ns	ns	-0.375*
Litter cover (%)	-0.675**	-0.782**	-0.681**	-0.795**	-0.711**	-0.795**
Height of vegetation (cm)	-0.369**	-0.395**	ns	-0.386*	-0.588**	-0.541**
Antecedent soil moisture (%)	-0.360**	-0.307*	ns	ns	ns	ns
Resistance to penetration(g m^{-2})	ns	-0.369**	ns	-0.393*	-0.444*	-0.580**
Total of porosity (%)	0.230*	0.357**	ns	ns	0.557**	0.599**
Water repellency (%)	ns	-0.391**	-0.619**	-0.817**	a	a
Soil organic matter (%)	-0.694**	-0.708**	-0.731**	-0.676**	-0.450*	-0.502**
Runoff (%)	.	0.917**	.	0.869**	.	0.948**

Significance level notations are: ** p<0.01, * p<0.05 level (1-tailed), ns: not significant, a: not available in this season.

Table 4. Spearman-rho correlations between runoff and erosion and some characteristics of the soils.

The role of organic matter in stabilizing aggregates against breakdown by water seems to be evident. In all the experiments, the organic matter content was negatively related to runoff and soil erosion (Rs: -0.694 and Rs: -0.708, respectively) (Table 4). Nevertheless, a more detailed analysis shows that after a hot, dry summer the organic matter in the top layer was more closely related to runoff (Rs: -0.731). In the wettest season, this variable seems to be less important in soil runoff and erosion rates, as the relationship has a lower significance (Rs: -0.450 for runoff and Rs: -0.502 for soil erosion). During this period, others variables show a highly significant correlation with runoff and sediment yield, such as total porosity (Rs: 0.557; Rs: 0.599) and resistance to penetration (Rs= -0.444; Rs= -0.580).

The high negative correlation between water repellency and runoff (Rs= -0.619) and soil erosion (Rs: -0.817) during the driest season inversely corresponds to what has been found in other studies, particularly at plot level, where a clear relationship between hydrophobicity and overland flow was detected (Doerr & Moody, 2004; Doerr et al., 2003; Ferreira et al., 2000). As Doerr & Moody (2004) state, apart from the spatial variability of repellent soil itself, additional spatially variable factors may influence the hydrological effects of water repellency: the variability of macropores (root channels, animal burrows) will affect infiltration and water movement in repellent terrain.

Although slope gradient has been identified as a very important factor affecting runoff generation and soil erosion intensity (Fox & Rorke, 2000; Morgan, 1986), our analysis shows that its influence on runoff and erosion during the two contrasting seasons is insignificant in terms of soil erodibility.

A positive correlation was found between eroded sediments and runoff generation in all the experiments (in dry and wet periods), despite the closer relationship obtained for the wet season (Rs: 0.948) as opposed to dry season experiments (Rs: 0.869).

The results of principal components analysis (Tables 5 and 6), which covered 77.6% of the variance in the first four axes, are determined for the first two as 53.4% of the total variability. The results therefore imply that at plot level quantitative data on surface characteristics helps to explain the processes. Axis 1 shows the contrast between the organic supply to the soil (soil cover, litter cover, soil organic matter) and erosion (surface runoff and the movement of sediment). Component 2 describes the positive plant cover relationship between herbaceous shrub cover and vegetation height. The data indicate that, regardless of the type of vegetation, the factors that offer most protection against erosion are total plant cover and soil litter. This concords with the data proposed by Elwell & Stocking (1976) and Casermeiro et al. (2004). The supply of organic carbon to the soil is also related to the role of vegetation. Soils with a higher organic carbon content appear to offer good protection against erosion. Slopes appear to be less important than plant cover in the generation of surface runoff and, therefore, in sediment transport.

Component number	Eigenvalue	Percent of variance	Cumulative percentage
1	4.361	36.342	36.342
2	2.044	17.033	53.375
3	1.487	12.390	65.766
4	1.417	11.808	77.574

Extraction Method: Principal Component Analysis.

Table 5. Total Variance Explained

Axis 3 shows both the expected opposition between soil porosity and resistance to soil penetration, and its positive relationship to the existence of lichens and mosses, which means less disturbance of the soil surface. Obviously, antecedent soil moisture does not favour water repellency, hence the opposition shown in Axis 4. These two components explain about 24 % of the total variance observed.

Soil parameters	Component 1	Component 2	Component 3	Component 4
Slope (%)	0.254	0.512	8.65E-02	-5.93E-02
Soil cover (%)	0.795	0.315	-0.411	-2.86E-02
Litter cover (%)	0.874	-0.265	-0.616	-0.198
Herbs+ shrubs (%)	-0.134	0.854	-0.321	-9.88E-02
Height of vegetation (cm)	7.16E-02	0.892	7.35E-03	-3.440E-02
Antecedent soil moisture (%)	0.399	8.16E-02	-0.113	-0.838
Resistance to penetration (g m^{-2})	6.65E-02	-1.00E-01	-0.873	4.72E-02
Total of porosity (%)	-8.79E-02	-0.118	0.816	7.13E-02
Water repellency (%)	0.405	3.60E-02	-7.87E-02	-0.833
Soil organic matter (%)	0.859	5.99E-02	9.41E-02	-9.09E-02
Runoff (%)	-0.757	-0.331	0.297	4.78E-02
Soil erosion (g m^{-2} h^{-1})	-0.556	-0.288	0.595	-1.73E-02

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization.

Table 6. Results of Rotated Component Matrix

5. Discussion

As pointed out by several authors (García-Ruiz, 2010; Kosmas et al., 1997; Mitchell, 1990), land use and soil cover are considered the most important factors affecting the intensity and frequency of overland flow and surface wash erosion. The results obtained agree with those observed by different authors in varied environments, who consider that runoff and sediment yield decrease with an increase in soil cover with vegetation (Bochet et al., 1998; De Ploey, 1989; Durán Zuazo et al., 2006; Elwell & Stocking, 1976; Francis & Thornes 1990; Roxo 1994). As can be seen in Figure 5, increasing vegetation cover leads to an exponential decrease in runoff, but only when this exceeds a threshold value of over 40%. Correspondingly, similar behaviour can be observed with regard to the relationship between sediment loss and vegetation cover.

However, wide variations in the percentage of plant cover were presented as critical between studies. Studies carried out in natural Mediterranean environments have shown that when vegetation cover drops below 30% soil erosion and runoff increase dramatically (Francis & Thornes, 1990; Gimeno-García et al., 2007). Thornes (1988) suggests that a value of 40% vegetation cover is considered critical, below which accelerated erosion dominates on sloping land. If the vegetation cover covers an area of more than 40%, it will act as a resilience or protective factor for the land. Molinillo et al. (1997) observed an increase in runoff and soil erosion in up to 60% shrub-cover and only above this value a reduction in runoff and erosion processes. Sauer & Ries (2008) consider that only plant cover exceeding 60% can significantly reduce soil erosion in semi-arid environments.

Land use and the type of management applied to each site explain, to a large extent, the variability in annual plant cover and, therefore, the occurrence of overland flow and soil erosion processes (De Luna et al., 2000; Francia Martínez et al., 2006; Gómez et al., 2004). Annually, as it involves mobilisation of the top layer (laying fallow and afforested land), ploughed soil erodes more easily and causes great soil loss. Cereal growth, mainly when it offers a good vegetal protection for the surface of the soil, enhances infiltration and reduces erosion rates. However, the results for soil erosion were greater in comparison with recent abandonment and were one hundred times greater if compared to land cover after very-long abandonment (Table 7). These results also enable us to conclude that traditional cereal cultivation, in particular ploughing in preparation for cereal crops, is a very negative land management practice due to the high runoff and water erosion response. Organic matter content, probably the most important component of soil quality, is also strongly influenced and registered very low figures of less than 1% for arable land. A limit of 1.7 per cent of soil organic matter content is considered an indicator of the pre-desertification stage (Pardini et al., 2002). The gradual depletion of nutrients, which reduces soil fertility and creates a high level of soil degradation, are further reasons for abandoning agricultural plots in the changing cultivation process (Paniagua et al., 1999). Planting trees, according the CAP measures for afforestation of marginal fields, with deep ploughing and bare soil has resulted in very high erosion rates during both rainfall seasons, as observed in other agro-ecosystems in Mediterranean Europe (Shakesby et al., 2002; Ternan et al., 1997; Van-Camp et al., 2004).

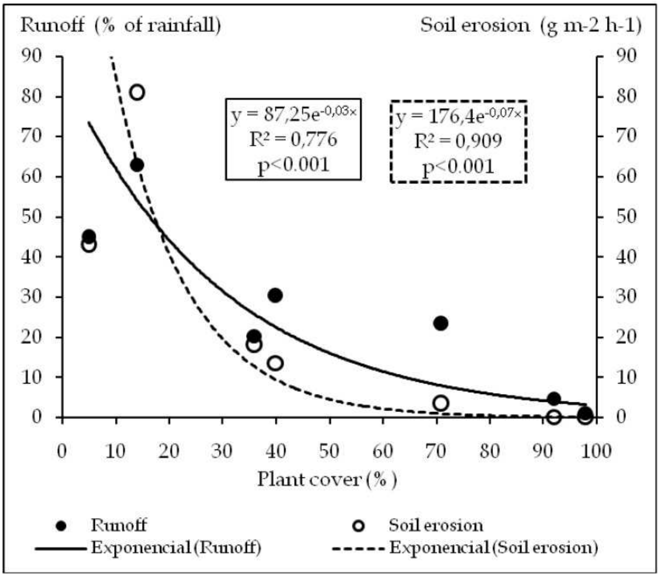

Fig. 5. Relationship between runoff and soil erosion and average percentage of plant cover

However, in large parts of marginal areas of the country farmland abandonment has enhanced plant colonisation, replacing historically highly erosive cereal fields with dense shrub and woodland communities. Herbaceous cover, the first successional stage in vegetation recuperation after land abandonment, seems not to enhance soil fertility after a crop cycle, but positively influences runoff and sediment yield, in addition to the higher values presented after a hot, dry period. These results stress the importance of non-ploughing as a soil protection measure.

When a permanently vegetated cover is dominant, as a result of a long plant succession, with shrub communities and oak-trees, even in recuperation, both soil erosion and surface runoff are very well controlled. Trees and shrub cover also ensure soil conservation and improve some of the soil characteristics, mainly the organic matter content, which registered a significant increase (Table 7). This hydrological and erosional behaviour, together with the soil properties, is closely interrelated and well understood in terms of the dynamics of plant and litter cycling. Vegetation and litter reduces direct raindrop impact on the soil, prevents the formation of mechanical crusts, enhances infiltration capacity and reduces soil erodibility (Nunes et al., 2010). In these soils, long-term spatially structured vegetation patterns play an important role in addition to cover, by increasing the stability and resilience of the system (Boer & Puigdefabregas, 2005; Cammeraat & Imeson, 1999). In general, our data agrees with other results obtained for the Mediterranean basin, in which land abandonment followed by natural vegetation regeneration is improving soil properties such as organic matter content, soil structure and infiltration rates, resulting in more effective protection against soil erosion (Cammeraat & Imeson, 1999; Francis & Thornes, 1990; Grove & Rackham, 2001; Kosmas et al., 2000; Morgan, 1986; Trimble, 1990).

Benefits compared to ploughing land			
Vegetation cover/stages of abandonment	Organic matter content (%)	Runoff (mm h^{-1})	Sediment loss (g m^{-2} h^{-1})
Fallow land or short-term abandonment	Not detected	-32.7%	-68.2%
Shrub land or long-term abandonment	+247.3%	-89.0%	-99.5%
Recovering oak or very long-term abandonment	+265.5%	-99.5%	-99.9%
Afforested land	+52.3%	+41.0%	+73.5%
Pastureland	+32.7%	-47.9%	-92.5%
Benefits compared to cereal crop			
Fallow land or short-term abandonment	Not detected	+49.2%	-24.4%
Shrub land or long-term abandonment	+247.3%	-76.4%	-98.8%
Recovering oak or very long-term abandonment	+265.5%	-98.8%	-99.9%
Afforested land	+52.3%	+212.8%	+312.6%
Pastureland	+32.7%	+15.6%	-82.1%

Table 7. Benefits detected in the comparison of cultivated land and the different vegetation cover/stages of abandonment.

Although abandoned land in humid and sub-humid regions self-regulates the development of natural vegetation (grass, weed, bushes, and later woodland) and normally does not need support except in the first years of abandonment, the cessation of traditional management practices, the creation of large homogeneous patches of vegetation and the accumulation of fuel due to fire exclusion policies are cited as some of the major causes of changes to the forest fire regime in Mediterranean Europe (Moreno, 1996). In fact, Portugal's burnt area has increased chiefly during the last three decades. This rising trend, although including some periods of lower burnt area, distinguishes Portugal from the other southern Member States with the highest burnt areas, particularly in the central and northern regions. It is commonly accepted that fire increases runoff and soil erosion (Benavides-Solorio & MacDonald, 2005; Cerdà & Doerr, 2005; Cerdà & Lasanta, 2005; Coelho et al., 2004; Ferreira et al., 2005, 2008; Shakesby et al., 1993, 1996, 2002). Increased erosion after forest fire stems primarily from the destruction of vegetation and changes in the soil physical and hydrologic properties that reduce infiltration rates and increase availability of loose sediment (Ferreira et al., 2005, 2008). The loss of vegetation and other ground cover due to wildfire reduces rainfall interception and attenuation, rainfall storage, and flow resistance (Martin & Moody, 2001). Rainfall-generated runoff therefore accelerates more quickly and less is retained as pounded water, resulting in reduced residence times and reduced total infiltration (Ferreira et al., 2008). In the Mediterranean basin, potential for post-fire soil erosion is very high as heavy autumn rainfalls commonly occur after summer wildfires.

Converting arable land into pasture can be positive, negative, or without impact depending on management practices. Several studies have evaluated how different grazing intensities affect both plant cover and water infiltration into the soil. These studies are consistent in showing that as grazing intensity is increased and soil cover is depleted, water infiltration declines and soil erosion increases (Rauzi & Smith, 1973). In fact, the direct impact of cattle hooves reshapes the land. Compaction is, perhaps, the strongest direct impact of force which leads to indirect consequences in terms of overland flow and soil erosion. Direct measurements of overland flow and soil loss rates from the pasture plots were more pronounced after the dry, hot season. During wet season, runoff and sediment yield decrease significantly.

Despite these negative effects, the conversion of arable land into extensive grassland had a strong, positive effect on surface runoff and erosion in the area monitored. A permanent plant cover of over 50%, in the form of vegetation or ground litter, provides a cushion between raindrops and the soil, preventing the "splash effect" or dislodging of soil particles by rain drops (Molinar et al., 2001). Research findings indicate a threshold at which removing the plant cover and volume have little effect on infiltration rates and soil protection. This threshold is generally about 50% of the current year's growth, which corresponds to the old adage of "take half and leave half" for sustainability (Wood, 2001).

The existence of marked seasonal dynamics related to the dominance of annual vegetation creates cycles and temporal differences in protecting the soil against geomorphic processes. At the end of the summer, with exception of ploughed land, the largest amount of runoff and sediment export from soils occurred, chiefly due to the greater erodibility of the soil surface after a warm, dry season and poor soil cover (Romero Díaz et al., 1999). The development of microcrusts in some plots encouraged runoff and, therefore, sediment transport. The water repellency observed in such soils (with shrub and tree species) after a long period without precipitation did not have a significant impact on overland flow generation and erosion rates. Soils with a higher organic matter content appear to offer good protection against runoff and soil erosion. This is provided by litter, from recovering *Quercus pyrenaica* and *Cytisus multiflorus*, for example.

As pointed out by Imeson (1990), the main characteristics affecting the vulnerability of the Mediterranean area to erosion are intense rainfall after a very dry summer. In fact, autumn is the most water erosive season as a consequence of the heaviest concentration of rainfall and rainfall erosivity (Nunes et al., 2011). Recent research into climate change in Portugal (the SIAM Project, Miranda et al., 2006) for the 21st century (including 3 greenhouse gas emission scenarios used by many global and two regional climate models), are homogeneous predicting a reduction in annual rainfall in mainland Portugal (within the range of 20 to 40% of the current value), as a result of a decline in the duration of the wet season. Predictions for temperature changes agree on an overall increase in the annual mean, with a much more pronounced maximum summer temperature particularly affecting inland areas of Portugal. This climatic trend will extend the long, dry, hot summers in the Mediterranean region and lead to more frequent and intense extreme weather events, which could increase the rates of erosion and the risk of desertification that is threatening substantial areas of Portugal (Nunes & Seixas, 2003; Nearing et al., 2005).

6. Conclusion

In Portugal, as well as in the Mediterranean countries, important land use and cover changes have occurred since the second half of the last century. The abandoning of traditional subsistence systems based on cereal cultivation, probably the most important change, has taken place mainly in the more disadvantaged areas where farming systems in general and livestock farms in particular are often operating close to the margins of sustainability. This was originally a consequence of the difficulties associated with adopting modern farming systems. Later, it was the result of the demographic exodus from these rural areas, and more recently it has been reinforced by the implementation of CAP measures. In several areas, cereal crop soils were neglected and a natural vegetation succession occurred, increasing plant recovery and establishing shrub and woodland areas. In other areas, the adoption of measures aimed at reducing intensive agricultural methods involved afforestation schemes and conversion to grazing land.

There are important differences in the hydrological and erosional functioning of the different land uses/cover types monitored. Shrub and woodland are considered better for soil and water conservation, producing less surface runoff and therefore less soil erosion. The results obtained also show a positive trend in organic matter content, highlighting the importance of vegetation in these very shallow soils with a low clay content in increasing structural stability and avoiding soil loss. The major threat to these ecosystems is associated with controlling the frequency of wildfires.

Conversely, cereal cultivation and tree planting accelerate runoff and soil erosion, which is attributed to soil tillage which loosens the soil and reduces anti-erodibility. Erosion and land degradation became a problem in Portugal when arable farming expanded into marginal areas over the decades. The poor water and soil protection provided by young pine is attributed to the poor ground coverage under the trees.

In fact, the amount of bare soil on a site is generally a good indicator of the soil's vulnerability to erosion and degradation. Good soil coverage is an essential element in soil conservation programmes. Vegetation protects the soil from eroding in various ways. Rainfall interception by the plant has two main consequences, the most important being that it reduces the erosive power of impacting raindrops. It also reduces the volume of water reaching the soil surface. Subsequently, soil erosion can be controlled by changing land use and increasing ground coverage, which was shown to be one of the basic approaches to controlling soil erosion in all land use types.

On the basis of the experiment results, pastureland should be encouraged, particularly for the degraded soils that are used to produce cereals in order to minimize the amount of soil loss by erosion, thus avoiding slumping and promoting stability. Accommodating pasture management with a weighted number of grazing animals per area unit and extending pasture rotation times could reduce soil erosion processes effectively and ongoing land degradation could be prevented according to the 'Directive of the European Parliament and of the Council Establishing a Framework for the Protection of Soil' (Commission of the European Communities, 2006). Additionally, is important to emphasise that extensive grazing is the main focus of landscape management in marginal areas of the Mediterranean region with very low population densities, only small resident communities, little mechanised agriculture and poor communications.

In addition to better pasture management, another possible consideration may be management of native shrub land and recovering oak. Land afforestation should be supported by a set of measures to minimise the impact of site preparation techniques, forest management and fire prevention on soils. Plough use as a tool in preparation of soils for sowing seeds in dry farming systems should be replaced in favour of other less pernicious tillage techniques.

However, in the study area, as well as in the majority of Portuguese rural areas, key problems remain and are complex to solve. They include: a) How to stop the demographic exodus that took place in the middle of the last century and continues nowadays? b) How to supply an appropriate income to attract young farmers to depopulated areas where the great majority of the population are elderly? c) How to improve farm structures that consist of small scattered plots? d) How to manage systems that favour soil conservation and combat land degradation but maintain economic viability? e) How to adjust Mediterranean agriculture to climate change scenarios for the 21st century?.

7. Acknowledgment

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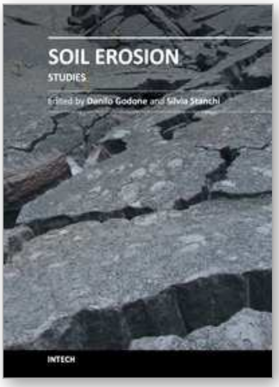

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Soil erosion affects a large part of the Earth surface, and accelerated soil erosion is recognized as one of the main soil threats, compromising soil productive and protective functions. The land management in areas affected by soil erosion is a relevant issue for landscape and ecosystems preservation. In this book we collected a series of papers on erosion, not focusing on agronomic implications, but on a variety of other relevant aspects of the erosion phenomena. The book is divided into three sections: i) various implications of land management in arid and semiarid ecosystems, ii) erosion modeling and experimental studies; iii) other applications (e.g. geoscience, engineering). The book covers a wide range of erosion-related themes from a variety of points of view (assessment, modeling, mitigation, best practices etc.).