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Spatial Distribution of Soils and their Properties as Indicators of Degradation/Regradation Processes in a Highly Disturbed Mediterranean Mountain Catchment

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Abstract

Mediterranean mountain environments have been intensively used for hundreds of years. Nowadays, extensification of land-use has lead to a homogenisation of landscape and processes as runoff generation, erosion and vegetation succession. Nevertheless, soils may show a high spatial variability, depending on topographical and lithological conditions and the actual vegetation and land-use status. So they can be used as indicators for the capability of rehabilitation of the landscape, its functions and the processes related. The indicators may be 1) chemical and physical properties and 2) the soil moisture dynamics during the year.
The results from a headwater catchment in the Flysch-Area of the Central Spanish Pyrenees are presented.
The soils show a high variability between the shady and the sunny aspect, but also inside these areas. The shady aspect is covered by deep Kastanozems and Phaeozems, as well as with Regosols. Mostly they show well structured topsoil with an enrichment of organic matter. On the sunny aspect Calcaric Regosols and Leptosols, with high active erosion dynamics can be found. Nutrient losses during the agricultural period, as well as the reduction of water storing capacity are important features of these soils. The valley bottoms are covered with Cambisols and Luvisols , showing vertic and stagnic conditions as well as high erosion and accumulation. Soil moisture reflects development conditions of the soils. Those with evidence of actual degradation processes tend to dry out rapidly whilst stable soils show slowly changes of soil moisture. These processes are intensively linked to the actual land-use.

Introduction

In the same way as other Mediterranean Mountain ranges, the Pyrenees have suffered during the last century, after intense land use for at least 2000 years, a dramatic extensification of land use, which has lead to strong changes in landscape (Lasanta Martinez, 1988; Lasanta Martinez, 1997; Lasanta Martinez et al., 2000; Lasanta, 1989; Vincente Serrano et al., 2000) and its functions (García-Ruiz et al., 2001). The most obvious change is the reduction of cultivated land. Within the Central Pyrenees, a decrease from nearly 30 % of the surface at the beginning of the 20th century to less than 3 % during its last decade was observed. But only about 7 % of these areas have been transformed into pastures, whilst 64 % have been changed to forests and almost 28 % are covered by scrubland of varying density (Beguería et al., 2003). The increase of vegetation cover does not imply a clear reduction of erosion processes in these areas (Garcia Ruiz et al., 1994; Molinillo et al., 1997; Ries et al., 2003). A more detailed view of the relationship between vegetation cover and geomorphodynamics is given by Ries in this issue.

Soil formation is conditioned by many factors including climate, lithology, vegetation and human activity. For this, soils, their properties and their degradation status can be indicators of past and present processes as well as their intensities. Many studies deal with the interpretation of soil qualitative status for understanding the degradation processes, especially those related to erosion (Fitzjohn et al., 2002.; Cammeraat and Imeson, 1999; Yanda, 2000) or especially dealing with the influence of land-use (Yong-Zhong et al., 2005; Zhao et al., 2005). In despite of the low velocity of soil formation, there may be found changes in soil properties, that indicate regradation processes after disturbance (Ruecker et al., 1998).

For this, soils may be used as representative for the landscape dynamics as well as they may reflect the capabilities of evolution of a landscape

There are many indicators that may be found in soils for interpreting them as representative for soil degradation status (Pardini et al., 1991; Cammeraat and Imeson, 1998). All authors highlight the importance of soil organic matter for aggregate stability and as expression of soil performance, but evident morphology, and especially surface stone layers, are taken into account, too (Mäckel and Walther, 1994). Even more dynamic characteristics, like soil water dynamics and porosity, may be used for characterisation (Seeger, 2001). All these indicators may be used for interpreting different processes of degradation and regradation at different time and intensity scales.

Materials and methods

Study area

The Arnás catchment is located in the Upper Aragón River Basin, a northern tributary of the Ebro River (Fig. 1). The bedrock is Eocene Flysch with alternating sandstones with carbonate cementation and marl layers sloping northward, which is characteristic of a wide sector of the Central Spanish Pyrenees.

The climate is mountainous Mediterranean with a strong oceanic influence, especially in winter. The average annual precipitation is about 1100 mm, mostly concentrated from October to May but divided by a secondary minimum in March. The average annual temperature is 10ºC.

The Arnás ravine drains a 284 ha headwater catchment into the Lubierre River, a small tributary of the Aragón River. The highest peak is at 1330 m a.s.l. and the outflow at about 900 m a.s.l. The ravine runs from west to east, building up a

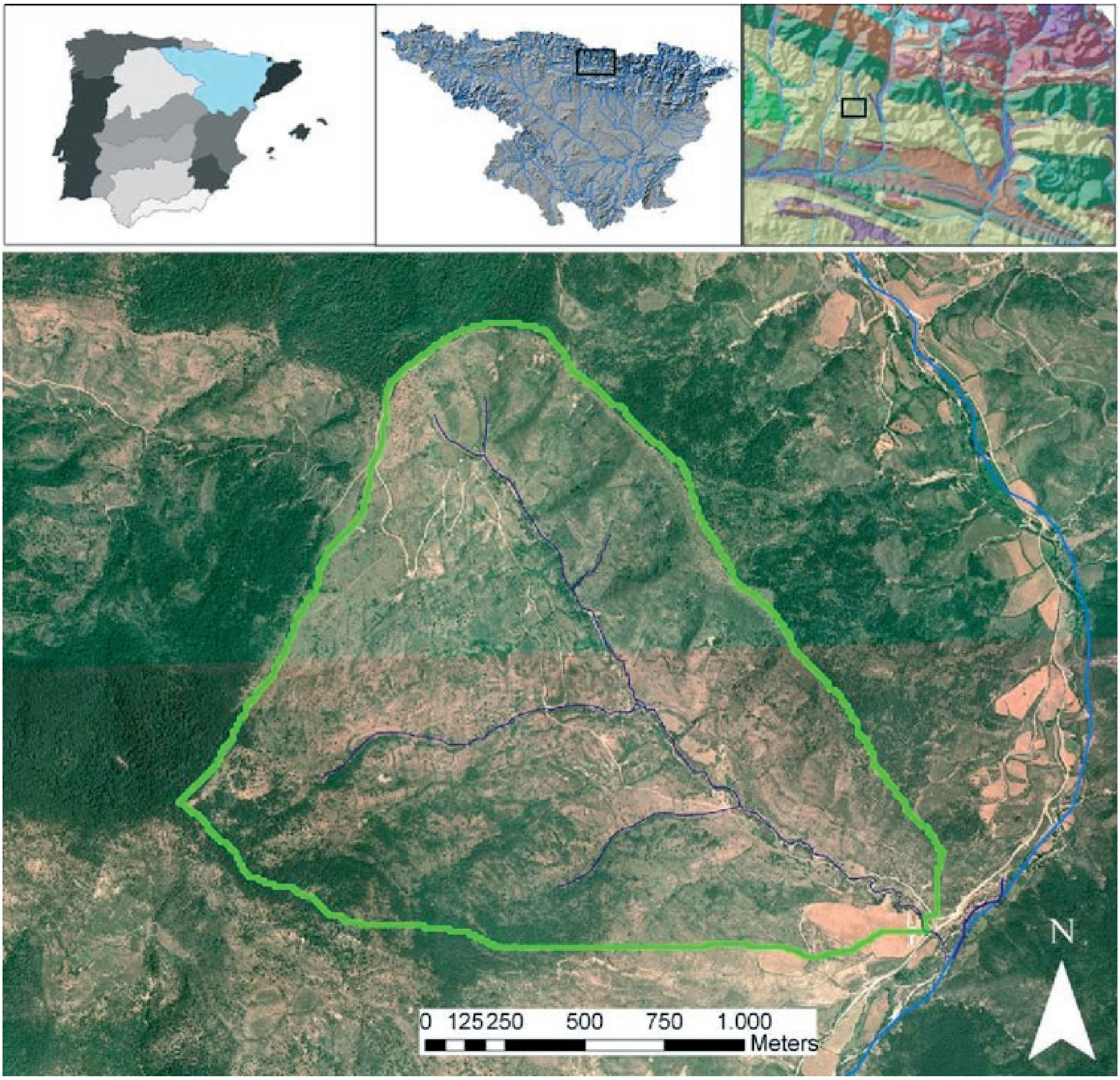

Fig. 1: Colour orthophoto of the Arnás headwater catchment showing its shape and the river. Note the low proportion of forested areas within the catchment. The upper images show the location and the lithological units.

valley with a strong contrast between the steep south facing slope and the gentle north facing slope.

The morphology of the slopes is characterised by big rotational landslides and earthflows. On the south facing slope there are some old and active debris-flows. Some poorly drained areas can be found related to the rotational landslides, especially in the shady aspect. They are mostly disconnected from the drainage network.

Most of the catchment is covered by shrubs. *Genista scorpius*, *Buxus sempervirens* and *Rosa canina* dominate the vegetation cover at the steep sunny aspect, whilst the highest areas have been partially colonised by *Pinus silvestris* and *Quercus cf. cerrioides*. Huge areas are covered by dense scrubs of *Echinospartum horridum*. Some areas, mainly at the valley bottom, are covered by herbaceous species (dominated by *Brachypodium ramosum*), but slowly colonised by *G. scorpius*. Due to sheep grazing, the vegetation succession is strongly retarded and absent on many trails (Ries et al., 2000; Ries et al., 2003).

Data collection

Soil characterisation in the field was performed according to AG Boden (1996) on 15 profiles, whilst the soils were classified according to the WRB (FAO et al., 1998). In addition, 78 soil samples were taken in a regular grid of 100 m width from the upper 20 cm of the topsoil. The 26 measuring points for soil moisture were sampled, too.

The retention curves were measured in laboratory with undisturbed soil samples. Soil texture was determined in laboratory by sedimentation analysis (DIN 19683). Additionally, nutrients and organic carbon were measured in laboratory.

Soil moisture was measured weekly between 1996 and 1998 at 26 sites located at contrasting morphological situations (concave and convex slopes, shady and sunny aspect) with a TDR (Tektronix Cable Tester). Some periods in winter were not sampled due to the low accessibility.

Vegetation cover data was gained by photo interpretation from aerial pictures taken in May 1996. The DEM was generated by photogrammetric measurement of the photographs generating altitude lines with 5 m distance and interpolating with the TOPOGRID algorithm of ArcInfo.

Map generation

Soil and soil characteristic maps were generated combining the derivates of the DGM as curvature and slope (ArcInfo procedures), maximum and minimum radiation (Zimmermann, 2000a), topographic position (Zimmermann, 2000b), terrain roughness (Felicísimo, 1994) by Principal Component

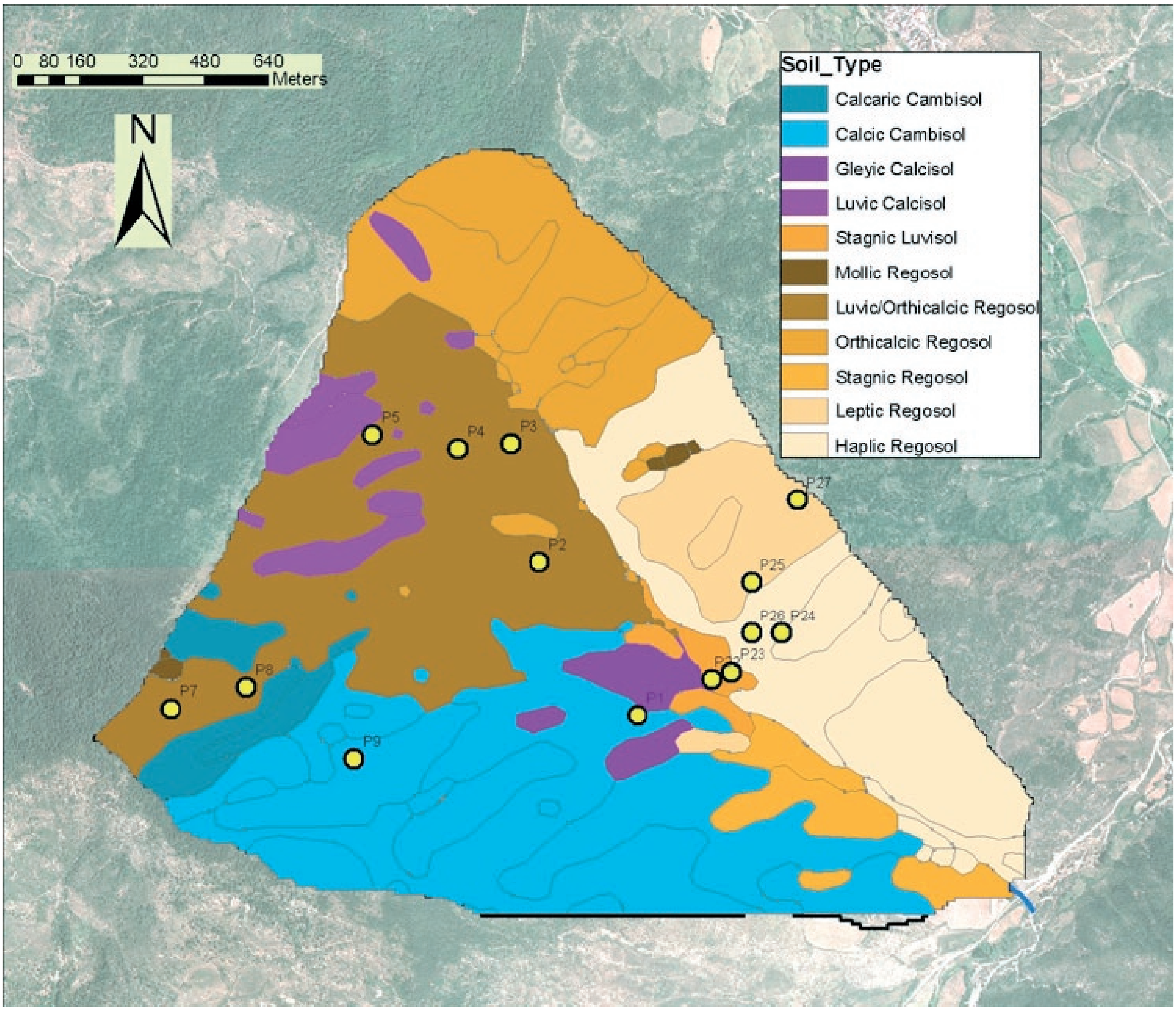

Fig. 2: Soil map of the Arnás catchment. Yellow dots show the location of the soil profiles.

Analysis. The first component, expressing more than 90 % of the variability, was used for interpolating soil data with the co-kriging procedure of ArcGIS 9.0. In this way, distribution maps of soil moisture and topsoil organic content were created. Soil map was generated by a classification procedure including topographical features (derivates from the DEM), interpolated and spatial vegetation data combined with expert knowledge in the field.

Results

In despite of the homogeneity of landscape after abandonment, characterised by the dominating *Genista* scrub cover, we can find contrasting soil types, representing different evolution status. They reach from slight developed soils like Regosols to soils with evidence of intense or long lasting soil formation processes like Calcisols, Cambisols and even Luvisols (Fig. 2).

The less developed Regosols, and here the ones showing evidence of intense degradation, are found on the steep, SW-exposed slope. The most representative ones are the Leptic (Fig. 3) and Haplic Regosols, which are shallow and contain high proportion of stones in all their profile, especially on surface and only low accumulation of organic matter within the topsoil. The Regosols are the dominant soil types, but show a high variability within the catchment, too. So, Mollic Regosols (Fig. 4) are found at the ridges or under dense *Echinospartum horridum*, showing evidence of decalcification together with the accumulation of the organic matter.

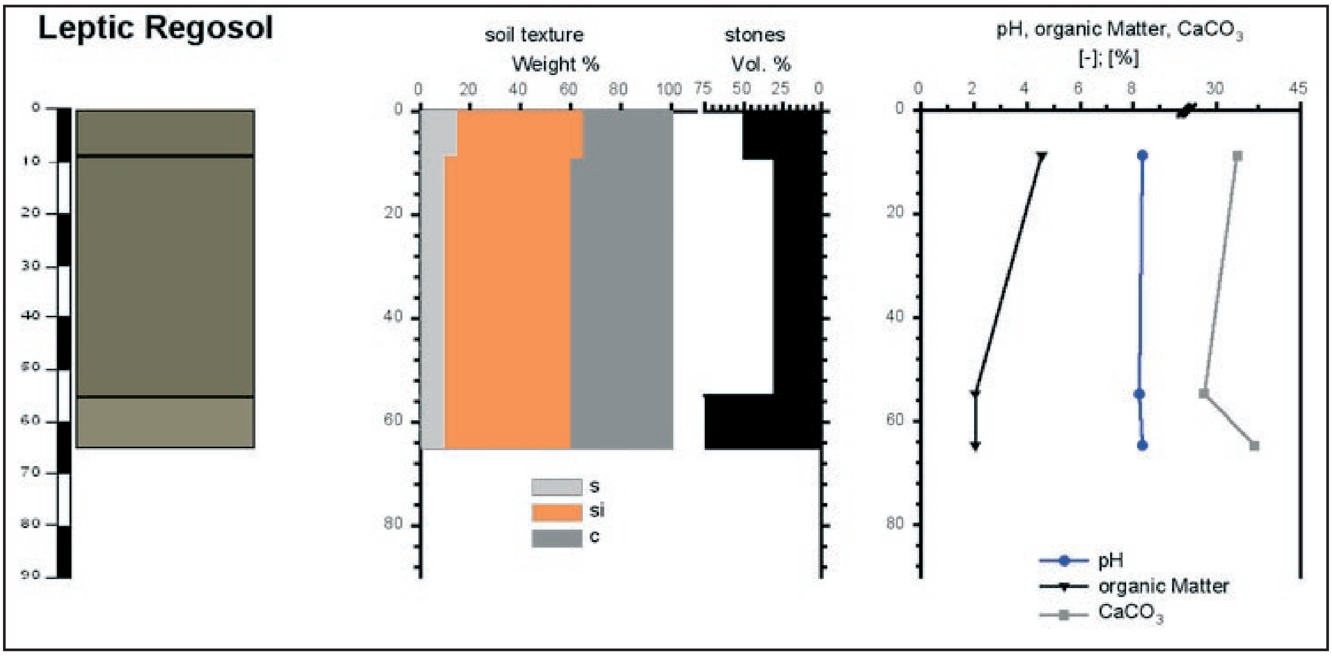

Fig. 3: Schematic view of a Leptic Regosol of the sunny aspect. In the middle, texture related data and stoniness, right some chemical properties (pH, organic matter, carbonates).

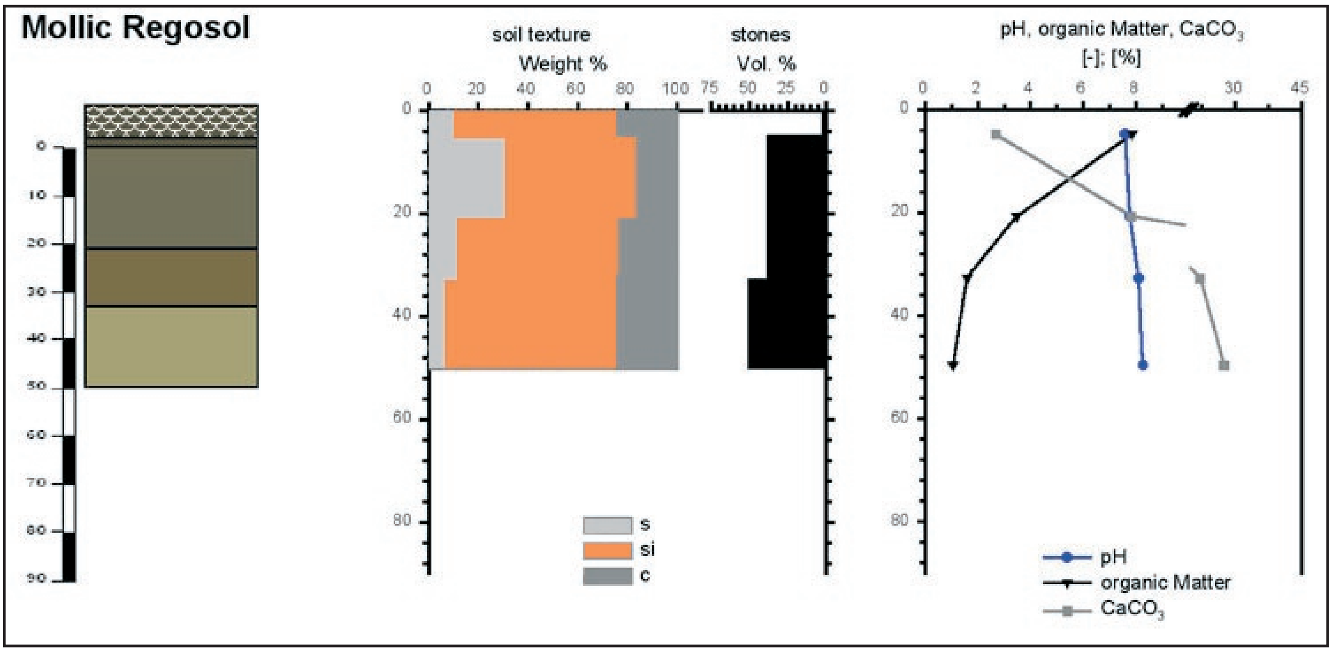

Fig. 4: Schematic view of a Mollic Regosol of the shady aspect. Note the accumulation of humus above the mineral soil. In the middle, texture related data and stoniness, right some chemical properties (pH, organic matter, carbonates).

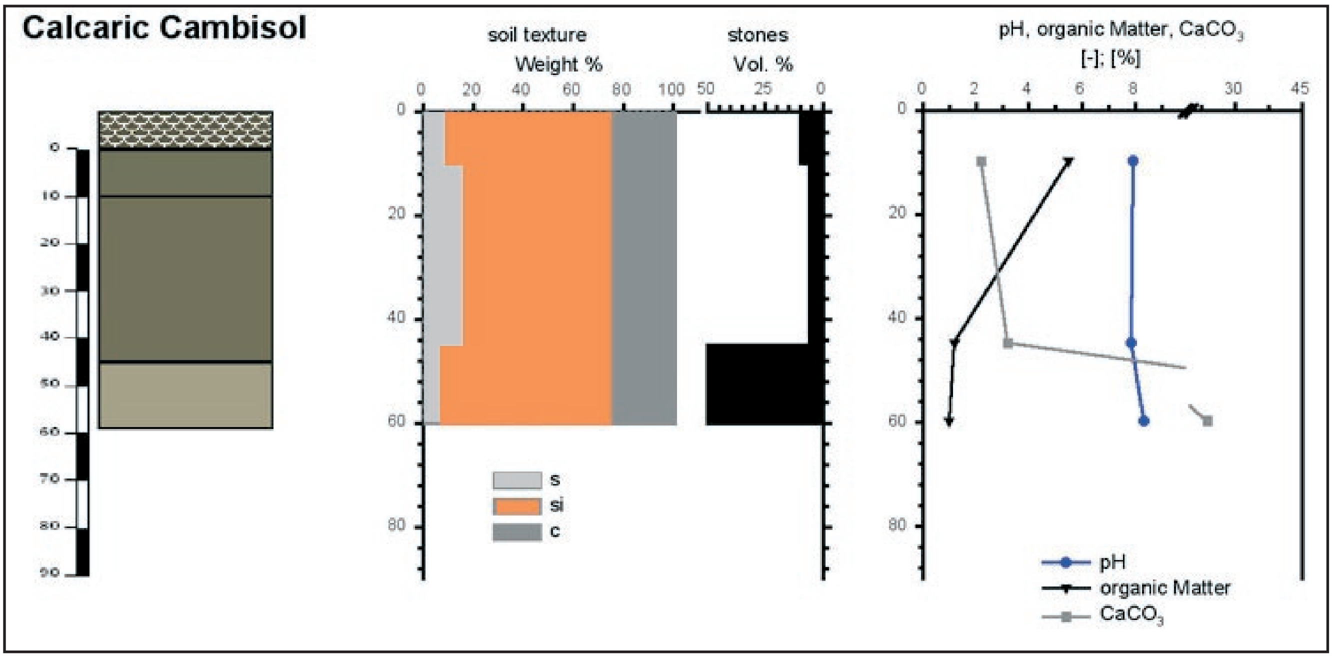

Fig. 5: Schematic view of a Calcaric Cambisol of the shady aspect. In the middle, texture related data and stoniness, right some chemical properties (pH, organic matter, carbonates). Note the intense decalcification of the topsoil horizons.

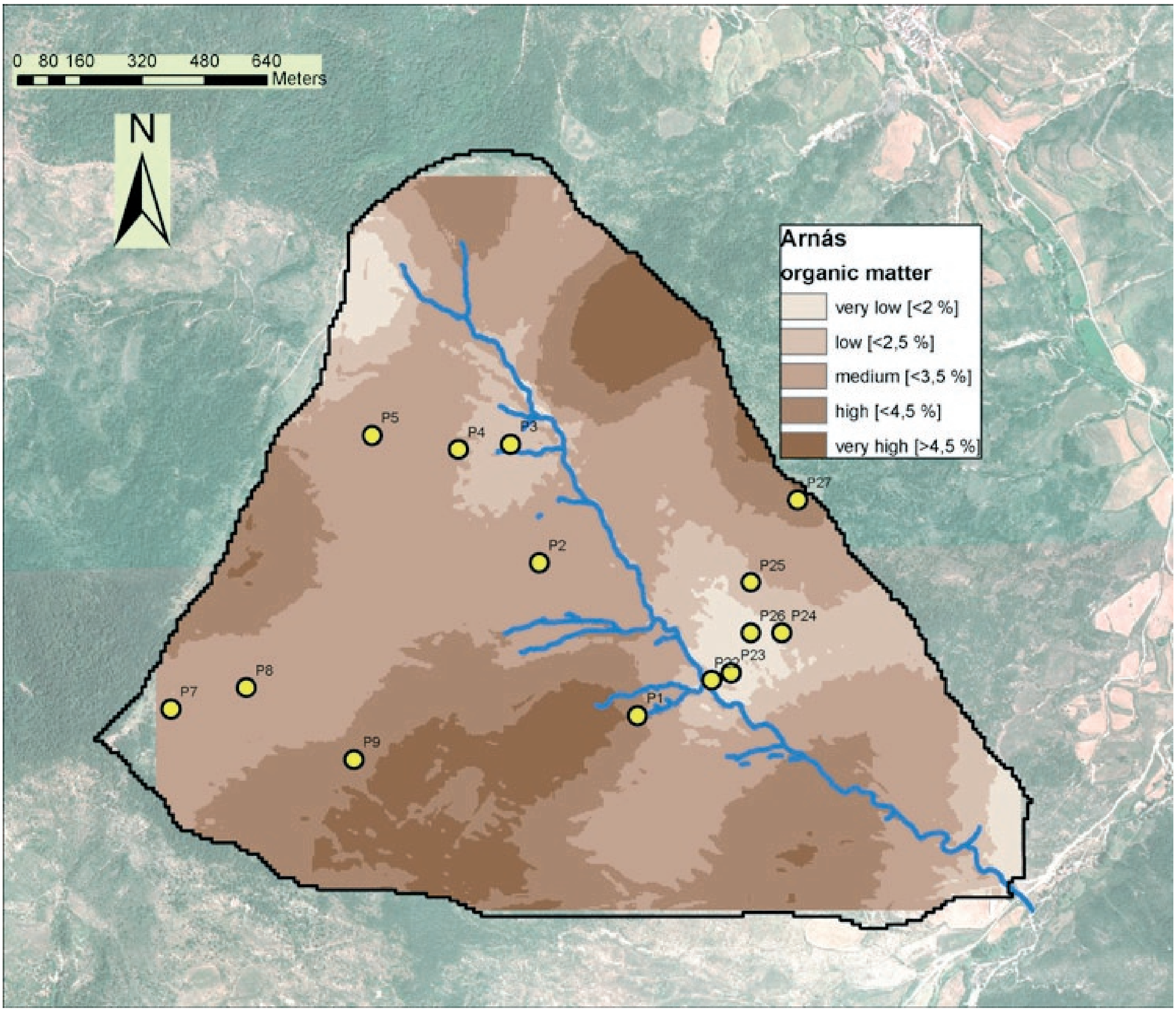

Fig. 6: Topsoil organic matter content and its spatial distribution in the Arnás catchment. Yellow dots show the location of the soil profiles.

Due to the parental material and the characteristic hydrological functioning of the catchment, with some seepage areas at the NE-exposed mid-slope, Gleyic Calcisols were developed on specific spots. They may accumulate organic carbon at the topsoil, but show at the same time extremely high concentration of carbonates due to the seepage of carbonate saturated water.

Luvic Calcisols are found under *Pinus* at the flat top-slopes of the shady aspect.

The best developed soils, the Cambisols (Fig. 5), are found at the old terraced fields of the NE-slope which are covered now by a young mixed oak forest. Here, the dominance of the calcareous parent material is evident, too. However, long lasting stable conditions have lead to a deep decalcification (down to 45 cm depth).

The valley bottom, which was stabilized by terraces, gave the possibility of accumulation of fine material and soil evolution. So, some Stagnic Luvisols, characterised by extremely low infiltration capacity (Seeger, 2001), are found. These soils show now evidence of erosion, showing extremely high accumulation of stones on top.

The content of soil organic matter is also extremely variable within the catchment (Fig. 6). It ranges from very low values (Saña Vilaseca et al., 1996) lower than 1 % to extremely high values with more than 8 % of organic matter accumulation in the topsoil. There is a clear spatial distribution: lowest values are found on the sunny aspect, excepting the ridges with Mollic Regosols. On the other hand, highest organic matter accumulations are found on the shady aspect under forest.

Soil water content after the rainy season shows a similar spatial distribution to the organic matter content. The sunny aspect reaches only values lower 80 % of saturation, but some spots tend to saturate, and these areas show a high susceptibility to land sliding in the field.

Discussion

The soil distribution in the Arnás catchment shows a clear zonation which can be related directly with the former land-use practices. The highest degraded soils, with lowest soil depths, lowest organic matter accumulation and lowest moisture storage are found at areas which were cultivated in *articas*, the traditional shifting agriculture practice. This management type has been identified as highly susceptible to erosion (Garcia Ruiz et al., 1996). In despite of their only low water retention capacity, the degree of saturation with water is only low after the rainy season, which can be attributed to (1) the exposition effect and (2) to higher runoff rates due to the steepness and the soil degradation.

But there must be stated, too, that the lowest organic matter content of the soil is found on the gentle slopes near the valley bottom. These are the areas with stagnic soils, with significant superficial stone accumulation, and both characteristics indicate actual erosion processes. These areas are the ones with the most intense grazing by flocks. Some investigations indicate, that the actual grazing intensity partially enhances geomorphodynamic activity on abandoned fields (Ries et al., 2000; Ries et al., 2003).

The former land-use practices are reflected in the distribution of the best conserved soils, too. The Cambisols are found at the areas stabilized by terraces, which are stable till now, what can be seen on the decalcification mentioned above. These areas are colonised by forest species very much more rapidly than others, reflecting with this the positive edaphic conditions. On the other hand, most degraded Regosols, with stone concentrations in the profile are found in the areas subject to the “artica” land management system, confirming with this experimental results (Garcia Ruiz et al., 1996). And these areas show with their low enrichment of organic carbon still a high geomorphodynamic activity, confirming that soil erosion is still active even under a medium dense scrub cover (Garcia Ruiz et al., 1994; Molinillo et al., 1997; Ries in this issue).

Conclusions

The study of the soils of the Arnás catchment, as representative for the areas subject of a dramatic extensification of land-use in Mediterranean mountains, show, that the former land-use systems were not able to conserve everywhere the resources. But further on, the highest degraded areas are still prone to go on with degradation, because the resources are limited and the unfavourable management practices were used on marginal areas.

On the opposite, some sites show still now the former sustainable use of the resources and the actual capability to regrade allowing vegetation to recover, like it can be seen at the sites with forest patches over Cambisols.

But it has to be emphasized, that the dominating soil type is the slightly developed Regosol, which is mostly covered by scrubs of varying density. This implies, that the areas characterised by abandoned fields have only a very low resilience on further disturbances, e.g. over grazing. For that, land management after extensification has to take into account this reduced potential.

On the other hand, it is obvious that the informations gained by the investigation of soils is very valuable to identify the evolution of the landscape during medium and short periods, especially taking into account human disturbance. And that it may give information about the potential of rehabilitation after ceasing of disturbance.

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