PROFILES OF ^{137}Cs and MAGNETIC SUSCEPTIBILITY AS INDICATORS OF SOIL PROCESSES AND LAND USES.

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Abstract

Preserving soil resources is a main environmental issue, especially in semiarid and subhumid areas that can be seriously affected under the perspectives of climate change and exploring the potential of using cost effective indicators is of interest to promote soil conservation strategies. In stable and well developed soils, the profiles of magnetic susceptibility gradually decrease from top layers to deeper layers as a result of the natural evolution of a soil but this pattern is not maintained in degraded soils. In mountain agroecosystems of Mediterranean environments erodible soils are threatened by erosion due to intensive land use and occurrence of erosive rainfalls. In Spain, agricultural land extends over large surfaces on mountain terrains and rainfed crops occupy many semiarid and subhumid areas. To maintain the sustainability of these productive agrosystems it is of interest to assess the status of the soil, in reference to its conservation or degradation. In this research an attempt to use profiles of magnetic susceptibility as indicators of soil processes and land uses is presented. The depth distribution of magnetic susceptibility is measured in soils that are characterized as eroded and deposition profiles by using fallout ^{137}Cs. Analyses of Fe, Al, and other heavy metals are combined to derive information for assessing the status of the soil.
Key words: Magnetic susceptibility; ^{137}Cs; heavy metals; soil indicators; conservation and degradation; Mediterranean agrosystems.

Resumen

La distribución de los minerales magnéticos en el perfil es un indicador del estado evolutivo del suelo. En agroecosistemas de montaña de ambientes Mediterráneos el suelo presenta un riesgo notable de erosión debido al uso secular intensivo, a la existencia de suelos de alta erodibilidad y por la ocurrencia de lluvias erosivas. En España, las tierras agrícolas ocupan superficies importantes de terreno montañoso y los cultivos de secano se localizan preferentemente en áreas semiáridas y subhúmedas. Para mantener la sostenibilidad de estos agrosistemas productivos es de interés evaluar el estado de conservación del suelo. En este trabajo se evalúa el uso de la susceptibilidad magnética como indicador de procesos de suelo y para diferenciar usos. La distribución en profundidad de los valores de susceptibilidad magnética se analiza en suelos que han sido caracterizados como perfiles de erosión o depósito mediante el radiotrazador ^{137}Cs. Los análisis complementarios de Fe, Al y de otros metales pesados junto con información general de propiedades de suelo tales como textura y contenido de materia orgánica se utilizan para extraer información sobre el estado del suelo. La preservación del recurso suelo es una cuestión ambiental clave, en especial en áreas semiáridas y subhúmedas que se pueden ver seriamente afectadas en condiciones de cambio climático. Por ello es de interés explorar el potencial de aplicar indicadores y técnicas eficientes para promover estrategias de conservación de suelos.
Palabras clave: Susceptibilidad magnética; ^{137}Cs; metales pesados; indicadores del suelo; conservación y degradación; agrosistemas Mediterráneos.

Introduction

The combination of intensive and long-term agricultural uses, abrupt topography, erosive rainfalls and erodible soils are all main factors in triggering soil losses. Arid and semiarid areas around the world are at risk of loosing their soil resources. Perspectives of climate change that for the Mediterranean region predicts increases of extreme rainfalls places mountain environments of subhumid areas at risk of loosing productive agricultural soils. On the other hand, cultivation has been identified as a main factor triggering erosion in semiarid and subhumid agroecosystems (Quine et al., 2004, Navas et al., 2005, Gaspar et al., 2011)

Preservation of soil resources requires assessing the status of the soil and the quantification of soil losses. Radiotracing techniques are increasingly being used in the last decades to provide data on soil erosion in a variety of environments. In rainfed agroecosystems of Mediterranean areas fallout ^{137}Cs has been successfully applied and information on the vertical distribution of the radionuclide delivered consistent information on the processes of soil erosion.

Iron components in the soil are good markers of soil development. In stable, undisturbed soils, increases in magnetic susceptibility (MS) parallel increases in iron from the bedrock towards the surface (e.g. Mullins, 1977; Thompson and Oldfield, 1986) but, in disturbed soils, erosion and the lost of soil particles prevents the concentration of iron components.

The use of soil magnetic signatures to assess soil degradation is based on differences in the specific behaviour of iron components, which have near full control over the magnetic order in the soil. The distribution of magnetic minerals within the soil profile provides a means of assessing the status of soil development or degradation. Research by Sadiki et al. (2006, 2009) in semiarid areas of the Rif (Morocco) found differences between stable and degraded soils based on the measurements of magnetic susceptibility.

In this work we measure magnetic susceptibility in selected soil profiles that are characterized for the main soil properties such as grain size and organic matter and identified by fallout ^{137}Cs as eroded or deposition profiles. In addition, Fe and Al together with other trace elements are analysed along the soil profile to derive information on the geochemistry of the soils that can be used in combination with values of MS. The objective of this research is to assess if magnetic susceptibility of soil profiles can be used in subhumid environments for assessing the status of a soil and to derive information on land uses and soil processes mainly concerning to soil degradation.

Materials and Methods

The soils selected for this study were sampled along a typical mountain toposequence located in the border of the central Ebro basin. The sampling sites were located at the upper part of the slope on Calcisols (P1 and P2) developed on limestones of the Muschelkalk facies under natural forest and at the lower part of the slope on Gypsisols (P3 and P4) developed on clay and marls of the Keuper facies that are under cultivation for cereals (Figure 1). Samples were collected using an 8 cm diameter automatic core driller to extract undisturbed cores. To characterize the depth distribution of MS, ^{137}Cs and heavy metals the soil cores were sectioned at 5 cm depth intervals, reaching a maximum value of 55 cm in depth. A total of 5 cores were collected. One of them to represent soil stability conditions was collected at a level site under natural vegetation cover. The rest of the profiles were selected to represent erosion and deposition sites as indicated by ^{137}Cs.

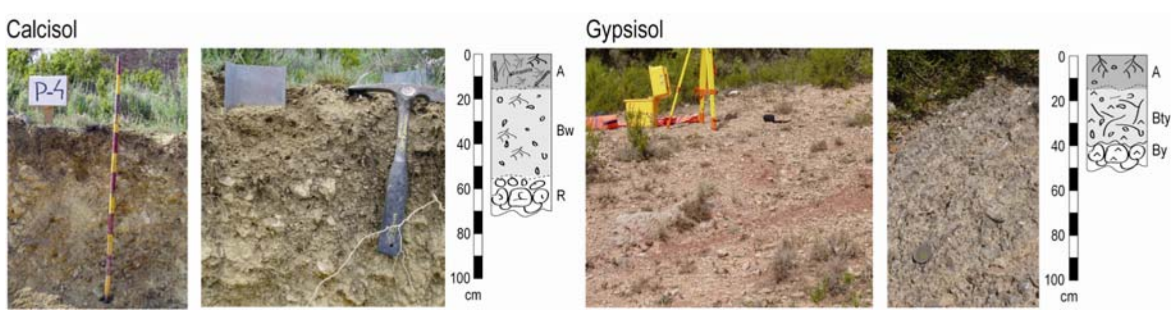

Figure 1. Characteristics of Calcisol and Gypsisol profiles.

Soil samples were air dried, disaggregated, and sieved (< 2 mm). For the analyses of MS, the 10-g profile subsamples were slightly compressed and placed into 10-ml containers. A Bartington susceptibilimeter with a MS2B probe was used for the measures of MS at low frequency (χ_{lf}, 0.47 kHz), and the values are of the mass-specific susceptibility (m^3kg^{-1}). The methods used in the analysis of ^{137}Cs are described in detail elsewhere (Navas et al., 2005). Gamma assays for ^{137}Cs were done using a Canberra high resolution, low background, hyperpure germanium coaxial gamma detector coupled to an amplifier and multichannel analyser. Subsamples of 50 g were loaded into plastic containers and counting times over 24 h provided an analytical precision of about ± 5 % at the 95% level of confidence. Activities were expressed as Bq kg^{-1} dry soil. Analysis of the clay, silt and sand fractions were performed using laser equipment. To eliminate the organic matter, samples were chemically disaggregated with 10 % H_20_2 heated at 80º C, then stirred and ultrasound was also used to facilitate particle dispersion. The analysis of the total elemental composition was carried out after total acid digestion with HF (48%) in a microwave oven. Samples were analysed for the following heavy metals: Fe, Al, Pb, Zn, Ni, Cu, Co and Cr. Analyses were performed by atomic emission spectrometry using an inductively coupled plasma ICP-OES (solid state detector). Concentrations, obtained after three measurements per element, are expressed in mg/kg. General soil properties analysed (CSIC, Consejo Superior de Investigaciones Científicas, 1976) were pH, electrical conductivity (EC), and contents of organic matter (OM), gypsum and carbonate content.
Basic statistics was done to characterize the MS, ^{137}Cs, soil properties and heavy metals in the studied profiles. Statistical analysis was performed by one-way analysis of variance (ANOVA), and the means were subjected to a least-significant difference test (F test) to indicate the main differences in the analysed variables.

Results

The soils are alkaline and differ in the content of organic matter, carbonate and stoniness which is significantly higher in Calcisols than in Gypsisols whereas CE and gypsum contents are higher in Gypsisols due to the presence of evaporitic materials in the facies Keuper (Table 1). The grain size distribution also reflects differences in the contents of clays that are higher in Gypsisols than in Calcisols while the contrary is observed for the sand contents (Table 1).

Table 1. Basic statistics of MS, ^{137}Cs and general soil properties in the studied soils

	MS 10^{-8} m^3kg^{-1}	^{137}Cs Bq kg^{-1}	pH	CE dSm^{-1}	OM %	$CO3^{=}$ %	gypsum %	sand	silt %	clay	> 2mm
					Calcisols						
n	11	11	11	11	11	11	11	11	11	11	11
mean	30.3	5.4	8.49	0.200	3.9	68.0	5.2	14.7	63.6	21.7	0.5
sd	4.5	7.5	0.09	0.047	1.5	4.5	1.3	15.5	18.3	19.0	1.0
min.	24.0	nd	8.38	0.147	2.0	63.4	3.9	0.0	22.1	11.3	0.2
max.	39.8	23.6	8.64	0.275	6.3	77.4	7.5	43.2	77.0	77.9	3.5
					Gypsisols						
n	22	22	22	22	22	22	22	22	22	22	22
mean	9.7	2.0	7.95	2.45	1.4	17.7	15.7	5.3	69.1	25.7	0.5
sd	4.4	1.9	0.05	0.15	0.7	2.8	14.2	18.1	17.5	14.3	1.0
min.	3.0	nd	7.88	2.29	0.2	14.4	5.6	0.0	14.4	0.6	0.0
max.	22.1	5.2	8.07	2.73	2.4	22.8	51.3	85.0	81.3	83.4	5.0

sd standard deviation

The means of MS are higher and significantly different in Calcisols than in Gypsisols. The activities of ^{137}Cs are higher and more variable in natural Calcisols than in the cultivated Gypsisols.

The depth distribution of ^{137}Cs in the selected soils exhibit very distinctive patterns (Figure 2). On the Calcisols under natural vegetation the depth of penetration of the radioisotope is between 20 and 25 cm and the ^{137}Cs activities decrease exponentially with depth. The reference inventory for the area is 1570 (± 8) Bq m^{-2} (Soto and Navas, 2008) and deviations from this value are used to indicate erosion or deposition at a particular site. The activity profiles and values of the ^{137}Cs inventory suggest that P1 has experienced erosion (eroded Calcisol, EC) whereas P2 experienced deposition (DC). On the Gypsisols the tillage mixed thoroughly the soil and as a result ^{137}Cs is homogeneously distributed within the profile resulting longer profiles (45 cm depth) with low ^{137}Cs activities. The ^{137}Cs inventories indicate that P3 (EG) is an eroded profile whereas P4 (DG) experienced deposition.

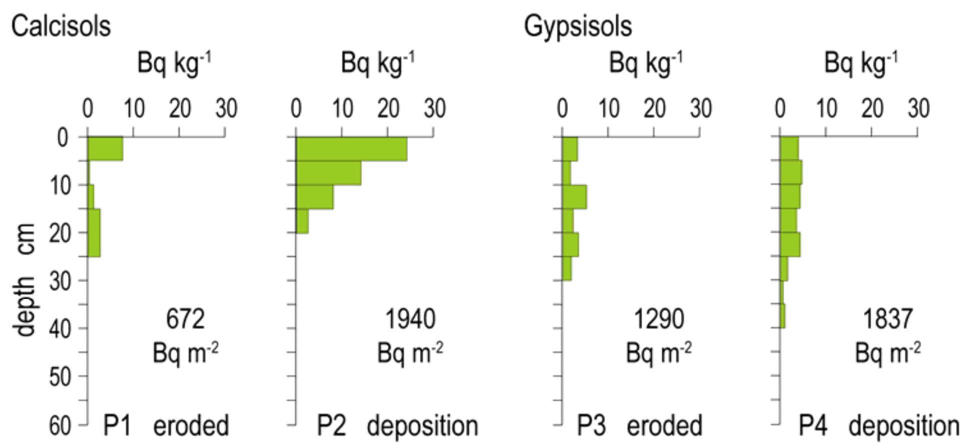

Figure 2. Depth distribution of ^{137}Cs activities and inventories in eroded and deposition profiles of Calcisols and Gypsisols.

The depth distribution of the MS values in the stable profile with an inventory within the range of stability for ^{137}Cs shows a decreasing pattern (Figure 3) in agreement with the depth distribution of the radionuclide found in stable soil profiles (Navas and Walling, 1992; Navas et al., 2005). It is known than in stable soils, magnetic susceptibility gradually increases between the deep soil layers to surface as a result of the natural development of soils that tend to concentrate iron components in surface layers. This pattern was also observed in stable soils of the Rif in Morocco (Sadiki et al., 2009).

In the Calcisols under forest cover, the depth profiles of MS show contrasting patterns between the eroded (P1, EC) and the deposition profile (P2, DC), the latter showing higher values of MS for all depth intervals. This coincides with documented patterns of either undetected MS or sharp MS decreases with depth in highly degraded soils. In the cultivated Gypsisols the MS profiles extend longer and they are mixed by tillage. The MS profiles do not show any distinctive pattern with depth. The values of MS are more variable in the eroded profile (P3, EG) and are lower in deeper layers of the profile by comparison with MS values in the deposition profile (P4, DG).

For the studied soil profiles the depth distribution of the MS values allows to distinguish the land use due to contrasting depth distributions in natural soils under forest and in cultivated soils. Under natural vegetation the distinction between eroded and deposition profiles is also possible by the pattern of the MS depth distribution. However, in tilled profiles such distinction is not possible due to the mixing of the soil although for the whole profile the values of MS are slightly lower in the eroded than in the deposition profile which is clearly evident in deeper layers of the eroded profile.

This fact is further confirmed by the depth distribution of Fe content which agrees with that of MS values along eroded and deposition profiles (Figure 3). In addition, the deposition profiles have higher contents of Al what can be expected because of its association with clay minerals. Clay minerals are generally more abundant at deposition sites due to accumulation of fine soil fractions whereas the contrary would occur at eroded sites where the loss of fine fractions bearing heavy metals will result in their depletion. This fact is further confirmed by the mean contents of heavy metals in the profiles that are presented in Table 2. The Calcisol profiles (P1, P2) have lower heavy metal contents than the Gypsisol profiles (P3, P4). In both soil types contents of Fe and Al are lower at eroding profiles (P1, P3) than at deposition profiles (P2, P4). This is further confirmed by similar patterns for the rest of heavy metals in Gypsisols and in Calcisols with exception of Ni and Co that are quite similar in both eroding and deposition profiles.

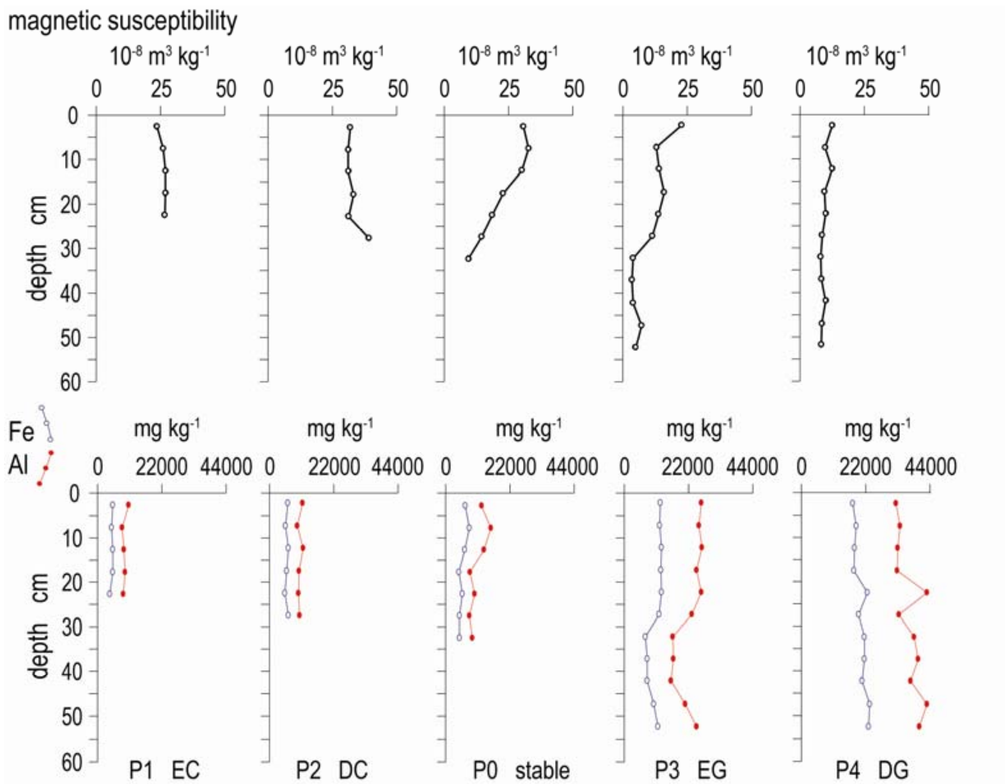

Figure 3. Depth distribution of MS, Fe and Al in stable (P0), eroded and deposition profiles of Calcisols (P1 EC, P2 DC) and Gypsisols (P3 EG, P4 EG).

Table 2. Basic statistics of heavy metals in the studied profiles

	n		Fe	Al	Pb	Zn	Ni	Cu	Co	Cr
						mg kg^{-1}				
P0 stable	7	mean	5768	10959	42.0	18.4	17.0	13.4	5.9	13.1
		sd	1302	2827	13.4	6.8	3.2	3.8	1.7	2.8
P1 EC	5	mean	4974	9275	38.4	45.7	15.6	10.2	4.7	10.0
		sd	388	823	3.6	69.6	0.4	0.9	0.5	0.9
P2 DC	6	mean	5740	10261	41.7	87.0	12.7	13.7	4.4	12.4
		sd	515	820	3.8	170.8	2.6	1.2	0.9	1.1
P3 EG	11	mean	10404	22036	75.1	42.4	15.9	18.3	5.7	26.1
		sd	2159	4225	15.5	91.1	3.7	3.3	2.0	6.4
P4 DG	11	mean	20091	36793	129.4	84.2	30.3	25.3	12.4	51.7
		sd	2160	4186	15.6	158.5	2.0	2.9	1.2	3.9

sd standard deviation

Conclusions

The distribution of magnetic minerals within the soil profile provides a means for assessing the status of a soil. The potential of using MS is enhanced in combination with data of radiotracers that confirm the existence of erosion or deposition at a particular site.
In stable soils, magnetic susceptibility gradually increases between the deep soil layers to surface but, in degraded soils, this pattern is absent and magnetic susceptibility is lower. Depth distributions of Fe and Al and contents of heavy metals in eroded and deposition sites of uncultivated and cultivated profiles served to confirm the patterns of the MS depth distribution. This methodology can be used to assess the status of the soil for a variety of soil types and land uses.

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