Soil fertility dynamics in a semiarid basin: impact of scale level in weighing the effect of the landscape variables

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ABSTRACT

Arid and semi-arid Mediterranean soils are particularly sensitive to degradation processes, and soil fertility could play important role in restoration/conservation practices. Our objective was to study the relationships between soil and landscape at different scales in order to understand the main drivers of soil fertility on a semiarid catchment. A stratified sampling plan was carried out to take soil and landscape representative variability. Multivariate statistic techniques were used to elucidate the relationship between both. The results showed that soil fertility are positively related with density of vegetation and topographical conditions favourable to soil moisture at small scale, while negatively with topographical factors that contributed erosion dynamic on erodebility lithologies at medium and large scale.

Key words: Landscape, soil fertility, resolution, semiarid, PCA and CCA.

INTRODUCTION

Arid and semi-arid Mediterranean soils are particularly sensitive to degradation processes what could even trigger erosion (Thornes et al. 1996) and/or desertification (Puigdefábregas & Mendizábal 1998). Soil restoration actions have been focused on improving and accelerating the implantation of vegetation canopies due to their positive effects on soil properties (Albaladejo et al. 1998). However, many reforestation works in Mediterranean basin had been severally criticized (Maestre & Cortina, 2004). Probably, one of the possible problems was to consider water as the exclusive factor controlling biological processes, when nowadays several works support the prediction that plants in these systems are not mainly limited by water but nutrients are co-limiting (James et al. 2005). Therefore, in order to implement soil conservation and restoration policies a good knowledge of the spatial variation of soil fertility could improve our knowledge.

The study of landscape-soil relationship is at the very beginning of soil science. There are several ways to the study of these relationships. The most common is to relate individual soil attributes to individual or multiple landscape attributes by multiple regression approach. On the other hand, multivariate techniques can be applied to extract main trends of the variation on the soil and then relate these new variables to landscape attributes. One step ahead is the use of canonical approaches where two matrices of data are simultaneously analyzed for extracting trends of variation that are maximally correlated between both sets.

Studies relating landscape and soil properties often show contradictory results. It may be attributed to scale which landscape variables are represented. On the one hand, the appropriate resolution of landscape variables will depend of the scale what environmental processes controlling soil properties (McKenzie & Ryan 1999). On the other hand, landscape variables generated by digital terrain analysis and remote sensing are scale dependent, whose calculation is strongly influenced by the input data resolution or the scale of observation (Deng et al. 2007)

Our objective was study the relationships between soil and landscape (topography, lithology, vegetation) on a semiarid catchment of SE Spain characterized by high landscape heterogeneity, in order to understand the main drivers of soil fertility.

METHODS

Study area.

The study was carried on the Cárcavo Basin. It is a catchment of 2713 ha in SE Spain. The climate is semiarid Mediterranean. The geology is dominates by steep peaks of Jurassic limestone and dolomites with calcareous colluvia piedmonts, Keuper gypsum marls and basin deposits of Cretaceous and Miocene marls. Ephemeral channels and gullies dissect the pediment surfaces, which are largely used for agriculture, or have been subject to reforestation with pines (*Pinus halepensis Mill.*). Most other slopes are covered with seminatural grasslands of the perennial gramineous *Stipa tenacissima L.* and *Rosmarinus offcilanlis.* The dominant soils on the limestone-dolomite area are Leptosols. On the colluvia areas Calcaric Xerosol is dominat. In the centre of the basin, on erodible marls there are weakly developed soils mainly Margalic Regosol, while Fluvic Calcisols are characteristic near to ephemeral channels. On Keuper saline marl and gypsum outcrops the Gypsic Regosol and Gypsisols are the main types.

Sampling design

We applied a stratified sampling plan along the lines of McKenzie and Ryan (1999). The purpose was reflecting the landscape attribute variation able to influence on soil properties at catchment-scale. Strata were simplified versions of topography, land use and lithology. For topography two primary attributes were used to stratification: slope (low (<5º), medium (>5º and <15º) and high (>15º)) and aspect (north-faced and south-faced sites). For land used, cultivated and abandoned fields were excluded and strata were shrubland/grassland, well conserved forest and reforestation plantation. For lithology, limestone-dolomite, limestone colluvia, marls, marl-limestones and gypsiferous Keuper marls were selected as dominant classes (information from RECONDES). The combination of strata produces 75 potential different levels. However, only 60 out these 75 levels there actually exist on the catchment. One of each environmental patches were randomly selected, and a plot of 6×6m were georeferenced. In order to study the relationships between soil and landscape variables, more complex landscape attributes were generated using routines implemented on ArcGis 9 (ESRI, Redlands, USA): Profile and plan curvature, flow accumulation, solar radiation, topographic wetness index, topographic relative moisture index and length slope factor. Fractional Vegetation Cover and Leaf Area Index were obtained as new vegetation attributes from a QuickBird image using VMESMA (García-Haro et al. 2005), moreover Normalized Difference vegetation Index was also calculated. In order to take into account possible influences of resolution scale in the results we resampled the original attributes resolution to 10, 20, 40 and 80 m. Soil samples were collected from two depths: 0–10 cm and 10–20 cm, and were analyzed to Soil organic C and total N, available P, soil exchangeable cations (K, Mg and Na), available Fe, Cu, Zn and Mn, total elements (B, Ca, Cu, Fe-t, K, Mg, Mn, Na, S and Zn), $CO_3^=$ content, soil pH, electrical conductivity, maximum soil water holding capacity, water content at field capacity and at permanent wilting point

Data analysis

Principal Components Analysis (PCA) was applied to identify the main trends of variation in soil and landscape attributes as well as to explore dominant environmental processes at different observational scales. Simple correlation analysis (SCA) between the factorial scores of PCs and canonical correlation analysis (CCA) between particular variables were also applied to discern the relationships between landscape and soil.

All analyses were conducted in SPSS 15.0 software and their significance were test to p-value of 0.05.

RESULTS AND DISCUSION

Principal component analysis (PCA)

For the landscape, the first three significant PCs had an environmental interpretation. Their accumulated explained variance moderately increased with diminishing resolution (increasing pixel size) from 47.8 to 54.4 % in the range 5-40 m to decrease at 80 m. The first PC at every scale was related with the presence of dense vegetation at convergent draining places on shady sides. Second PC characterized flow convergence areas over abrupt Keuper gypsiferous marl landscape where vegetation was not abundant, probably because the activity of channels. The third PC was dominated by the presence of limestone/dolomite and high slope gradient at every scale, clearly indicating the landscape of Jurassic limestone/dolomites characterized by steep angles with shrub presence.

For the soil, at 0-10 cm the first PC was dominated by the presence of soil organic carbon and N and macro and micronutrients on available form as well to high capacity of retaining water. The second PC had positive loads of total content of micronutrients. The third PC confronted high boron and sulfur against high CO_3 and phosphorus. At 10-20 cm PCs were similar, but on the first PC capacity of cationic exchange becomes relevant and the second PC had high values of electrical conductivity (EC).

Simple correlations between soil and landscape PCs

Pearson's correlations (Table 1) showed that soils with high organic carbon, nutrients and availability water (S-PC1) were significatively associated to landscape units with dense vegetation and optimal topographical conditions to plant growth (L-PC1) while negatively associated to areas of flow convergence where vegetation was not abundant, probably because the activity of channels on erodibility lithologies (L-PC2). Interestingly, simple correlation across scales of S-PC1 to L-PC1 and L-PC2 were parallel as they were opposite on sign.

Table1: Pearson correlation between Soil and Landscape PCs (*p<0.05; **p<0.01).

resolution	Landscape PC	Soil PC		
		1	2	3
5	1	**0,418** **	-0,036	-0,051
	2	-0,230	**-0,270** *	0,080
	3	-0,046	0,087	0,234
10	1	**0,405** **	-0,048	-0,053
	2	**-0,299** *	-0,077	0,121
	3	0,145	**0,346** *	0,160
20	1	**0,340** **	0,025	0,052
	2	**-0,399** **	-0,058	0,071
	3	0,052	**0,268** *	0,095
40	1	**0,263** *	0,032	0,183
	2	**0,489** **	0,074	-0,004
	3	-0,071	-0,135	-0,061
80	1	**0,457** **	0,045	0,192
	2	**-0,317** *	-0,119	0,137
	3	-0,018	-0,035	0,124

Canonical Correlation Analysis (CCA)

In spite of general high canonical correlation values (upper to 0.9 for the three first), only the two first canonical correlations were significant, except at 5-m resolution with only the first one significant. At small scales (5 and 10-m resolution), the landscape canonical variate was constructed by the high loading on vegetation (NDVI and FCV) and lithologies attributes (keuper and limestone Vs marl and marl-limestone). It was positively associated to canonical soil variate defined by organic carbon, available nutrients (N, K and Mn) and water (CC1 at 5-m and CC2 at 10-m) and only with total Mg in CC1 at 10-m. At medium scale (20-m resolution) CC1 showed a landscape dominated by intense flow dynamics (high flow accumulation, length slope factor and topographic wetness index) on keuper lithology, while CC2 is similar to CC1 at 5 and CC2 at 10. At 40-m resolution, CC1 correlated vegetation indicators (FCV, LAI and NDVI) and low radiation zones on keuper lithology with organic carbon, available nutrients (N, K, Fe and Mn) and water in soils, while CC2 associated low radiation zones with vegetation presence (NDVI) on limestone with organic carbon and available nutrients (N, P, K, Mn and Mg) in soil. Finally, at big scale (80-m resolution) CC1 associated concave surface limestone places and vegetation presence (NDVI) with organic carbon, available nutrients (N, P, Fe and Mn) and water in soil, while CC2 represented marl zones with water accumulation (high flow accumulation and topographic wetness index) in high $CaCO_3$ content soils.

CONCLUSIONS

Different landscape properties were related with available nutrients, organic carbon content and water holding capacity, which could symbolize soil fertility in semiarid lands.

Soil fertility was enhanced under dense vegetation cover on keuper or limestone lithologies with topographical condition favouring soil moisture, while was diminished in marl or marl-limestone areas of flow convergence and high water in which where vegetation is not abundant.

The resolution changes showed that at small scale (5-10m) the density of vegetation cover was the dominant landscape factor controling soil fertility, while at medium-large scale (20-40-80m) topography was more important. Lithology had a similar weigh in all scales.

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