SOIL MAGNETIC SUSCEPTIBILITY AND SURFACE TOPOGRAPHIC CHARACTERISTICS IN CULTIVATED SOILS

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Abstract

The spatial distribution of the concentration of magnetic soil minerals can be assessed through the characteristics of the surface topographic attributes. The topography of the land surface controls the pathways of runoff and the redistribution of soil that affect the spatial variability of magnetic minerals contained in the soil. In this contribution, the soil magnetic susceptibility has been studied with different surface topographic attributes in a small cultivated field in order to infer the relationships between the magnetic susceptibility measured in situ in the field and some physical characteristics of the land surface such as elevation, slope, concavity-convexity, plan curvature and aspect. These relationships can be used to describe the spatial pattern of the concentration of magnetic minerals in soils.

Resumen

La distribución espacial de la concentración de los minerales magnéticos en el suelo se puede evaluar a partir de las características de los atributos topográficos. La topografía de la superficie del terreno controla los patrones de la escorrentía y la redistribución del suelo, estos procesos afectan a la variabilidad espacial de los minerales magnéticos presentes en el suelo. En este estudio la susceptibilidad magnética se ha relacionado con diferentes atributos topográficos en un pequeño campo de cultivo con bordes delimitados de forma natural para inferir las relaciones entre la susceptibilidad magnética medida in situ y algunas características físicas de la superficie del terreno como la elevación, la pendiente, la concavidad-convexidad, la perpendicular a la curvatura y el aspecto. Estas relaciones pueden utilizarse para describir el modelo espacial de la concentración de los minerales magnéticos en los suelos.

Introduction

The most important magnetic minerals in soils are the iron oxides, such as magnetite and maghemite (Mullins, 1977). In soils unaffected by pollution, the main source of magnetic minerals is the parent material through the pedogenesis processes and other soil formation processes. The spatial variability of the concentration of magnetic minerals is due to the same processes and factors that affect soil redistribution. A common technique to detect the presence and concentration of magnetic minerals is the measurement of the magnetic susceptibility in soils. Soil magnetic susceptibility can be related to different terrain topographic attributes such as the slope, elevation and concavity -convexity of the surface terrain to explain the distribution of magnetic minerals within soils. Several studies have shown that the combination of one to five terrain attributes derived from a digital elevation model can explain 20% to 88% of the variation in selected soil properties (Thompson et al., 2006).

Materials and methods

The study site is a small cultivated field located in northeast Spain (Figure 1). The average altitude is approximately 632 m a.s.l. The climate is continental Mediterranean, with mean annual temperature of 13.4 ºC and mean annual rainfall of about 500 mm. The drainage area within the field and their divides were defined based on a detailed digital elevation model (DEM) together with field observations. Measures with a total topographic station (TTS) at the points of 5 × 5 m intersections improved the original DEM.

The magnetic susceptibility (κis) was measured in the field on a grid at the point intersections of 5×5 m totaling 155 points. It was measured by using a MS2 susceptibility meter and a MS2D probe handle (Bartington Instruments Ltd.). Three readings were taken at each point and the average of these measures was the value considered. These mean values were corrected for smooth surfaces.

The analysis of the spatial distribution from the primary topographic attributes which were derived directly from the DEM (Wilson and Gallant, 2000) was made using ESRI ArcGIS 9.3 software. The Ordinary Kriging method was used to interpolate the magnetic susceptibility data into a continuous map. The improvement of high-resolution DEM and the increasing use of the GIS software package are good tools for mapping and modelling small-scale landscapes (Murphy et al., 2011).

Figure 1. Location of the sampling points.

Results

From the DEM (Figure 2) a total of five topographic attributes of the field area, namely elevation (m), slope gradient (º), concavity-convexity (dimensionless), plan curvature (dimensionless) and aspect (º) were calculated (Table 1). The concavity-convexity is the maximum or minimum of curvature in a point and the plan curvature is the curvature of the surface perpendicular to the slope direction. In both terrain attributes a positive value indicates that surface is convex, a negative one indicates that surface is concave and a value of zero indicates that the surface is planar. The aspect identifies the direction that a topographic slope faces expressed in degrees from the north (Tesfa et al. 2009).

Table 1. Descriptive statistics of the soil magnetic susceptibility and the terrain topographic attributes.

	n	mean	s.d.	median	variance	min.	max.
κis [10^{-5} SI]	155	33.6	13.5	33.3	182.6	8.4	61.7
Elevation [m]	155	632.5	1.9	632.7	3.8	628.7	639.2
Slope [degrees]	155	6.4	4.2	5.6	17.3	1.5	25.6
Concavity-convexity	141	-0.3	1.6	-0.4	2.6	-4.1	3.8
Plan curvature	147	-0.08	0.9	-0.03	0.9	-3.2	3.6
Aspect [degrees]	155	133.1	42.9	132.8	1841.9	48.7	204.3

The elevation and the slope in the study area decreased from north to south and a zone with lower values of elevation and slope was identified in the center of the field along an alignment corresponding to a preferential water accumulation and circulation (Figures 2 and 3).

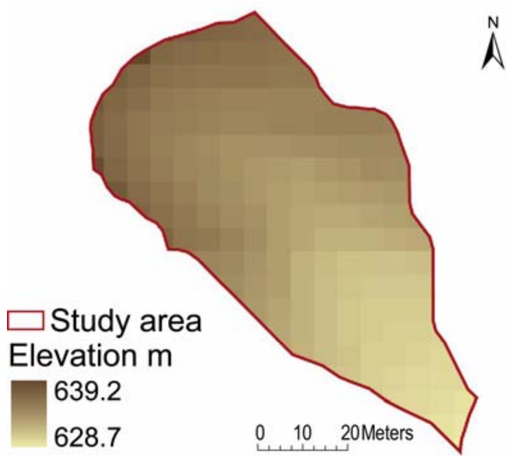

Figure 2. DEM of the study site.

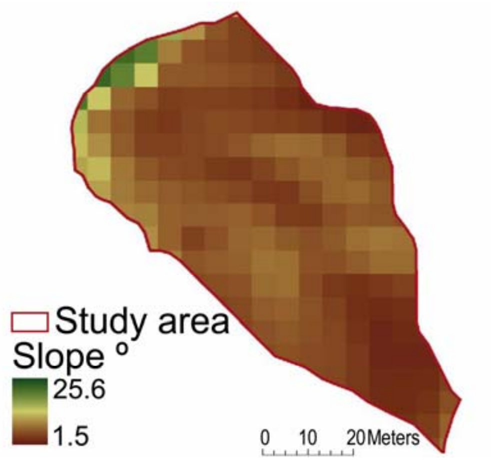

Figure 3. Slope map.

In the figure 4 the concavity-convexity values are represented. However the plan curvature provides more clean information of the terrain characteristics (Figure 5). It was found that the lower values of elevation and slope correspond to concave areas. In the field, there were four main different downslope directions (Figure 6) the northeast where the values of slope, elevation and concavity-convexity were relatively higher than at east and south orientations. The southeast orientation was characterized by lower values of slope, elevation and plan curvature.

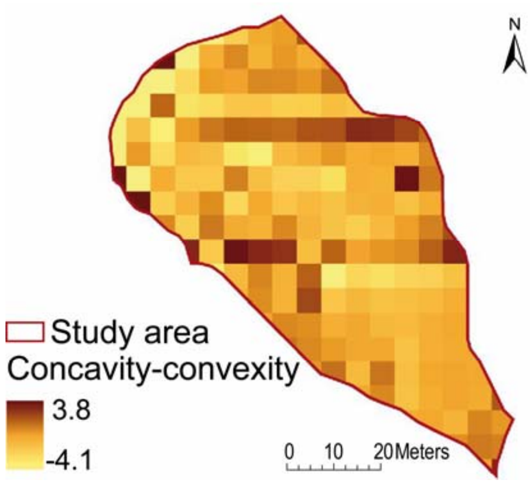

Figure 4. Concavity-convexity map.

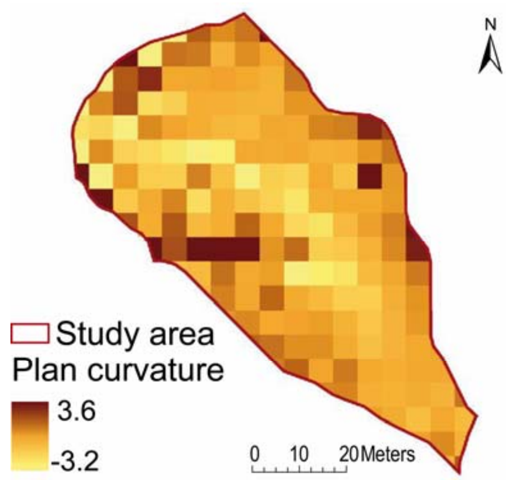

Figure 5. Plan curvature map.

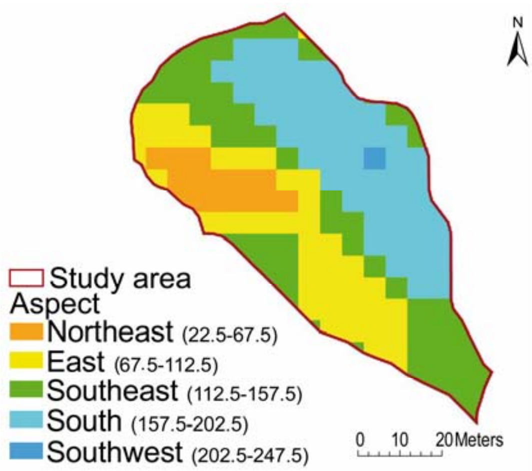

Figure 6. Aspect map.

The highest values of magnetic susceptibility were found at upslope positions in agreement with findings by Williams and Cooper (1990). On the contrary the lowest magnetic susceptibility values were at downslope positions (Figures 7 and 8). The relationships between the slope and elevation with the magnetic susceptibility values were direct and statistically significant (Figures 9 and 10).

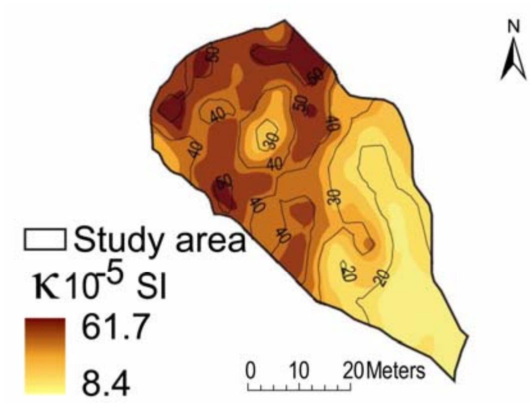

Figure 7. Kriging of κis values.

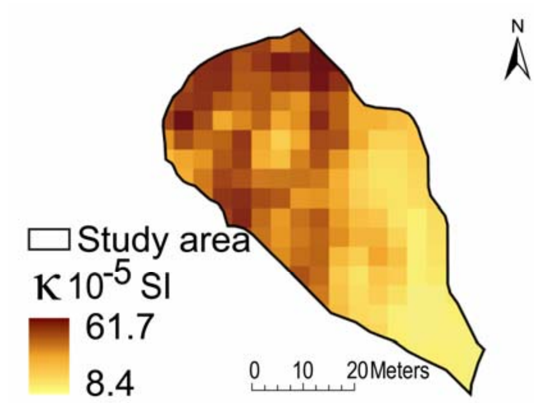

Figure 8. Spatial distribution of κis.

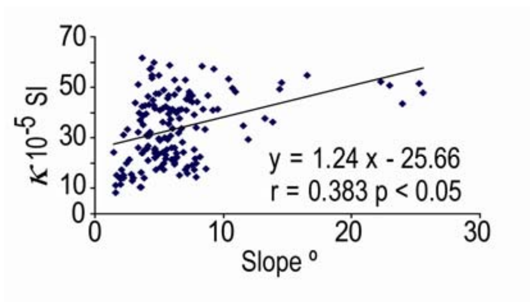

Figure 9. Linear regression between slope gradient and κis.

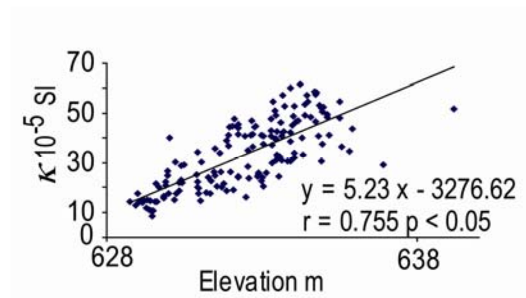

Figure 10. Linear regression between elevation and κis.

The concavity and convexity values allow interpreting the areas of high and low water flow accumulation, respectively (Bolstad et al. 1998). The curvature map showed that at the concave areas the magnetic susceptibility values were lower than at the convex ones. The plan curvature is related to the divergence (positive values) or convergence (negative values) of water flow on the surface terrain. The values of magnetic susceptibility were higher in divergence areas and showed the same pattern than for the concavity-convexity map interpretation. The aspect map showed the orientation and the direction of the downslope faces that controls the drainage pattern of runoff and the insolation. In the study area the southeast orientation correspond to concave areas that have lower magnetic susceptibility values.

Conclusions

This study examined the control that topography has over soil properties and in particular on the concentration of soil magnetic minerals through the measurements of the magnetic susceptibility. It was found that magnetic susceptibility values are overall affected by the elevation and slope position. The measures of magnetic susceptibility in the field are higher at upslope than downslope positions. Also complementary terrain attributes to the slope characteristics such as concavity-convexity, plan curvature and aspect were related with the surface water movement and soil redistribution within the study area which showed that in concave areas where flow can accumulate the magnetic susceptibility values were lower. The spatial analysis of the terrain attributes derived from a DEM and the mapping of the magnetic susceptibility measured in the field can be useful tools to infer the spatial distribution of the soil magnetic minerals and might represent an approximation to the soil redistribution processes.

Acknowledgements

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