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Morphological and geochemical properties of soil accumulated in hedge-induced terraces in the Massif Central, France

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Abstract

Hedges are part of the landscape in many regions of the world. Among many important roles, they limit soil translocation. Hedges perpendicular to the slope at the lower end of sloping fields result in the formation of soil terraces. Quantification of fluxes of matter at the landscape scale has shown that terraces cannot be neglected. In this study, we try to quantify and explain the origin of the morphological and geochemical properties of terraces. The morphology of the terraces and corresponding stocks of soil material and chemical elements are assessed through a microtopographic study. The 11-ha study area is located on a rolling landscape in the Massif Central (France). The study is focused on three particular terraces. Two DEMs (2.5-m resolution) were established on the study area. The first DEM (DEM_1) represents the actual elevation, using 4600 elevation spots. Elevation cross-sections were computed to determine the extent of the terraces, and a second DEM (DEM_2) was then calculated, excluding all the elevation spots located in terraced areas. The thickness of soil material stored in each terrace is given by $DEM_{st} = DEM_1 - DEM_2$. It varies between 0 and 0.63 m, representing a soil accumulation of 3–7 $m^3\ m^{-1}$ hedge length. One-hundred and seventy-three samples were taken in the topsoil, and the content in some major and trace elements (Ca, Mg, K, Fe, Mn, Cr and Co) measured and mapped using ordinary kriging. The stock of these elements accumulated in the terraces was computed and compared to the stock eroded considering uniform erosion from the upper part of the fields. Results show a difference in stocks exceeding more than 20% for several elements, showing that uniform erosion is not a satisfactory explanation for the accumulations observed in the terraces. A higher contribution of the area located immediately upslope form the terraces results in a better agreement in the stocks comparison for most of the chemical elements studied. Evidence from coarse fragments study, particle size distribution, soil depth in the upslope part of the fields and microtopography show that the formation of the terraces is probably mainly due to redistributions through tillage. The geochemical properties of the terraces are probably exclusively the result of this mechanical redistribution, except for Mn and Co. Indeed, it is likely that since the plantation of the hedges, seasonal waterlogging conditions have significantly affected the mobility of these two elements through geochemical processes that resulted in their leaching downwards as well as perhaps out of the field.

Keywords: Hedges; Terrace; Digital elevation model; Stock calculations; Chemical elements; Spatial distribution

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DEM	digital elevation model
DEM_1	DEM corresponding to the present topography
DEM_2	DEM excluding the soil material currently stored in the terraces
DEM_{st}	storage thickness due to the presence of hedges
E_t	thickness of soil material potentially eroded from a given contributing area and thickness of soil material of a given terrace that has never been eroded considering uniform erosion
ICP-AES	inductive coupled plasma-atomic emission spectrometry
S_{acc}	stock of a given chemical element accumulated in a given terrace considering uniform erosion
S_{er}	stock of a given chemical element potentially eroded from a given contributing area
S_{st}	stock of a given chemical element stored in a given terrace
TIN	triangulated irregular network
V_{sp}	volume of soil material stored per metre of hedge length in a given terrace
V_{st}	volume of soil material stored in each terrace taken separately

1. Introduction

Hedges are a major feature of the landscape in many rural areas of the world. They are of major utility to the farmers, as they act among other roles as windbreak, and/or limit erosion processes that could otherwise result in losses of soil and water.

Of particular interest are the hedges that are perpendicular to the slope, and located at the lower boundary of sloping fields. These types of hedges provide efficient barriers to the redistribution of solid soil material, as it is retained inside the limits of the field (Govers et al., 1999). This results in the accumulation of soil material immediately to the upslope of the hedges creating a gentler slope than in the field (Dabney et al., 1999), and thus forming terraces that can be up to several metres high (Papendick and Miller, 1977; Carnet et al., 1979; Revel and Rouaud, 1985). The soil material accumulated in these terraces is rarely taken into account for the calculation of fluxes of matter and related chemical elements in the large watersheds to evaluate the rate of change of the landscape (Trimble, 1977). However, these can represent a far from negligible component of the total soil stored as alluvium or colluvium in the landscape (Macaire et al., 2002). The morphological and chemical properties of the terraces are obviously linked for an important part to the mechanical redistribution of soil material downslope. The mechanisms of formation of these terraces have been studied using various methods, as for example, using caesium-137 to determine the respective influence of water and tillage erosion (Quine et al., 1999).

In this study, we aim at quantifying and explaining the origin of the morphological and geochemical properties of the soil accumulated in terraces in a rolling landscape of Massif Central, France. The emphasis has been put on the elucidation of the respective influence of the mechanical (solid matter) and geochemical (dissolved matter) redistributions at the field cultivation timescale. To achieve this, we have used a method combining both the use of accurate topographic data and chemical analyses measured for several fields. The volumes of soil material stored in terraces, as well as the related stocks of chemical elements were compared to the potential sources of material upslope.

2. Study area

The study area is located in the 2500 km^2 Aigurande plateau in the northern part of the Massif Central in France (Fig. 1). The Aigurande plateau was formed in Palaeozoic metamorphic and intrusive granitic rocks (Quenardel and Rolin, 1984). Agriculture is extensive, and mainly consists of cattle production. The land is thus mainly used for pastures and fodder crops. As in many transitional areas between the plains and mountains in France, fields remain narrow and limited by a very dense network of hedges in spite of the regrouping of land that occurred everywhere else in the country prior to the end 1980s.