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Modeling the erosion-induced fractionation of soil organic carbon aggregates on cultivated hill slopes through positive matrix factorization

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ABSTRACT

The lack of information concerning the compositions and erosion-induced redistributions of soil aggregates will limit our understanding regarding the stability and the fate of eroded soil organic carbon (SOC). In this work, we develop a tool for modeling the erosion-induced fractionation of soil aggregates and characterizing their compositions and redistribution pathways in the landscapes. Erosion-induced redistributions of soil organic carbon (SOC) on cultivated hill slopes with contour hedgerows planted to reduce soil and nutrient losses were investigated by the ^{137}Cs tracing technique combined with soil composition characterization. The soil composition in 56 samples taken across cultivated plots was treated using the positive matrix factorization (PMF) method of receptor modeling. Five factors driving the interrelationships between the soil parameters and ^{137}Cs in the plots were interpreted as representing the five types of soil aggregates, which were fractionated in situ according to their compositions, specific densities, and redistribution pathways under erosion forces combined with tillage and conservation measures. According to the PMF model, approximately three quarters of the ^{137}Cs activity was attributed to the SOC aggregated with sand particles, which accounted for 33% of the SOC concentration and was identified as the light, labile SOC fraction. There was another labile SOC-sand aggregates, which did not contain ^{137}Cs and accounted for 13% of the SOC concentration. The heavy, stable fraction that accounted for 44% of SOC concentration was in the SOC-clay aggregates, which contain the largest amounts of N, P, K, K_{dis}, and the highest CEC. The labile SOC-sand aggregates were concentrated in the depositional areas above the hedgerows whereas the stable SOC-clay aggregates were found in the eroding areas between the hedgerows. Labile SOC was depleted in the cultivated plot without conservation measures, but it was retained appreciably in the four cultivated plots with hedgerows.

1. Introduction

Soil erosion degrades agricultural lands and also contributes to the land use-associated flux of CO_2 to the atmosphere (Lal, 2004). In soil erosion, some of the soil organic carbon (SOC) removed from eroding areas is transferred to lower situated lands or to aquatic ecosystems, some is redistributed across the landscape with subsequent sequestration at depositional sites or decomposition into CO_2 through mineralization. Based on the balance between the SOC loss or gain in these processes, the global impact of agricultural land erosion has been estimated by many researchers over the last decade, but the discrepancies between the estimates are very large, spanning from a net source (Lal, 2004) to a potential net sink (Stallard, 1998; Van Oost et al., 2007; Quine and van Oost, 2007; Harden et al., 2008) of atmospheric greenhouse gases. In light of this situation, field-scale experimental studies to characterize the erosion induced redistribution patterns of different SOC pools are vital for improving our understanding of the extent to which agricultural soil erosion can offset the fossil fuel emissions of greenhouse gases.

^{137}Cs nuclear test fallout has been widely used as an environmental tracer for soil and SOC redistributions on the landscape (Ritchie and McHenry, 1990; Walling and Quine, 1991). In many studies on soil erosion in upland areas, ^{137}Cs and SOC concentrations were found to be significantly correlated (Mabit et al., 2008; Ritchie and McCarthy, 2003; Li et al., 2006; Zhang et al., 2006; Xiaojun et al., 2010), suggesting their similar physical redistribution pathways in erosion transport (Ritchie and

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McCarthy, 2003). This view, however, has been challenged by weak or insignificant correlations between ^{137}Cs and SOC found in other studies (Theocharopoulos et al., 2003; Aslani et al., 2003; Hancock et al., 2010; Martinez et al., 2010; Fang et al., 2012).

Weak correlations between ^{137}Cs and SOC indicate their different redistribution pathways that may be reflected in the correlations of ^{137}Cs and SOC with other soil components (Hien et al., 2013; Gaspar and Navas, 2013). Thus, information related to the interrelationships between ^{137}Cs, SOC and soil components are needed to shed light on the fate and dynamics of SOC, especially with regard to sequestration and mineralization processes in erosion transport.

Significant correlations between various soil components, both positive and negative, were determined in our previous work (Hien et al., 2013), the primary objectives of which were to estimate erosion rates and to investigate the effectiveness of conservation measures for the cultivated hill slopes by using the ^{137}Cs tracing technique combined with characterization of the soil composition. It was suggested that such intercorrelations reflect the redistributions of the various soil aggregates that are fractionated in situ according to their compositions, specific densities, and sizes by erosion forces combined with tillage and conservation measures.

To further elaborate on this idea, this report presents a method for modeling the erosion-induced fractionation of soil aggregates. Positive matrix factorization (PMF) of factor analysis is used to derive factors driving the intercorrelations between soil components in the landscape. These factors will be interpreted as representing the various types of soil aggregates involved in erosion transport. The PMF model consists of the factor contributions and the factor compositions. The former represents the redistribution pathways of soil aggregates on the landscape. The latter characterizes the compositions of the fractionated soil aggregates, particularly those incorporating ^{137}Cs and SOC. Based on the PMF model, soil aggregates containing stable and labile SOC could be distinguished and the soil capability in C-sequestration could be evaluated.

2. Site description and experimental method

The experiments were carried out at the erosion control demonstration site of the National Institute for Soils and Fertilizers (NISF), some 50 km southwest of Hanoi in northern Vietnam (105.548E, 20.908N). The soil in this area is classified as a haplic acrisol, which is a strongly weathered acidic soil containing

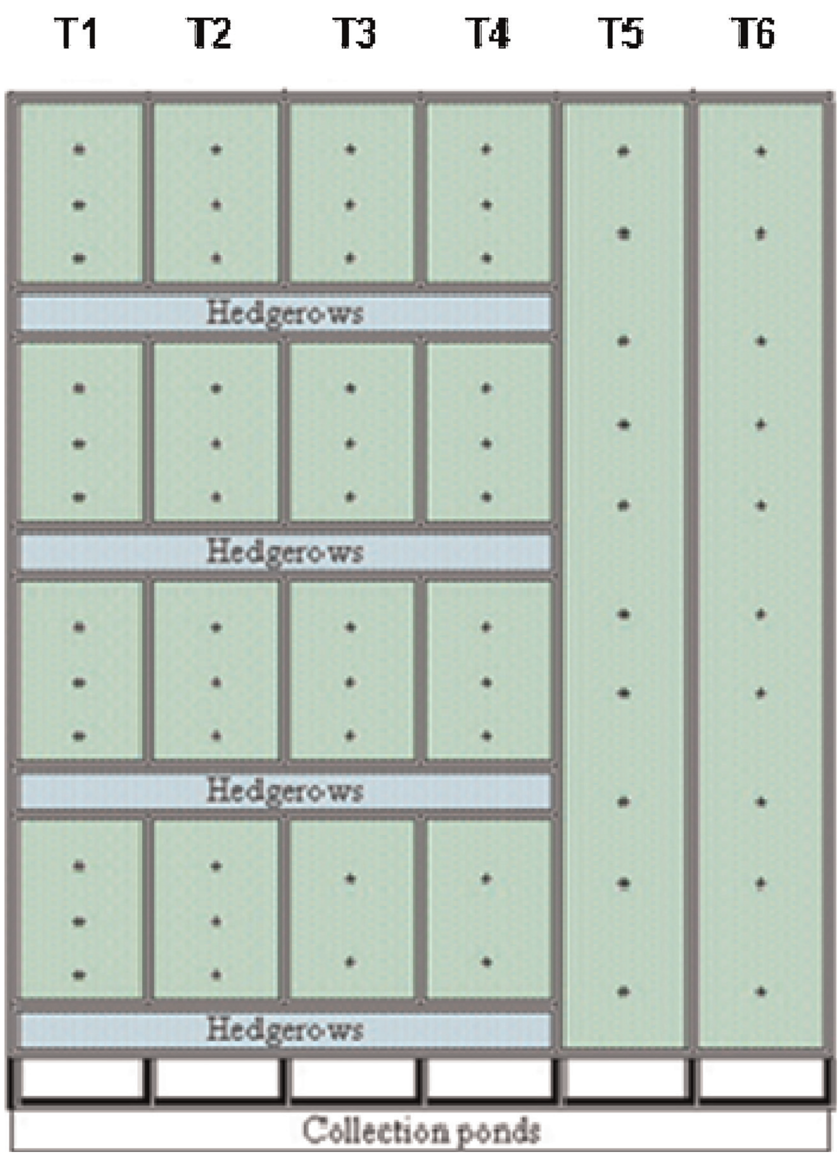

Fig. 1. Layout of the runoff plots. The sampling locations are marked with stars.