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Erosion of bulk soil and soil organic carbon after land use change in northwest Vietnam

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ABSTRACT

Soil erosion by water and tillage are major drivers for soil degradation in the mountainous regions of NW Vietnam. Data on cumulative and recent erosion of bulk soil and soil organic carbon (SOC) are needed for carbon budgeting and to evaluate e.g. the impact of erosion on climate change, environmental services and subsequent socioeconomic consequences. Thus, the aims of the present study were (1) to quantify cumulative erosion and recent erosion rates of bulk soil (2) to quantify cumulative eroded SOC and (3) to estimate the proportions of water and tillage induced soil erosion after land use change from primary forest to continuous maize cultivation for up to 21 years. Soil erosion rates were determined by ^{137}Cs and ranged from 12 to 89 t ha^{-1} a^{-1}. A large part of the variation of cumulative bulk soil ($R^2 = 0.79$) and SOC loss ($R^2 = 0.67$) between the sites was simply but effectively explained by the ratio of site specific cumulative RUSLE LS factors to clay contents. The newly developed CIDE approach, which attributes SOC changes on steep slopes to either carbon input, decomposition or erosion, delivered 20% higher (up to 0.7 kg m^{-2}) and more reliable estimates on cumulative SOC erosion than a traditional approach, because CIDE considered the effects of soil profile truncation, decomposition and humification, which all affected SOC simultaneously to soil erosion. Tillage induced soil flux accounted for 38 ± 3 kg m^{-1} per tillage pass, which was lower than found in similar studies. Soil erosion by water was higher than tillage induced erosion in middle and foot slope positions, accounting for 86 to 89% of total soil erosion. To prevent further soil degradation, erosion protection measures should be implemented.

1. Introduction

The effect of soil management practices on soil fertility and soil carbon emissions has become increasingly present on the agenda of developing countries (Hartemink, 2008; UNDP, 2011). Data on cumulative and recent erosion of bulk soil and soil organic carbon (SOC) are needed for carbon budgeting and to evaluate e.g. the impact of erosion on climate change (Lal & Pimentel, 2008), environmental services (Lal, 2001) and subsequent socioeconomic consequences (Saint-Macary et al., 2010).

In NW Vietnam, deforestation of primary forest and subsequent cultivation of steep slopes, heavy rainfall and temporary low soil cover make soils highly vulnerable against soil erosion (Dung et al., 2008). The use of ^{137}Cs to quantify cumulative (since deforestation) net bulk soil erosion or deposition is a widely accepted methodology (Ritchie & McHenry, 1990; Sutherland, 1996; Zapata, 2002) but few studies have addressed bulk soil loss after land use change from forest to continuous maize cultivation in Southeast Asia. For example, Tuan et al. (2014) and Pansak et al. (2008) measured erosion rates under maize cultivation in Southeast Asia, but they conducted their studies in areas with a long land use history.

In contrast to cumulative bulk soil erosion, determination of cumulative SOC erosion remains a methodological challenge because, unlike bulk soil loss, SOC stocks of a cultivated site are not only affected by erosion. Decomposition and SOC input are major SOC pathways which act simultaneously to soil erosion. An easy but subjective method to determine cumulative SOC erosion is to compare the thickness of topsoil horizons between an eroded and an uneroded site (Aguilar et al., 1988). However, diffuse horizon boundaries or mixing of horizons by tillage makes this method error-prone.

In the present paper two approaches to determine cumulative erosion of SOC are compared. Both are based on a fixed sampling depth (e.g. 0–10 cm). In the first approach cumulative SOC erosion is calculated as the sum of annual eroded SOC, which is a product of annual soil loss (e.g. determined by ^{137}Cs) and the SOC content which is found after a specific time since land use change (e.g. determined by a function of SOC change over time; (Gottschalk et al., 2010)). Chronosequences are a widely used method to determine such SOC change functions over time (Cadisch et al., 1996; Jolivet et al., 1997; Lemenih et al., 2005). The second approach is the recently developed CIDE (carbon, input, decomposition, and erosion) approach (Häring et al., 2013b). CIDE is an improved stable carbon isotope based method, which

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calculates SOC loss by decomposition, erosion and SOC inputs based on the comparison of uneroded reference sites with eroded cultivated sites. To highlight the errors made when calculating cumulative SOC erosion, we compared the traditional approach with the CIDE approach.

Under the present management system soils are not only vulnerable to erosion by water but also by tillage. Tillage induced erosion is increasingly recognized as a serious soil degradation process (Van Oost et al., 2006). In addition, tillage plays a double role: It usually increases not only soil loss but also accelerates decomposition (Govers et al., 1994). Although non-motorized plowing (e.g. with buffalos) is widely spread throughout the tropics, soil relocation induced by this tillage system has not yet received enough attention (e.g. Turkelboom et al. (1997), Zhang et al. (2004)).

Thus, the aims of the present study were (1) to quantify cumulative erosion and recent erosion rates of bulk soil (2) to quantify cumulative eroded SOC and (3) to estimate the proportions of water and tillage induced soil erosion after land use change from forest to maize.

2. Material and methods

2.1. Study area and site characteristics

The research area was located in the Yen Chau District in NW Vietnam at the UTM zone 48Q 427145 2325797 (Fig. 1). The erosion of bulk soil and SOC was quantified for sites on three soil types which differed in duration of maize cultivation (up to 21 years since land use change) and relief position (Table 1). Soil types were mapped and classified according to the WRB classification as Cutanic Alisol (Chromic) on Triassic limestone (63.4 ± 2.5% clay at 0–10 cm depth), Cutanic Luvisol on Triassic clayey shale (55.4 ± 1.2% clay) and Haplic Vertisol (Chromic) on Cretaceous marl (45.2 ± 3.4% clay, Table 2, WRB, 2007). All sites had a straight curvature along the contour line and along the slope gradient regardless of their position at the upper, middle or foot slope. Inclination ranged from 40 to 66% (Table 1). The altitudes of the sites on the adjacent Luvisol and Alisol were between 920 and 1040 m asl. The Vertisol

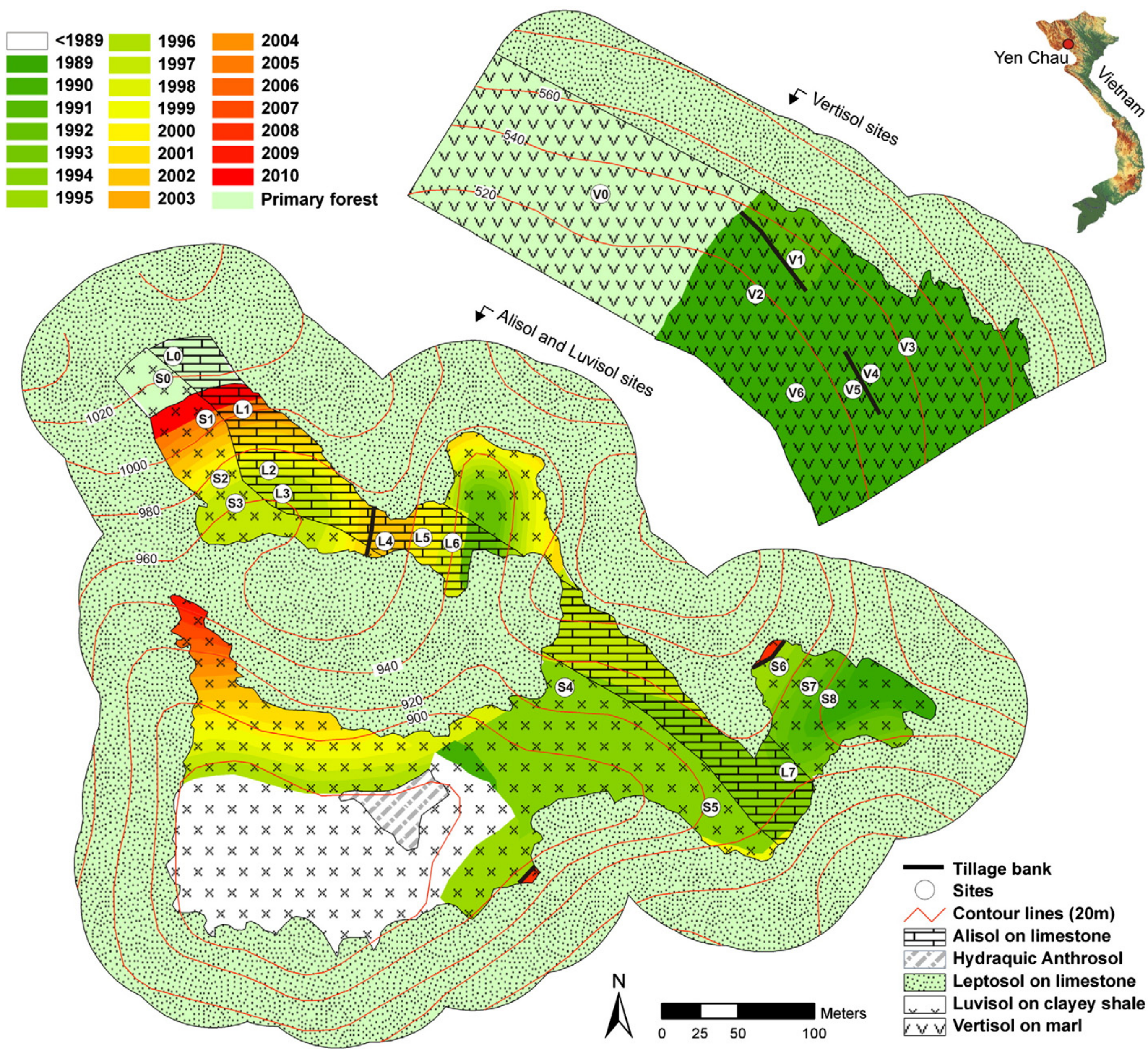

Fig. 1. Research area in the Yen Chau District, Son La Province, NW Vietnam.