137Cs tracing dynamics of soil erosion, organic carbon, and total nitrogen in terraced fields and forestland in the Middle Mountains of Nepal

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Abstract: The Middle Mountains is one of the regions of Nepal most vulnerable to water erosion, where fragile geology, steep topography, anomalous climatic conditions, and intensive human activity have resulted in serious soil erosion and enhanced land degradation. Based on the 137Cs tracing method, spatial variations in soil erosion, organic carbon, and total nitrogen (TN) in terraced fields lacking field banks and forestland were determined. Soil samples were collected at approximately 5 m and 20 m intervals along terraced field series and forestland transects respectively. Mean 137Cs inventories of the four soil cores from the reference site was estimated at 574.33 ± 126.22 Bq m⁻² (1 Bq (i.e., one Becquerel) is equal to 1 disintegration per second (1 dps)). For each terrace, the 137Cs inventory generally increased from upper to lower slope positions, accompanied by a decrease in the soil erosion rate. Along the entire terraced toposequence, 137Cs data showed that abrupt changes in soil erosion rates could occur between the lower part of the upper terrace and the upper part of the intermediate terrace within a small distance. This result indicated that tillage erosion is also a dominant erosion type in the sloping farmland of this area. At the same time, we observed a fluctuant decrease in soil erosion rates for the whole terraced toposequence as well as a net deposition at the toe terrace. Although steep terraces (lacking banks and hedgerows) to some extent could act to limit soil sediment accumulation in catchments, soil erosion in the terraced field was determined to be serious. For forestland, with the exception of serious soil erosion that had taken place at the top of slopes due to concentrated flows from a country road situated above the forestland site, spatial
variation in soil erosion was similar to the "standard" water erosion model. Soil organic carbon (SOC) and TN inventories showed similar spatial patterns to the $^{137}$Cs inventory for both toposequences investigated. However, due to the different dominant erosion processes between the two, we found similar patterns between the <0.002 mm soil particle size fraction (clay sized) and $^{137}$Cs inventories in terraced fields, while different patterns could be found between $^{137}$Cs inventories and the <0.002 mm soil particle size fraction in the forestland site. Such results confirm that $^{137}$Cs can successfully trace soil erosion, SOC and soil nitrogen dynamics in steep terraced fields and forestland in the Middle Mountains of Nepal.

**Keywords:** Nepal; $^{137}$Cs inventory; Soil erosion/deposition; Soil organic carbon; Total nitrogen

**Introduction**

Accelerated erosion exacerbated by anthropogenic perturbations depletes soil fertility, degrades soil structure, reduces the effective rooting depth, and in effect destroys the most basic of all natural resources (Lal 2003; Zhang et al. 2006). Accelerated erosion processes that result in soil losses and crop yield reductions in sloping farmlands is the most widespread form of soil degradation (Quine and Zhang 2002; Su et al. 2010). Accordingly, there is growing recognition that more attention should be paid to the adverse impacts of accelerated soil erosion on soil degradation, food security, and water quality/sedimentation in sloping farmland of fragile and sensitive ecosystems (Lal 2001; Li et al. 2004; Oyedele and Aina 2006; Rachman et al. 2003; Zhang et al. 2012).

Nepal is home to one of the most unique regional ecological areas in the world and is the regional “hot spot” of accelerated erosion due to the Himalayan–Tibetan ecosystem (Lal 2003; Nie et al. 2010). Numerous studies have indicated Nepal extremely prone to soil erosion and susceptible to sediment catastrophes due to the fragile geology, steeply sloping rugged mountain topography, anomalous climatic conditions, and intensive anthropogenic activities (Byers 1986; Gabet et al. 2008; Heimsath and McGlynn 2008; Joshi et al. 1998). Nepal is subdivided into the following five major tectonic zones: the Tibetan-Tethys Zone, the Higher Himalayan Zone, the Lower Himalayan Zone, the Sub-Himalayan Zone, and the Terai Zone, which roughly corresponds to its physiographic zones (i.e., the High Himal Zone, the High Mountain Zone, the Middle Mountains Zone, the Siwaliks Zone, and the Terai Zone) from north to south (LRMP 1986). The geology of Nepal is governed by a complex sequence of historical events that have resulted in the extensive elevation of the Himalaya. Owing to these events, the mountains and hills are young, unconsolidated, and fragile due to tectonic activity in the course of orogenic belt movement (Joshi et al. 1998). Nepal is a classic example of a mountainous nation. Approximately 86% of the area is characterized by steep hills and mountains (Bhandari 2014). Great topographical variety causes diverse climatic conditions in Nepal. Annual precipitation is approximately 1530 mm, with variations from 300 mm in the north to 5000 mm in the central Nepal. Agriculture is the primary source of livelihood for the local population, while population pressure is overloading the production system (Gardner and Gerrard 2003). At the same time, overgrazing, deforestation, fire, and road construction are also major anthropogenic activities that have accelerated erosion and resulted in environmental degradation. It is estimated that as much as 1.63 mm of topsoil is displaced from the total land surface of Nepal each year due to accelerated surface soil erosion induced by anthropogenic activity (Bhandari 2014). Until now, little attention has been paid to the role of soil erosion in the development of within-field spatial variation of surface soil properties and soil degradation. There is therefore an urgent need to study the soil erosion status and the decline of soil quality caused by soil erosion from farmland activity.

Although remote sensing has been widely used to investigate soil erosion in the hilly areas of Nepal (Ghimire et al. 2006; Watanabe 1994), accurately quantifying soil erosion rates on sloping farmland and dense forests is difficult using this approach. Moreover, some previous studies attempted to evaluate the applicability of erosion models (RUSLE model) to assess soil erosion rates in mountainous terrain ( Kouli et al. 2009; Vaezi and Sadeghi 2011), but certain model parameters proved difficult to determine due to a lack of long-