Geoderma 232-234 (2014) 352–362

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Linkages among land use, macronutrient levels, and soil erosion in northern Vietnam: A plot-scale study

Pham Thi Quynh Anh [a,*], Takashi Gomi [b], Lee H. MacDonald [c], Shigeru Mizugaki [d], Phung Van Khoa [e], Takahisa Furuichi [f]

[a] Department of Symbiotic Science of Environment and Natural Resources, Tokyo University of Agriculture and Technology, Fuchu, Tokyo, Japan
[b] Department of International Environmental and Agriculture Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo, Japan
[c] Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523-1476, USA
[d] Civil Engineering Research Institute for Cold Region, Public Works Research Institute, Sapporo, Japan
[e] Forest Resources and Environmental Management Faculty, Vietnam Forestry University, Xuan Mai, Chuong My, Hanoi, Vietnam
[f] Science Devision, Department of Science, IT, Innovation and the Arts, GPO Box 5078, Brisbane, 4001, Queensland, Australia

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 12 May 2014
Accepted 16 May 2014
Available online 11 June 2014

Keywords:
Soil erosion
Soil organic carbon
Soil organic nitrogen
Ground cover
$^{210}Pb_{ex}$
Land management

ABSTRACT

Objective: This study examined the interrelations among vegetative cover and biomass, soil macronutrient levels, and soil erosion in northern Vietnam.
Methods: We selected ten dominant land-use types in a hilly area of western Hanoi including bare soil, agriculture (cassava or lemon grass), shrub land, five types of plantation forest, and indigenous forest. We measured the understory biomass, litter biomass, canopy openness, soil moisture content, soil pedestal height, soil hardness, soil bulk density, ^{137}Cs and $^{210}Pb_{ex}$ activities, and soil carbon and nitrogen on three 1 m^2 plots for each land-use type. Soil erosion was calculated from both pedestal heights and radionuclides. Multivariate statistical analysis was used to identify the key factors controlling soil erosion and nutrient accumulations.
Results: Understory biomass ranged from 2 to 375 g m^{-2}, and this tended to be higher in most of the forest types and shrubland than in cassava and lemon grass. In contrast, the amount of ground cover varied more by forest type than between the agricultural land uses and forest lands. The height of soil pedestals indicated that short-term soil erosion was negligible when understory biomass was greater than 130 to 150 g m^{-2}. ^{137}Cs was only detected in the cassava plots, whereas $^{210}Pb_{ex}$ indicated widely different erosion rates across the land uses, with lower values in the agricultural lands and two types of forest plantations, although this may be due to soil management practices. Both the correlation and principal component analyses showed that soil organic carbon and nitrogen were positively correlated to understory biomass and strongly and inversely influenced by bulk density. Soil erosion as indicated by soil pedestal height was strongly and inversely controlled by ground cover, litter, and understory biomass. Soil erosion was also heavily influential to soil chemical richness and bulk density.
Conclusions: Ground vegetation cover and the resultant soil erosion processes altered the production and accumulation of SOC, while forest cover did not always result in high soil fertility or low erosion. A simple characterization of forest or non-forest is not sufficient to calculate carbon and nutrient stocks, or assess erosion risk.
Practice: Understory biomass of at least 130 g m^{-2} and high ground cover are essential for reducing soil erosion and sustaining short- and long-term soil productivity.
Implications: Rapidly developing areas in Southeast Asia, including hilly areas in North Vietnam, need to maintain understory biomass and ground cover for soil and nutrient conservation.

1. Introduction

Soil erosion is a major environmental problem that threatens sustainable land use and is especially important in areas that are being converted from forests to agriculture or undergoing rapid development such as urbanization (Lal, 1990; Montgomery, 2007). Twenty-three percent of the Earth's land surface has been severely affected by soil erosion, with an estimated 5–10 million ha being affected each year (Stavi and Lal, in press). Asia historically has had the highest percentage of degraded land at 31%, followed by Africa at 27% (Oldemal, 1994). The high proportion of degraded land in Asia is due to both rapid population growth and the associated land-use changes, combined with inadequate land-use planning and regulations to control soil erosion (Lal, 2004; Phan Ha et al., 2012; Quynh et al., 2005).

Soil erosion reduces soil productivity by decreasing soil macronutrients, such as nitrogen and phosphorus, and soil moisture storage capacity (Kuhn et al., 2009; Takenaka et al., 1998; Teramage et al., 2013). Soil

* Corresponding author at: 3-5-8 Saiwaicho, Fuchu-shi, Tokyo 1838509, Japan.
E-mail address: quynhanh.vfu@gmail.com (P.T.Q. Anh).

http://dx.doi.org/10.1016/j.geoderma.2014.05.011
0016-7061/

erosion was reported to be the main mechanism for nutrient loss in areas devoted to growing cassava in the north central coastal region of Vietnam (Andersson, 2002; Maglinao et al., 2002; Podwojewski et al., 2008). In northern Vietnam, soil loss varies greatly with land use and location. The total soil loss in a 250-ha watershed covered by agricultural and forested land ranged from 16.3 to 172.2 g m^{-2} $year^{-1}$ in Vinh Phuc province (Mai et al., 2013). Soil losses of 14 to 150 g m^{-2} $year^{-1}$ were reported from Hoa Binh province (Phan Ha et al., 2012). Other studies reported soil losses of up to 1305 g m^{-2} $year^{-1}$ in Hoa Binh province (Podwojewski et al., 2008) and up to 17,000 g m^{-2} $year^{-1}$ for maize fields in Son La province (Tuan et al., 2014). These high soil loss rates will decrease land productivity, increase the need for chemical fertilizers, and contribute to regional biodiversity loss (Lal, 1998). High soil loss rates also can induce socioeconomic problems, including lower household incomes, food insecurity, and regional poverty (Ananda and Herath, 2003; Oldemal, 1994). Sediment delivery to streams and rivers can cause flooding and reservoir sedimentation as well as negative effects on water quality and aquatic resources (Chappell et al., 2004; Gomi et al., 2006).

Surface cover by litter or live vegetation is one of the important parameters controlling infiltration, surface runoff and erosion, and macronutrient levels (i.e., Nanko et al., 2008). Infiltration capacity generally increases with increasing density of understory vegetation (Hiraoka and Onda, 2012). The loss of ground cover due to deforestation, agriculture, over-grazing, and fires can lead to the formation of a soil crust, which results in increased overland flow and surface erosion (Larsen et al., 2009; Singer and Le Bissonnais, 1998). The presence of litter and understory vegetation also increases flow resistance, thereby reducing overland flow velocities (Tabacchi et al., 2000). In addition to providing litter and protecting the soil from erosion, understory vegetation also contributes to forest ecosystems through nutrient and carbon turnover during decomposition (Teramage et al., 2013) and facilitates increased rates of biogeochemical cycling (Yarie, 1980).

Monitoring erosion and macronutrient levels is difficult, particularly in rural areas of developing countries like Vietnam, because of the cost for regular sampling and the long time period needed to detect trends. These problems have led to the development of alternative methods for estimating soil erosion. Short-term erosion can be estimated by measuring soil pedestal heights (Okoba and Sterk, 2006; Sidle et al., 2004; Stocking and Murnaghan, 2001). A soil pedestal is a column of soil that is above an eroded surface because a rock or other object protected the underlying soil from rainsplash erosion. The difference in height between the top of the pedestal and the adjacent soil surface can be used to estimate storm or seasonal erosion rates (Sidle et al., 2004). Erosion rates over a few decades can be estimated by studying the distribution of radionuclides in the soil, particularly ^{137}Cs and $^{210}Pb_{ex}$ (Navas et al., 2012; Walling and He, 1999). Both $^{210}Pb_{ex}$ and ^{137}Cs are deposited from the atmosphere, and these radionuclides are rapidly adsorbed by organic matter and mineral topsoil. The distribution of $^{210}Pb_{ex}$ with depth will reflect the erosion and deposition of soil. Similarly, the global fallout of ^{137}Cs provides a unique marker for evaluating soil erosion because deposition peaked in 1963 and then ceased. Comparisons of ^{137}Cs and $^{210}Pb_{ex}$ between sites with similar soils but different land uses can therefore indicate how land use affects longer-term erosion rates (Li and Nguyen, 2010).

Although vegetation and litter cover are important controls on soil erosion and nutrient accumulation, interactions among vegetation, soil erosion, and macronutrient levels have rarely been investigated. Most previous studies have focused on the relationships between vegetation cover and soil erosion (Miyata et al., 2009; Mohammad and Adam, 2010; Zhou et al., 2008), or soil nutrient levels in relation to soil erosion (Kinderiene and Karcauskiene, 2012; Stolte et al., 2009), or between vegetation cover and soil nutrient levels (Fierer and Gabet, 2002; Yarie, 1980). However, the comprehensive interactions among land use, nutrient levels, vegetation and litter production, soil physical properties, and soil erosion have been rarely reported. An understanding of these factors and their interactions for different land uses is important for sustaining short- and long-term ecosystem productivity (Angers and Caron, 1998; Lal, 2004; Schlesinger, 1990). The alternative to long-term and much expensive studies is to measure a more comprehensive suite of physical, chemical, and biological parameters across different land uses and then to apply multivariate analysis techniques. None of the previously-cited studies of soil erosion in northern Vietnam have provided this more comprehensive assessment of site factors and attempted to then analyze the various relationships among land use, vegetation, soil chemical and physical properties, and erosion.

Here, we hypothesize a strong linkage among soil nutrients, land use, and soil erosion in northern Vietnam, and that a simple characterization of land use may not be adequate to characterize soil nutrient status and erosion rates. Hence the objectives of this study were to: 1) characterize the vegetation and litter cover, soil physical properties, and nutrient levels in replicated plots with different land uses in northern Vietnam; 2) assess short- and long-term soil erosion using soil pedestals and radionuclides; and 3) evaluate the relationships and potential feedbacks between land use, macronutrient levels, physical soil properties, the amount of vegetation and litter, and soil erosion.

2. Methods

2.1. Study area and design

This study was conducted in and around Luot mountain (20°54′N, 105°34′E), which is adjacent to the campus of Vietnam Forestry University (VFU) in Xuan Mai town, Chuong My district, northern Vietnam (Fig. 1). The study area was about 110 ha and is dominated by ferralitic soils. Seventy-five percent of the study area is hilly with complex topography that is relatively typical of northern Vietnam (Nhuan, 1996). Soil degradation is a major concern as a result of the land-use changes initiated by the rapidly growing population and associated economic development.

The study area ranges from 5 to 140 m above sea level and has a tropical monsoon climate. Average annual precipitation and temperature are 2268 mm and 23 °C, respectively, based on 20 years of data from the Kim Boi station located 18 km west of Xuan Mai. About 80% of the annual precipitation occurs during the rainy season from May to September. The underlying bedrock is largely porphyritic and the soil depth is approximately 1 to 2 m, although some areas have shallower soils. Humus content is typically 5–8%. The dominant land uses are agriculture and forestry, but population growth has caused the agriculture to change from shifting cultivation to more continuous cropping. Similarly, the native forests are often being replaced by plantations, and cutover forests - if not replanted-revert to shrubland dominated by *Eupatorium odoratum* and *Heliotropium indicum*.

Prior to the 1980s, the area was dominated by dense wild grass and shrubs mixed with local cultivation of cassava, taro, and maize. After VFU was established in 1984, various exotic forest plantations were established on a 129-ha hilly area. These include *Acacia mangium*, *Pinus massoniana*, and *Eucalyptus exserta*. In 1993 some indigenous trees also were planted, including *Elaeocarpus dubius*, *Aphanamixis grandiflora*, and *Dalbergia tonkinensis*. Many of the lands surrounding the VFU campus that are too steep or otherwise not suitable for growing paddy rice are now used for growing cassava (*Manihot esculenta*) and lemon grass (*Cymbopogon marginatus*).

This study focused on 10 major land-use types around VFU: (1) >20-year-old *P. massoniana* plantation, (2) >20-year-old *A. mangium* plantation, (3) 15-year-old forest of indigenous species (e.g., *E. dubius*, *A. grandiflora*), (4) >20-year-old forest dominated by *E. exserta* and *D. tonkinensis*, (5) 3-year-old forest composed of a hybrid of *A. mangium* and *Acacia auriculiformis* ("*Acacia* spp."), (6) agricultural land planted with cassava, (7) agricultural land planted with lemon grass, (8) shrubland, (9) bare land, and (10) 5-year-old ornamental