Evaluating the interactions between soil erosion and nutrient accumulation with various vegetation ground cover conditions

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Pham Thi Quynh Anh

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by

PHAM THI QUYNH ANH

B.S., Vietnam Forestry University, Hanoi, 2006

M.S., Tokyo University of Agriculture and Technology, 2011

APPROVED BY SUPERVISORY COMMITEE:

Chairperson: Professor Takashi Gomi

Member: Professor Yoshiharu Ishikawa

Member: Professor Yasuhiro Shuin

Member: Professor Hiroto Toda

Member: Professor Katsushige Shiraki

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ABSTRACT

Soil erosion was known as one of important factors for controlling soil physical properties and nutrient conditions. Soil erosion typically links to vegetation and/or soil cover conditions which also related to land use changes and resultant ecosystem dynamics of vegetation. Serious soil erosion by agriculture activities and changes in vegetation types could result soil degradation such as changes in soil bulk density, soil porosity and availability of organic matter. 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 of the previous studies have focused only on the relationships either between vegetation cover and soil erosion, or between vegetation and soil nutrient levels. The comprehensive interactions among soil erosion, nutrient levels, and vegetation and litter have been rarely investigated. An understanding of these factors and complex interactions for different land use and/or land cover is important for developing site specific soil conservation and sustainable resources management. . Therefore the objective of this Ph.D. thesus is (1) to characterize land use type and the interaction among vegetation, soil nutrient, and soil erosion, (2) to investigate spatial patterns of soil erosion and nutrient accumulation under various vegegation ground covers in a headwater catchment, (3) to estimate soil erosion rate with comparison of global soil erosion and production rate, and (4) to provide management application for controlling soil erosion and soil conservations in both plot and catchment scales. This study was conducted in Vietnam and Japan. Both sites had serious soil degradation associated with changes in vegetation ground cover. In Vietnam, rapid development associated coverting to land surface from forest to agriculture or from natural forest to

planation forest. In Japan, deer overgrazing alter depuration of ground vegetation and litter and induced soil erosion.

First of all, I conducted study in Luot Mountain in northern Vietnam located 30 km from Hanoi. I selected 10 dominant land use types (3 plots (1 x 1 m) of each type) including pine forest (*Pinus massoniana*), Acacia forest (*Acacia mangium*), native forest (*Elaeocarpus dubius*), Eucalyptus forest (*Eucalyptus exserta*), young Acacia forest, cassava (*Manihot esculenta*), lemon grass (*Cymbopogon marginatus*), shrub land, bare land, and landscape planation (*Roystonea regia*). Understory vegetation biomass, litter biomass, canopy openness, soil moisture content, soil pedestal height, soil hardness, soil bulk density were measured at site and samples. For long term soil erosion rate, I estimated ^{137}Cs and $^{210}Pb_{ex}$ activities in soil surface. For nutrient accumulation, I analyzed soil carbon and nitrogen. Understory biomass ranged from 2 to 375 g m^{-2} with greater values of forest and shrub lands than in agriculture fields. The height of soil pedestals (0-3.3 cm) indicating short-term soil erosion was negligible when understory biomass was greater than 130 to 150 g m^{-2}. Soil carbon and nutrient ranged from 0.79 to 5.17% and 0.07 to 0.29% with 10.6 to 19.1 C/N ratio. $^{210}Pb_{ex}$ indicated widely different erosion rates across the land uses with low values in the agricultural lands and two types of forest plantations. Principal component analyses showed that concentriation of soil organic carbon and nitrogen were positively correlated to understory biomass and strongly and inversely influenced by bulk density. This finding showed that understory biomass and bulk density are the most important parameter for preventing soil erosion even in forested landscape.

Secondary, I focused on the spatial patterns of soil erosion, vegetation, ground cover, and nutrients in 7 and 4.6 ha headwater catchments in the Oobora-zaawa watershed, Tanzawa mountain, Japan. We collected 53, 13 and 13 spatially distributed samples in 2010, 2012 and 2013, respectively. We collected 12 soil profiles with 30 cm soil depth including 2 reference sites. Ground surface biomass ranged from 1.4 to 95.5 g m^{-2} for all plots. Total soil carbon and nitrogen concentration ranged from 10.5 to 10.8% and 0.76 to 0.87 % in the 2.5 cm of reference sites with 12.4 to 13.8 of C/N ratio. ^{137}Cs reference inventory in 2010 ranged from 20 to 54 Bq/kg, while ^{137}Cs reference inventory became 610 to 932 Bq/kg in 2012 after deposition of accident of Fukushima Daiichi Power Plant (FDNPP). Vegetation biomass had negatively correlated with soil pedestal (r = - 0.39, p=0.05). When the biomass was greater than 100 g m^{-2} no soil pedestal was formed based on the continuous monitoring in 2010 to 2013. For the depth profile in various land cover, depth profile of ^{137}Cs and ^{134}Cs was inconsistent to the reference profiles. This patterns of radionuclide accumulation of soil profile suggested that soil surface turn over occurred due to the movement of soil and litter. Soil nitrogen tended to relate to slope gradient and ^{137}Cs in 2010 data. Similary, soil nitrogen and carbon correlated to slope gradient and bulk density in 2012. Princple component analysis also showed that soil organic carbon (SOC) and total nitrogen (TN) were well correlated with ^{137}Cs. These chemical parameters thus were related to long-term soil erosion processes. Because the vegetation ground cover tended to be low in near stream channels in the watersheds, soil erosion and resultant nutrient movement near stream channel induced sediment supply to headwater channels and potentially affect downstream sedimentation. This study suggested the spatial patterns of understory vegetation and litter cover within catchments provided us target areas for providing additional conservation practices for increase in ground cover up to 100 g m^{-2}.

In the third, I estimated soil erosion rate in different land surface condition using data from Vietnam and Japan and compared the global data sets. Based on the equation by Walling and He (1999b) using ^{137}Cs and $^{210}Pb_{ex}$, estimated soil erosion rate became 1.2 to

32.4 mm yr^{-1} in Vietnam. Estimated soil erosion was low in Eucalyptus planation with 1.2 mm yr^{-1} and high in bare land with 32.4 mm yr^{-1}, estimated soil erosion rate in bare land located near stream channels in Tanzawa ranged from 10.1 to 13.8 mm yr^{-1}. Based on global soil erosion rate summarized by Montgomery (2007), natural soil erosion rates ranged 0.001 to 1 mm yr^{-1}. Agriculture land tended to be high with 0.001 to > 52.93 mm yr^{-1} depending on the land. In general, soil production rate ranged from 0.4 – 1 mm yr^{-1}. Therefore, soil erosion rate is lower than 1mm yr^{-1} can be important for preventing soil degradation. Soil erosion rate estimated in Vietnam is generally exceeded soil production rate in tropical and subtropical areas (14 to 32.4 mm yr^{-1}). In Tanzawa, soil erosion rate near stream channel also exceeded soil production rate in temperate forest (1.4 to 3.0 mm yr^{-1}). Our finding showed that estimated long-term perspectives of soil erosion rate are important for understanding the soil production and land conservation.

Finally, we summarized our findings and management implication in the following way. This study provides snapshots about the vegetation and soil condition in Northern Vietnam and Japan. The vegetation biomass was strongly correlated with short-term soil erosion in both Vietnam and Japan. 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. The simplest way to reduce soil erosion is to maintain understory biomass above 150 g m^{-2} in tropical region like Vietnam or above 100 g m^{-2} in temperate region like Japan. It suggested that ground cover is very important factor controlling understory biomass, and it should be sufficient especially during rainy season to avoid soil erosion. Hence, monitoring soil erosion and nutrient is still difficult because of the cost for regular sampling and the long time period needed to detect trends. Therefore, in order to implement this knowledge in local manager and farmers as practices, scientific information and simplied values such as vegetation biomass with their spatial patterns we can important for appropriated plantation and cultivation practices for preventing soil degradation.

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CHAPTER 1INTRODUCTION

1.1. Introduction to soil nutrients and soil erosion impacts

1.1.1. What causes of soil erosion?

The soil is a natural resource, non-renewable in the short-term or very difficult to improve following erosion. The intense and ever increasing pressure on land and water resources throughout the world leads to land degradation and pollution, which in turn may result in decreasing biological productivity and declining biodiversity. Globally, it has been estimated that nearly 2 billion hectares of land are affected by human-induced soil degradation (UN, 2000). According to UNEP (1992), 23 percent of all usable land (except mountains and deserts) has been affected by degradation from a sufficient degree to reduce its productivity (UNEP 1992). The highest proportions were reported for Europe (25%), Asia (18%) and Africa (16%); the least in North America (5%) (Oldeman et al., 1991). Figure 1.1 presents the state of global soil degradation, from the Global Assessment of Human-induced Soil Degradation study in 1997. Very degraded soils are found especially in semi-arid areas (Sub-Saharan Africa, Chile), areas with high population pressure (China, Mexico, India) and regions undergoing deforestation (Indonesia). Degraded soils reduce the possibilities for agriculture, increases the expansion of drylands/desert and hightens the risk for erosion.

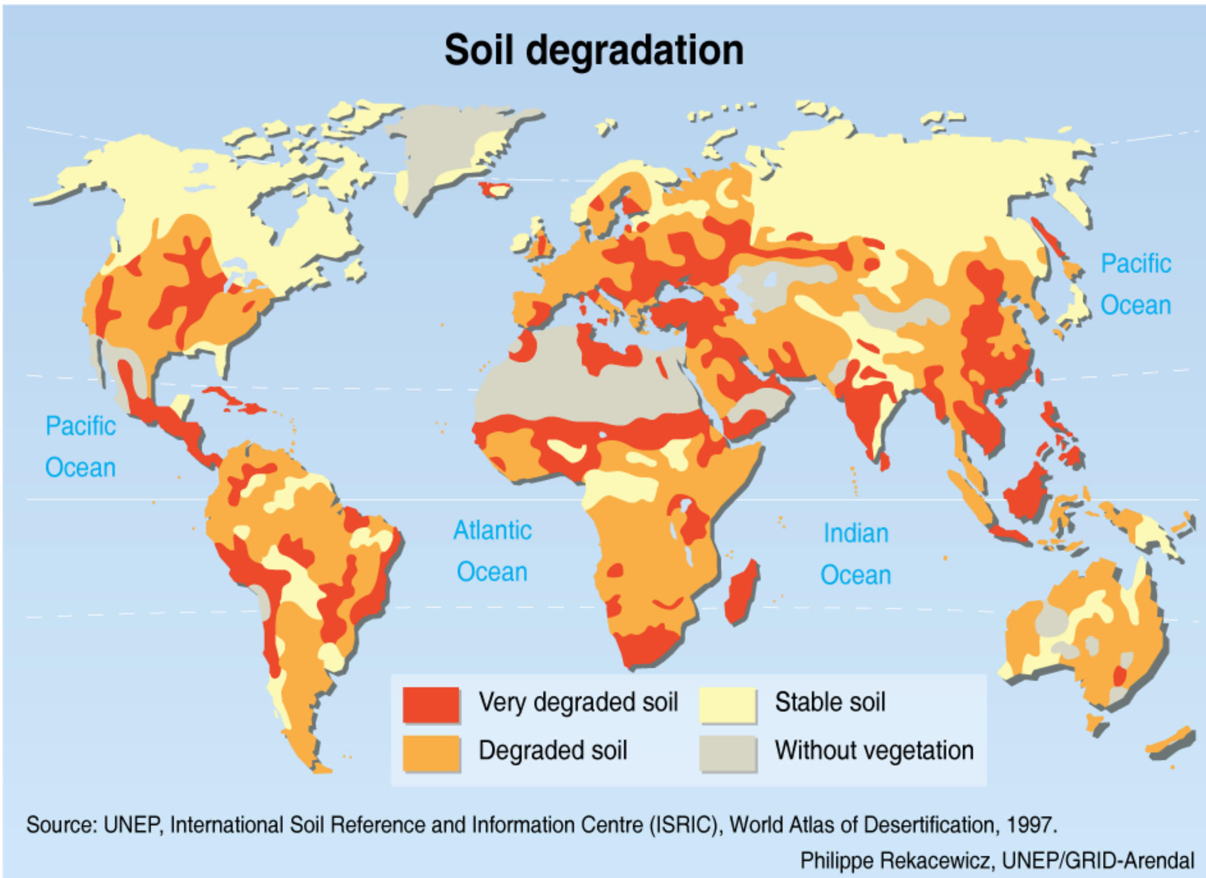


Figure 1.1. The state of global soil degradation. Source: UNEP, International Soil Reference and Information Centre (ISRIC), World Atlas of Desertification, 1997

As a proportion of the degraded area, soil erosion is regarded as one of the major and most widespread forms of land degradation (83% of the area degraded worldwide) (Oldeman et al., 1991). Even though erosion originally is a natural process, it is accelerated by human activities such as forest cutting, burning, pasture establishment, abandoned plantation forest (Mizugaki et al., 2008), and excess pressure of wildlife (Ghahramani et al., 2011). Soil erosion depends not only on soil properties, climate, and slope, but also on land use and vegetation ground cover. In forested headwater catchment, understory vegetation and litter play an important role in driving the processes and functions by affecting the below-ground processes including decomposition, soil nutrient cycling and soil water conservation, infiltration, surface runoff and erosion, and macronutrient levels (Yarie, 1980). Due to the sensitivity of understory vegetation and litter, they have been known as an indicator of landform characteristics, disturbance history, and altered environmental conditions across the landscape and over time (Kamisako et al., 2007; Meilleur et al., 1992). The extent of vegetation and litter cover reduces overland runoff and soil erosion (Castillo et al., 1997; Cerdan et al., 2002; Marston, 1952; Miyata et al., 2009), whereas 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 and produces excess sediment to downstreams (Singer and Le Bissonnais, 1998). Soil erosion can induce severe degradation of both soil physical and geochemical properties (Montgomery, 2007).

1.1.2. How does soil erosion affect environment and soil nutrients?

Mitigating soil erosion is a challenging issue of soil conservation in the world today. It has been recognized as a serious hazard not only agricultural land but also areas used for forestry, transport, and recreation, and it seriously threatens the natural environment. Soil erosion therefore should never be ignored because of its importance in affecting sustainability of regional development (Jiao et al., 2008; Wilson et al., 2008). The loss of valuable topsoil to erosion is compounded by the loss of plant nutrients and organic matter and then reduces the productivity of all natural ecosystems (Logan, 1990; Troeh et al., 2004). In many developing countries, especially in sub-Saharan Africa, soil nutrient loss associates less productive for agriculture. Average nutrient loss for sub-Saharan Africa was 22 kg N, 2.5 kg P, and 15 kg K per year and made decrease soil fertility cost farmers an estimated 4 billion USD (Stoorvogel et al., 1993).

Soil erosion leads to sedimentation of reservoirs and increases suspended sediment concentrations in streams, with consequent effects on ecosystem health (Flügel et al., 2003). 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., 2005; Gomi et al., 2006). 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., 2012).

Vegetation ground cover and litter can prevent both soil erosion and nutrient loss. Fierer and Gabet (2002) showed that hillslope vegetation types had strong effects on the loss of soil carbon and nitrogen. 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., 2012), and facilitates increased rates of biogeochemical cycling (Yarie, 1980). Removal of vegetation ground cover generally causes transient increases in nutrient exports to streams (Hornbeck et al., 1990). The elevation of soil erosion, soil nutrient accumulation export resulting from vegetation removal has been found to depend greatly on the intensity and extent of removal.

1.2. Effect of scale on soil erosion inventory

Although we realize the importance of vegetation and litter ground cover, most of the previous studies were conducted mostly in hillslope plot scales, which are rather small areas (e.g., 1 x 1 m and 10 x 10 m). Erosion spans a wide range of spatial scales that includes the simple plots of specific sites, the field observation across hillslope, and catchment scale (Imeson, 1995; Kirkby et al., 1996). Numerous studies on water erosion from arable lands have indicated that soil erosion rate from field observation areas are much lower than those from plot areas, stressing the importance of the scale (Boardman and Favis-Mortlock, 1993; Evans, 1993) (Figure 1.2).

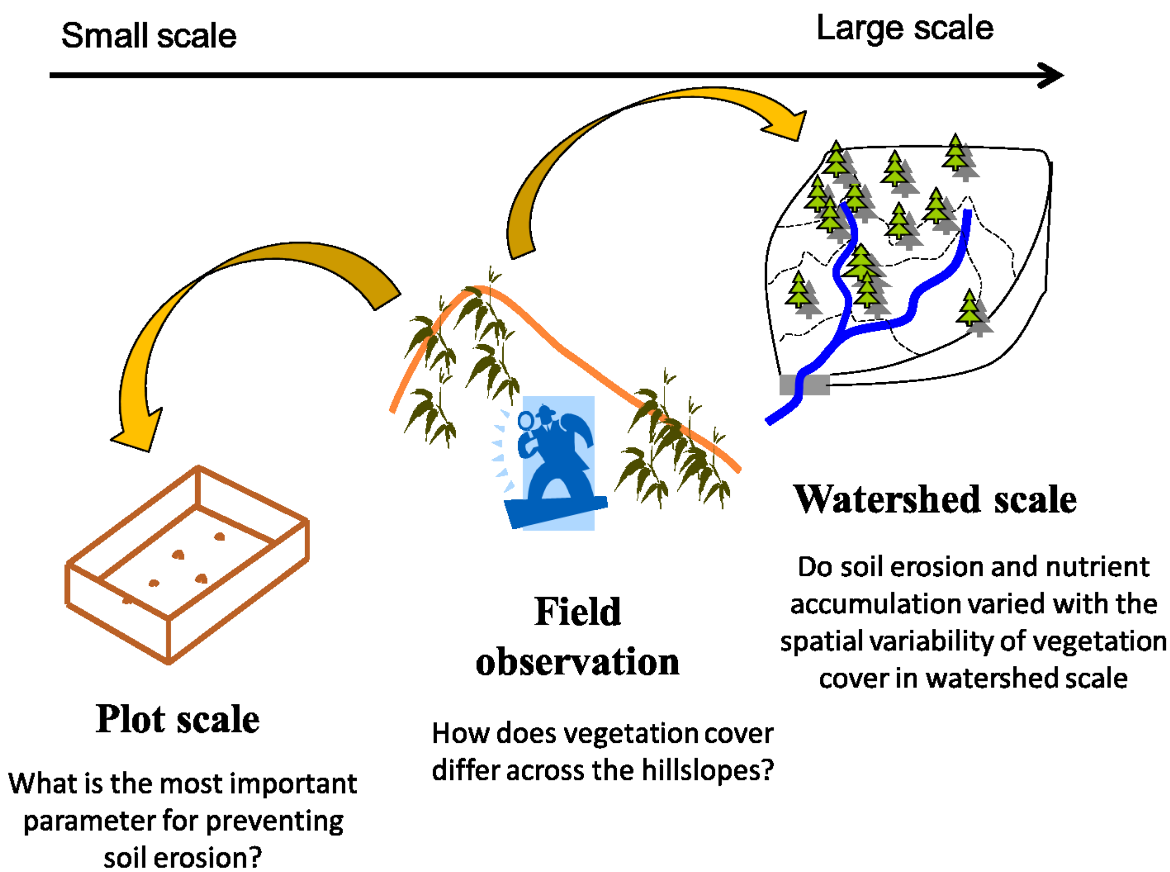


Figure 1.2. The scale of this study

Because soil erosion is a multivariate issue, loss of soil can be associated with many factors such as vegetation, soil physical properties, chemicals, and metrological conditions. Any field inventory will be suffered from two types of variations known as temporal and spatial variations in addition to measurement variability. The advantage of plot-scale study is that we can reduce spatial variation, thus we can expect to see clearly the correlation among variables and its real contribution to soil erosion. These correlations may reveal many interesting underlying mechanism and insightful interaction among variables, which is very important for management of soil erosion. On the other hand, there relationships may be seen only in plot-scale study, and it may not be seen in larger scale because of the interference of spatial variation of all variables (Wei et al., 2012). However, this is a real outcome from the interaction among variables and spatial variations.

Assessing the severity of erosion under a various land-uses from plot measurement is resource and time consuming. Besides, erosion plots cannot reproduce all the processes that take place at the field or watershed scale. Identifying, the sources actually contributing to the measured sediment loss is an even more completed tacks (Lal, 1994). For the forest, land, and water management, watershed scale studies are always difficult because of their wide area and the special heterogeneities of soil, topography, and vegetation conditions (Wei et al., 2012). Most of the study monitored discharge and sediment at one location (outlet points of watersheds). It is very difficult to identify the processes from hillslope to streams in the entire watersheds.

On the other hand, exploring the complex driving forces and dynamics of erosion across different scales is urgent for for the adoption of suitable erosion control measures (Wang et al., 2002). Among the main techniques used worldwide to measure soil erosion on different scales are plot experiments, surveys, and tracers. There is a paucity of long-term erosion rate data derived from direct measurements. Many of the problems associated with long-term monitoring of soil redistribution can be overcome by using methodology to trace soil movement. Since the fallout radionuclides methodology provides accurate, quick, and efficient net soil flux measurements aggregated over different time scales for different land use types, it has been applied successfully in numerous studies throughout the world (Belyaev et al., 2009; Li et al., 2009; Ritchie et al., 2007; Wakiyama et al., 2010; Walling, 1998; Zhang et al., 2006).

1.3. Soil erosion problem in Japan and Vietnam

Soil erosion has been reported in several areas in Vietnam such as 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 0.02 to 0.2 mm yr^{-1} in Vinh Phuc province (Mai et al., 2013). In northern Vietnam soil losses of 0.01 to 0.02 mm yr^{-1} were reported from Hoa Binh province (Phan Ha et al., 2012). Other studies reported soil losses of up to 1.3 mm yr^{-1} in Hoa Binh province (Podwojewski et al., 2008) and up to 17 mm yr^{-1} for maize fields in Son La province (Tuan et al., 2014). 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.

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 both short- and long-term ecosystem productivity (Angers and Caron, 1998b; Lal, 2004; Schlesinger, 1990). The alternative to long-term and much more expensive studies is to measure a more comprehensive suite of physical, chemical, and biological parameters across different land uses and then to apply more sophisticated 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 analyse the various relationships among land use, vegetation, soil chemical and physical properties, and erosion.

In Japan, approximately 67% of the land area is covered by forests, with most of which grow on sloping terrains. Soil erosion therefore had been known as a high potential occurrence in these forests due to the steep topography and heavy seasonal rainfall (Forestry Agency, The Ministry of Agriculture, Forestry and Fisheries of Japan, 2003). The Japanese cypress plantations (*Chamaecyparis obtusa*) is making up 26% of all forest and becoming a major commercial tree species in Japan. The dense coverage of the tree canopies causes the forest floor to become too dark for understory vegetation, and cypress litter can easily break into small pieces after falling to the ground (Sakai and Inoue, 1988), eventually becoming washed away (Hattori et al ., 1992). Soil erosion thus represents an important threat to the long-term sustainability of Japanese cypress plantations (e.g. Miura et al ., 2002; Fukuyama et al ., 2008).

Changes in hillslope condition can be propagating toward streams and further downstreams in watershed scales. Removal of vegetation ground cover generally causes transient increases in nutrient exports to streams (Hornbeck et al., 1990). The elevation of soil erosion soil C and N accumulation export resulting from vegetation removal has been found to depend greatly on the intensity and extent of removal. Although we realize the importance of vegetation and litter ground cover, most of the previous studies were conducted only in hillslope plot scales, which are rather small areas (e.g., 1 x 1 m and 10 x 10 m). For the forest, land, and water management, watershed scale studies are always difficult because of their wide area and the special heterogeneities of soil, topography, and vegetation conditions. Therefore, to quantify the impacts of soil erosion and soil carbon and nitrogen accumulations under the changes of vegetation ground cover in headwater catchment is urgently required for land and water management.

Soil erosion generally occurs as irregular and catastrophic events. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands. However, monitoring erosion and macronutrient levels is difficult because of the cost for regular sampling and the long time period needed to detect trends. Therefore, the alternative methods for estimating soil erosion have been developed. We combine both of the soil pedestal heights and radionuclides measurements in erosion monitoring to develop an understanding of how these two processes are likely to impact soil carbon and nitrogen accumulation in plot-scale in Vietnam in hillslope catchment in Japan. Soil pedestal heights can be measured and used to like the indicator for short-term erosion (Anh et al., 2014; Okoba and Sterk, 2006; Sidle et al., 2004). Overcomes many of the limitations associated with traditional approaches, estimating erosion rates for a long-term based on using the distribution of ^{137}Cs in the soil has been approved as an effective method of studying erosion and deposition (Li et al., 2003; Navas et al., 2012; Ritchie et al., 1974; Walling and He, 1999a; Walling et al., 1999; Zapata, 2003). ^{137}Cs is deposited from the atmosphere, and rapidly adsorbed by organic matter and mineral topsoil, and then predominantly moved in the environment due to physical processes. ^{137}Cs is therefore a unique tracer for studying erosion for long-term.

1.4. Objectives and structure of this study

This study combined soil erosion and nutrient accumulation under various ground covers in both plot scale and watershed scale. The objectives of this study were:

(i) To characterize land use type and the interaction among vegetation, soil nutrient, and soil erosion,

(ii) To investigate spatial patterns of soil erosion and nutrient accumulation under various vegetation ground covers in a headwater catchment,

(iii) To estimate soil erosion rate with comparison of global soil erosion and production rate, and

(iv) To provide management application for controlling soil erosion and soil conservations in both plot and catchment scales.

This study therefore combined the information about soil erosion and nutrient loss on different vegetation ground cover in plot scale and hillslope scale for land management (Figure 1.2). This study was organized into five chapters (Figure 1.3). Chapter 1 introduces the importance of ground cover condition and spatial scales on studying soil erosion and nutrient accumulation. Otherwise, the main objectives and structure of this thesis was also mentioned. Chapter 2 presents the characteristic of short- and long-term soil erosion and soil nutrient accumulation using soil pedestals and radionuclides at plot scale. We also evaluate the relationships and potential feedbacks between land use, macronutrient levels, physical soil properties, the amount of vegetation and litter, and soil erosion. Chapter 3 addresses the large-scale issue of the distribution of soil erosion and nutrient accumulation (influenced by the various ground cover) alters water land management of headwater catchment. In particular, this chapter highlighted the functional roles of headwater systems and their linkages with downstream systems. The objective of Chapter 4 is to explore the potential soil erosion rates using ^{137}Cs and $^{210}Pb_{ex}$ measurements in both Vietnam and Japan study site. Such information is need to design and target effective soil and water conservation in forested headwater catchment. The chapter 5 is summary of important findings; the scale issue was also discussed along with conclusions and soil erosion management and application in Vietnam and Japan.

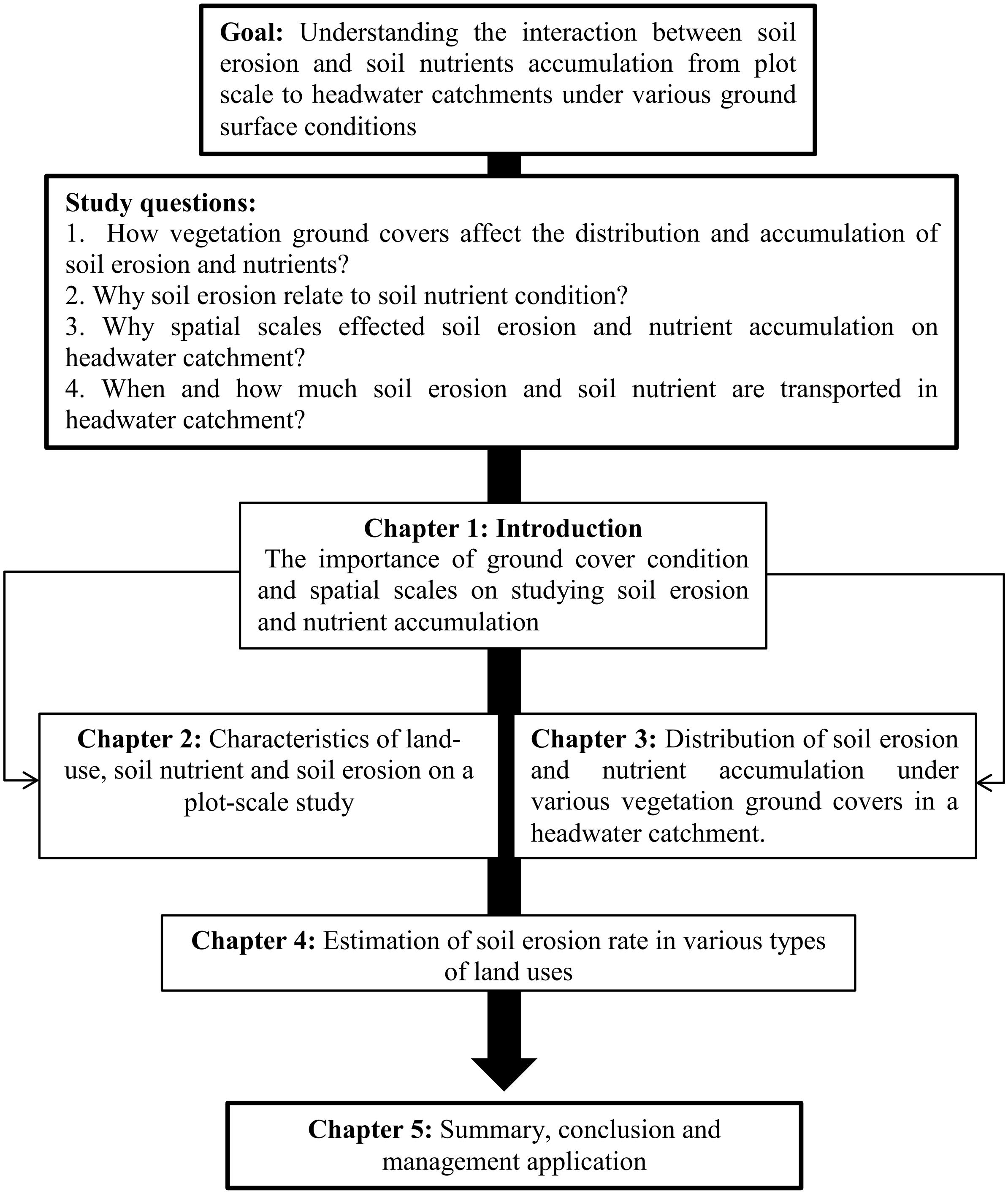


Figure 1.3 Structure of this study

CHAPTER 2CHARACTERISTICS OF LAND-USE, SOIL NUTRIENT, AND SOIL EROSION ON A PLOT-SCALE STUDY

2.1. 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, 2014). 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., 2012). Soil 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 0.02 to 0.2 mm yr^{-1} in Vinh Phuc province (Mai et al., 2013). In northern Vietnam soil losses of 0.01 to 0.2 mm yr^{-1} were reported from Hoa Binh province (Phan Ha et al., 2012). Other studies reported soil losses of up to 1.3 mm yr^{-1} in Hoa Binh province (Podwojewski et al., 2008) and up to 17 mm yr^{-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., 2005; 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 (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, overgrazing, and fires can lead to the formation of a soil crust, which results in increased overland flow and surface erosion (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., 2012) 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 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, 1999a). 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 both short- and long-term ecosystem productivity (Angers and Caron, 1998b; Lal, 2004; Schlesinger, 1990). The alternative to long-term and much more expensive studies is to measure a more comprehensive suite of physical, chemical, and biological parameters across different land uses and then to apply more sophisticated 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 analyse 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..

2.2. Methods

2.2.1. Study area

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 (Figure 2.1). 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.

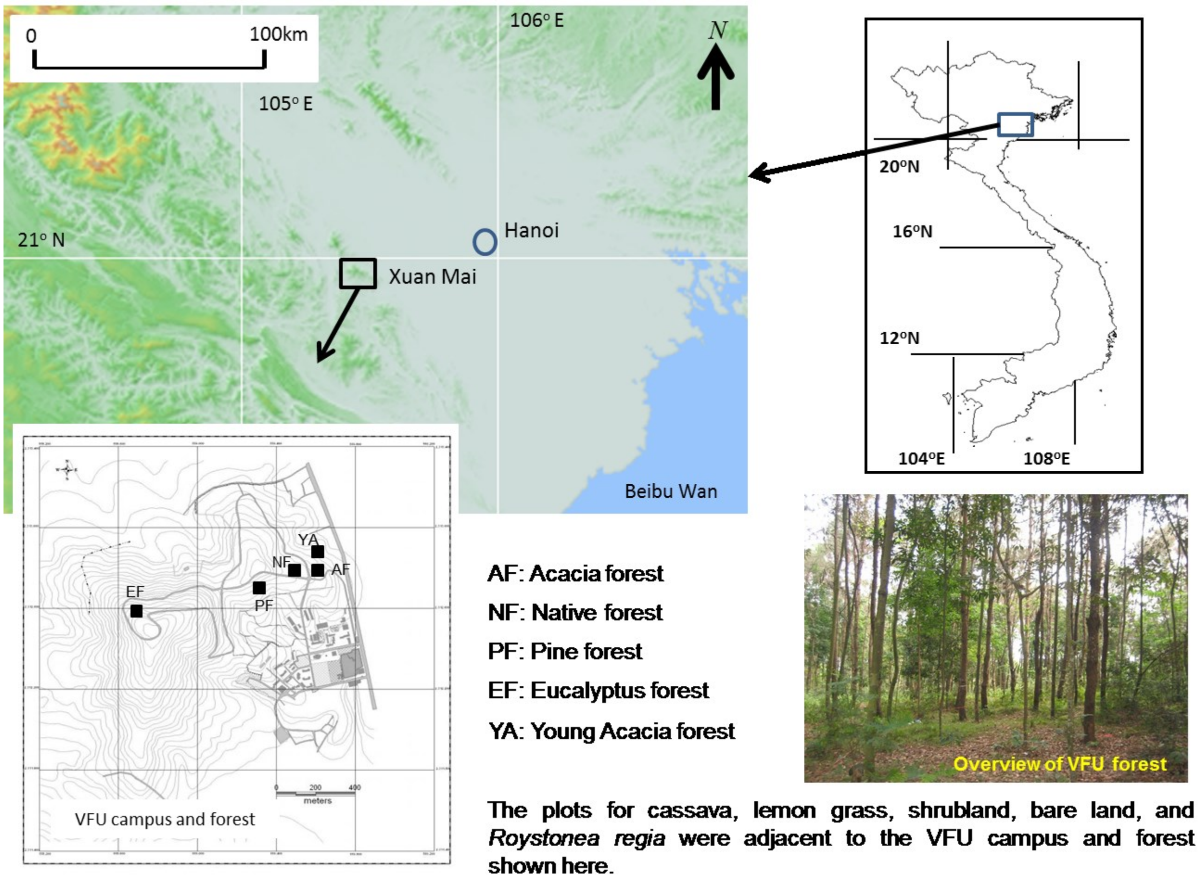


Figure 2.1. Location of the study area and some of the forest types sampled in this study

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^{o}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 shrub lands 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 *Pinus massoniana* plantation, (2) >20-year-old *Acacia mangium* plantation, (3) 15-year-old forest of indigenous species (e.g., *Elaeocarpus dubius*, *Aphanamixis grandiflora*), (4) >20-year-old forest dominated by *Eucalyptus exserta* and *Dalbergia tonkinensis*, (5) 3-year-old forest composed of a hybrid of *Acacia mangium* and *Acacia auriculiformis* ("*Acacia* spp."), (6) agricultural land planted in cassava, (7) agricultural land planted in lemon grass, (8) shrubland, (9) bare land, and (10) 5-year-old ornamental tree plantation (*Roystonea regia*) (Figure2.2; Table 2.1). In typical years cassava is propagated by cutting the stem into sections and planting in April, and harvested the following March. Lemon grass is a perennial crop and the leaves are most intensively harvested from mid-December to January. No fertilizer was applied to any of the plots used in this study. The cassava plots were probably subjected to ploughing prior to planting, and the *Roystonea regia* plots were in an area with small, crudely-built, sloping terraces. By altering the slope length and steepness terracing can alter local runoff and other characteristics such as soil moisture (Chow et al., 1999).

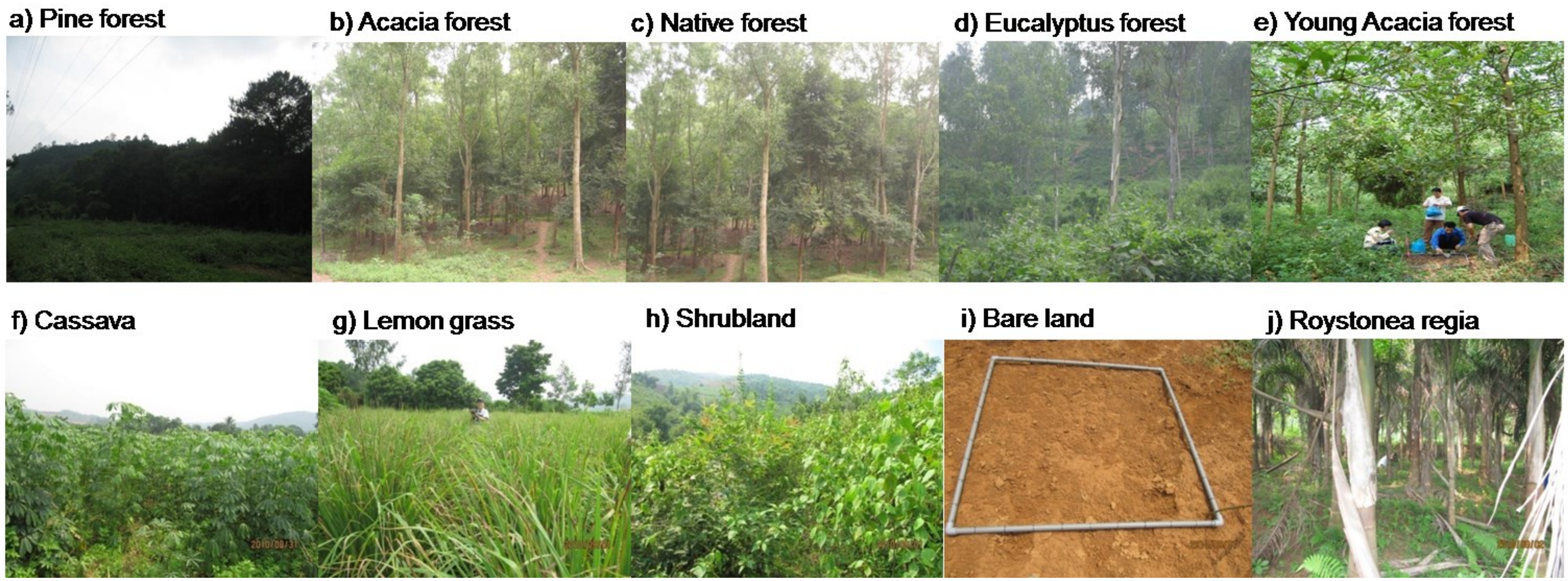


Figure 2.2. Photos of each land use: a) Pinus massoniana forest; b) >20-year old Acacia mangium forest; c) native forest; d) Eucalyptus exserta forest; e) young Acacia spp. forest; f) cassava; g) lemon grass; h) shrub land; i) bare land; and j) Roystonea regia.

Table 2.1. List of land use types, dominant vegetation, duration of land use, slope, canopy openness, and surface cover. Values are means of three plots and values in parentheses are the standard deviation.

No.	Categories	Vegetation type	Duration of land use (years)	Slope (degrees)	Canopy openness (%)	Understory biomass (g m^{-2})	Litter biomass (g m^{-2})	Total ground cover (%)
1	*Pinus massoniana*	*Pinus massoniana*	> 20	21 (14)	12 (4)	10 (9.7)	260 (75)	63 (15)
2	*Acacia mangium*	*Acacia mangium*	> 20	11 (5)	14 (5)	115 (67)	180 (51)	76 (2)
3	Native forest	*Elaeocarpus dubius*	15	13 (9)	7 (2)	90 (93)	320 (70)	83 (4)
4	*Eucalyptus*	*Eucalyptus exserta*	> 20	19 (8)	18 (3)	80 (34)	260 (97)	79 (12)
5	Acacia spp	*Acacia mangium*	3	20 (6)	34 (7)	230 (54)	265 (100)	100 (0)
6	Cassava	*Manihot esculenta*	5	5 (2)	29 (11)	55 (20)	265 (140)	63 (28)
7	Lemon grass	*Cymbopogon marginatus*	10	4 (2)	59 (6)	65 (128)	115 (433)	79 (14)
8	Shrub	Various types of low shrubs	5 - 10	20 (2)	59 (6)	375 (63)	1020 (107)	91 (5)
9	Bare land	Not applicable	10	28 (9)	84 (0)	2 (2.8)	0	1 (1)
10	*Roystonea regia*	*Roystonea regia*	5	3 (3)	10 (4)	25 (22)	50 (44)	55 (23)

The area to be sampled for each land use type was selected to be representative of the typical conditions based on local knowledge, and was selected to have similar lithology, soils, and climate. Once a representative land use type was selected, three plots were located from about 10-50 m apart in “typical” conditions. A random selection of land use types was not possible because of the need to obtain permission for sampling, maintain close proximity and comparable conditions, and to avoid areas that had been fertilized or were otherwise not appropriate to the objectives of the study. Three 1 x 1 m plots were established for each land-use type because the primary goal of the study was to compare the variation among a wide variety of land uses rather than to conduct a more detailed sampling of a few land use types, and three plots were thought to be sufficient to identify the potentially large differences between land uses.

2.2.2. Field data collection and measurement of soil parameters

Field data were collected towards the end of the growing season in August-September 2010. In each plot we measured the overstory canopy cover, understory biomass, litter biomass, ground cover, and a variety of soil physical and chemical properties. Overstory canopy openness was measured from hemispherical photographs taken 50 cm above the ground surface with an 8-mm fish-eye lens using Gap Light Analyzer (Frazer et al., 1999) (Figure 2.3). Understory biomass was measured by clipping all live leaves and branches from the ground surface to a height of 50 cm, and litter biomass was removed by hand (Figure 2.4). Both the understory biomass and litter samples were oven-dried for 12 h at 105^{o}C and weighed to obtain the dry mass. Ground cover by vegetation plus litter within the plots was calculated by a digital analysis of pictures taken from 50 cm above the ground using Adobe Photoshop CS (Chu et al., 2010) (Figure 2.5). Mean slope was calculated from three measurements in each plot with a clinometer.

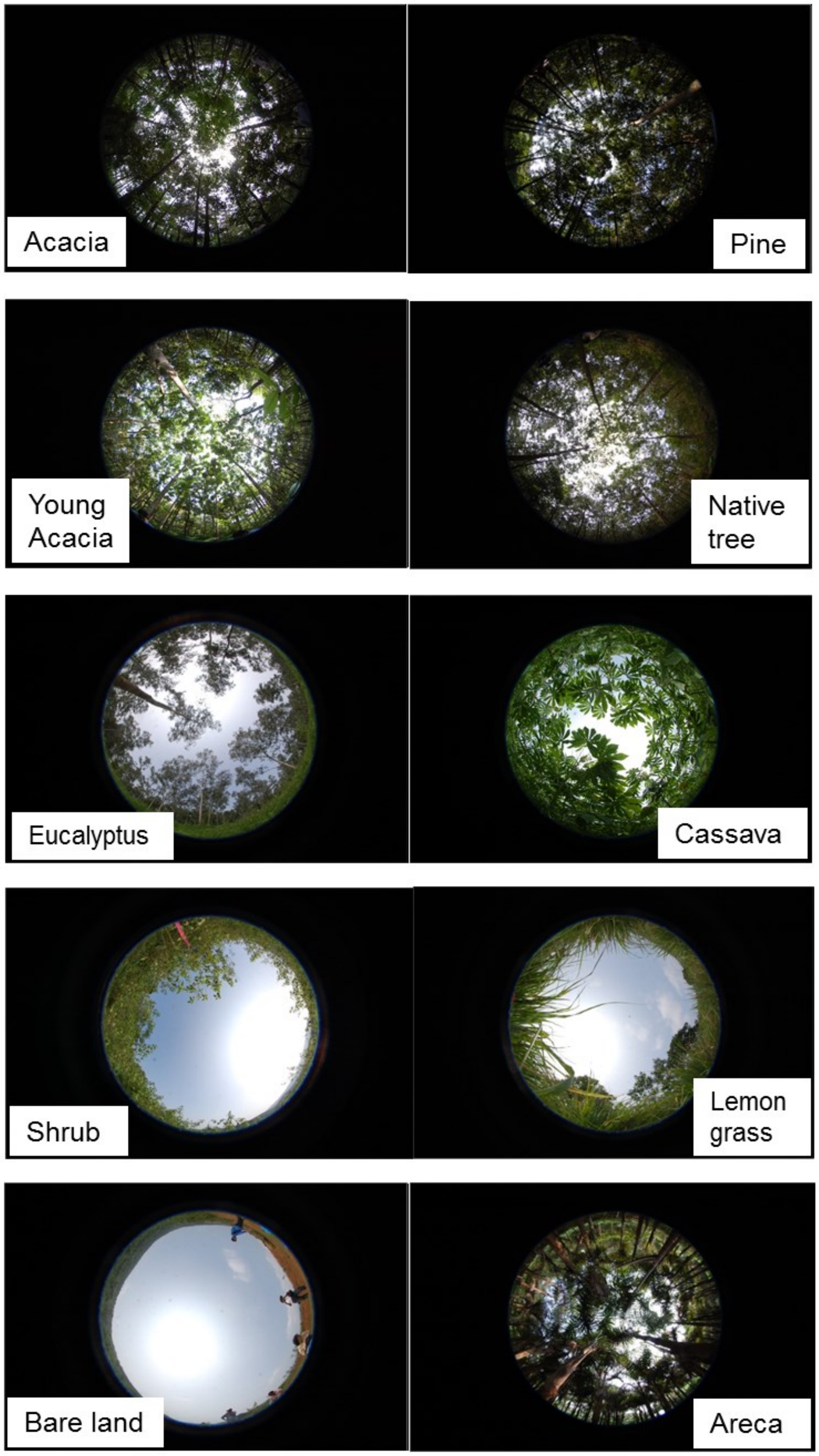


Figure 2.3. Hemispherical images for analysis canopy openness

Figure 2.4. Overviews of understory vegetation and litter collection

Figure 2.5. 1 x 1 m^2 plots images for analysing vegetation and litter ground cover

Soil pedestal height, soil hardness, and soil moisture content of the surface soil were measured at the end of rainy season in September at three locations in or immediately adjacent to the plots. Soil hardness (cm) was measured using a push-cone hardness indicator (Daiki Rika Kogyo, Saitama, Japan), and converted to Pascals. Mean soil moisture content from 0–12 cm was measured at three locations in each plot using a CS620 Hydrosense probe (Campbell Scientific, USA). The mean height of three representative pedestals in each plot was assumed to represent the soil erosion during the May to August monsoonal rainy season (Sidle et al., 2004) (Figure 2.6).

Figure 2.6. Soil pedestal measurement

Two soil samples were taken from each plot (Figure 2.7). First, a bulk density sample 5 cm in diameter from a depth of 0-5 cm was taken, and this was dried at 105^{o}C for 48 hours to determine the dry mass. The second soil sample was taken in the center of each plot using a PVC cylindrical soil sampler that was 11.7 cm in diameter and 5.35 cm long, and this sample were used to determine soil texture as well as macronutrient and radionuclide concentrations. After air drying for a few days the larger pieces of organic matter such as roots were removed from this sample by hand. The particle-size distribution of the coarser particles was determined by dry sieving with meshes of 10.0, 5.0, and 2.0 mm. One gram of the fraction less than 2 mm was mixed with 6% H_2O_2 and the clay, silt, and sand fractions were determined using a laser diffraction particle-size analyzer (SALD-3100, Japan).

Figure 2.7. Overview of soil sample collection

The remainder of the fraction < 2 mm was used to determine soil organic carbon (SOC), soil organic nitrogen (SON), and soil organic phosphorous (SOP) following (Bremner, 1996; Kuo, 1996; WALKLEY, 1947), respectively. The resulting mean percentages of SOC and SON for each land use were converted to C and N storage in grams per square meter using the area and depth of the soil sample and the mean bulk density.

Long-term soil erosion rates were estimated using two radionuclides, ^{137}Cs and $^{210}Pb_{ex}$. A representative fraction (< 2 mm) of each dry sample was placed in a plastic pot for more than 20 days to achieve equilibrium conditions prior to analysis (Pennock and Appleby, 2010; Mizugaki et al., 2012). Each sample was analyzed with a high-resolution gamma-ray spectrometry system (GWL-120-15; ORTEC, Oak Ridge, TN, U.S.A.) coupled with a multichannel analyzer (EG&G MCA7600; SEIKO, Tokyo, Japan). The ^{137}Cs and $^{210}Pb_{ex}$ concentrations in Bq g^{-1} and Bq m^{-2} were calculated following Pennock and Appleby (2010). In general, the continuous fallout of $^{210}Pb_{ex}$ and the pulsed fallout of ^{137}Cs are rapidly and strongly adsorbed by clay minerals and organic matter, so the depth profile of $^{210}Pb_{ex}$ shows an exponential decline with depth and most of the measured $^{210}Pb_{ex}$ is in the top few centimeters (Wakiyama et al., 2010). Over time, however, the radionuclides can be mixed within the soil profile by biological processes such as earthworms or treethrow, or physical processes such as ploughing or terracing. For a given site the total inventory of $^{210}Pb_{ex}$ and ^{137}Cs will only change due to radioactive decay if there is neither erosion nor deposition (Zhang et al., 2006). While a complete inventory of radionuclides requires sampling throughout the soil profile, the high concentration of radionuclides at the soil surface means that our sampling from 0 to 5.35

cm should provide a reasonable approximation of the total inventory and a relative index of erosion rates among the different land uses. The surface inventory was calculated by:

$$I_s = C\,Bd\,D_2\,d \qquad [1]$$

where I_s is surface inventory in Bq m^{-2}, C is radionuclide activity in Bq kg^{-1}, Bd is the soil bulk density in kg m^{-3}, D_2 is defined as the percent of soil particles less than 2 mm in diameter, and d is the sampling depth.

The duration of individual land-use types was determined from field observations, local knowledge, and land-use classification using remote sensing. Most of forest age was estimated to be 25 years because the area around VFU campus had been cultivated land or grassland prior to the establishment of VFU in 1984. The duration of agricultural land use was determined by analyzing LANDSAT Thematic Mapper (TM) images by LANDSAT-5 taken on 27 December 1993, 17 September 2000, and 8 November 2007 (Figure 2.8). The resolution of the LANDSAT-TM images from visible to short wavelength infrared (bands 1 to 5) was 30 m. We applied an unsupervised classification with an iterative self-organizing data analysis algorithm using bands one to five (Yang, 2007). Topographic features such as ponds and road junctions around the VFU campus were used as geographical reference points. All of the image analyses were conducted using the Multi-Spec software package (Biehl and Landgrebe, 2002). Because some land classifications may appear to be similar to each other, we conducted a ground-truth calibration for land use types, particularly for the 2007 image. Images taken in 1993 and 2000 were ground-truthed by interviews with local people.

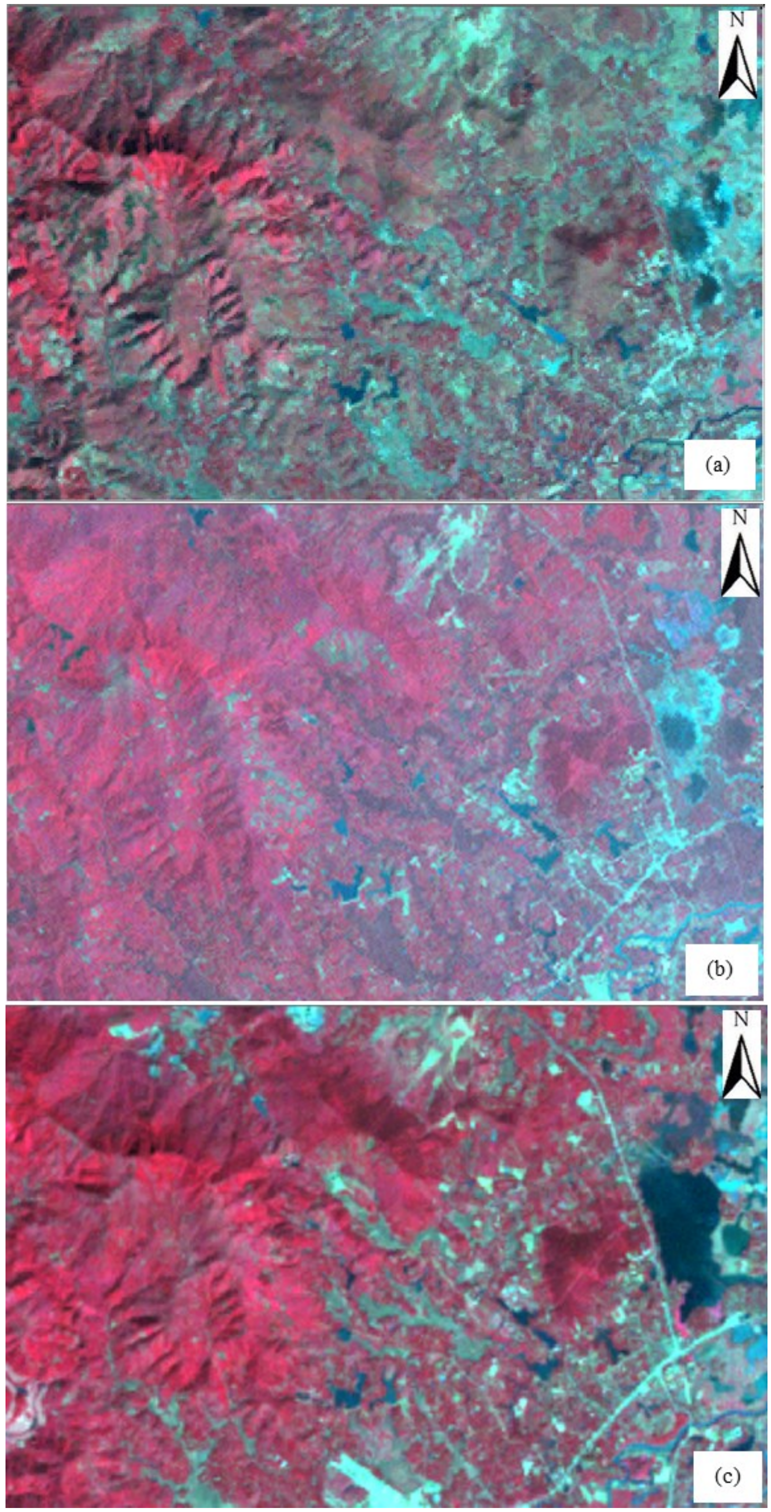


Figure 2.8. False color composite map of Landsat TM image: (a) 1993, (b) 2000, (c) 2007

2.2.3. Statistical analysis

Pearson's correlation coefficients were calculated to characterize the relationships between the various vegetation and soil properties. Principal component analysis (PCA) also was used to identify the main factors controlling soil erosion and nutrient accumulations, and to reduce the number of soil-vegetation variables. Only components with eigenvalues greater than unity were selected to determine the main components. Variables with absolute eigenvector coefficients ≥ 0.70 were selected and considered significant in each component (Wotling et al., 2000). Multivariate statistical analysis was conducted using the SPSS software package (Ver. 19.0).

2.3. Results

2.3.1. Land use history, vegetation properties and soil characteristics

The remote sensing analysis indicated that the *Pinus massoniana*, *Acacia mangium*, and *Eucalyptus exserta* forests around VFU had been present for more than 20 years (Table 2.1). The duration of other land uses ranged from 3 to 15 years (Table 2.1). Canopy openness ranged from 84% to 7%, with bare land having the highest openness followed by lemon grass and shrub land at nearly 60%, then cassava and Acacia spp. at about 30%, and all the other forest types had less than 20% canopy openness (Table 2.1). Mean plot slopes were less than 5 degrees for the agricultural and bare land as well as the terraced *Roystonea regia* plots, while the shrub and other forest land uses had mean slopes of 11 to 28 degrees (Table 2.1)

Understory biomass ranged from 2 g m^{-2} for bare land to 375 g m^{-2} for shrub land (Table 2.1; Figure 2.9). Forest and shrub lands generally had high understory biomass compared with agricultural land, except for *Pinus massoniana* and *Roystonea regia*. *Pinus massoniana* had the lowest understory biomass at 10 g m^{-2} but similar litter biomass to the other forest types. *Roystonea regia* also had very little understory biomass and litter. Litter biomass was highest in the shrub land at 1020 g m^{-2}, whereas the mass of litter in the forest plantations except for *Roystonea regia* ranged from 180 to 325 g m^{-2} (Table 2.1). Understory dry mass and litter dry mass were significantly correlated, but this was largely due to the one point from the shrub land plots (Figure 2.9).

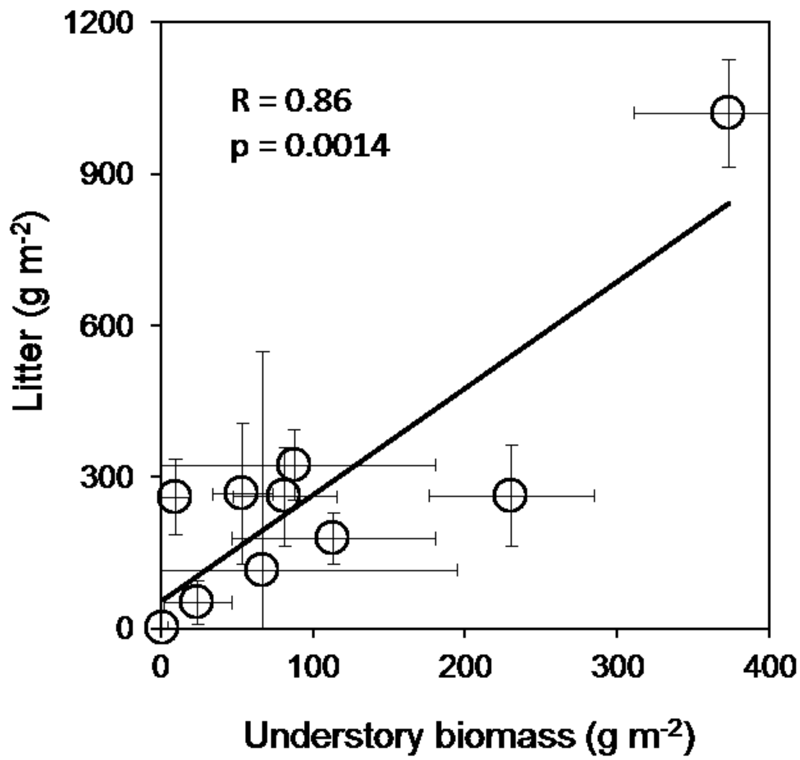


Figure 2.9. Relationship between the dry mass of litter (g m^{-2}) and the understory biomass (g m^{-2}). Circles indicate the mean of each land-use type, and the bars indicate the standard error of each land-use type

Mean percent ground cover was highest in the shrub land plots at 91%, while ground cover in the forest plots ranged from 55% in *Roystonea* to 83% in the indigenous forest. Cassava and lemon grass had 63% and 79% ground cover, respectively, indicating no clear difference in ground cover between the latter stages of these crops and the various forest types (Table 2.1). Mean percent ground cover was correlated with understory biomass ($r = 0.51$) and inversely correlated with canopy openness ($r = -0.44$), but these correlations were not statistically significant.

Soil texture did not vary greatly among the land-use types, as percent silt plus clay was always at least 74% (Table 2.2). Lemon grass had the lowest mean clay content and the highest mean sand content. Whereas cassava had the highest mean clay content and the lowest percent sand (Table 2.2). Notably, the bare land also had relatively high mean percent sand at nearly 26% (Table 2.2).

Table 2.2. Mean soil texture, bulk density, soil hardness, water content, and pedestal height by land use type

	Clay (%)		Silt (%)		Sand (%)		Soil bulk density (g cm^{-3})		Soil hardness (mm)		Soil water content (%)		Soil pedestal height (cm)	
	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]
Pinus massoniana	17.4	1.1	61.6	0.8	21.0	0.5	0.98	0.13	10.6	1.3	23.3	9.5	3.0	0.6
Acacia mangium	23.7	4.4	56.7	3.2	19.5	3.0	1.02	0.08	12.0	2.3	33.1	8.3	0.6	1.0
Native forest	20.2	1.5	59.1	1.4	20.7	0.6	1.02	0.04	9.7	3.8	29.4	1.7	0.0	0.0
Eucalyptus	13.4	3.5	63.6	1.9	23.1	1.7	1.14	0.15	10.6	4.6	25.9	6.0	0.0	0.0
Acacia spp.	14.9	6.1	63.0	2.6	22.2	3.5	0.86	0.08	7.9	3.4	17.6	3.3	0.0	0.0
Cassava	30.3	0.6	53.7	0.7	16.0	0.3	1.17	0.03	6.7	2.1	15.6	2.7	1.8	0.6
Lemon grass	13.2	2.3	61.1	1.0	25.7	1.6	1.00	0.03	15.8	0.7	44.7	4.4	0.0	0.0
Shrub	14.1	1.9	65.1	1.7	20.8	0.6	1.31	0.10	10.1	1.3	35.6	5.6	0.0	0.0
Bare land	19.1	4.4	55.4	3.1	25.5	1.5	1.02	0.12	15.2	0.9	32.4	2.0	3.3	0.2
Roystonea regia	17.7	2.2	58.9	1.4	23.4	1.2	1.18	0.06	13.2	2.2	50.4	2.5	1.1	0.3

[a] The standard deviation

Soil bulk densities ranged from 0.86 to 1.31 g cm^{-3} with the highest bulk density being in the shrub land (1.31g cm^{-3}), followed by *Roystonea regia* (1.18 g cm^{-3}) (Table2.2). Soil bulk densities in the forest land types ranged from 0.98 to 1.18 g cm^{-3}, with the highest density in the *Roystonea regia* stands and the lowest in *Pinus massoniana* and *Acacia* ssp.

Soil hardness was highest in the lemongrass and bare land at over 15 mm or more than 18 MPa. The forest and shrub lands generally had values below 11 mm except for the *Roystonea* plots at 13 mm and the *Acacia mangium* plots at 12 mm (Table 2.2). There was no clear pattern in mean soil water content between the plots (Table 2.2), and this can be attributed to the varying rainfall over the sampling period.

2.3.2. Soil organic carbon, nitrogen, and phosphorus

Measured SOC, SON, and SOP were relatively high in lemon grass, young *Acacia* spp. and *Acacia mangium* plots, whereas they were low in *Eucalyptus exserta,* cassava, and *Roystonea regia* plots, except for the normal SOP level in the *Roystonea regia* plots (Table 2.3). The highest mean SOC was 5.2% in the lemon grass land, followed by 4.8% in *Acacia* spp. forest. *Roystonea regia* had the lowest SOC at 0.9%, and this can be ascribed to the disturbance due to terracing. Similarly, the highest SON was found in *Acacia* spp., lemon grass, and *Acacia mangium* plots at 0.29, 0.27 and 0.26%, respectively, while the lowest mean SON was in the *Roystonea regia* plots (Table 2.3). *Eucalyptus* had relatively low SON and the lowest SOP at 0.09%, whereas the highest mean SOP was for *Acacia mangium* at 0.49%. Bare land also had low macronutrient values with 2.39% SOC, 0.14% SON, and 0.24% SOP. C/N ratios all fell between 15.4 and 17.7 except for the very low value of 10.6 for *Roystonea regia* and the relatively high value of 19.1 for lemon grass due to its very high value for SOC (Table 2.3).

Table 2.3. Mean soil organic carbon, organic nitrogen, C/N ratio, organic phosphorus, and $^{210}Pb_{ex}$ values per kilogram and per square meter by land use type

	SOC (%)		SON (%)		C/N ratio		SOP (%)		$^{210}Pb_{ex}$ (Bq kg^{-1})		$^{210}Pb_{ex}$ (Bq m^{-2})		$^{210}Pb_{ex}$ (Bq kg^{-1})		$^{210}Pb_{ex}$ (Bq m^{-2})	
	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]
Pinus massoniana	3.18	0.19	0.19	0.01	16.6	0.4	0.24	0.03	116.1	16.9	5678	825	ND[b]	ND[b]	ND[b]	ND[b]
Acacia mangium	4.41	1.63	0.26	0.07	17.0	3.0	0.49	0.15	90.4	25.7	4632	1319	ND[b]	ND[b]	ND[b]	ND[b]
Native forest	3.41	0.27	0.20	0.01	17.1	0.4	0.30	0.20	84.0	31.9	4280	1625	ND[b]	ND[b]	ND[b]	ND[b]
Eucalyptus	1.98	0.31	0.13	0.04	15.4	0.8	0.09	0.01	82.4	19.5	4697	1112	ND[b]	ND[b]	ND[b]	ND[b]
Acacia spp.	4.79	0.47	0.29	0.03	16.4	1.5	0.40	0.09	45.5	17.6	1957	759	ND[b]	ND[b]	ND[b]	ND[b]
Cassava	1.92	0.06	0.12	0.01	15.7	1.3	0.19	0.14	42.3	3.6	2476	213	3.2	2.8	159	4
Lemon grass	5.17	0.72	0.27	0.00	19.1	1.1	0.33	0.02	39.0	11.9	1951	593	ND[b]	ND[b]	ND[b]	ND[b]
Shrub	2.48	0.22	0.16	0.01	15.5	1.8	0.44	0.06	77.4	22.2	5067	1453	ND[b]	ND[b]	ND[b]	ND[b]
Bare land	2.39	0.55	0.14	0.03	17.7	2.2	0.24	0.11	32.0	38.1	1634	1941	ND[b]	ND[b]	ND[b]	ND[b]
Roystonea regia	0.79	0.11	0.07	0.01	10.6	0.3	0.35	0.11	ND[b]	ND[b]	ND[b]	ND[b]	ND[b]	ND[b]	ND[b]	ND[b]

[a] The standard deviation

[b] Not detected

2.3.3. Soil pedestals and radionuclide concentrations

Soil pedestal heights varied from 0.0 to 3.3 cm (Table 2.2). Soil pedestals were highest in the mature *Pinus massoniana* forest (3.0 cm) and on bare land (3.3 cm) where the understory biomass and percent ground cover were both low (Figure 2.10; Table 2.1). Soil pedestal heights were 1.8 cm and 1.1 cm in the cassava and *Roystonea regia* plot, respectively, and both of these land uses also had relatively low values for understory biomass and percent ground cover (Table 2.1). In contrast, no soil pedestals were found in the indigenous forest, *Acacia* spp. forest, *Eucalyptus exserta* forest, shrub land, or lemon grass; each of these land uses had relatively high percent ground cover (Table 2.1, Table 2.2). A plot of soil pedestal height against understory biomass showed that the highest pedestals were associated with the lowest understory biomass and lowest percent ground cover (Figure 2. 10).

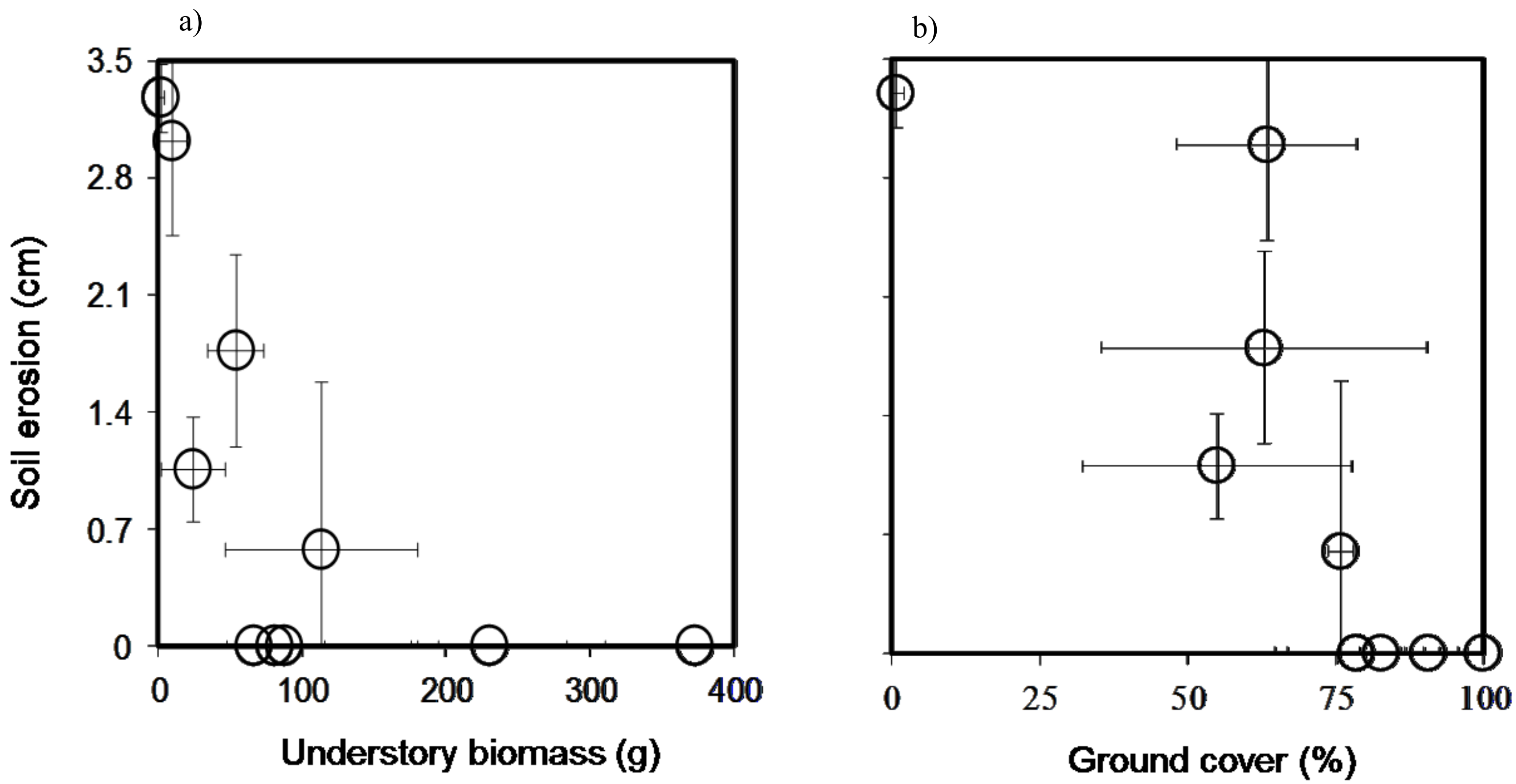


Figure 2.10. Relationship between soil erosion as indicated by soil pedestal height (cm) and a) understory biomass (g); and b) ground cover (%). Circles indicate the mean of each land-use type, and bars indicate standard errors

Measured $^{210}Pb_{ex}$ varied from 0 to 116 Bq kg^{-1}, and this converts to 0 to 5678 Bq m^{-2} (Table 2.3). The concentration of $^{210}Pb_{ex}$ generally was highest in the forest and shrub lands, and substantially lower values in agricultural and bare land (Table 2.3). *Roystonea regia* had the lowest amount of $^{210}Pb_{ex}$ (not detected), and this can be attributed to the terracing. The lower rates in the bare and agricultural lands are due to some combination of erosion, as indicated by the pedestal heights, and land disturbance, such as ploughing. Within these broad groups there was not a consistent pattern in the relationship between the amount of $^{210}Pb_{ex}$ and percent ground cover, as the highest $^{210}Pb_{ex}$ values were in *Pinus massoniana* and *Eucalyptus exserta*, even though these two forest types did not have the highest ground cover (Table 2.1 and Table 2.3), and *Acacia* spp. a relatively low mean $^{210}Pb_{ex}$ value but 100% ground cover. Since measurable amounts of ^{137}Cs were only detected in the cassava plots (3.2 Bq kg^{-1} or 159 Bq m^{-2}), the statistical analysis only used the $^{210}Pb_{ex}$ values.

2.3.4. Correlation and ordination

The correlation analysis showed a strong and significant positive correlation between understory biomass and the amounts of litter (r = 0.86), SOC, and SON (Table 2.4). In contrast, the amount of litter was positively but not significantly related to SOC and SON. Bulk density was negatively correlated with SOC (r = -0.70) and SON (r = -0.70) as well as percent slope (Table 2.4) (r = -0.74). $^{210}Pb_{ex}$ was not significantly correlated with any of the other variables, although SOC tended to increase with increasing $^{210}Pb_{ex}$ (Figure 2.11 and Figure 2.12).

Table 2.4. Correlation table for the physical and chemical characteristics measured in this study

	Understory biomass	Litter biomass	Canopy openness	Total ground cover	Soil hardness	Soil water content	Bulk density	SOC	SON	SOP	C/N ratio	Clay content	Soil pedestal height	Slope	$^{210}Pb_{ex}$
Understory biomass	-	***.860***	.202	.502	.207	.155	-.410	***.780***	***.746***	.279	.484	-.363	-.591	.199	-.151
Litter biomass		-	.114	.361	.270	.175	-.288	.627	.541	-.029	.541	-.208	-.379	.202	.002
Canopy openness			-	-.437	.451	.152	.056	.126	.050	.043	.428	-.252	.219	.411	-.346
Total ground cover				-	-.513	-.174	-.008	.429	.508	.340	.011	-.260	***-.818***	-.387	.356
Soil hardness					-	***.785***	-.082	.101	-.002	.108	.166	-.323	.175	.380	-.305
Soil water content						-	.294	-.127	-.183	.353	-.295	-.334	-.171	-.212	-.427
Bulk density							-	***-.697***	***-.701***	-.074	-.511	.111	-.123	***-.737***	-.108
SOC								-	***.987***	.447	***.759***	-.229	-.330	.441	.295
SON									-	.501	***.679***	-.249	-.373	.387	.317
SOP										-	-.002	-.150	-.336	-.279	-.027
C/N ratio											-	-.018	.030	***.644***	.402
Clay content												-	.364	-.306	.0.031
Soil pedestal height													-	.395	-.021
Slope														-	.139
$^{210}Pb_{ex}$															-

Note: Values in italics and bold are significant at $p<0.05$

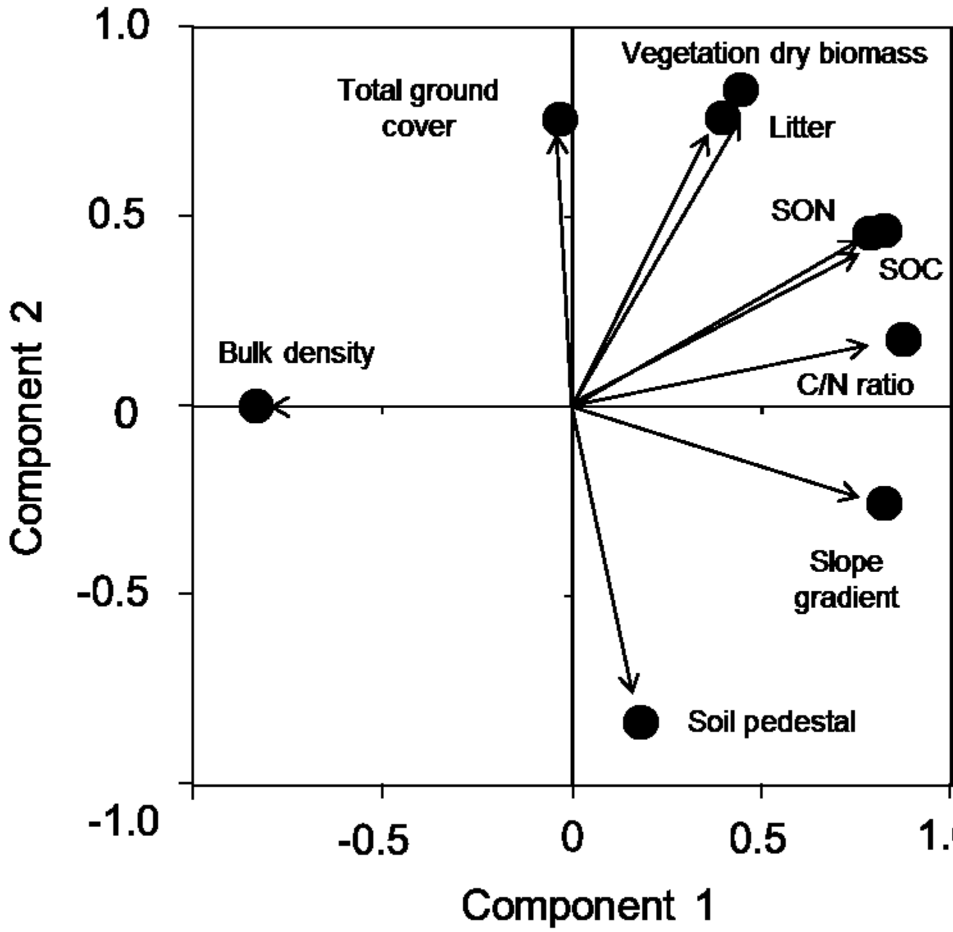


Figure 2.11. Ordination plot by principal components analysis. Components 1 and 2 represent 28% and 21% of the total variance, respectively

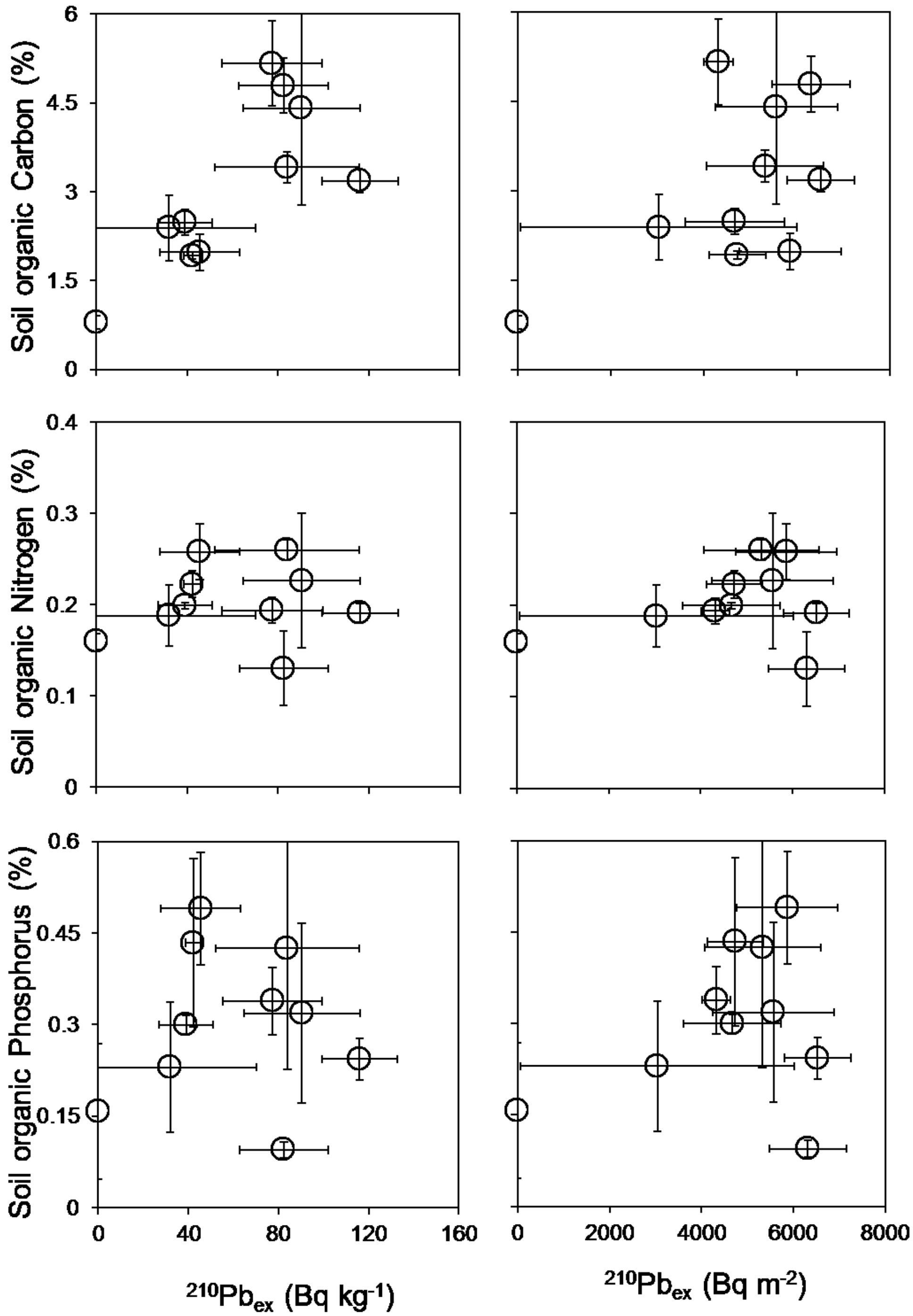


Figure 2.12. Relationship between $^{210}Pb_{ex}$ in Bq kg^{-1} and Bq m^{-2} and a) SOC, b) SON, and c) SOP. Circles indicate the mean of each land-use type, and the bars indicate the standard error

Five principle components explained 87.6% of the observed variation in the soil and vegetation data (Table 2.5; Figure 2.11). The first component had high positive loadings for SOC, SON, C/N ratio, and slope, and a strong negative loading for soil bulk density (Table 2.5). This component reflects the soil chemical status and physical degradation due to terracing or cultivation, and it explained 28% of the total variance. The second component had positive loadings on understory biomass, mass of litter and total cover, and a negative loading on soil pedestal height (Table 2.5). This component is an indicator of soil cover and short-term soil erosion, and it accounted for an additional 21% of the total variance. The third component was dominated by $^{210}Pb_{ex}$ (-0.79), which was indirectly related to ground cover. The fourth and fifth components were dominated by clay content and total phosphorus, and each of these last three components explained between 11 and 16 percent of the total variance (Table 2.5).

Table 2.5. Results of PCA. Variables underlined with absolute eigenvector coefficients ≥ 0.70 are considered significant

	Rotated Component Matrix				
	Component				
	1	2	3	4	5
Understory biomass	0.443	**0.836**	0.242	0.118	0.124
Litter biomass	0.396	**0.761**	0.242	0.137	-0.168
Canopy openness	0.282	-0.068	0.681	0.151	-0.096
Total ground cover	-0.034	**0.758**	-0.597	-0.021	0.221
Soil hardness	0.156	-0.130	0.649	0.653	0.127
Soil water content	-0.356	0.095	0.505	0.613	0.384
Bulk density	**-0.836**	0.002	0.052	0.026	-0.080
Total carbon	**0.820**	0.465	-0.061	0.031	0.323
Total nitrogen	**0.782**	0.459	-0.163	0.004	0.381
Total phosphorus	0.080	0.152	0.009	0.040	**0.966**
C/N ratio	**0.870**	0.178	0.087	-0.036	-0.133
Clay content	-0.096	-0.284	0.064	**-0.875**	0.069
Soil pedestal height	0.180	**-0.833**	0.247	-0.154	-0.237
Slope	**0.821**	-0.256	0.155	0.295	-0.318
$^{210}Pb_{ex}$	0.350	-0.093	**-0.790**	0.107	-0.063
Eigenvalues	4.17	3.21	2.37	1.75	1.64
Variance (%)	27.8	21.4	15.8	11.7	10.9
Cumulative explanation	27.8	49.2	65.0	76.7	87.6

2.4. Discussion

2.4.1. Interactions between understory biomass, litter, and soil properties

Understory biomass tended to be lower in agricultural land than most forest types, but both *Pinus massoniana* and *Roystonea regis* had very low understory biomass. Like some forest types in Japan (Gomi et al., 2008; Hiraoka and Onda, 2012), these two forest types both had a relatively dense canopy that limits solar radiation and the growth of understory vegetation. *Roystonea regis* also had relatively little understory biomass and also very low litter biomass, and this may be due to the fact that this was a relatively young stand. In contrast, the native forest (*Elaeocarpus dubius*) had the highest canopy cover, but still had a moderate amount of understory biomass and a high litter mass and ground cover.

Percent ground cover showed the expected positive relationships with understory biomass and litter and decrease with increasing canopy openness (Table 2.4), but these relationships were not significant due to the variation in forest ages and trade-offs between understory biomass and overstory openness. For example, *Acacia mangium* had a more open canopy but a higher understory vegetative biomass and the highest ground cover (Table 2.1). This shows how different forest types can vary greatly in the amount of canopy cover, understory biomass, and litter biomass, and that there can complex interactions between canopy openness, understory vegetation, the amount of litter, percent cover, and forest age. Even greater complexity is introduced by the variability in the agricultural crops, as cassava had less canopy openness and therefore less understory biomass and less surface cover than lemon grass, but it had much more litter biomass (Table 2.1). Shrub lands tended to be intermediate with high canopy openness but also high understory and litter mass, resulting in more than 90% ground cover. This makes simple generalizations difficult, except for bare land having very little overstory, biomass, and percent cover.

Soil organic carbon and nitrogen were most strongly correlated with understory biomass rather than litter biomass or ground cover (Table 2.3). Litter biomass was much more closely correlated with understory biomass than canopy openness (Table 2.4), and the combination of higher litter and understory biomass can produce more soil nutrients via decomposition processes. Soil bulk density was significantly and negatively correlated with soil nutrients (Table 2.4), and again the variability among forest types is striking. For example, *Acacia* spp. has a high SOC (4.79%) and a very low bulk density of 0.86 g/cm^3, whereas *Roystonea regia* has a low SOC (0.79 %) and a high soil bulk density of 1.18 g/ cm^3 (Table 2.2). The The first axis in the principle component analysis clearly showed the strong contrast between bulk density and soil macronutrients, and the inverse relationship between soil macronutrients and bulk density can be explained in part by the increased in soil microbial activities and root development with higher nutrient levels, which create more and larger soil pores that decrease soil bulk density (Lister et al., 2004). A denser vegetative cover also affects soil physical properties due to litter production and root development (Guidi et al., 1985; Hiraoka and Onda, 2012). Since both SOC and SON can be mobilized in porous spaces within the soil matrix, low bulk density of soil can stored a higher amount of SOC and SON. Our results agree with previous studies of soil carbon storage in various land uses. Abera and Belachew (2011) found that carbon stores in forest soils were about twice the values in agriculture soils. Similarly, John et al., (2005) reported that forests had 52% more soil carbon content than grassland soils.

2.4.2. Soil erosion by land-use type

Soil pedestal heights indicated that short-term soil erosion was greatest in the four land use types with the least understory biomass (Figure 2.10). The correlation analysis showed that pedestal height was most strongly related to percent ground cover, as the four land uses with the highest pedestal heights did not have more than 63% ground cover (Table 2.1 and Table 2.2), while none of the land uses with more than 76% cover had any soil pedestals. Other studies also have shown soil erosion under a forest canopy with sparse understory vegetation and ground cover (Miyata et al., 2009). Taken together, these results indicate that both understory biomass and ground cover are important for reducing rainfall kinetic energy and rain splash, but ground cover is more important. This result is supported by both modeling and field studies that show a strong, nonlinear relationship between percent surface cover and erosion (Miller et al., 2009; Miyata et al., 2009). The main difference between these other studies and our data set in Figure 2.10b is that the threshold for no erosion is at least 76% ground cover. This relatively high value can be attributed to the much higher amounts and intensities of rainfall in the study during the summer monsoon rainy season.

The $^{210}Pb_{ex}$ inventories for four of the forest types in our study and the shrublands ranged from 4280 to 5678 Bq m^{-2}, even though this was only measured in the top 5.35 cm. The very low value for *Roystonea regia* can be attributed to the effect of terracing, while it not clear why the $^{210}Pb_{ex}$ value for *Acacia* spp. is so low as there was no evidence of soil pedestals. For comparison, the $^{210}Pb_{ex}$ inventories for 0 to 30 cm at reference sites in Indonesia were nearly identical to most of our forest values at 4122 to 5322 Bq m^{-2}. Other comparisons also indicate that the $^{210}Pb_{ex}$ inventories for four of our forest types and the shrub lands are generally within the range of reference conditions for a monsoon tropical climate (Wakiyama et al., 2010; Zhang et al., 2006). The lack of any detectable ^{137}Cs in nine of the ten land use types suggests that this is due to very low levels of ^{137}Cs fallout (Dercon et al., 2012; Uchida et al., 2009) rather than excessive erosion. Taken together, these results indicate that erosion rates for most of the forested areas on Luot Mountain have generally been low for much longer than the age of the current tree plantations and the replanted native forest.

The low $^{210}Pb_{ex}$ contents in agricultural and bare lands were attributed to erosion by rain splash and overland flow, and this is supported by the observed pedestal heights in the cassava and bare land. Since silt-sized particles comprise 55-65% of the fine (<2 mm) fraction, the soil is highly susceptible to rain splash and the resultant transport of small particles (Miller et al., 2009). Bare land is also susceptible to soil sealing, and the increase in rain splash and overland flow are key reasons why soil erosion rates generally are so much higher in agricultural lands than forests (Montgomery, 2007). No pedestals were observed in the lemon grass plots, but previous agricultural activities may be responsible for the current low inventory of $^{210}Pb_{ex}$. Because the spatial variability of soil erosion and radionuclide deposition can be high (Belyaev et al., 2009; Dercon et al., 2012), additional radionuclide data should be collected to confirm our initial results.

2.4.3. Linkages of vegetation, macronutrients and soil erosion

Our findings suggest that the changes in land management and the associated changes in understory and ground cover can alter soil physical properties, macronutrient contents, and both short- and long-term soil erosion rates. Production of SOC, SON comes from vegetation.

SOC then will be stored in soil. However, SON becomes available for Nitrogen cycle and usage processes. Therefore only a little will be stored. When soil erosion occurs, SOC loss increase with increase of soil loss but not in SON (Figure 2.13). The decrease in understory vegetation and ground cover is believed to be the primary cause of the increase in soil erosion and decrease in macronutrients (Table 2.4). Similarly, soil chemical richness is strongly linked to understory biomass litter biomass, and possibly the degradation of soil physical properties as exemplified by bulk density.

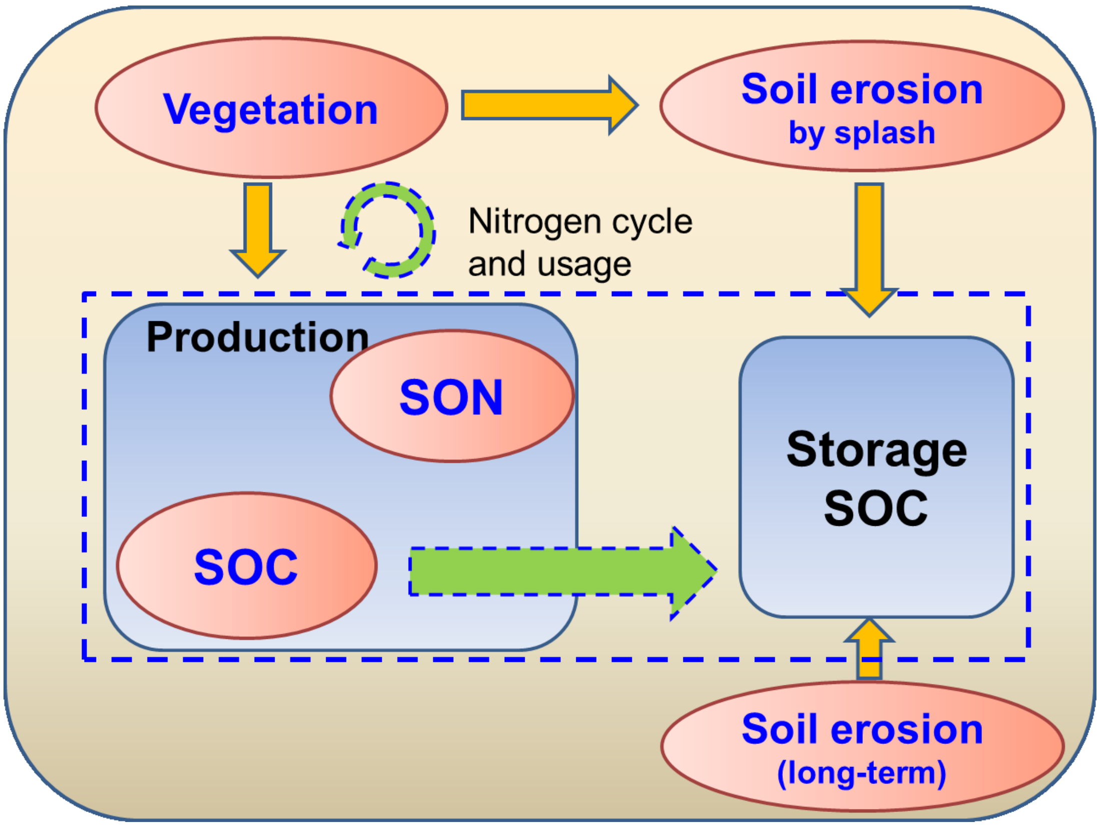


Figure 2.13. The interaction among understory vegetation, nutrients and soil erosion in Vietnam study

The linkages among vegetation, macronutrients and soil erosion also can be seen in component 2 of PCA which indicates vegetation condition and the short-term soil erosion in ten land-use types (Table 2.5). In general, each principal component in PCA is a group of linkable variables with similarity. In this component the effect of vegetation was quantified through the high positive loadings of understory biomass, litter biomass, and total ground cover, and soil pedestal height had an equivalent negative loading (Figure 2.11). The relative highest loadings were soil erosion indicator (soil pedestal height), and vegetation (known as understory biomass, litter and total ground cover), followed by soil nutrients such as total carbon and macronutrient (SOC and SON) in component 2, which indicates their tight linkage. Previous studies have shown that soil vegetation cover alters SOC and SON (VanderSchaaf et al., 2004). In flatter downslope areas deposition can enrich SOC and radionuclide inventories (Frye et al., 1982), but all of our plots were in sloping source areas. An upslope-downslope design focusing on a few land use types would be necessary to quantify both the loss and the redistribution of soils and macronutrients, and thereby apply the present results to larger scales.

2.5. Summary and conclusions

Soil organic carbon and nitrogen were strongly related to the amount of understory biomass than the amount of litter, although there was a strong correlation between the amount of litter and understory biomass. The amount of ground cover was a more complex function as this was positively but not significantly correlated with both understory biomass and litter biomass, and inversely related to canopy openness. Soil organic carbon and nitrogen levels significantly declined with increasing bulk density and this may be a reflection of both current and prior land use activities. Soil pedestal height was most closely related to the amount of ground cover, and ground cover also was the strongest explanatory variable for the amount of $^{210}Pb_{ex}$.

Forests did not necessarily have the highest amounts of litter or ground cover, or the lowest bulk densities. Hence they did not necessarily have the highest concentrations of soil organic carbon, nitrogen or phosphorus, or the lowest erosion rates. These results indicate that understory biomass, ground cover, and bulk density are the most important characteristics influencing soil nutrient status and erosion rates, and these three controlling factors are governed more the specific characteristics of different types of forests or agricultural crops rather than the broad classification of land use (e.g., forest vs. agriculture).

The substantial differences in vegetation and soil physical properties among the specific land uses affect soil carbon and nutrient levels as well as erosion rates, indicating an important feedback loop between vegetation, soil conditions, and erosion rates. A simple characterization of forest or non-forest is not sufficient to calculate carbon and nutrient stocks, or to assess erosion risks. For these purposes, and for guiding land management in hilly areas such as North Vietnam, more specific information is needed on the local soils and vegetation characteristics.

CHAPTER 3DISTRIBUTION OF SOIL EROSION AND NUTRIENT ACCUMULATION UNDER VARIOUS VEGETATION GROUND COVERS IN A HEADWATER CATCHMENT.

3.1. Introduction

Accelerated soil erosion on steep forested hillslopes is a serious global and local problems, causing to decrease productivity of agricultural and forest land as well as environmental and ecological degradations (Li et al., 2009; Morgan, 2005). Soil erosion also related to river sedimentation and water pollution in downstreams. It reduces the water-holding capacity, promotes critical losses of nutrients, soil organic matter and soil biodiversity of biota (Fornes et al., 2005).

The importance of vegetation ground cover in controlling erosion in steep mountainous watersheds is widely known (Kinderiene and Karcauskiene, 2012; Miyata et al., 2009; Mohammad and Adam, 2010). Vegetation and litter groundcover acts as a protective layer for maintaining soil physical properties and soil conservation from erosion (Almagro and Martínez-Mena, 2014; Geddes and Dunkerley, 1999). Litter and vegetation ground cover protect soil from raindrop splashes by intercepting rainfall, preventing surface sealing and crusting of soil, extend the time of soil infiltration, and enhance sediment deposition by increasing soil surface roughness (Geddes and Dunkerley, 1999; Sayer, 2006; Walsh and Voigt, 1977), thus lead to reduce soil and nutrients loss.

The accumulation of total C and N in soil surface can be used as a surrogate for soil organic matter (McFarlane et al., 2009; Ogle and Paustian, 2005) and is vital for soil profile development and restoration of ecosystem functions (Dolhanczuk-Srodka et al., 2011; Iurian et al., 2011). Soil erosion is believed to be the main geomorphic processes with the potential to drive soil carbon and nitrogen in steepland by Schipper et al. (2010). However, the using this component for the assessment of the dynamic redistribution of total C and N at the field level still lacks of direct measurements. For obtaining a clearer understanding of this role, the evaluation of soil carbon and nitrogen accumulation of long-term soil redistribution by erosion on soil quality variations is urgently task.

Changes in hillslope condition can be propagating toward streams and further downstreams in watershed scales. Removal of vegetation ground cover generally causes transient increases in nutrient exports to streams (Hornbeck et al., 1990). The order of magnitude of soil erosion resulting from vegetation removal has been found to depend greatly on the intensity and extent of removal in mountainous areas. Although we realize the importance of vegetation and litter ground cover, most of the previous studies were conducted only in hillslope plot scales, which are rather small areas (e.g., 1 x 1 m and 10 x 10 m) (Miyata et al., 2009; Phan Ha et al., 2012). For the forest, land, and water management, watershed scale studies are always difficult because of their wide area and the special heterogeneities of soil, topography, and vegetation conditions. Therefore, to quantify the impacts of soil erosion and soil carbon and nitrogen accumulations under the changes of vegetation ground cover in headwater catchment detail investigation of spatial patterns.

Monitoring erosion and macronutrient levels is difficult because of the cost for regular sampling and the long-term period needed to detect their trends. Soil pedestal heights can be measured and used to like the indicator for short-term erosion (Sidle et al., 2004; Okoba and Sterk, 2006; Anh et al., 2014). A soil pedestal height is an evidence of the effect of raindrops on the soil surface and the removal of topsoil layers by action of the sheet wash (Okoba and Sterk 2006). 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). Overcomes many of the limitations associated with traditional approaches, estimating erosion rates for a long-term based on using the distribution of ^{137}Cs in the soil has been approved as an effective method of studying erosion and deposition (Ritchie et al., 1974; Walling and He, 1999a; Walling et al., 1999; Zapata, 2003; Li et al., 2003; Navas et al., 2012). ^{137}Cs is deposited from the atmosphere, and rapidly adsorbed by organic matter and mineral topsoil, and then predominantly moved in the environment due to physical processes. ^{137}Cs is therefore a unique tracer for studying erosion for long-term. Therefore, the alternative methods for estimating soil erosion have been developed. We combine both of the soil pedestal heights and radionuclides measurements in erosion monitoring to develop an understanding of how these two processes are likely to impact soil carbon and nitrogen accumulation in hillslope catchment.

For understanding concomitant changes in soil erosion and nutrients levels, we hypothesize that the gain in soil carbon and nitrogen at study sites may have decreased due to decreases in vegetation ground cover and soil surface erosion in headwater catchments. The objectives of this study were to: (1) Investigate the effects of vegetation ground cover on soil erosion; (2) Evaluate the relationship between soil erosion and nutrient accumulations; and (3) Examine the interactions among vegetation cover, soil erosion and nutrient accumulation in forested hillslope.

3.2. Methodology

3.2.1. Study site

Field experiments were conducted on a hillslope in the Oborasawa Watershed, which is located, in the western part of Kanagawa Prefecture, Japan (35° 28'N, 139° 12'E). We monitored two adjacent headwater catchments in the eastern part of the Tanzawa Mountains named as Watershed No. 3 and Watershed No. 4. Areas of this waterseds were 7 and 4.6 ha, respectively (Figure 3.1). The elevation of hillslope ranges from about from 432 to 878m. The climate is moist and cool, with approximately 3000 mm of mean annual precipitation (Nishimura, 2013) and 12.5^{o}C mean annual temperature. The area typically has two rainy seasons associated with low-pressure systems: the Baiu season from the late May to July and the typhoon season from late August to November. Most of hillslope gradient was more than 45^{o}, which are located to adjacent to channels. Soil depth in hillslope ranges from 2 to 3m, and the topsoil consisted of sandy loam soils.

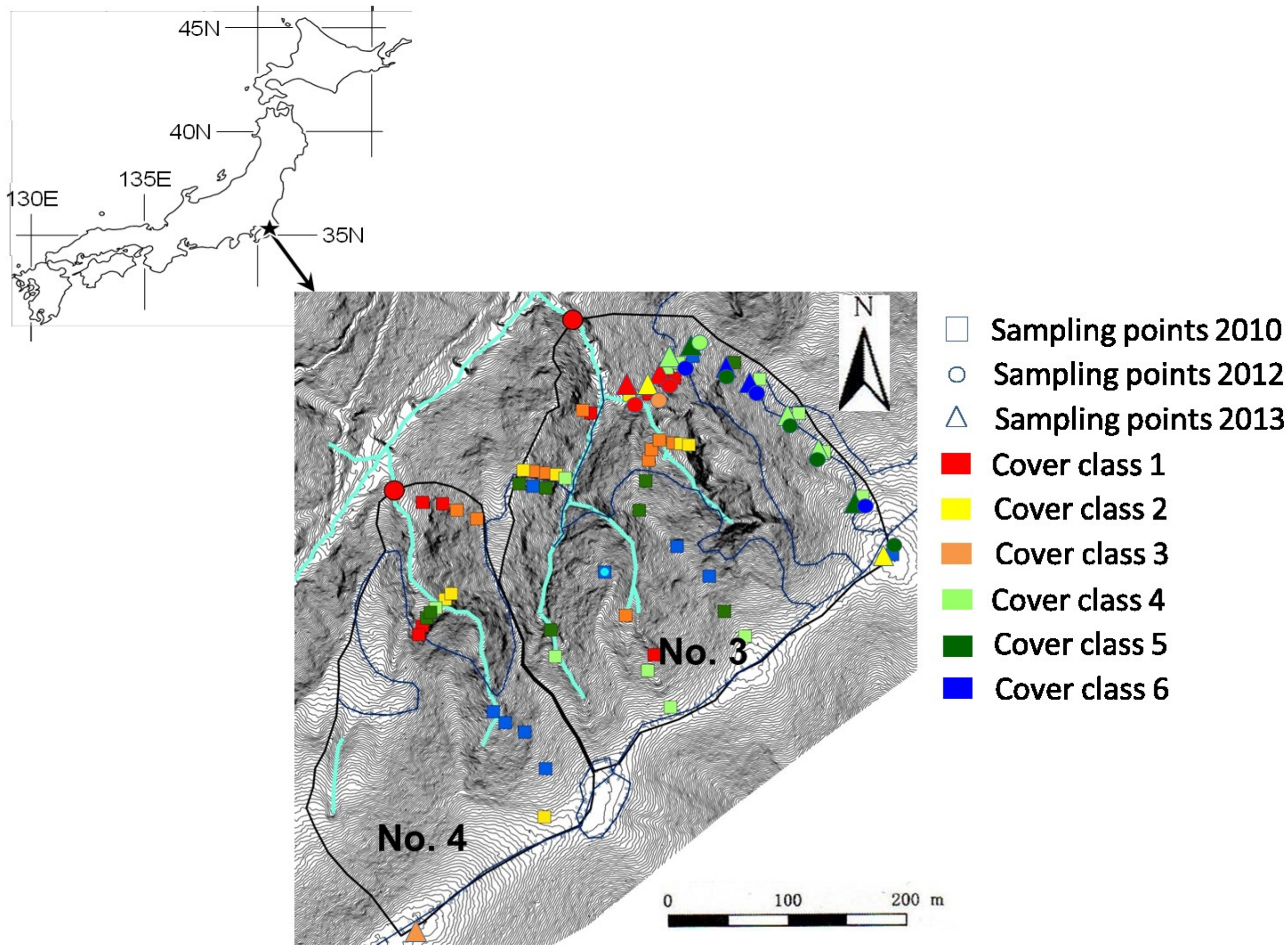


Figure 3.1. Location of the study area and the sampling points in this study

The dominant overstory vegetation is covered with a mixed stand of 20–30 year old coniferous trees (Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtuse*)) in the high altitude area (Oda et al., 2013) (Figure 3.2). In hillslope to the stream channel was cover by deciduous broad-leaved forest. Understory vegetation is covered by a short period herbaceous (mainly *Boenninghausenia japonica, Oplismenus undulatifolius* and *Carex japonica*) (Gomi et al., 2013). Due to overgrazing by very dense wild deer populations lead to decreases the amount of understory vegetation and litter in forested slopes, and thus soil surface erosion becomes a major problem of forest soil and water resources management (Ghahramani et al., 2011).

Figure 3.2. Overview of hillslope: (a) Plantation forest of Japanese cedar and cypress; (b) Deciduou broad-leaved forest

3.2.2. Experimental plots

Experimental areas were established in the summer of 2010, and field data collection carried out between August and September in 2010, 2012 and 2013. In 2010, we selected 58 points located within catchments including near stream channels to the ridge lines. In 2012 and 2013, we selected 10 points along an altitudinal transect in an attempt to characterize vegetation patterns in the proposed research area. These location are selected by based on the vegetation ground cover. Both understory vegetation and litter conditions together with soil physical and biological properties were measured along transects at or around selected points. Based on field observation data about ground cover condition, we then classified into six categories (Figure 3.3): (1) bare land, (2) sparse litter cover, (3) rich litter cover, (4) understory groundcover < 40%, (5) understory groundcover 40 - 80%, (6) and understory groundcover > 80% (Hiraoka et al., 2013).

Figure 3.3. Photos of each Cover class: (1) bare land, (2) sparse litter cover, (3) rich litter cover, (4) understory groundcover < 40%, (5) understory groundcover 40 - 80%, (6) and understory groundcover > 80%.

For each selected points, we set 0.5 x 0.5 m plots for measurement of above-ground biomass of understory and litters. All living biomass was measured by clipping all live leaves and branches from the ground surface to a height of 1 m. Then litter and twigs was removed by hand. Both the understory biomass and litter samples were oven-dried for 24 h at 105°C and weighed to obtain the dry mass. For estimating overstory vegetation structure, hemispherical photographs were taken with an 8-mm fish-eye lens mounted on a digital camera (Nikon D40) on a tripod 50 cm above the ground surface. Canopy openness was estimated using Gap Light Analyzer (Frazer et al., 1999).

Soil pedestal height, soil hardness, and soil moisture content of the surface soil were measured at three locations in or immediately adjacent to the plots. Mean pedestal height was estimated from three representation pedestals inside each plot (Sidle et al., 2004). Soil hardness (cm) was measured using a push-cone hardness indicator (Daiki Rika Kogyo, Saitama, Japan), and converted to Pascals. Mean soil moisture content from 0–12 cm was measured at three locations in each plot using a CS620 Hydrosense probe (Campbell Scientific, USA).

3.2.3. Soil sampling

Two soil samples were taken from each plot. First, bulk density samples 5 cm in diameter from a depth of 0-5 cm were taken from the center of each plot using a 100cc cylinder soil sampler. The second soil sample was taken for determining macronutrient and radionuclide concentrations. In 2010 and 2013, the representative soil samples from each of cover class were collected randomly at a depth of 5 cm using a PVC cylinder soil sampler

(11.7 cm diameter and 5.35 cm depth) into each plot to study the concentration of ^{137}Cs and nutrient accumulation in soil (Figure 3.4). In order to study the depth distribution of fallout radionuclides in surface soil, we used a stainless core sampler (30 cm in length, 3 cm in diameter) to collect samples with a random spatial distribution in each cover class (Figure 3.5). 10 samples were collected along an altitudinal transect. Reference soil samples were collected from a nearby site located on the top of hillslope with relatively high soil development features. This site had the similar parent material as did the study site. We assumed that the selected reference site had not been affected by accelerated soil erosion or deposition and had a permanent grass and shrubs. Two soil profile samples were collected from the reference site with a depth of 30 cm to measure the vertical distribution of ^{137}Cs and ^{134}Cs. The core samples were divided into 5 portions (0–2.5 cm, 2.5–5.0 cm, 5.0–10 cm, 10–20 cm and 20–30 cm) to examine the depth profiles of soil (Figure 3.5b).

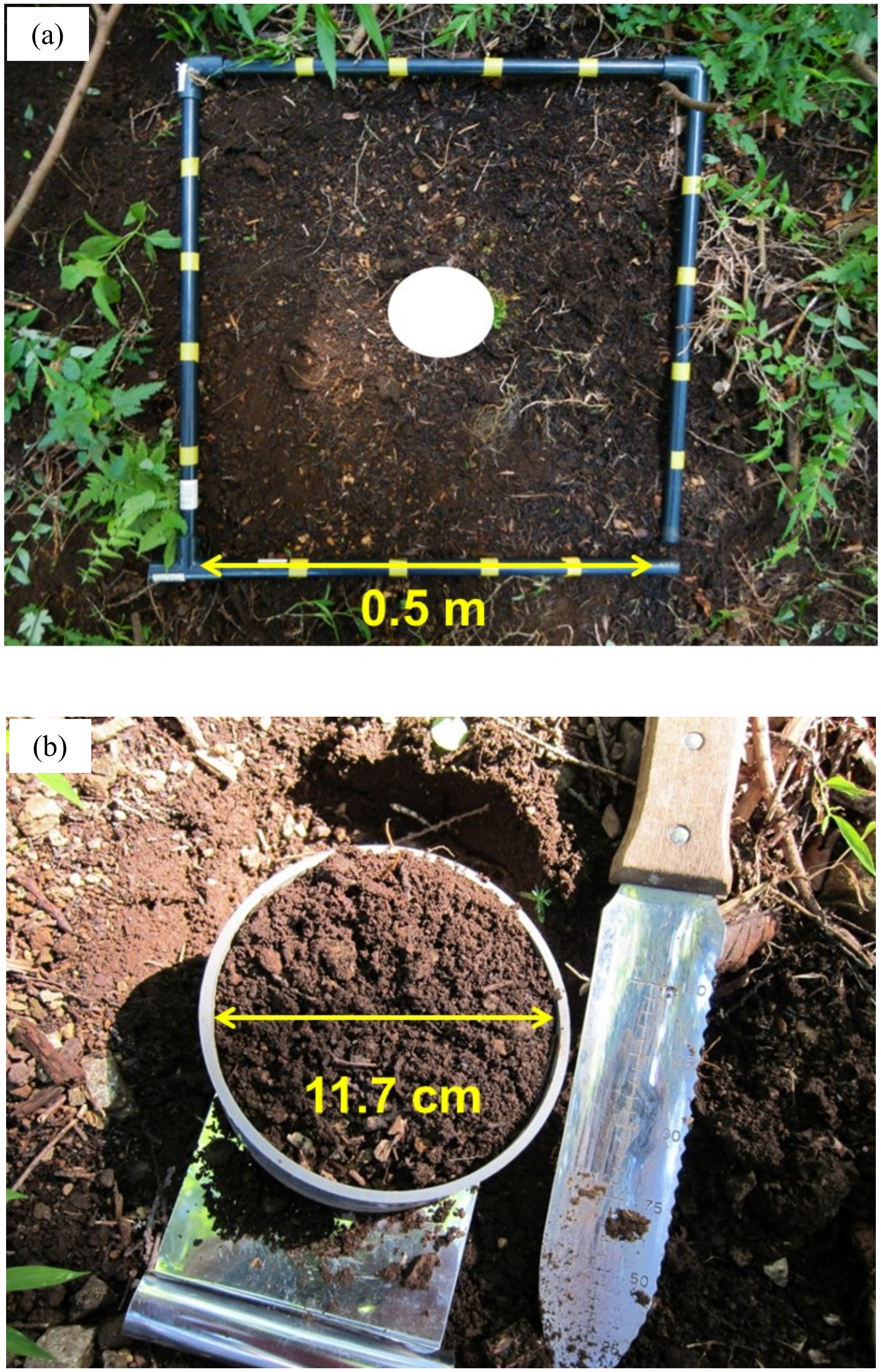


Figure 3.4. Soil sample collection at surface in hillslope catchment in 2010 and 2013: (a) Soil sampling location; (b) Soil sample at 5 cm depth

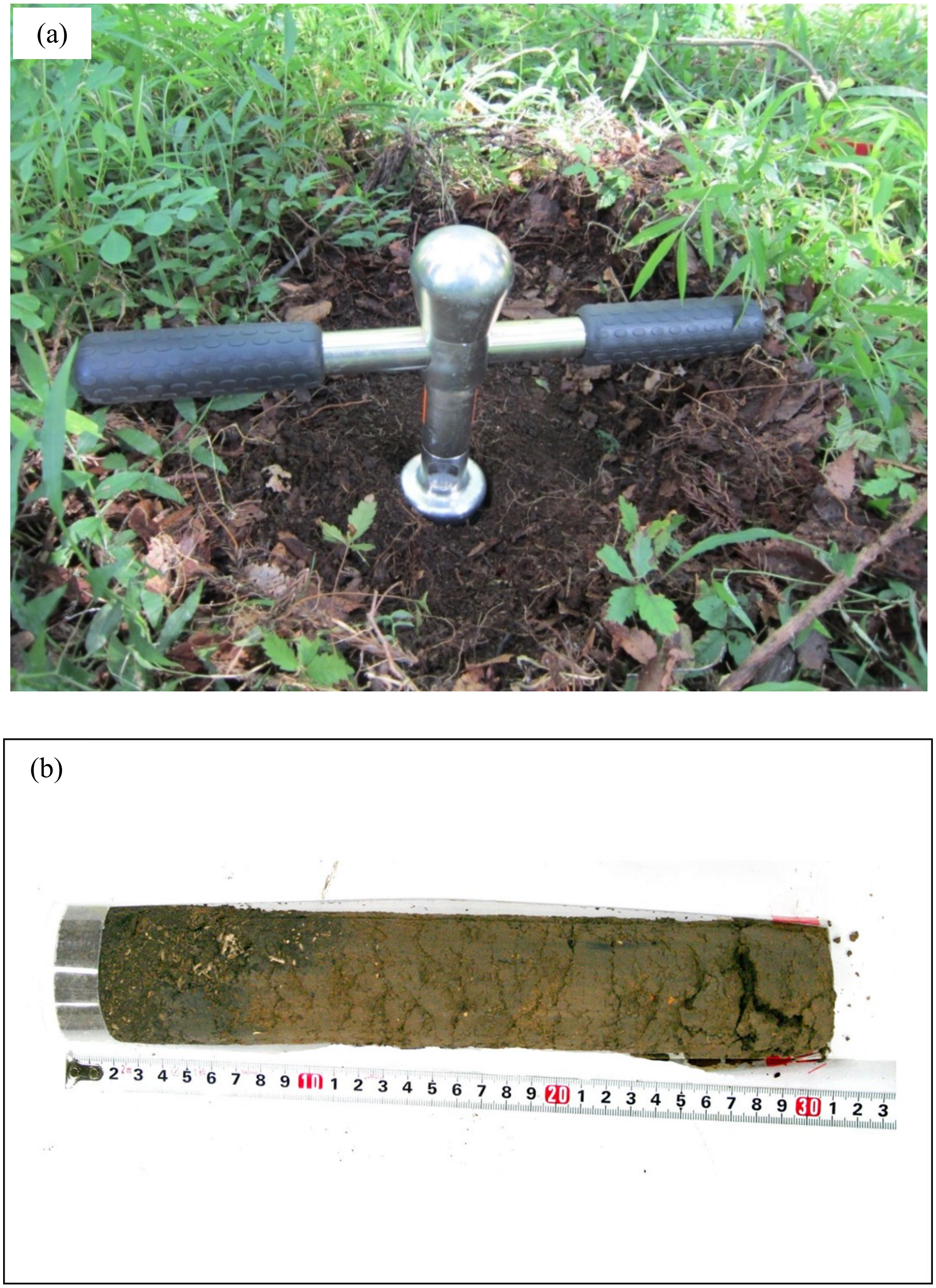


Figure 3.5. Soil sample collection at 30 cm depth in hillslope catchment in 2012: (a) Soil sampling location; (b) Soil sample at 30 cm depth

All of the sampled soils were then shipped to the laboratory for analyzing. Bulk density samples were dried at 105^{o}C for 48 hours to a constant weight and then weighed for determining the dry mass. Soil bulk density was calculated using the core method (Blake and Hartge, 1986). Soil samples were dried for 48h at 105^{o}, removed the larger pieces of organic matter such as roots from this sample by hand, and sieved to pass through a 2 mm by sieve shaker, then preserved in clean plastic bottles to determine soil Carbon, Nitrogen, and radionuclide concentrations. Total carbon and nitrogen contents were determined using a Carbon and Nitrogen Analyzer (CN corder; MT-700 Yanaco Analytical Industry Co., Ltd) (Figure 3.6). One gram of the fraction less than 2 mm was mixed with 6% H_2O_2 and the clay, silt, and sand fractions were determined using a laser diffraction particle-size analyzer (SALD-3100, Japan).

Figure 3.6. Carbon and Nitrogen Analyzer

For samples in 2010, the radionuclides ^{137}Cs were quantified using a high-resolution gamma-ray spectrometry system including a well-type HPGe gamma detector (GWL-120-15; ORTEC, Oak Ridge, TN, U.S.A.) coupled with a multichannel analyzer (EG&G MCA7600; SEIKO, Tokyo, Japan) at the Civil Engineering Research Institute for Cold Region, Public Works Research Institute, Hokkaido, Sapporo, Japan (Figure 3.8). For samples in 2012 and 2013, the radioactivity of ^{134}Cs and ^{137}Cs was determined by gamma-ray spectroscopy. Gamma-ray emissions at energies of 604.7 keV (^{134}Cs) and 661.6 keV (^{137}Cs) were measured using a high-purity germanium coaxial detector system (Ortec, GEM20-70) coupled to a multi-channel analyzer (Ortec, DSPEC jr 2.0) at Watershed Hydrology and Ecosystem Management Laboratory, Tokyo University of Agriculture and Technology (Figure 3.7). The energy and efficiency calibrations for this detector were performed using standard and blank (background) samples. For the analysis of radionuclide activity, each sample was measured during 3 to 12 hours depending on the error. All activities were corrected for decay from the sampling date prior to statistical analyses. The ^{137}Cs and ^{134}Cs concentrations in Bq Kg^{-1} and Bq m^{-2} were calculated following Pennock and Appleby (2010).

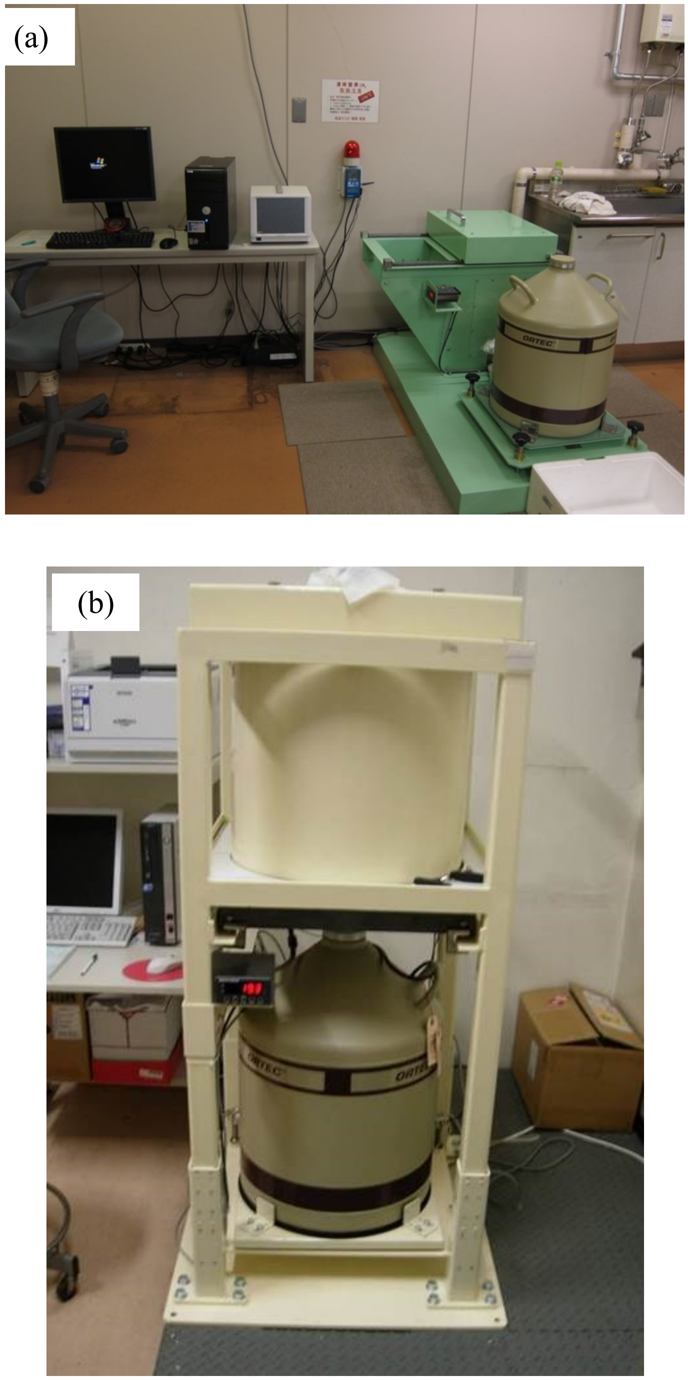


Figure 3.7. Germanium semiconductor detector: (a) Ge detector in Public Works Research Institute on Cold Region; (b) Ge detechtor in Tokyo University of Agriculture and Technology

3.2.4. Indicator of short-, mid- and long-term soil erosion

Short-term effects orccur within a season, such as damage to infrastructure, lost of crop area, lower yields due to less water. Long-term effects are generally manifested over decates, such as an accelerated nutrient decline, lower plant available water capacity and siltation of dam. We therefore classified the duration of soil erosion based on two methods of analysis. Height of perdestal that directly effect by slope gradient, rainfall and ground cover, was measured as an indicator of short-term soil erosion. For estimated a mid- and long-term soil erosion potential, we were using fallout radionuclides such as ^{134}Cs, ^{137}Cs and $^{210}Pb_{ex.}$ (Figure 3.8).

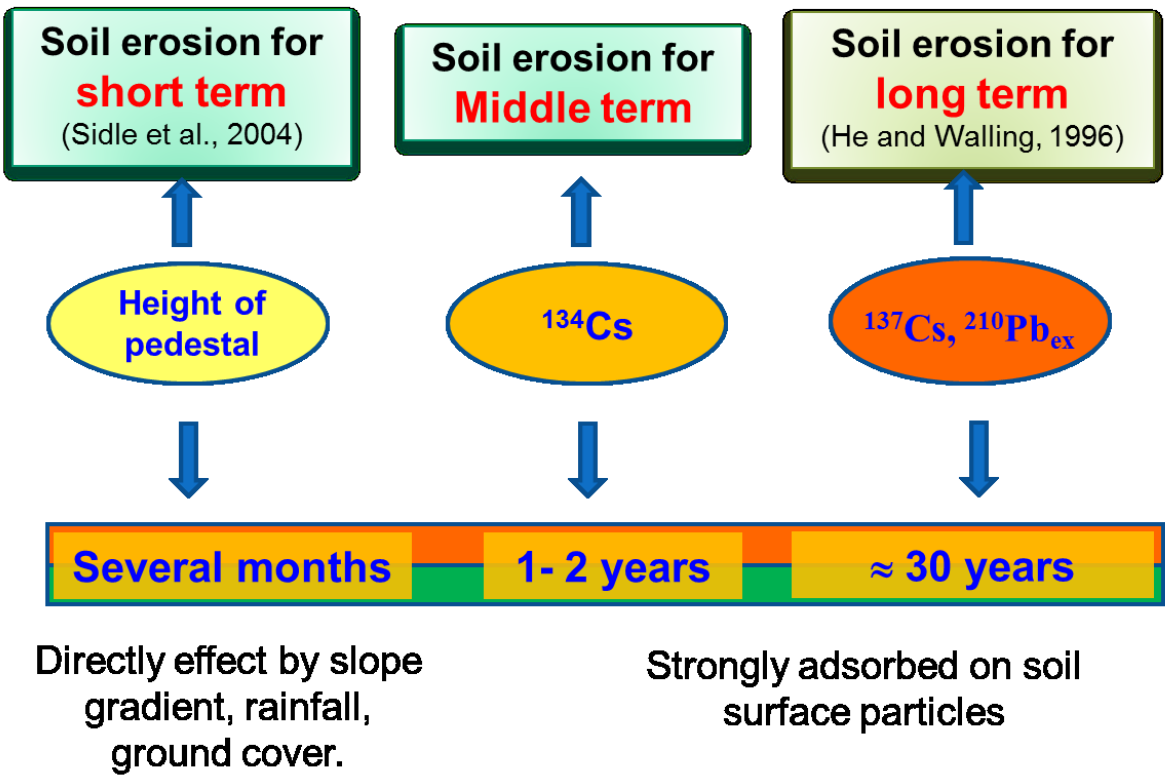


Figure 3.8. Indicators of soil erosion

3.2.5. Statistical analysis

A Pearson's correlation coefficient was calculated to identify the relationship between the various vegetation covers and soil properties. Principle component analysis (PCA) was also used to identify the main factors controlling soil erosion and nutrient accumulations, and to reduce the number of soil-vegetation variables. Components with eigenvalues greater than 1 and a cumulative percentage of variance greater than 80% were selected to determine the main components. Variables with correlation coefficients $\geq$ 0.70 were selected and considered significant (Wotling et al., 2000). Multivariate statistical analysis was conducted using the SPSS software package (Ver. 19.0).

3.3. Results

3.3.1. Characteristic of sample location

Characteristics of sample location were shown in Table 3.1 and Table 3.2. 58 plots in 2010 that including 9 plots of bare land (cover class 1), 10 plots of sparse litter cover (cover class 2), 8 plots of rich litter cover (cover class 3), 12 plots of understory groundcover < 40% (cover class 4), 8 plots of understory groundcover 40 - 80% (cover class 5), and 11 plots understory groundcover > 80% (cover class 1), were examined from two hillslope catchments No 3 and No 4 in Tanzawa mountain, Kanazawa prefecture (Table 3.1). The map of forest floor coverage distribution was developed by spatial analysis in ArcGIS as Figure 2.9. Bare ground tended to be distributed on the steep hillslope near stream channels where low ground cover areas (bare land and sparse litter) were. Understory vegetation cover in middle and top of catchment were higher than in down slope. Mean slope of cover class from 1 to 6 were 41.8°, 40.1°, 35.6°, 30.8°, 34.4° and 29.8°, respectively. Cover class 1 and 2 with sparse litter cover or bare land were appeared in the steep slope over 40°. Slope in cover class 3 to 6 tended to be lower with more surface cover by understory and litter.

Based on field observation in 2012 and 2013, the understory vegetation tended to be concentrated in the middle and top of catchment. Amount of understory vegetation in 2012 and 2013 became higher than in 2010. At the sampling location, the understory vegetation in each cover class in 2010 remained the same cover class in 2012 and 2013. Because vegetation and litter ground cover condition were considered one of main factors that influenced the characteristics of soil erosion and nutrient conditions. The increase of vegetation and litter is important for land managerment in water catchment.

Table 3.1. Characteristics of the study sites in 2010

	Understory cover class											
	Bare land		**Sparse litter**		**Rich litter**		**<40% understory cover**		**40 - 80% understory cover**		**>80% understory cover**	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Number of plots	9		10		8		12		8		11	
Slope (^{o})	41.8	0.8	40.1	1.1	35.6	4.4	30.8	1.3	34.4	2.4	29.8	3.1
Canopy openness (%)	3.9	0.7	4.6	0.8	3.8	0.6	5.4	1.2	6.9	1.4	12.8	2.0
Understory biomass (g/m^2)	2.0	1.9	1.4	1.0	1.8	1.0	15.3	5.1	45.0	11.1	95.5	16.4
Litter (cm)	0.0	0.0	2.2	0.5	6.4	1.5	2.1	0.5	1.3	0.6	0.9	0.3
Undecomposed layer (cm)	0.0	0.0	0.8	0.2	2.3	0.5	0.8	0.3	0.6	0.4	0.2	0.1
Soil pedestal (cm)	2.2	0.5	2.8	0.3	1.5	0.4	1.0	0.3	1.5	0.5	0.4	0.2
Soil hardness (kPa)	42.9	9.0	51.1	13.8	55.2	15.7	86.8	13.8	57.7	11.7	92.2	14.2
Soil moiture (%)	19.7	1.9	23.4	3.1	20.8	2.8	22.8	1.6	22.6	2.1	27.2	2.3
Soil bulk density (g/cm^3)	0.7	0.0	0.6	0.0	0.5	0.1	0.5	0.1	0.6	0.1	0.5	0.1

Table 3.2. Characteristics of the study sites in 2012 and 2013

		Understory cover class											
		Bare land		Sparse litter		Rich litter		<40% understory cover		40 - 80% understory cover		>80% understory cover	
		Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Number of plots	2012	2		2		1		3		1		1	
	2013	1		1		1		3		2		2	
Slope (^{o})	2012	41.8	1.3	42	1.4	44.5	-	32.5	2.8	29.5	-	30	-
	2013	46	-	44	-	42	-	31.7	3.8	33	4.6	38.3	3.7
Understory biomass (g/m^2)	2012	2.4	1.7	0.2	0.1	0	-	26.8	6.9	59.2	-	84.4	-
	2013	0	-	0	-	6.9	-	6.8	0.4	31.5	7.3	44.7	1.2
Litter (g/m^2)	2012	265.6	143.1	325.8	21.6	1385	-	473	75.1	1750	-	402	-
	2013	34.9	-	60	-	77.4	-	185.3	53.8	144.1	28.2	107.6	30.1
Soil pedestal (cm)	2012	3.7	0.6	5.1	0.1	2.3	-	0.9	0.8	0	-	0	-
	2013	2.5	-	3.5	-	4.5	-	0	0.0	1.4	1	0	-
Soil hardness (kPa)	2012	50.3	3	68.4	24	42	-	99.8	36.8	79.1	-	90.3	-
	2013	101.3	-	20.3	-	79.8	-	46.9	6.5	118.8	6.8	90.6	4
Soil moiture (%)	2012	18.7	0	24	1.6	8	-	18.7	2.9	21	-	NA[a]	NA[a]
	2013	26	-	15.3	-	23	-	13	3.8	20.2	0.1	21.2	0.1
Soil bulk density (g/cm^3)	2012	0.8	0.1	0.5	0.1	0.7	-	0.7	0.1	0.4	-	0.5	-
	2013	0.8	-	0.7	-	0.7	-	0.6	0.0	0.6	-	0.5	-

[a] NA: Not available

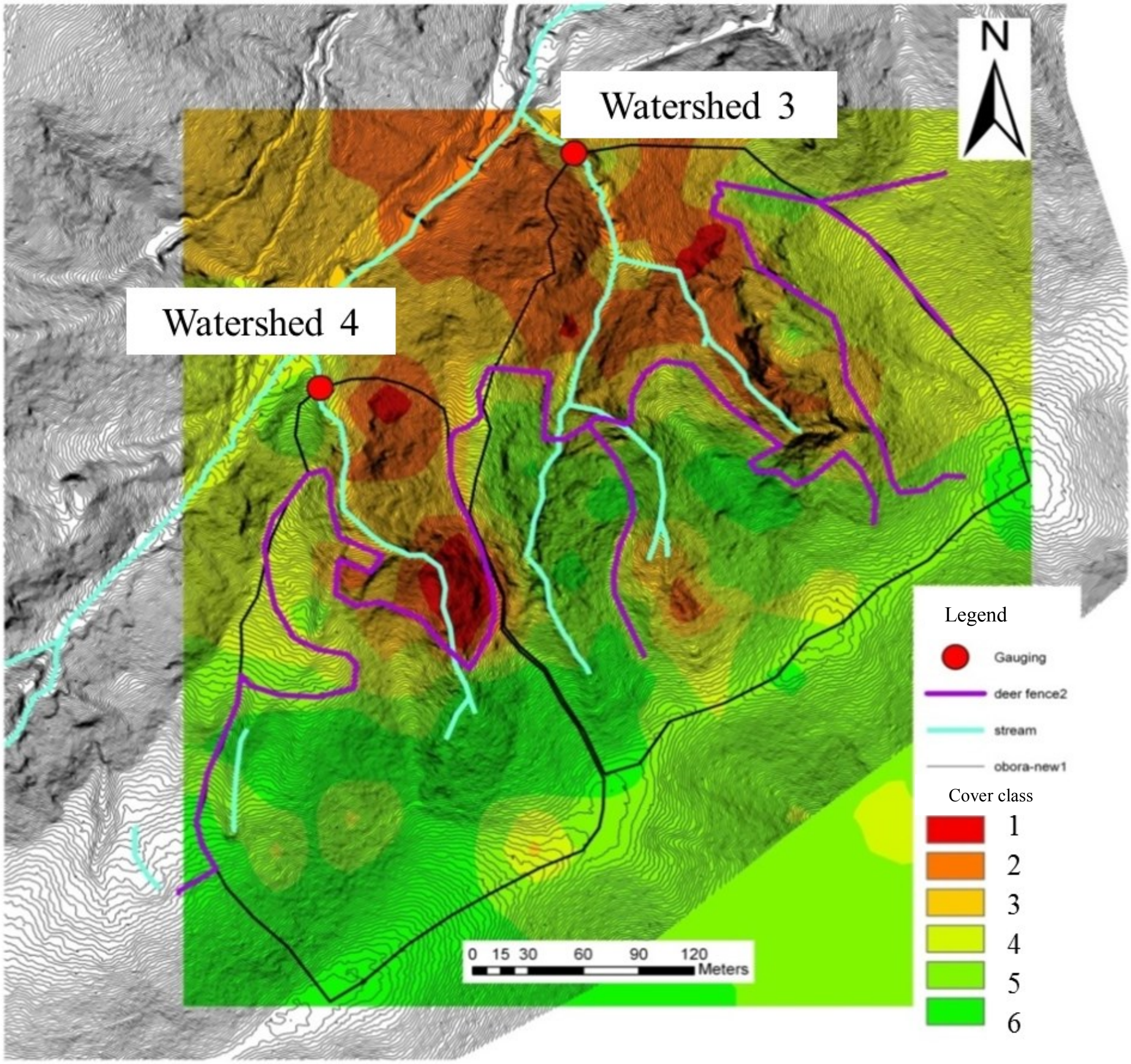


Figure 3.9. Map of forest floor coverage distribution

For data in 2010, soil bulk density tended to be relatively high in cover classes 1 to 3 with the ranged of mean from 0.5 g cm^{-3} to 0.7 g cm^{-3} with standard error (SE) ranged from 0 to 0.1. In cover classes 4 to 6, mean bulk density become low from 0.4 g cm^{-3} to 0.5 g cm^{-3} with SE ranged from 0 to 0.1 (Table 3.1; Figure 3.10). Despite great variability among plots, mean soil moisture did not vary much among cover classes, ranged from 20% to 27%. For the soil hardness also, mean values of the cover classes varied from 48 to 95 kPa (Table 3.1). The mean of soil pedestal heights of cover class 1 to 6 were 2.2 cm, 2.8 cm, 1.5 cm, 1.0 cm, 1.5 cm and 0.4 cm, respectively (Table 3.1). Soil pedestals were highest in sparse litter cover and on bare land where canopy openness and understory biomass were all relatively low. In contrast, lower soil pedestal development was found in cover class 6 where there was high understory vegetation cover (Figure 3.11).

For data in 2012 and 2013, soil bulk density tended to be lower with higher in cover classes. Mean values the ranged of mean from 0.5 g cm^{-3} to 0.8 g cm^{-3} with SE ranged from 0 to 0.1 (Table 3.2; Figure 3.10). Mean soil moisture did not vary much among cover classes in 2012, ranged from 18.7 % to 24%. However, mean soil moisture among cover class in 2013 is varied from 13 to 26%. For the soil hardness also, mean values of the cover classes varied from 42 to 99.9 kPa in 2012 and 20.3 to 101.3 kPa in 2013, respectively (Table 3.2). The mean of soil pedestal heights of cover class 1 to 6 ranged from 0 to 5.1 cm in 2012 and 0 to 4.5 cm in 2013, respectively (Table 3.2). Data in 2012 and 2013 is generally similar with data in 2010.

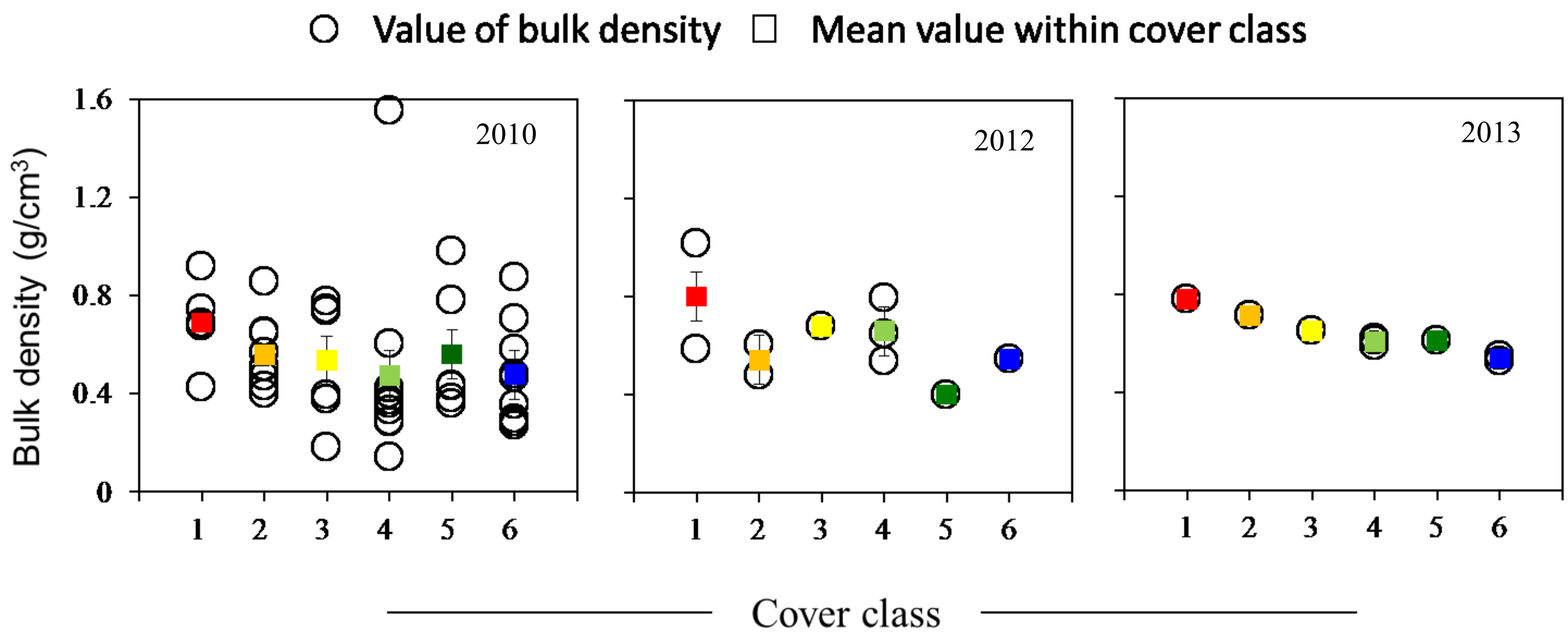


Figure 3.10. Soil bulk density under various cover classes

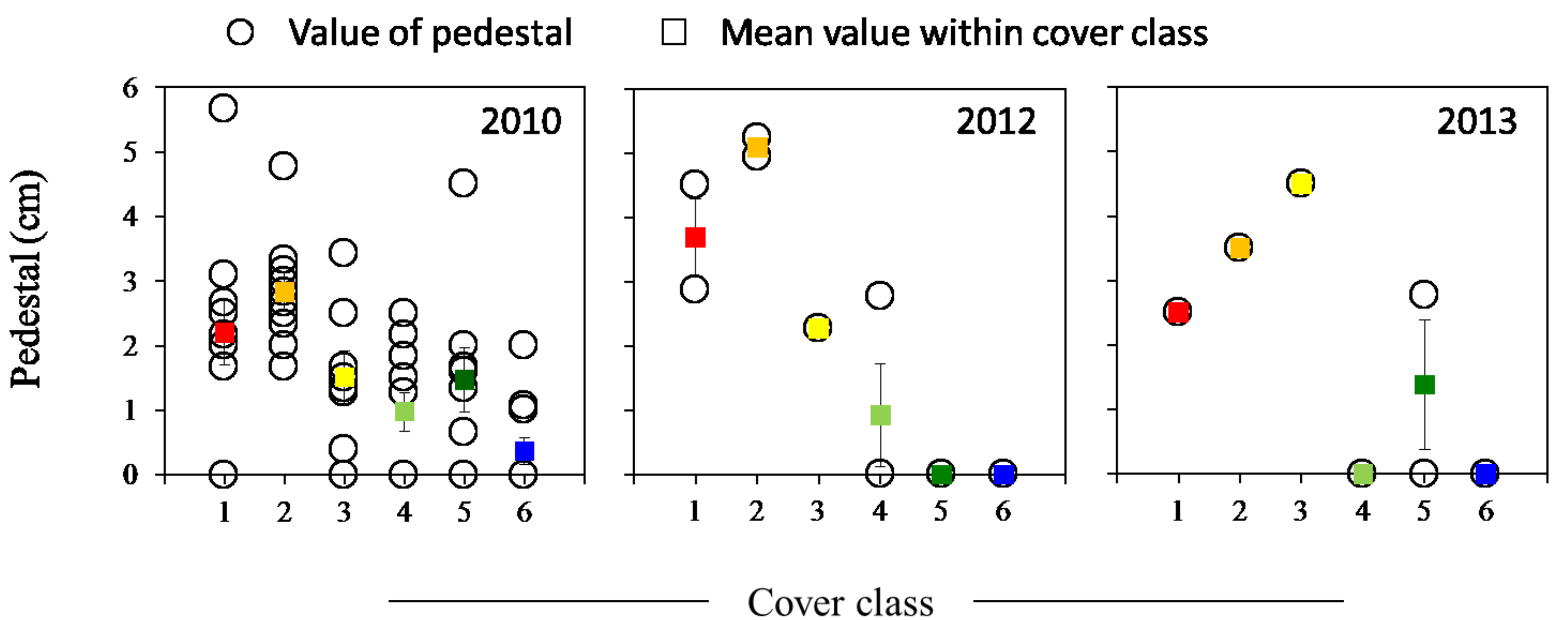


Figure 3.11. Height of soil pedestal under various cover classes

In cover classes 1 to 3, canopy openness ranged from 3.8% to 4.6%, while cover classes 4 to 6 canopy openness ranged from 5.4% to 12.8% (Table 3.1). Mean percentages of canopy openness differed among cover classes, being lower in cover classes 1 to 3, and greater in cover classes 4 to 6. Mean of understory biomass in cover class 1 to 6 in 2010 were 2.0 g m^{-2}, 1.4 g m^{-2}, 1.8 g m^{-2}, 15.3 g m^{-2}, 45.0 g m^{-2} and 95.5 g m^{-2} (Table 3.1). Gennarally, the amount of the biomass tended to be increased with the increase of cover class during period from 2010 to 2013 (Figure 3.12). In particular, there was rapid increase of biomass from cover class 4 to 6 that were associated with growth of the height of understory vegetation. The highest litter thickness was distributed in cover class 3 with average of 6.4 cm.

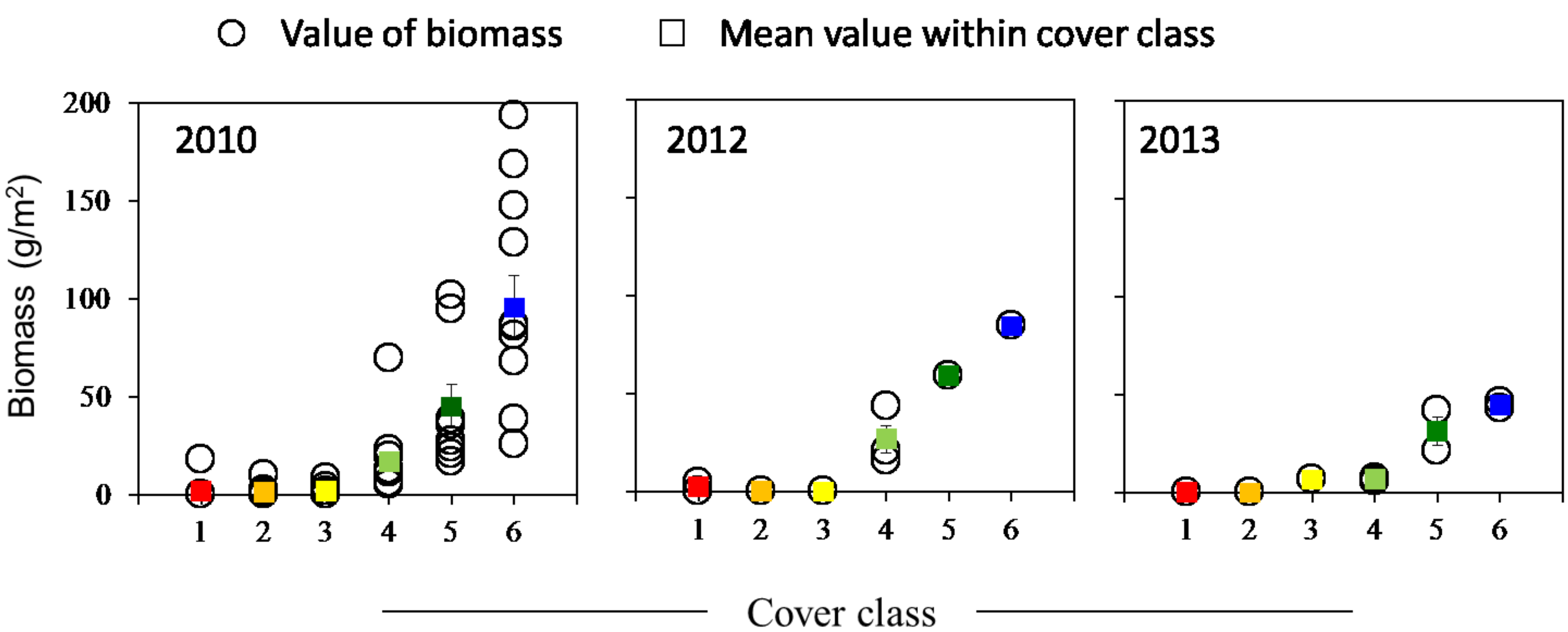


Figure 3.12. Understory vegetation cover under various cover classes

3.3.2. Soil carbon and nitrogen

The summary for total carbon (TC) and total nitrogen (TN) contents and soil C/N ratios at a depth of 0–2.5 cm under six different cover classes are shown in Table 3.3. In 2010, TC and TN contents were the highest variation in the cover class 3 and they varied from 3.41 to 19.13 % (Coefficient of variation (CV) = 69%) and from 0.33 to 1.03 % (CV = 46%), respectively. The maximum values for TC and TN contents were obtained in the cover class 3, and these were 19.13% and 1.03%, respectively. The minimum values for TC and TN contents occurred in the cover class 4, and these were 0.58% and 0.09 %, respectively. On mean values, TC and TN contents tended to be increased with increase in litter cover, but that in vegetation ground cover became similar level in 2010 (Figure 3.13).

In 2012, TC and TN contents tended to be increased with increased of cover class (Figure 3.13). The maximum of the mean values for TC and TN contents were obtained in the cover class 6, and these were 10.67% and 0.79%, respectively (Table 3.3). The minimum of the mean values for TC and TN contents occurred in the cover class 1, and these were 5.46% and 0.40 %, respectively (Table 3.3).

Soil C/N ratios were not varied under different cover classes. The effect of change in ground cover on soil C/N ratios was not the same as that for TC and TN (Table 3.3). On average, soil C/N ratios tended to be increased with increase in both litter and understory vegetation cover. Soil C/N ratios had the maximum and minimum values (18.63 and 6.45) in cover class 3 and 4, respectively. The mean values varied from about 12 to 15 in the six different cover classes, but not significantly different under litter or understory vegetation cover.

Table 3.3. Mean soil organic carbon, total nitrogen, C/N ratio in various cover classes

Understory cover class	Year	SOC (%)					TN (%)					C/N				
		Mean	SD	CV	Max	Min	Mean	SD	CV	Max	Min	Mean	SD	CV	Max	Min
1	2010	4.42	1.23	28	5.74	2.02	0.31	0.07	22	0.40	0.18	14	2	11	16	11
	2012	5.46	1.83				0.40	0.12				14	1			
2	2010	6.44	1.90	29	9.40	3.74	0.43	0.13	30	0.69	0.27	15	1	8	17	13
	2012	7.07	0.52				0.56	0.05				13	1			
3	2010	7.65	5.28	69	19.13	3.41	0.52	0.24	46	1.03	0.33	15	2	13	19	12
	2012	7.28	-				0.53	-				14				
4	2010	6.66	3.27	49	14.46	0.58	0.51	0.20	40	0.96	0.09	12	2	17	15	6
	2012	8.44	0.88				0.58	0.01				15	2			
5	2010	5.21	1.27	24	6.86	2.63	0.40	0.09	22	0.49	0.20	13	1	7	15	12
	2012	8.94	-				0.69	-				13				
6	2010	6.36	1.77	28	11.07	4.68	0.47	0.11	23	0.67	0.30	14	1	11	17	12
	2012	10.67	0.12				0.79	0.05				14	1			

SD: Standard deviation
CV: Coefficient of variation

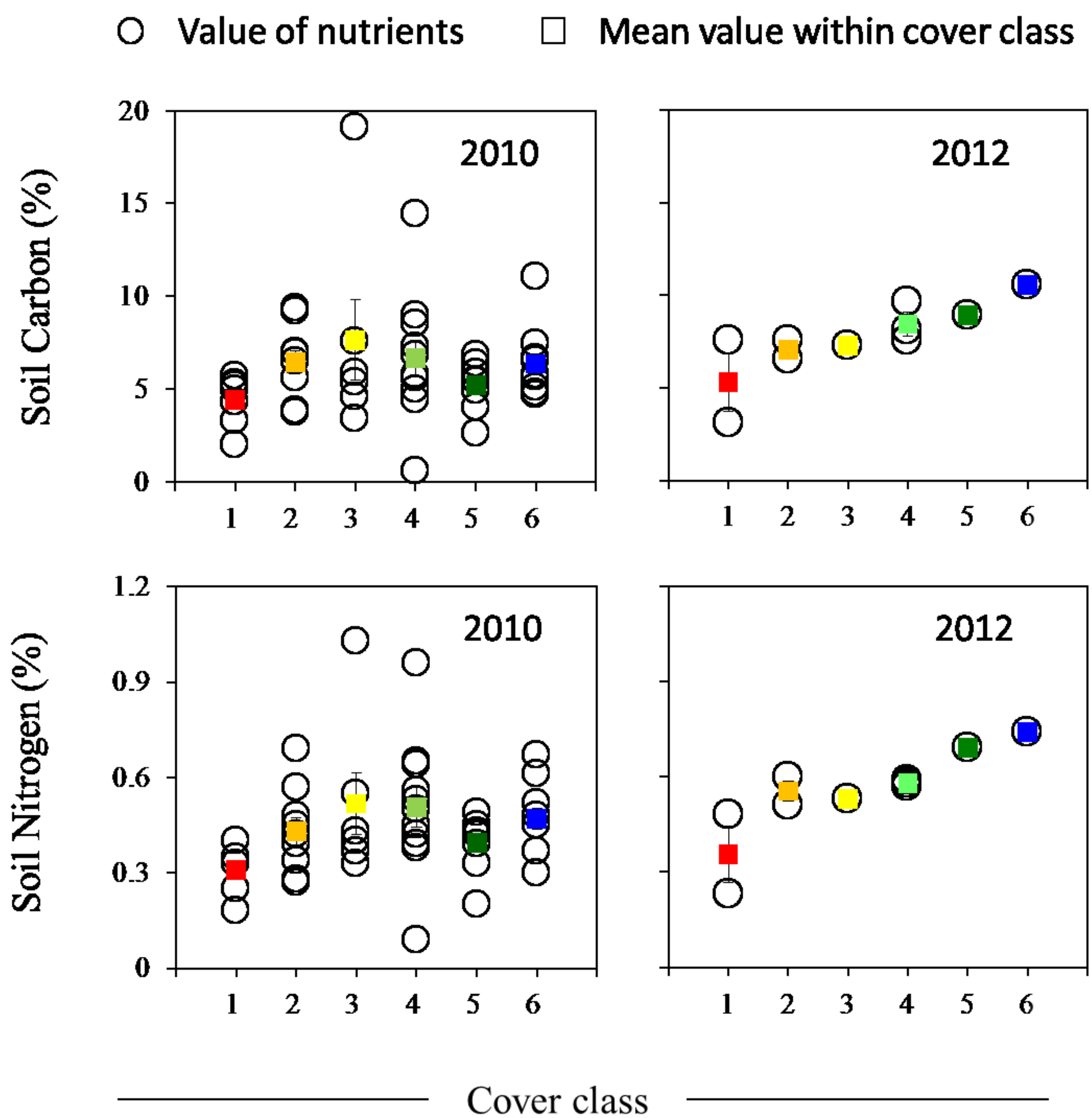


Figure 3.13. Soil nutrients content under various cover classes

The distribution pattern of TC and TN differed by the soil depth. The TC and TN distribution had similar shapes among various cover classes, with peak concentrations in the surface soil (0–5 cm) (Table 3.4). The maximum values for TC contents were obtained in the cover class 6, and these values in various soil depths were 10.55%, 8.00%, 6.28%, 3.87% and 2.88%, respectively. Simmilar, the maximum values for TN contents in various soil depths were 0.74%, 0.61%, 0.55%, 0.35% and 0.26%, respectively (Table 3.4). The minimum values for TC and TN contents occurred in the cover class 1 (Table 3.4).

Table 3.4. Distribution of soil organic carbon and total nitrogen in various cover classes in 2012

Depth (cm)	Cover class 1 (3)		Cover class 2 (1)		Cover class 3 (1)		Cover class 4 (3)		Cover class 5 (1)		Cover class 6 (1)	
	TC (%)	TN (%)	TC (%)	TN (%)	TC (%)	TN (%)	TC (%)	TN (%)	TC (%)	TN (%)	TC (%)	TN (%)
0 - 2.5	5.46 ± 1.83	0.40± 0.12	7.58 ± 0	0.60 ± 0	7.28 ± 0	0.53 ± 0	8.44 ± 088	0.58 ± 0.01	8.94 ± 0	0.69 ± 0	10.55 ± 0	0.74 ± 0
2.5 - 5.0	5.00 ± 1.33	0.38 ± 0.11	9.1 ± 0	0.73 ± 0	8.26 ± 0	0.59 ± 0	7.99 ± 0.65	0.58 ± 0.01	9.45 ± 0	0.76 ± 0	8.00 ± 0	0.61 ± 0
5.0 - 10	4.24 ± 1.14	0.35 ± 0.11	8.04 ± 0	0.68 ± 0	6.65 ± 0	0.51 ± 0	6.47 ± 0.85	0.52 ± 0.07	8.39 ± 0	0.68 ± 0	6.28 ± 0	0.55 ± 0
10 - 20	2.99 ± 0.60	0.26 ± 0.03	5.22 ± 0	0.46 ± 0	5.35 ± 0	0.44 ± 0	3.69 ± 1.12	0.33 ± 0.10	4.13 ± 0	0.33 ± 0	3.87 ± 0	0.35 ± 0
20 - 30	2.38 ± 1.09	0.21 ± 0.07	0.67 ± 0	0.07 ± 0	5.08 ± 0	0.44 ± 0	3.73 ± 1.96	0.31 ± 0.14	4.70 ± 0	0.37 ± 0	2.88 ± 0	0.26 ± 0

The number between brackets is number of sample.

3.3.3. ^{134}Cs and ^{137}Cs concentration

Reference soil samples were collected at the same location among 2010, 1012 and 2013 that located at a nearby site on the top of hillslope with relatively high soil development features (Figure 3.14). The selected reference site had not been affected by accelerated soil erosion or deposition and had a permanent grass and shrubs. Mean ^{137}Cs reference inventories for the study area were estimated to be 1.5 kBq m^{-2} and 0.3 kBq m^{-2} in 2010. The inventories of ^{137}Cs and ^{134}Cs for the two points from the area of undisturbed grassland within three years are detected. The ^{137}Cs reference inventory obtained in this study in 2012 and 2013 was higher than what have been reported in 2010 due to the effect of the Fukushima accident (Figure 3.15 and Figure 3.16).

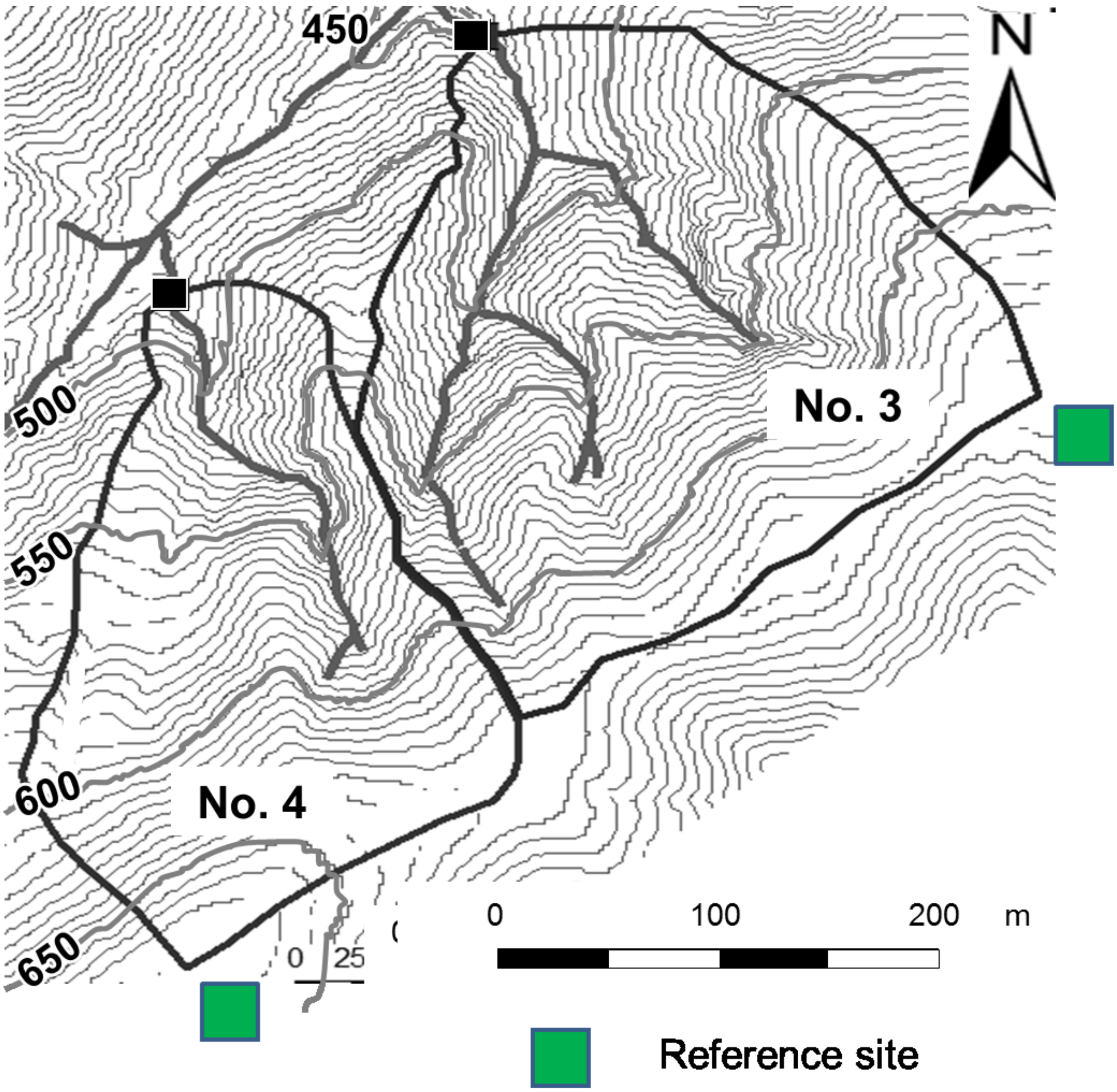


Figure 3.14: Location of reference site in this study

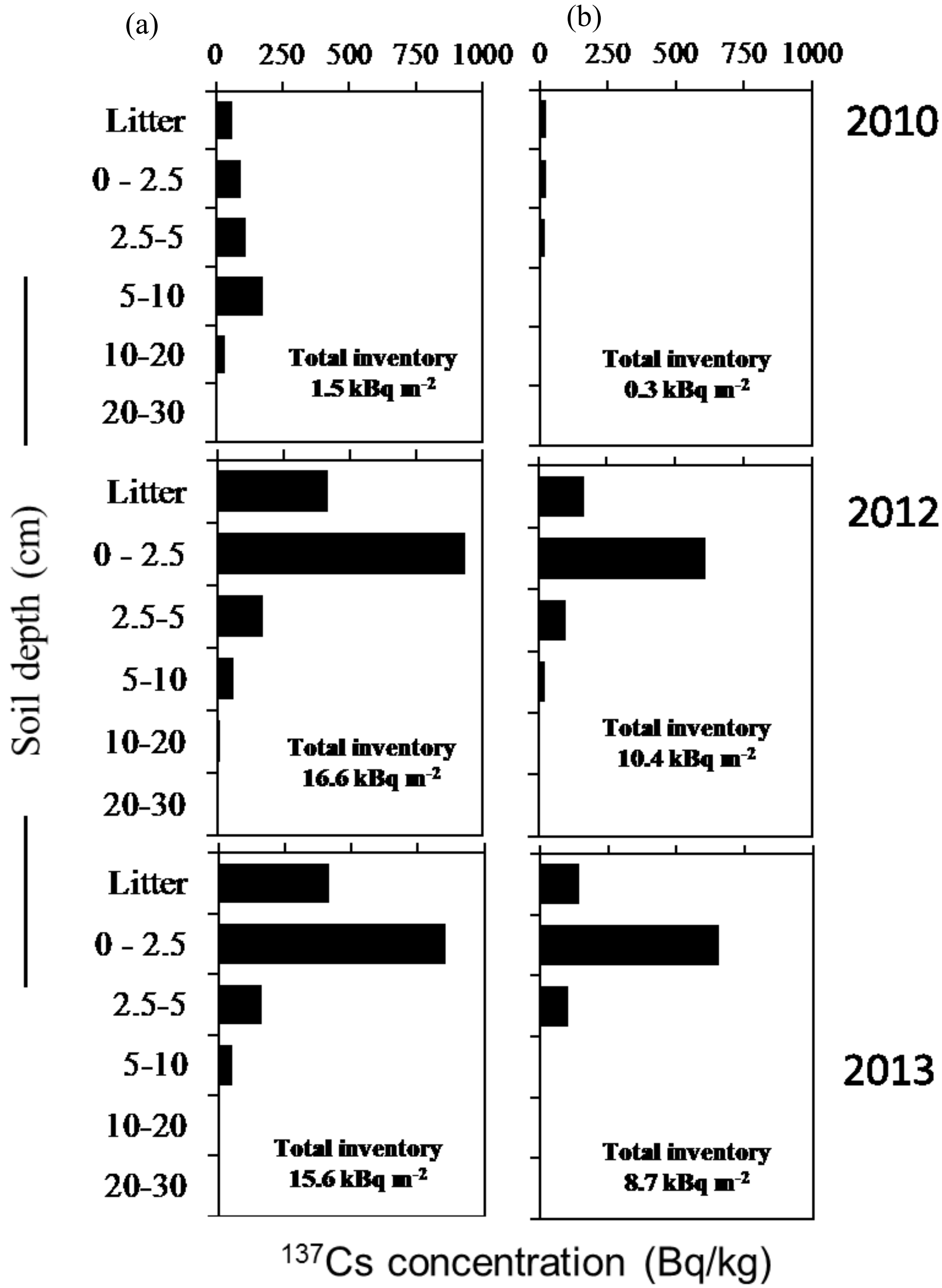


Figure 3.15. ***^{137}Cs depth distributions documented for the reference sites located on the top of hillslope with relatively high soil development features: (a) Reffernce 1; (b) Reffernece 2***

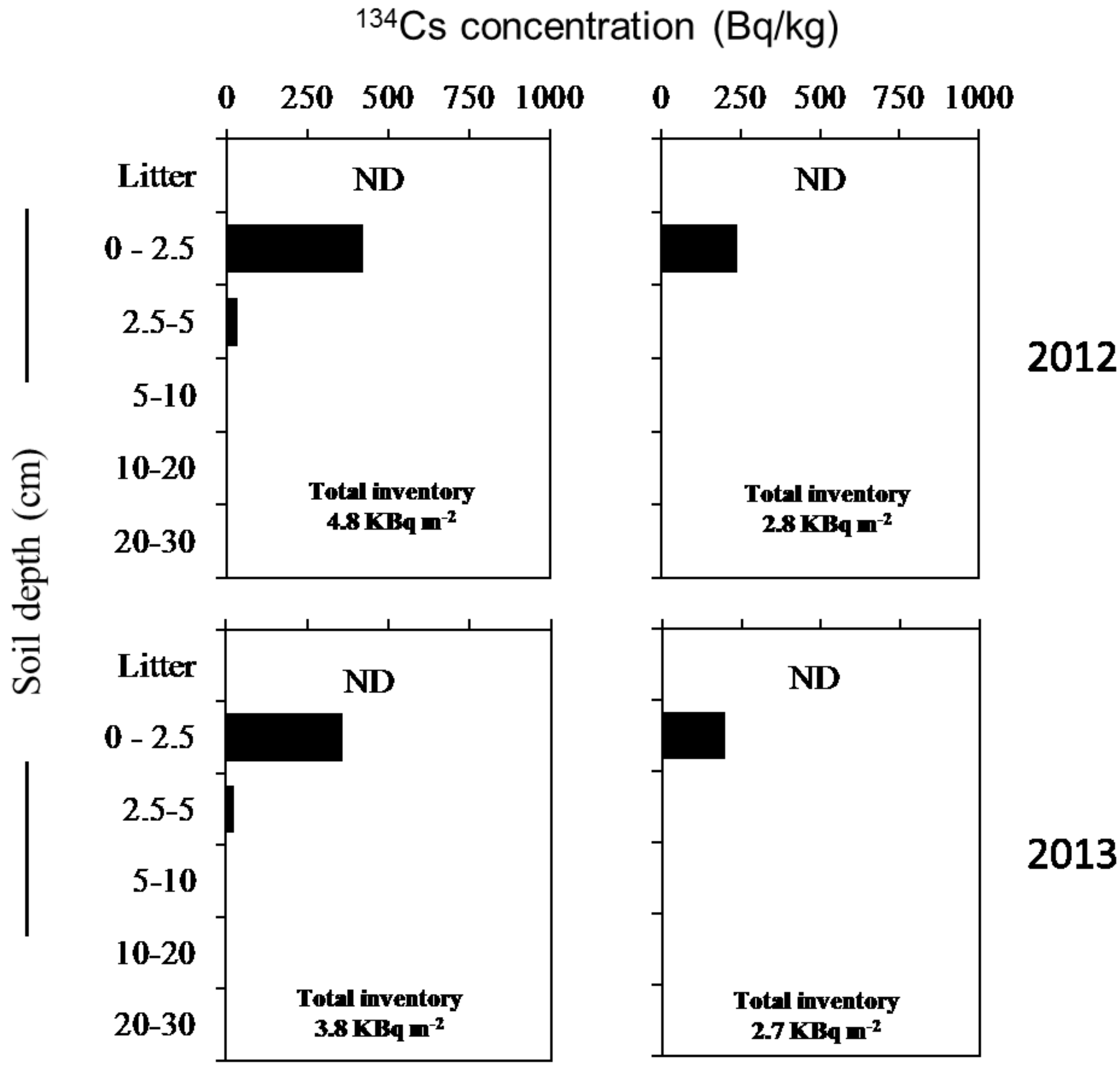


Figure 3.16. ***^{134}Cs depth distributions documented for the reference sites located on the top of hillslope with relatively high soil development features. ND: Not detected***

The average concentration of ^{137}Cs was lower in cover class 1 (20.2 ± 11.4 Bq/ kg), 2 (411 ± 192 Bq m^2), 3 (415 ± 170 Bq m^2), 5 (472 ± 186 Bq m^2) and 6 (428 ± 177 Bq m^2) than in cover class 5 (584 ± 153 Bq m^2) (Table 3.5). ^{134}Cs and ^{137}Cs were mainly deposited in surface soil at 0-2.5 cm (Figure 3.17; Figure 3.18) and tended not to move downward to depth soil layer via vertical infiltration (Figure 3.19; Figure 3.20). The maximum and minimum values for ^{137}Cs inventory were found in cover class 2 (866 Bq m^2 and 134 Bq m^2) (Table 3.5).

Table 3.5. Mean ^{137}Cs concentration and ^{137}Cs inventory at 5 cm depth in various cover class in 2010

Understory cover class	^{137}Cs (Bq/kg)					^{137}Cs (Bq m^2)				
	Mean	SD	CV	Max	Min	Mean	SD	CV	Max	Min
1	20.2	11.4	0.6	31.6	8.8	353	190	54	543	163
2	28.5	7.8	0.3	40.5	11.5	411	192	47	866	134
3	37.2	18.4	0.5	62.2	18.7	415	170	41	612	134
4	54.3	3.0	0.1	57.9	50.5	584	153	26	760	387
5	46.8	23.2	0.5	66.9	8.1	472	186	39	636	157
6	33.7	14.1	0.4	63.8	14.1	428	177	41	653	162

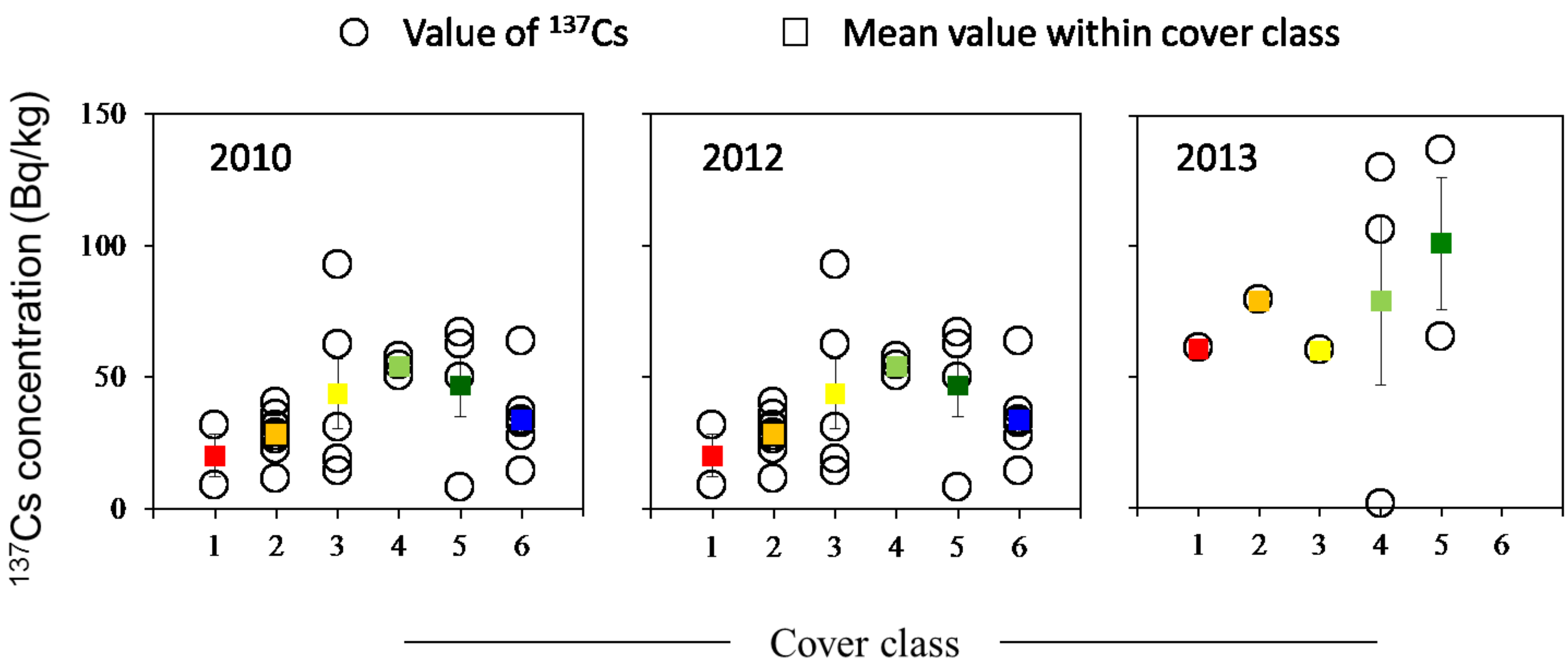


Figure 3.17. ^{137}Cs concentration under various cover classes in 2010, 2012 and 2013

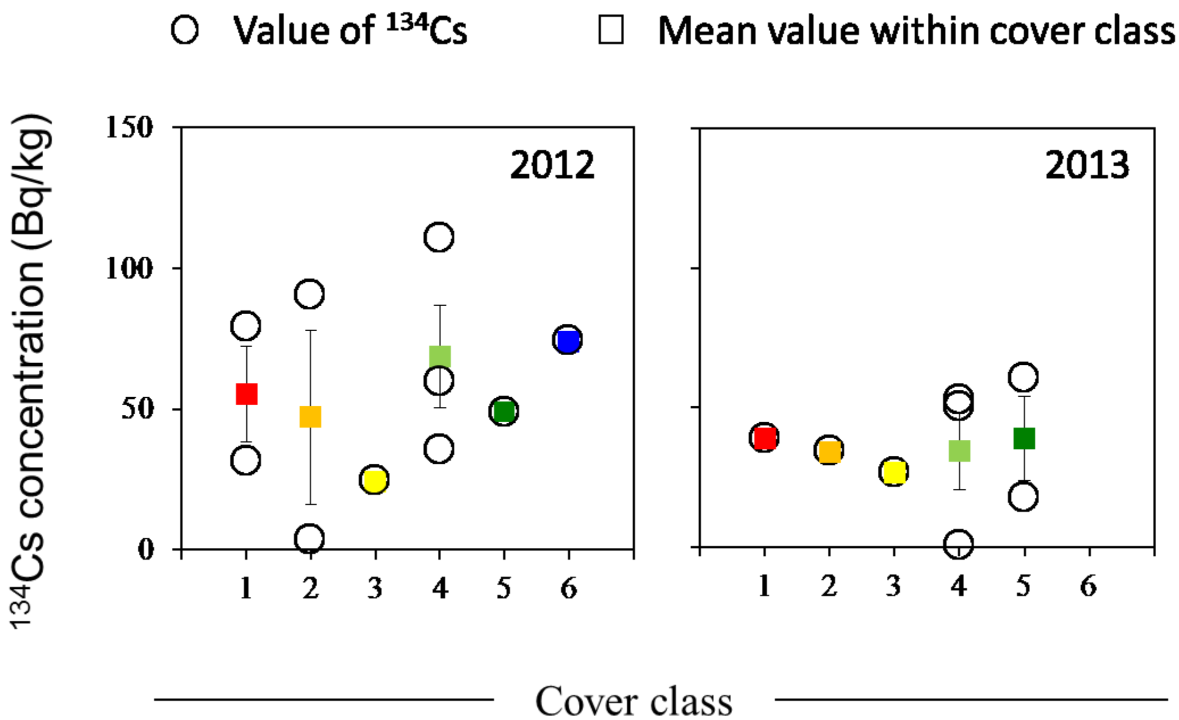
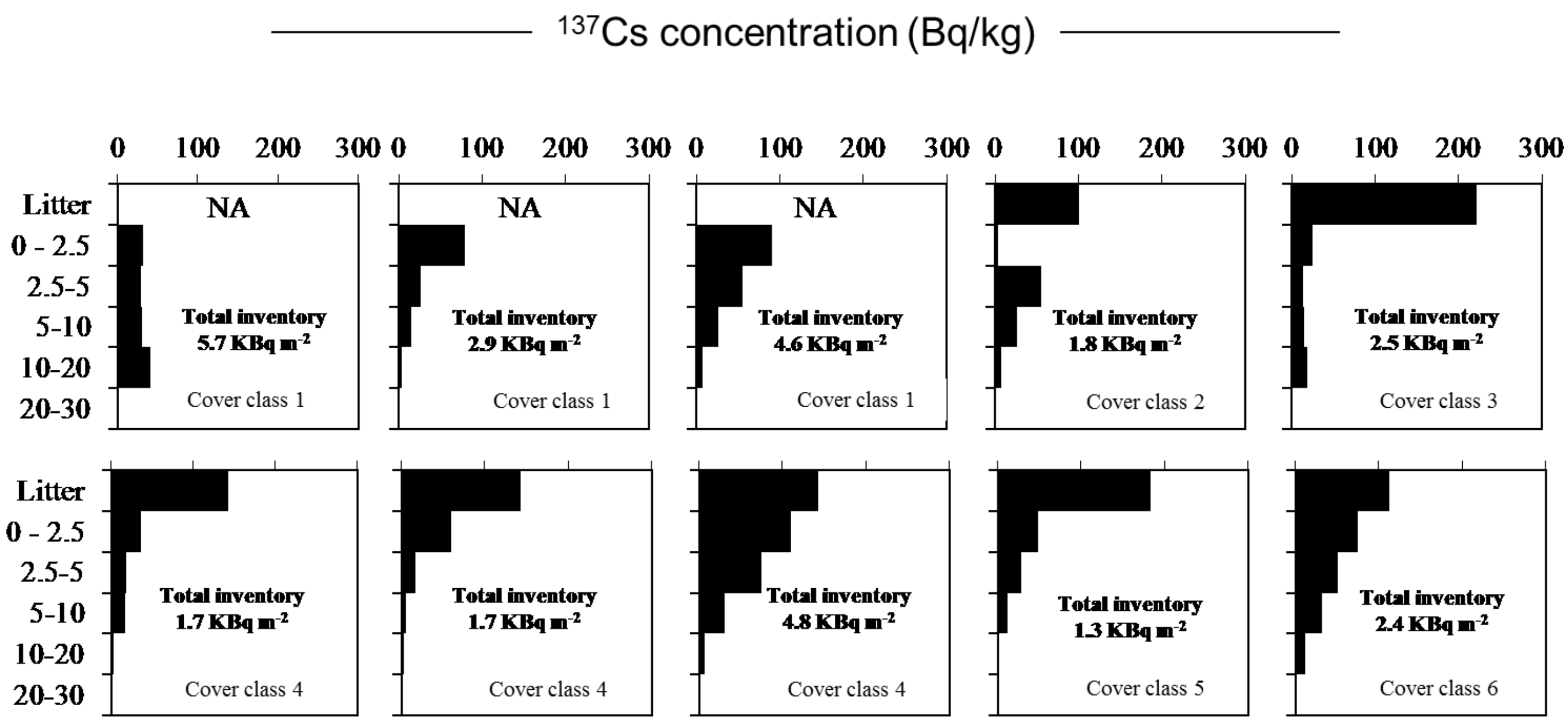


Figure 3.18. ^{134}Cs concentration under various cover classes in 2010, 2012 and 2013

Figure 3.19 and Figure 3.20 shows the ^{137}Cs and ^{134}Cs depth distribution which was collected from study site in 2012. The ^{137}Cs concentriation in cover class 1 is mostly higher in the soiltops even there is no litter cover in the surface. We also found that the high of ^{137}Cs concentration in cover class 2 to 6 (Figure 3.19). When ^{137}Cs reaches surface, it is rapid and tightly adsorbed by fine particles of soil. However in cover class 2 and 3, there is little ^{137}Cs in soil surface. This result may be related in soil erosion prosess in this area. Except cover class 5, ^{134}Cs was not detected in litter cover. Concentrations of ^{134}Cs were lower with soil depth with peak concentrations in the surface soil (0–2.5 cm) except coverclass 2 (Figure 3.20). The ^{137}Cs and ^{134}Cs depth distributions presented in Figure 3.19 and Figure 3.20 confirm that the behaviour of radiocaesium in the study catchment conforms to the normal expectations, when using ^{137}Cs measurements to estimate rates of soil redistribution (Zapata, 2003).



NA: Not available

Figure 3.19. Depth profiles of ^{137}Cs in the soil of study site

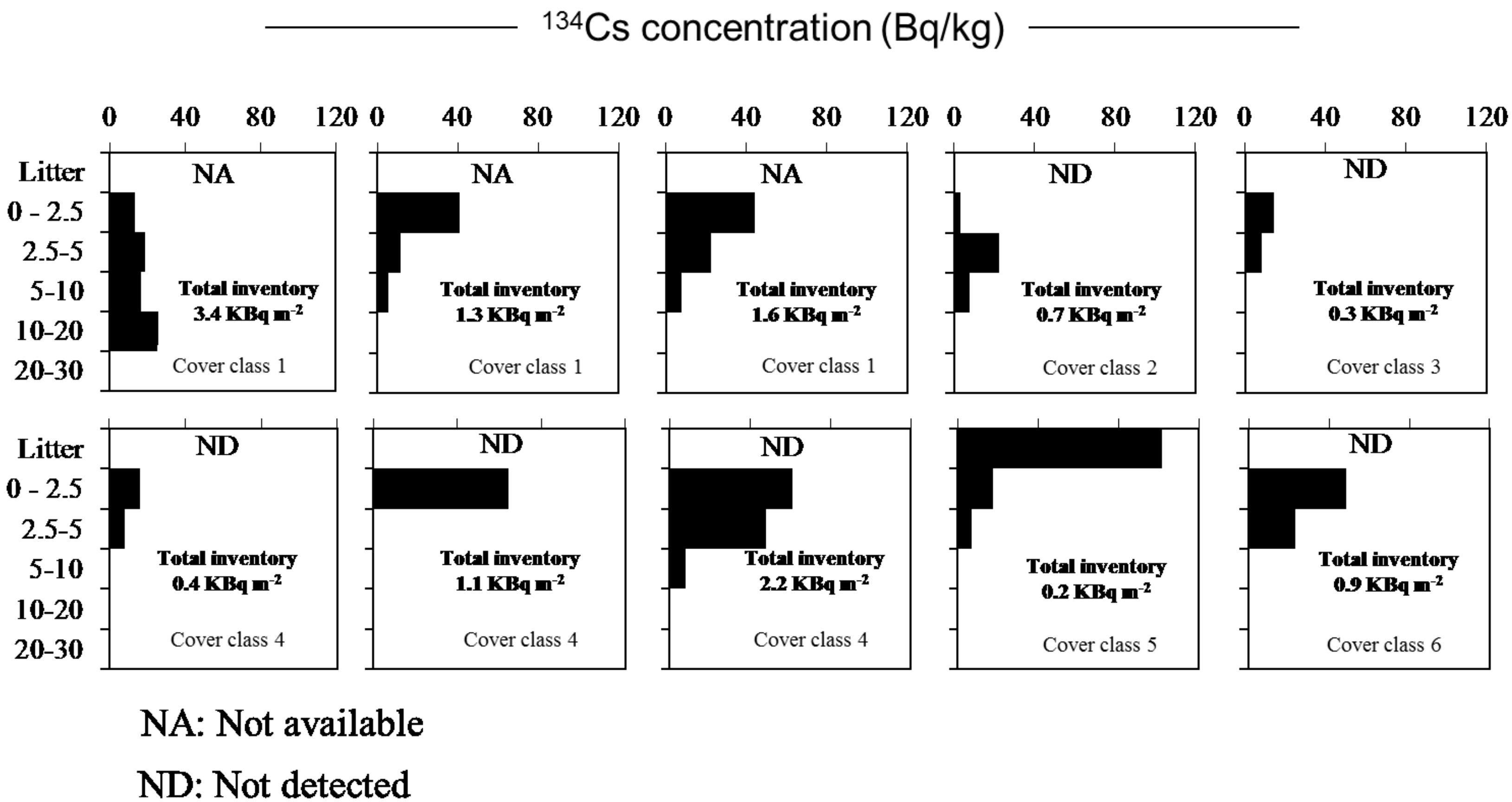
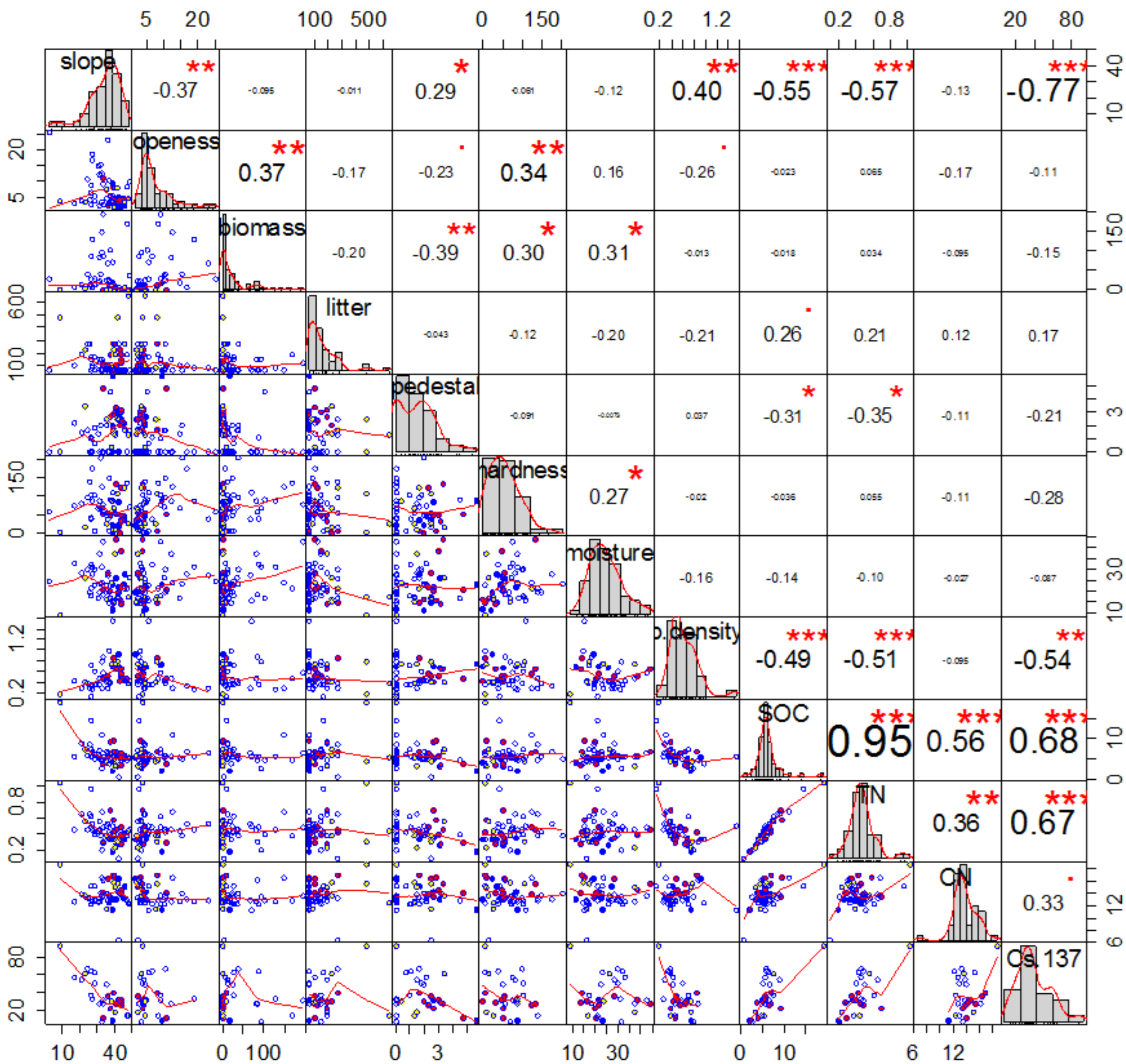


Figure 3.20. Depth profiles of ^{134}Cs in the soil of study site

3.3.4. Correlation and ordination

In order to analyze the interaction of the observation field factors in 2010, a correlation analysis was calculated (Figure 3.21). The correlation analysis suggested that the vegetation cover and soil properties are both positively and negatively correlated to various magnitudes (Figure 3.21). For instance, a strong correlation was established among slope, SOC, TN, and ^{137}Cs, for example, a positive correlation between SOC and SON (r = 0.95) or between SOC and ^{137}Cs (r = 0.68) (Figure 3.21 and 3.22). Understory biomass correlated with canopy openness (r = 0.37) and soil pedestal (r = -0.39), whereas litter did not have a clear correlation with SOC and TN and biomass.



*, **, ***: *95%, 99%, 99.9% confidence interval*

Figure 3.21. Persons correlation coefficients among factors in 2010

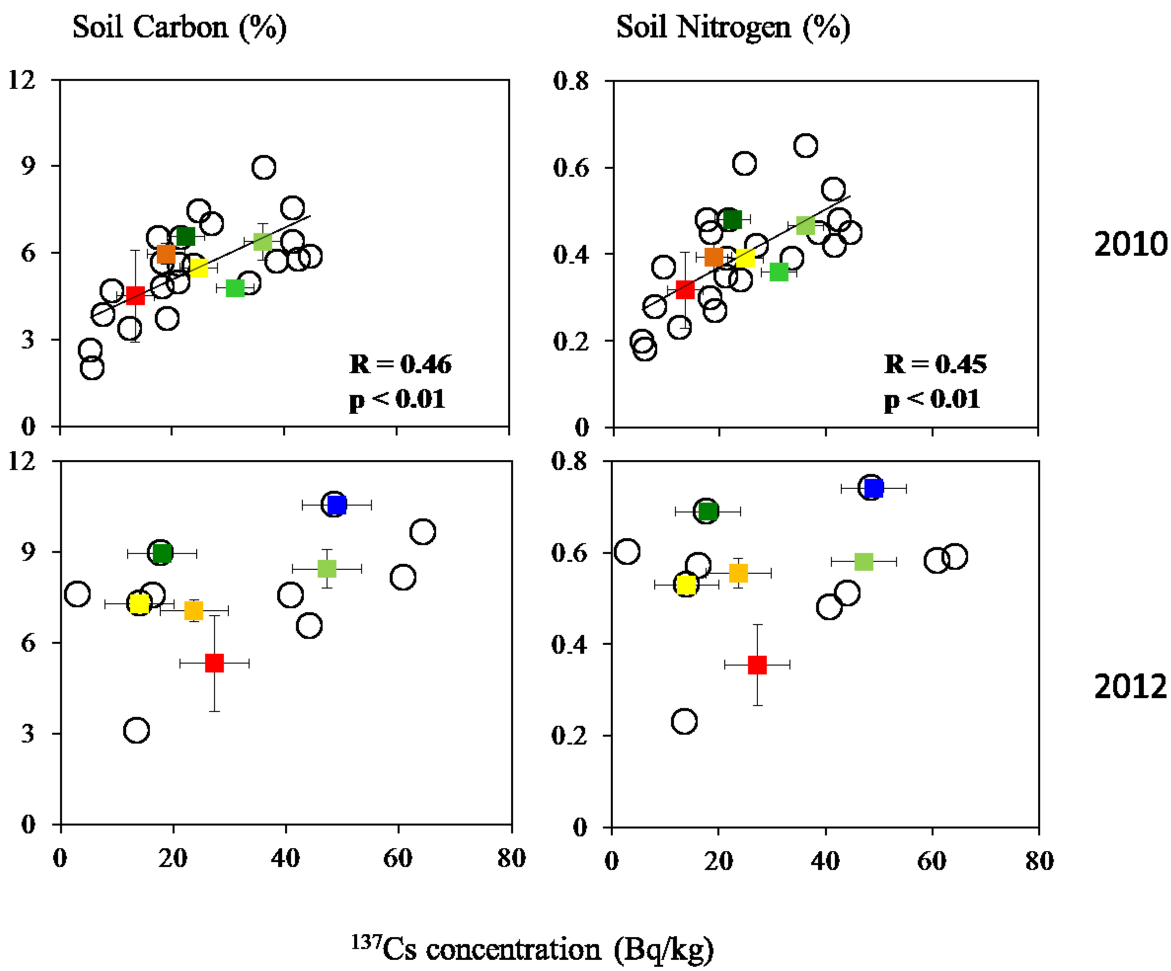


Figure 3.22. Relationship between soil nutrients and ^{137}Cs concentration

The relationship between understory biomass and soil pedestal was shown in Figure 3.23. This figure indicated that soil pedestal tend to be decreased with increase of understory biomass. When the understory biomass was larger than 100 g/m^2, there will be no soil pedestal in this study site. Soil pedestal had low negative correlation with SOC and TN (Figure 3.24).

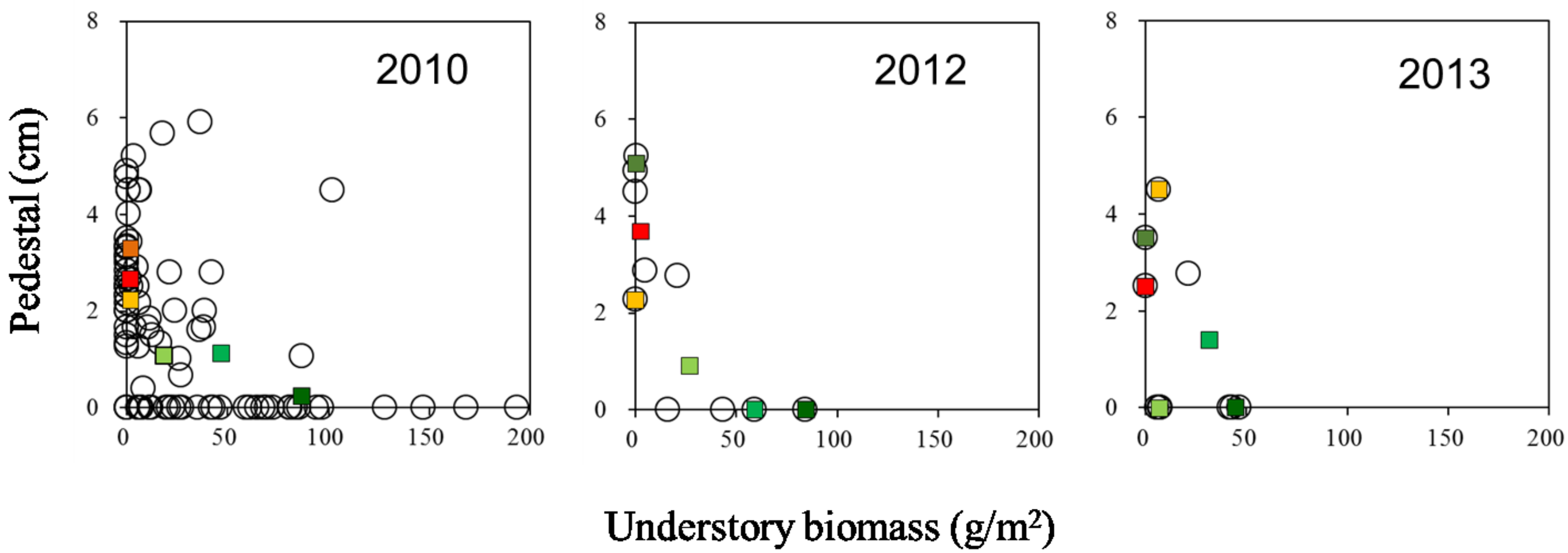


Figure 3.23. The relationship between ground biomass and soil pedestal

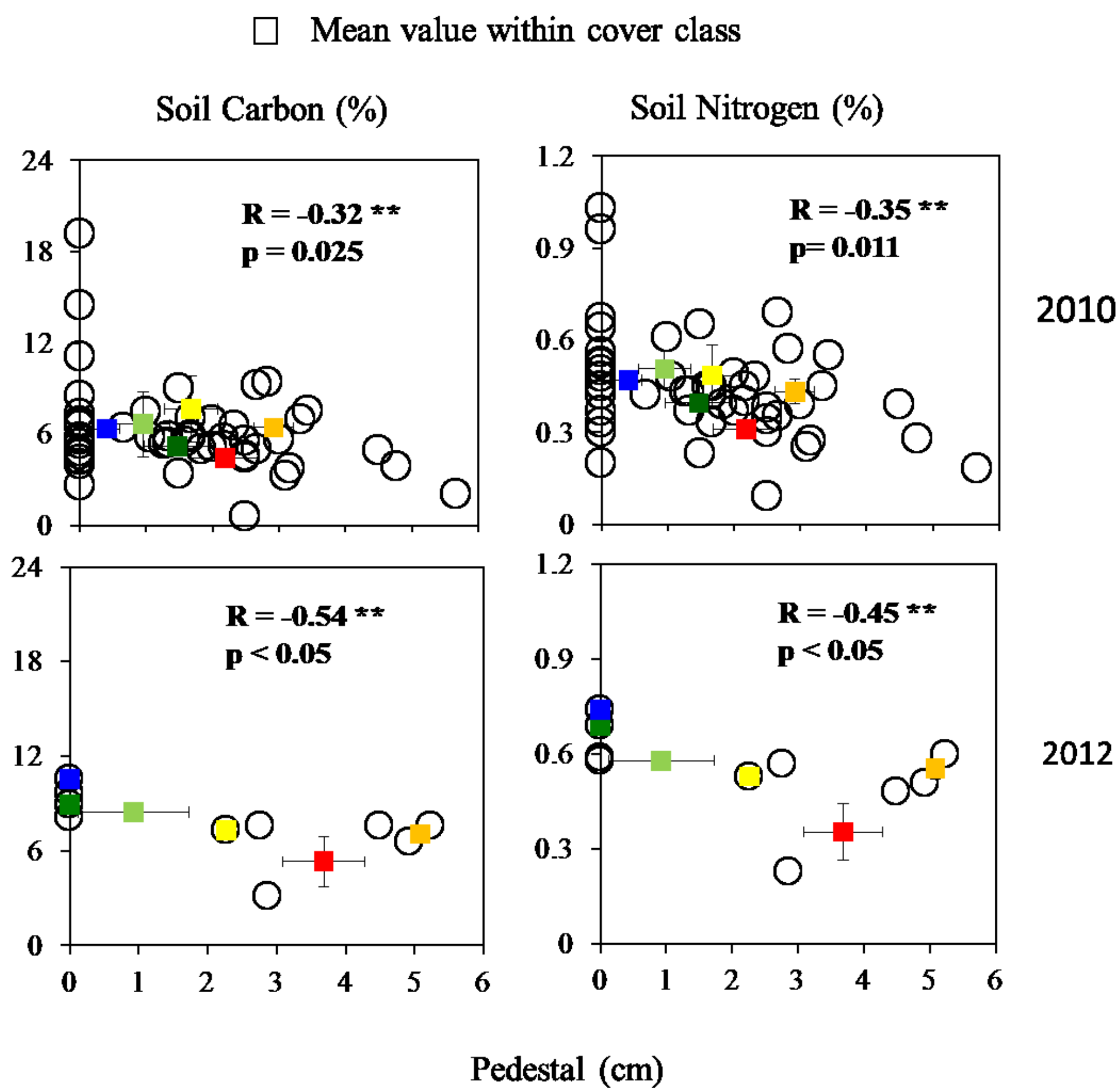


Figure 3.24. The relationship between soil Carbon and Nitrogen content and soil pedestal

Two principal components (PC) which explained 74.5 % of the observed variation in the soil and vegetation data were extracted from PCA analysis (Table 3.6; Figure 3.25). The first component presented high positive loading on the canopy openness, understory biomass, soil hardness and soil moisture, but a negative loading on gradient slope and soil pedestal (Table 3.6). This component reflects the relationship between understory vegetation and physical properties and implied the short-term soil erosion characteristics of study areas. The second principal component (PC2) had positive loadings on SOC, TN and litter. This component showed the relationship of litter on soil nutrients.

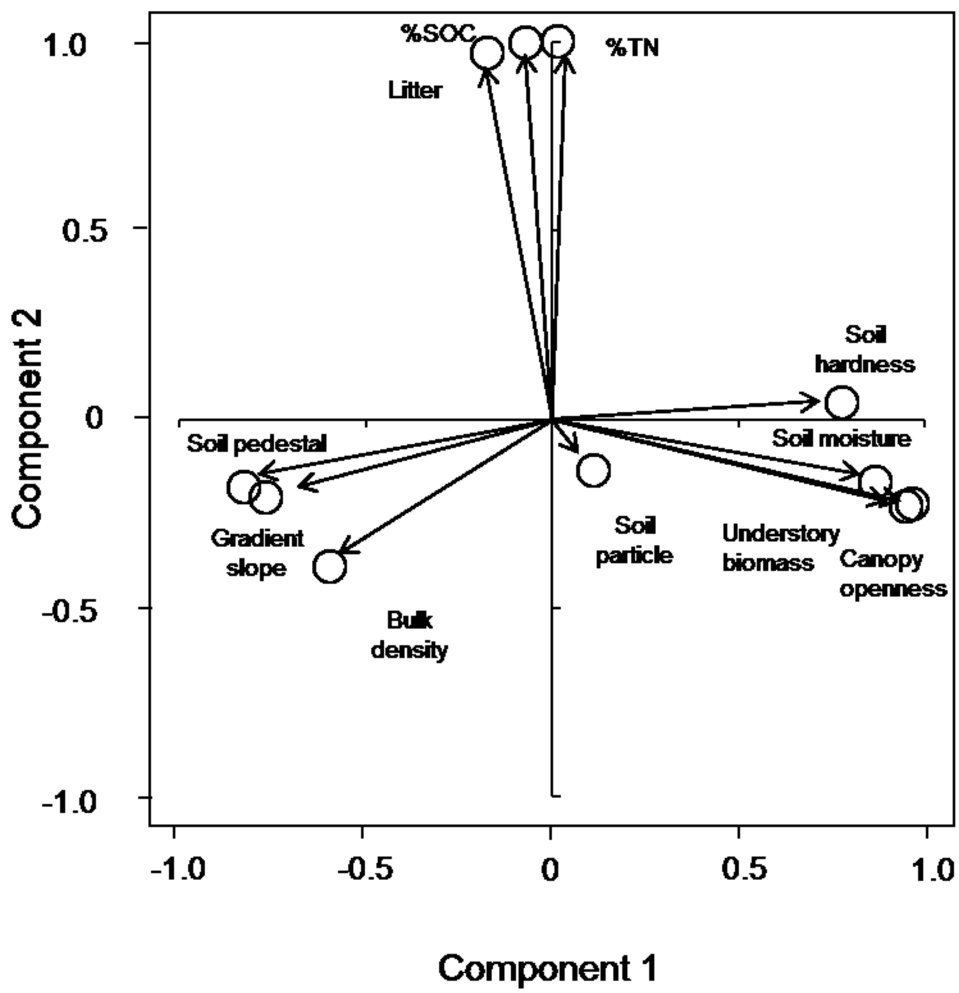


Figure 3.25. Ordination plot by principal components analysis. Components 1 and 2 represent 44% and 30% of the total variance, respectively

Table 3.6. Results of PCA. Variables underlined with absolute eigenvector coefficients ≥ 0.70 are considered significant

Rotated Component Matrix[a]		
Factors	Component	
	1	2
Gradient slope	<u>-0.764</u>	-0.210
Canopy openness	<u>0.970</u>	-0.228
Understory biomass	<u>0.953</u>	-0.235
Litter	-0.172	<u>0.969</u>
Soil Pedestal	<u>-0.823</u>	-0.183
Soil hardness	<u>0.782</u>	0.041
Soil moisture	<u>0.869</u>	-0.171
Bulk density	-0.592	-0.394
Soil particle	0.113	-0.138
% SOC	-0.068	<u>0.995</u>
% TN	0.017	<u>0.998</u>
Eigenvalues	4.876	3.314
%Variance	44.324	30.130
Cumulative Explanation	44.324	74.454

3.4. Discussion

3.4.1. Characteristics of sample location of Tanzawa forest

Tanzawa watershed located in Tanzawa natural forest. Even though it has many steep surfaces with the slope ranging from 2 - 48^{o}, and the slope average of 35^{o} the soil erosion is expected to be low because of its high groundcover percentage. The soil has relatively high organic carbon and total nitrogen contents of 6.12 and 0.44 % respectively and low bulk density (Table 3.1), which is typical condition of volcanic ash soil in Japan.

3.4.2. Relationship among these factors and the underlying implication

The correlation showed in Figure 3.21 exhibited two major relation trends among physical factors and chemicals in study area. The first trend was evident in the correlations among the slope and chemical concentrations in soil such as soil organic carbon total nitrogen and cesium-137, where the absolute correlation among these parameters were relatively high, r = -0.55 ~ -0.77 (Figure 3.21). The increase in the slope tended to alter the decrease in SOC, TN and ^{137}Cs concentration. The relation suggests that the slope affected long-term soil erosion which was removing elements from soil. In general, the canopy openness known as an indicator of plantation density and understory biomass are important factors indicating soil nutrients in soil since they are the sources of organic carbon and nitrogen in soil. In contract, both canopy openness and understory biomass had very low correlations with SOC and TN in this study, thus what would be the underlying these correlations? In fact, it required a longtime to convert from the fallen materials of living plans and dead understory vegetation knows as biomass to litter and then soil nutrients such as SOC and TN, therefore SOC and TN can be consider as a long-term parameters like the slope as mentioned previously (Figure 3.26). On the other hand, the canopy openness and biomass was subjected to be rapidly changed depended on seasons in a year, in other word, they can be consider as short-term parameters in forestry inventory. In this study, we measured these parameters one time in the summers after rainy season when they plantation and understory vegetation are expected to fully develop, thus the measured canopy openness and biomass would not reflect thus current status of SOC and TN in the soil at the monitoring time, in other word, the correlation are expected to be low as what we observed.

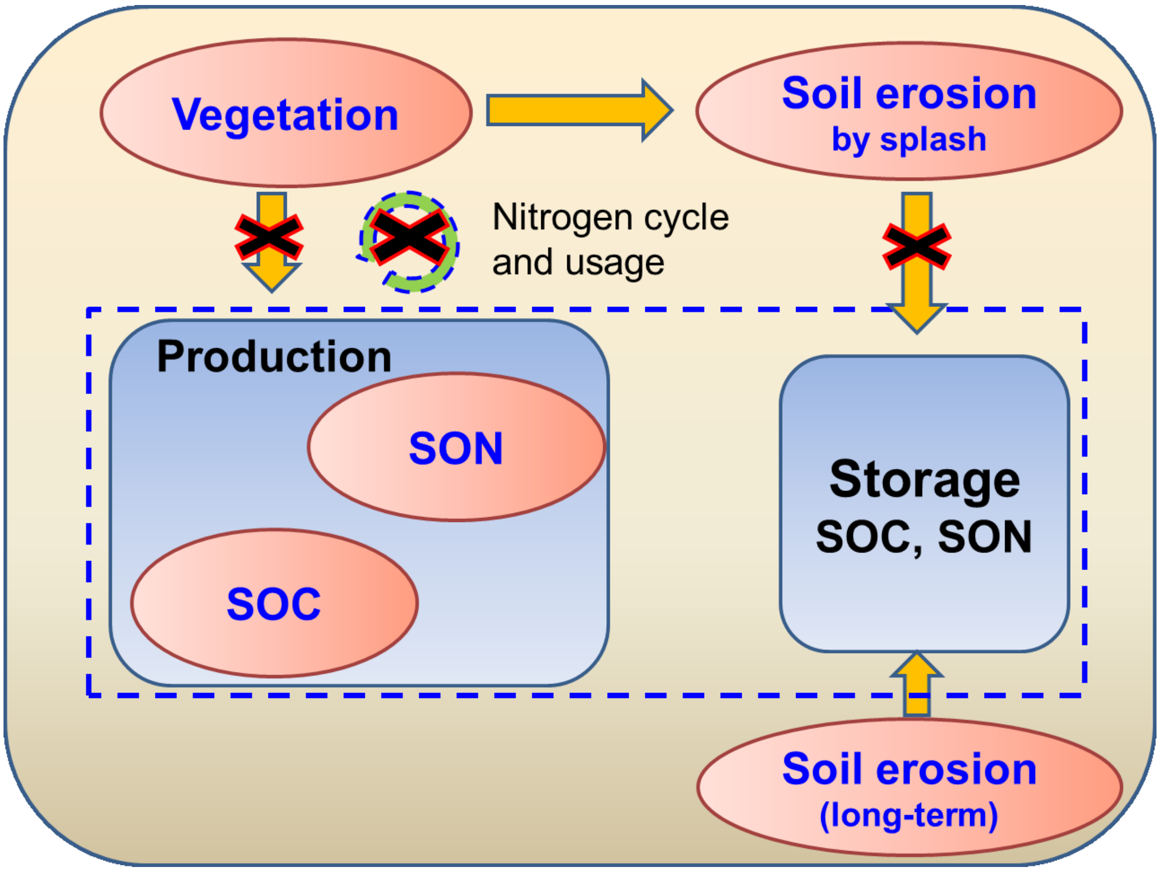


Figure 3.26. The interaction among understory vegetation, nutrients and soil erosion in Japan study

The production of litter plays a fundamental role in the biogeochemical cycle of organic matter and mineral nutrients, thus becoming a key component in the functioning and stability of forest ecosystems. Organic residues coming in the form of litter fall and accumulated on the ground are a major reservoir of organic matter and nutrients, and influence or regulate most of the functional processes occurring throughout the ecosystem (Gosz et al., 1972; Cuevas and Medina, 1988; Maguire, 1994). Under vegetation cover, SOC and TN contents were consistent despite changes in biomass. These results indicated understory plants may utilize soil Carbon and nutrient (Figure 3.27). Plants uptake some nutrients from soil. But soil carbon is not uptaken by plant directly. Soil carbon is decomposed and disappeared (CO2 emission) by microbial.

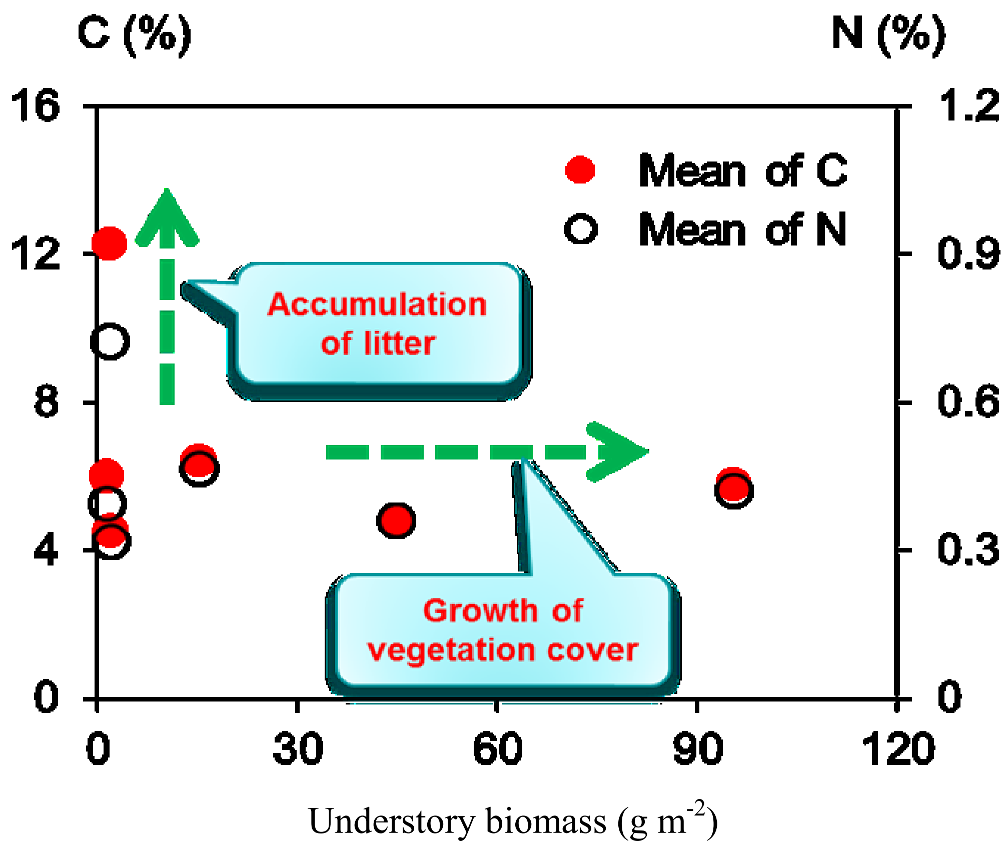


Figure 3.27 Linkage between soil carbon and nutrient and understory biomassin 2010

The second trend was the negative correlation of -0.39 between understory biomass and soil pedestal, which indicated the process in short-term soil erosion. Understory biomass is a short-term parameter in forest inventory as we mentioned in the previous paragraph. In addition, soil pedestal was considered as short-term indicator of soil erosion (Anh et al. 2014, Sidle, 2004). The higher understory biomass resisted surface flow and soil erosion that prevented the formation of soil pedestal.

PCA analysis was summarized in Table 3.6. In general, PCA will classify parameters into different groups that can explain the typical characteristics of study area. The Table 3.6 clearly shows the two distinct characteristics of study site. The tightly relationship among vegetation and soil physical properties were exhibited in PC1 that elucidated the underlying short-term erosion process whereas the relation of chemical richness or soil nutrient and litter were found in PC2. PC1 explained 44.3 % of total variance. Canopy openness and biomass have the highest positive component loaning in PC1 (Table 3.6). They are known as the two major factors that prevent soil from erosion. Canopy openness directly affects the development of understory biomass. The land that has higher canopy openness would expect to have a higher understory biomass. The relationship among the two factors can been in Figure 3.21 where their correlation was a 0.37. The availability of biomass will retard surface flow and then reduce soil erosion. In contrary, gradient slope and soil pedestal have high negative loading in PC1. The negative loading indicated that they tend to promote soil erosion process. It is easy to image the positive relationship between slope and soil erosion and why the slope could promote soil erosion. Soil pedestal has recently considered as an important indicator for short-term soil erosion (Anh et al., 2014 2004). Although soil pedestal could promote soil erosion, but they are indication of soil erosion thus their negative loading appeared in PC1 is understandable. Consequently, PC1 presents a tightly relationship of soil erosion and understory biomass and soil pedestal and that is one of the typical characteristics of study area.

PC2 consists of litter, SOC and TN, explaining 30% of total variance. Litter is placed in top surface soil layer, thus it is a main source supplying organic matter to the top soil layer. The transfer of organic matter from litter to organic carbon in surface soil is typical nutrient cycle in study area since the soil was very fertile, and contained relatively high organic carbon content. The evident of a high correlation between SOC and TN in Figure 3.21 also suggest this fact. Our finding agreed with a study on soil nutrients in a tropical forest in Northern Vietnam where a high correlation between SOC and TN was also observed (Anh et al.).

3.4.3. Spatial pattenr of understory vegetation cover

Based on field observation, comparisons over time showed that understory vegetation cover in 2012 was significant increased than in 2010 at this study site (Figure 2.28). However, the difference in understory vegetation in 2010 and 2013 were insignificant even the amount of biomass increased in 2013. The observed increase in the amount of understory vegetation in 2012 and 2013 may well be attributed a fence to control the deer activities. Our findings suggest that the changes in land management and the associated changes in understory and ground cover can alter soil physical properties, macronutrient contents, and both short- and long-term soil erosion rates. The increase in understory vegetation and ground cover is believed to be the primary cause of the decrease in soil erosion and macronutrients loss.

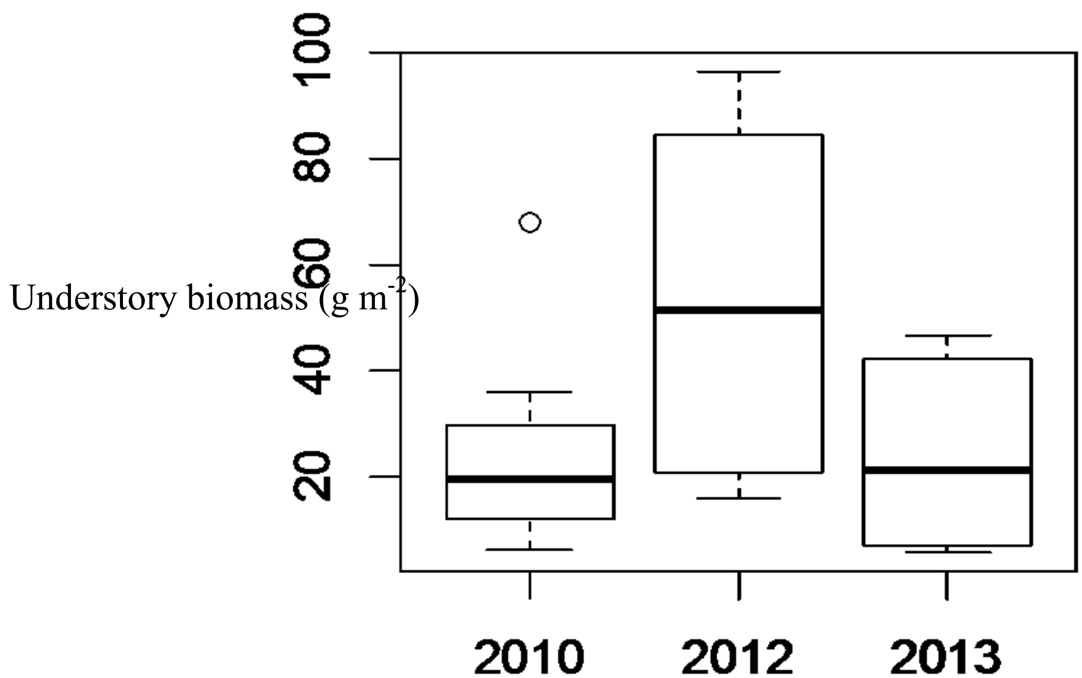


Figure 3.28. Comparison of understory biomass in 2010, 2012 and 2013

3.4.4. Effects of deer activities on understory vegetation and soil condition

Rapid increase in deer population in Tanzawa mountain has raised a concern on its impact on forest environment and soil erosion. Deer grazing and trampling disturbs ground vegetation and increase soil erosion. Based on our observation in 2010, deer ate leaves and branches and barks of young trees, thus it significantly decreased the density of shrubs and many tree species as well as ground coverages, and severely damaged ground vegetation. Our survey was conducted in 2010 when fences have not been installed, thus study area had been influenced by beer activities for years. After the measurement, we protected a part of study area in ridge 1 of catchment 3 from deer by fencing. The data measured in 2012 and 2013 were without disturbance of deer.

After 2 years fence installation in ridge 1, we observed a significant change in litter in all soil cover classes, and understory biomass in soil cover class 4 - 6 whereas the change in understory biomass in soil cover class 1 - 3, and others factors were insignificant between 2010 and 2012 (Figure 3.28). It is evident that the deer activity only affected the area with high ground vegetation or understory biomass and it increased litter possibly because of the increase in understory biomass. Liter and understory biomass in 2013 tends to be higher in theses in 2010, however, the difference in understory biomass and litter in 2010 and 2013 were insignificant. As a fact the variation of understory biomass and litter are depended on many factor such as soil conditions, weather condition, thus the comparison understory biomass and litter between 2010 and 2013 was not represent for the effect of deer on ground vegetation. We suggest a comparison in a short period such as between 2010 and 2013 is more likely appropriated.

3.4.4. Short-term, mid-term and long-term soil erosion

Soil erosion information is indispensable for evaluating soil quality in forestry; however it is not always easy to measure due to its complexity, laborious and uncertainty. Many alternative methods and indirect measurement methods have been invested to assess short-term and long-term soil erosion. Recently, soil pedestal, and ^{137}Cs have been reported to be good indicators for estimating short-term and long-term soil erosion, respectively (Anh et al., 2014). Since nuclear power plant has happen in Fukushima city that is 270 km far from our studies site, in March 11, 2011, during our monitoring period, in addition to soil pedestal and ^{137}Cs, we also measure ^{134}Cs as a mid-term soil erosion indicator as reported by (Walling and He, 1999a). The advantage of using ^{137}Cs and ^{134}Cs in this case is that we can accurately estimate the loss of ^{134}Cs in recently years then infer the mid-term soil erosion.

The relationship between understory biomass and soil pedestal indicated that a high biomass area could expect to have a low soil pedestal, which implies a low soil erosion rate. We also found that when the ground biomass was larger than 100 g/m^2, there will be no soil pedestal or in other word, soil erosion would not happened at the areas where understory biomass was greater than 100 g/m^2. Meanwhile, if the biomass was not available, soil pedestal could go up to 6 cm-height, which indicated a serious soil erosion condition (Figure 3.23). Soil pedestal had low correlation with SOC and TN, as mentioned previously (Figure 3.24). SOC and TN was a long-term parameter thus it did not correlate with other short-term parameters such as soil pedestal known as short-term soil erosion indicator.

^{137}Cs tends to highly correlated with SOC and TN (Figure 3.22). Due to the nature property of Cs, it has a strong absorption affinity to organic matter in soil thus it can be consider as indicator of long-term soil erosion but also a indicator for the availability of organic carbon in soil. Most of ^{137}Cs and ^{134}Cs were found in the top soil layer.

^{134}Cs and ^{137}Cs were mainly deposited in surface soil at 0-2.5 cm and tended not to move downward to depth soil layer via vertical infiltration (Figure 3.19 and Figure 3.20). ^{137}Cs was known as a less hydrate ionic element. It prefers to stay in relatively high organic carbon region and trongly bound to soil particles especially clay particles. As the fact that after fallout, ^{137}Cs quickly absorted to organic faction and clay in surface soil and trapped there because the binding is very stable and partly irriversitble. In addition, most of organic matter in soil was deposited in the surface soil thus they retard the ^{137}Cs from moving downward. The downward migration of ^{137}Cs can be estimated based on is its sorption coeffient and rainfall. Many reaseach has been reported that Cs has relatively high sorption coefficient in soil (Kd ~ 500 L/kg) (Ishikawa et al. 2007, Radioisotopes, 56: 519-528). The retardation factor (R) of a solute migrated downward in soil was estimated as R = 1 + (soil bulk density/ water content) × Kd (Soil Physics 6th ed. by Jury and Horton). Roughly, the retardation factor of ^{137}Cs, $R_{Cs\text{-}137} = 1 + (0.9 / 0.3) \times 500 \cong 1500$. Assuming that rainfall is 1500 mm/ yr, and all rainfall is infiltrated, after 10 year, the maximum water infiltration would be 10 x 1500 mm/ yr = 15000 mm, then ^{137}Cs would migrate 15000 mm / 1500 = 10 mm. It means that, after 10 year, ^{137}Cs can migrate downward only 10 mm.

Only ^{137}Cs was detected in 2010 at relatively low concentration, which was consider to be formed from radionuclide fallout in previous nuclear weapon testing activities around the word and nuclear bomb in Japan in 1945. The soil erosion can be estimated using a model as suggested by Walling and He (1999). Both ^{134}Cs and ^{137}Cs were detected in soil profile at relatively high concentration in 2012 and 2013 because of the effect of nuclear power plant (NPP) accident happened in Fukushima prefecture in March 03, 2011. The concentration of ^{137}Cs in reference site was considered to be unchanged in reference site and decrease in other sites due to soil erosion because its radio degradation half-life was relatively high (more than 30 years), however, ^{134}Cs concentration decline in reference site was assumed to solely due to radio degradation and, theses in other sites were a combination of radio degradation and soil erosion.

Our observation showed that cesium concentrations in 2012 and 2013 were higher than theses in 2010 in the most of location due to NPP accident in 2011. However there were two extreme cases, concentration in plot number of 1-8 and 1-9 were significantly increased from 31.43 and 35.49 Bq/kg to 8145.92, and 2455.89 Bq/kg in case of ^{137}Cs, and from 13.70 and 16.38 Bq/kg to 2455.89 and 2630.14 Bq/kg for case of ^{134}Cs in 2012 and 2013, respectively. The phenomenon was likely different from the conventional effect of soil erosion on radioactive Cs, the migration of ^{134}Cs and ^{137}Cs in to lichen and moss and their surrounded area (Dolhanczuk-Srodka et al., 2011; Iurian et al., 2011) and relocation of Cs from other area via surface runoff and soil colloid transport (Nishimura, 2013). The result indicate that the assessment of long-term soil erosion based on ^{137}Csconcentration is a potential approach however, one should pay attention on some special migration mechanisms of ^{137}Cs under the driving forces of lichen, moss and soil colloid which are likely available in temperate and tropical region where the soil organic matter are expected to be high. Because of the possible outlier of Cs concentrations in 1-8 and 1-9, where ^{137}Cs concentration was approximately 25 times greater than previous year, the estimation of soil erosion should neglect these concentrations. As we can see the concentration of ^{134}Cs in top 0-2.5 cm decreased from about 400 to 50 kBq/m^2, approximately 87.75% -95% of ^{134}Cs concentration in the reference site (Figure 3.20), which was signal of high soil erosion had occurred in in study areas. The distribution of ^{134}Cs likely depended on the distribution of organic carbon in soil (Figure 3.22). It again confirmed that ^{137}Cs is strongly bound to organic mater in soil. However, which processes really dominate the binding of Cs to organic matter? The mechanism can be seen by the chemistry of Cs in soil. In the periodic table, Cs belongs to grounp 1 together with Li, Na and K, thus it expected to have some chemical properties similar to Li, Na and K. For example, Cs ion is highly soluble in water. However, because Cs has a larger molecular radius than K thus it is less hydrate and tend to be absorbed to charged surface like soil particles especially humus and clay particles. Humus is known as an indicator of soil organic carbon. When the fallout occurred, Cs in surface soil tended to sorpt to organic matter and clay particle in surface soil. Because of the strong bound of Cs and organic matter in soil thus, when the rainfall occurred, Cs migrates in the same fashion with organic matter in soil via soil deposition in surface soil and downward migration via infiltration. Therefore we alway observe a high correlation of Cs and organic carbon content in soil. Similar to observation of ^{137}Cs in surface soil, the distribution of both ^{134}Cs and ^{137}Cs measured in 2012 and 2013 were highly correlated with SOC, and they were mainly deposited in top 0-2.5 cm surface soil layer.

3.5. Conclusions

Soil erosion is a natural process which has been greatly accelerated by human action. A reduction in understory vegetation cover can intensify erosion processes that diminish soil properties. In this areas with the effect of understory vegetation and litter cover, it is urgent protect the soil by understanding degradation processes and establishing adequate management measures. Moreover, the proven efficiency of the understory vegetation and litter covers for the restoration of nutrient accumulation should be considered more widely.

The activity of deer in forest significantly affected litter and the understory biomass at highly ground cover vegetation. The effects of deer activity on understory biomass at low ground cover vegetation were not significant. The effects of deer activity on soil nutrients were temporarily insignificant in a short-term (2 years). However a long-term affect are needed to be monitored for a better assessment of deer activity on soil nutrients.

Understory biomass had negatively correlated with soil pedestal ($r = -0.39$, $p=0.05$). When the biomass was greater than 100 g m^{-2} no soil pedestal was formed based on the continuous monitoring in 2010 to 2013. For the depth profile in various land cover, depth profile of ^{137}Cs and ^{134}Cs was inconsistent to the reference profiles. This patterns of radionuclide accumulation of soil profile suggested that soil surface turn over occurred due to the movement of soil and litter.

Soil nitrogen tended to correlate to slope gradient and ^{137}Cs in 2010 data. Similary, soil nitrogen and carbon correlated to slope gradient and bulk density in 2012. Princple component analysis also showed that SOC and TN were well correlated with ^{137}Cs. These chemical parameters thus were related to long-term soil erosion processes. Because the understory ground cover tended to be low in near stream channels in the watersheds, soil erosion and resultant nutrient movement near stream channel induced sediment supply to headwater channels and potentially affect downstream sedimentation. This study suggested the spatial patterns of understory vegetation and litter cover within catchments provided us target areas for providing additional conservation practices for increase in ground cover up to 100 g m^{-2}.

CHAPTER 4ESTIMATION OF SOIL EROSION RATE IN VARIOUS TYPE OF LAND USES

4.1. Introduction

Soil erosion has been identified as an important cause of land degradation in many countries (Angers and Caron, 1998a). Evaluation of soil erosion in forested and agricultural areas played the importance roles in the development of appropriate management practices. However, qualification of soil erosion is one of the greatest challenges in natural resource and environmental planning. Many methods for estimating soil erosion such as plot, trapping, and various surveying methods have been developed and used to quantify the soil erosion under both natural and artificial meteorological conditions in the last few decades (Ampofo et al., 2002; Hudson et al., 1993; Phan Ha et al., 2012; Vacca et al., 2000). Monitoring erosion 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. The use of fallout radionuclides in the soil, particularly ^{137}Cs and $^{210}Pb_{ex}$ offers considerable potential (Li et al., 2009; Li et al., 2003; Uchida et al., 2009; Walling and He, 1999b). This technique can avoid costly, time-consuming and labour intensive to monitor sites over extended periods (Mabit et al., 2008).

The potential for using ^{137}Cs fallout to quantify soil erosion and sedimentation rates has been successfully demonstrated on both cultivated lands and undisturbed soil in a wide range of environments around the world (Ritchie and McCarty, 2003; Wakiyama et al., 2010; Walling, 1998; Zapata, 2003). The ^{137}Cs method provides estimates of soil redistribution averaged from the beginning of global fallout until the time of sampling. It is therefore particularly useful for providing estimates of long-term soil erosion rates. Erosion rates can be calculated by comparing the radionuclide inventory in the soil of an individual sampling point to a local reference inventory that represents the total amount of the fallout radionuclide in the study area. The ^{137}Cs is globally distributed (Walling and He, 1999a) and has been used successfully for investigating mainly water-induced soil erosion on both cultivated lands and undisturbed soil in a wide range of environments in different regions (Bujan et al., 2003; Collins et al., 2001; Li et al., 2003). Unlike ^{137}Cs, deposition of fallout^{210}Pb from the atmosphere has been relatively constant through time because of its natural origin (Crickmore et al., 1990). ^{210}Pb$_{ex}$ method has been applied successfully in diverse agricultural landscapes of the world (Uchida et al., 2009; Wakiyama et al., 2010; Walling and He, 1999b; Zhang et al., 2006). However, at present its potential as a tracer of soil erosion is less widely recognized than ^{137}Cs and to date there have been few attempts to compare erosion rates estimated using both ^{137}Cs and ^{210}Pb.

This study reports an attempt to explore the use of ^{137}Cs and ^{210}Pb$_{ex}$ fallout to estimate soil erosion rates on uncultivated land. It focuses on ten land-uses type located in Xuan Mai town, Chuong My district, northern Vietnam, and forested headwater catchment in Japan for which measurements of sediment output are available.

4.2. Methodology

4.2.1. Theoretical basis for estimating soil redistribution rates

^{137}Cs with a half- life of 30.2 years is a man-made radioisotope, which was released into the environment as a product of the thermonuclear weapons testing during the period from the mid- 1950s to the early 1970s (Mabit et al., 2008). In most environments, ^{137}Cs is rapidly and strongly fixed by the fine particles of the topsoil after deposition. In cultivated soils, ^{137}Cs will be uniformly distributed within the plough layer, as a result of the mixing activities by tillage. In uncultivated soils, however, ^{137}Cs activity is generally characterized by an exponential decrease with depth. Its subsequent redistribution in the soil profile and across the land surface will be controlled by its interaction with land use practices, erosion, and sedimentation processes (Walling et al. 1999).

^{210}Pb (half-life 22.3 years) is a naturally occurring radionuclide from the ^{238}U decay series. It is derived from the decay of gaseous ^{222}Rn (half- life 3.8 days), the daughter of ^{226}Ra (half-life 1622 years). ^{226}Ra is found naturally in soils and rocks and most of it will produce ^{210}Pb in situ. This component of ^{210}Pb will be in equilibrium with its parent ^{226}Ra and is therefore termed supported ^{210}Pb. However, a small quantity of ^{222}Rn will be released into the atmosphere, where it will generate ^{210}Pb. This component of ^{210}Pb, which will not be in equilibrium with its parent, will be deposited on surface soils and sediments as fallout, and is termed unsupported or excess ^{210}Pb ($^{210}Pb_{ex}$). Like ^{137}Cs, $^{210}Pb_{ex}$ will be rapidly adsorbed by clay minerals and organic matter once it reaches the land surface as fallout. The shape of the $^{210}Pb_{ex}$ depth distribution in both cultivated and uncultivated soils is generally similar to those of ^{137}Cs. Subsequent redistribution of $^{210}Pb_{ex}$ within the soil profile and across the land surface is also similar to ^{137}Cs. Unlike ^{137}Cs, however, the $^{210}Pb_{ex}$ fallout is continuously deposited on the land surface and its inventory will remain essentially constant at sites with stable conditions and no erosion or deposition (Zhang et al.). Assessment of erosion and deposition rates is commonly based on a comparison of the radionuclide inventory at individual sampling points in the landscape with that for a reference site, where neither erosion nor deposition has occurred. Reduction of the radionuclide inventory, relative to the reference value, provides evidence of erosion, whereas areas of sediment deposition are characterized by an increased radionuclide inventory. The erosion or deposition rates can be estimated using conversion models which mathematically define the relationship between the amounts of soil gained or lost and the increase or decrease in the radionuclide inventory relative to the reference value (Walling and He, 1999b).

4.2.2. Sample analysis proceduce

We also analyzed radionuclide attached by soil particles. ^{137}Cs and $^{210}Pb_{ex}$ reaching the land surface as fallout from the atmosphere will be rapidly adsorbed by the surface soil and its subsequent redistribution within the landscape will reflect the movement of soil and sediment particles associated with soil erosion and sediment transport processes (Navas et al., 2012; Walling and He, 1999b). Because the several previous studies found clear relationships between radionuclide and soil organic carbon, this approach can potentially apply for evaluating the dynamics of soil carbon and nitrogen (Li et al., 2006; Ritchie et al., 2007). The benefit of using radionuclide (^{137}Cs and/or $^{210}Pb_{ex}$) techniques is for providing retrospective information of rather long term redistribution patterns of soil within the given land use (Li et al., 2006). Radionuclide such as ^{137}Cs and $^{210}Pb_{ex}$ was typically used as a tracer for estimating soil erosion rates. Hence, because the global fallout of ^{137}Cs is limited and soils are often disturbed during Vietnam war in the late 1960 (during highest level of global fallout), we only used $^{210}Pb_{ex}$ as an indicator of soil erosion. Moreover, some of the previous studies showed that $^{210}Pb_{ex}$ is appropriate indicator for investigation of soil erosion and nutrient accumulation (Mengistu et al., 2010).

A representative fraction (< 0.2 mm) of each dry sample was placed into a plastics pot and sealed for a period of more than 20 days prior to assay. This process ensured achievement of equilibrium conditions between ^{226}Ra and its daughter ^{222}Rn. Measurement of $^{210}Pb_{ex}$ activity in the soil samples was undertaken simultaneously using a high resolution, low background, low energy, hyper-pure n-type germanium coaxial y-ray detector (Ortec LOAX HPGe). The samples were counted for 40000-43200 second, providing 5% precision at the 95% level of confidence for the measurements. The total ^{210}Pb activity of the samples was measured at 46.5 keV. The $^{210}Pb_{ex}$ concentration of a sample was calculated by subtracting the ^{226}Ra-supported ^{210}Pb concentration from the total ^{210}Pb concentration (Li and Nguyen, 2010). The results of $^{210}Pb_{ex}$ were originally calculated on a per unit mass basis (Bq g^{-1}) and were then converted to the inventory (Bq m^{-2}).

4.2.3. Estimation of soil erosion rate

The redistribution of ^{137}Cs and $^{210}Pb_{ex}$ within the soil profile represents the result of a complex set of mechanisms including physical, physico-chemical and biological processes within the soil profile. Physical movement of soil can affect the concentration and inventory of ^{137}Cs and $^{210}Pb_{ex}$. We therefor used the diffusion and migration model (DM model) proposed by (Walling and He, 1999a) and also included the software by (Walling D.E. et al., 2006) to convert the measured ^{137}Cs and $^{210}Pb_{ex}$ inventories to estimates of soil erosion at the sampling sites.

$$A(t) = A(t_0)e^{-\int_{t_0}^{t}(PR/d+\lambda)dt'} + \int_{t_0}^{t}[1-P\gamma(1-e^{-\Delta tR/H})]I(t')e^{-(PR/d+\lambda)(t-t')}dt' \quad (1)$$

Where: A(t) and A(t_0) are inventory of ^{137}Cs and $^{210}Pb_{ex}$ at time t and initial condition at time t_0 (Bq m^{-2}).

P is particle size correction factor to take account of differences between the ^{137}Cs and $^{210}Pb_{ex}$ concentration of the mobilized sediment and the original soil.

d is the cumulative mass depth representing the average plow depth (kg m^{-2}).

λ is decay constant of ^{137}Cs and ^{210}Pb fallout (yr^{-1}).

γ is the proportion of the annual ^{137}Cs and ^{210}Pb fallout that is susceptible to removal by erosion prior to incorporation into the soil profile by tillage.

H is relaxation mass depth (kg m^{-2}).

I is the annual ^{210}Pb fallout deposition flux.

Therefore, we applied and estimated soil erosion rate using the fallout ^{210}Pb inventory as the follow,

$$A(t) = A(t_0)e^{-(PR/d+\lambda)(t-t_0)} + \frac{I(1-P\gamma(1-e^{-\Delta tR/H}))}{PR/D+\lambda}[1-e^{-(PR/d+\lambda)(t-t')}] \quad (2)$$

The value of γ is dependent on the timing of cultivation and the local rainfall intensity. In this case, all the ^{137}Cs and ^{210}Pb already accumulated at the soil surface as well as the ^{137}Cs and ^{210}Pb input directly associated with this rainfall will be susceptible to remove by erosion. The value of γ thus can be assumed to be 1.0. For agriculture land, cultivation depth was assumed to be 0.15 m based on field investigation. For forested land, cultivation depth was set as 0.05 m because of minimal but no negligible soil movement on surface. Therefore, soil depth by unit area weight *d* was calculated 150 to 196 kg m^{-2} in agriculture land and 43 to 58 kg m^{-2} in forested land.

4.3. Results

4.3.1. Erosion rates on cultivated area in the Northeast of Vietnam

The annual soil erosion rates associated with cultivated area Vietnam estimated from the $^{210}Pb_{ex}$ measurements are presented in Table 4.1. The soil erosion rates range between 14 t ha^{-1} yr^{-1} (1.2 mm yr^{-1}) and 330 t ha^{-1} yr^{-1} (32.4 mm yr^{-1}) with different land-use types (Figure 4.1). The highest erosion rate occurred on bare land, whereas the lowest value was found on Eucalyptus plantation. Mean estimated soil erosion rates were 52.3 t ha^{-1} yr^{-1} in the forested land ranging from 14 to 85 t ha^{-1} yr^{-1} (1.2 to 8.3 mm yr^{-1}) (Table 4.1). Soil erosion rate of agriculture land ranged from 135 to 140 t ha^{-1} yr^{-1} (11.5 to 14.0 mm yr^{-1}) with mean of 137.5 t ha^{-1} yr^{-1}. Erosion rate of shrub land was 174 t ha^{-1} yr^{-1} (13.3 mm yr^{-1}), while the reason rate of the bare land was 330 t ha^{-1} yr^{-1} (32.4 mm yr^{-1}) (Table 4.1). Our estimated soil erosion in forested land (14 to 85 t ha^{-1} yr^{-1}) was similar to the understand land reported by 50 t ha^{-1} yr^{-1}(Morgan et al., 1984). Conversely, in the agriculture land, reported soil erosion rate from 40 to 90 t ha^{-1} yr^{-1} (Van De et al., 2008) were a bit lower compare to our estimated values.

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Table 4.1. The annual soil erosion rates from different land-use types in the Northeast Vietnam

No.	Categories	Vegetation type	Duration of land use (years)	R (t ha^{-1} yr^{-1})	R (mm yr^{-1})
1	Mature forest - VN	*Pinus massoniana*	> 20		
2	Mature forest - VN	*Acacia mangium*	20 --25	66	6.4
3	Mature forest - VN	*Elaeocarpus dubius*	10--15	85	8.3
4	Mature forest - VN	*Eucalyptus exserta*	20 --25	14	1.2
5	Young forest - VN	*Acacia mangium*	3	44	5.1
6	Agriculture - VN	*Manihot esculenta*	Major production	135	11.5
7	Agriculture - VN	*Cymbopogon marginatus*	Major production	140	14.0
8	Shrub - VN	Various types of low shrubs	5 - 10	174	13.3
9	Bare land - VN	Not applicable	No vegetation	330	32.4
10	Lanscape Plantation - VN	*Roystonea regia*	Landscape plants		

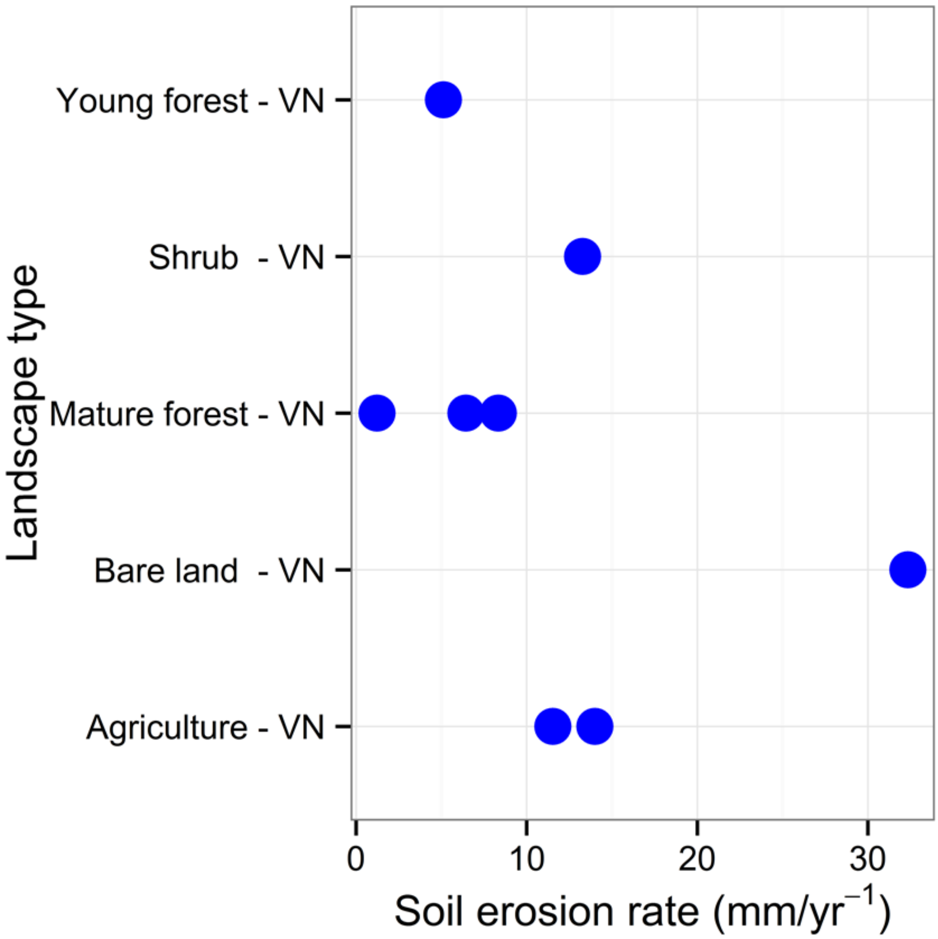

Figure 4.1. Soil erosion rates in Vietnam study

4.3.2. Erosion rates on forested area in the headwater catchment in Japan.

Table 4.2 shows the estimated average soil erosion rates on various cover classes that estimated by ^{137}Cs measurement. This result indicated that soil erosion rates were not much difference among six cover classes in headwater catchment, Japan (Figure 4.2). The highest average soil erosion rate of 18 t ha^{-1} yr^{-1} (3 mm yr^{-1}) was found on cover class 1 without understory vegetation and litter cover. The soil erosion rates with cover class 2 and 3 were a bit higher than the soil erosion rates with understory vegetation.

Table 4.2. The annual soil erosion rates in various cover class within the headwater catchment

Categories	*Year*	Cover class	R (t ha^{-1} yr^{-1})	R (mm yr^{-1})
Natural forest - JP (class 1)	2010	1	18	2.6
Natural forest - JP (class 2)	2010	2	15	2.5
Natural forest - JP (class 3)	2010	3	15	3.0
Natural forest - JP (class 4)	2010	4	7	1.4
Natural forest - JP (class 5)	2010	5	12	2.0
Natural forest - JP (class 6)	2010	6	14	2.8

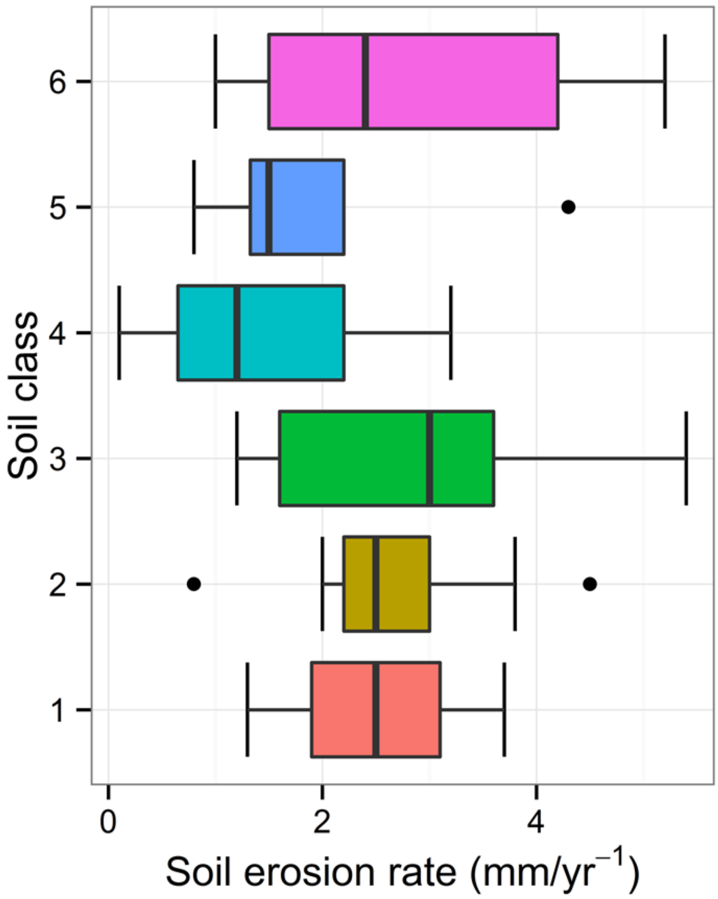

Figure 4.2. Soil erosion rates in Japan study

4.3.3. Comparison of estimated soil erosion in various studies

The soil erosion rate was converted to unit of mm/yr (Table 4.1 and Table 4.2) for comparison with a review by Montgomery (2007). The comparisons are showed that soil erosion rate in Vietnam were greatly varied depended ground vegetation cover types, whereas there was not much difference in soil erosion among six cover classes in Japan (Figure 4.1 and 4.2). Soil erosion rates in both of Vietnam and Japan exceeded nature erosion but they are still in the range of soil erosion in agricultural land from Montgomery (2007). Even the hilly area in Vietnam, soil erosion rate was higher than steep mountain in Japan. This is related to the land management and development in this area. Therefore the further investigation to estimated soil erosion rate is necessary for soil conservation.

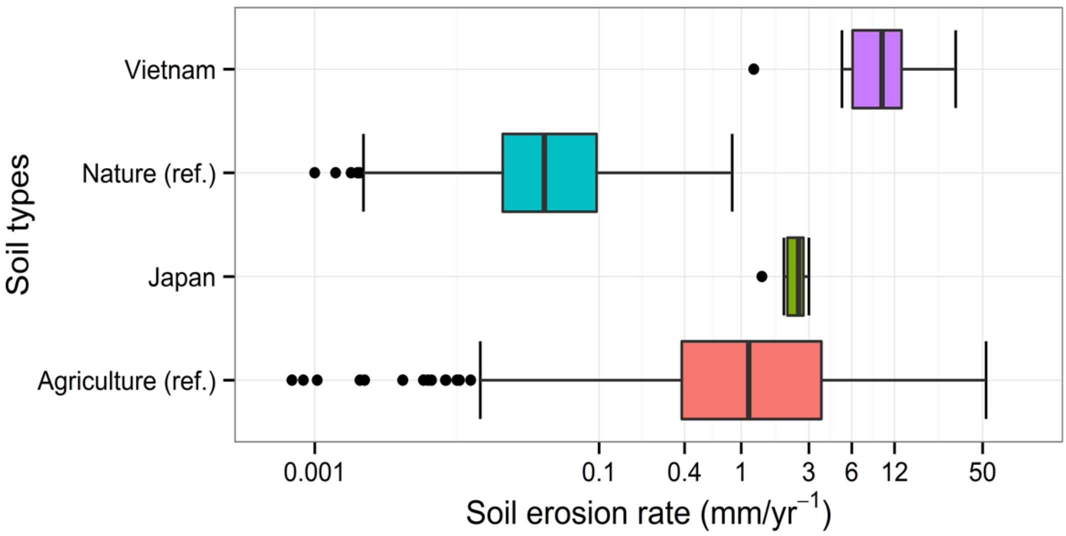

Figure 4.3. Comparison of soil erosion rate from Montgemery (2007) and the estimated soil erosion rate of Northern Vietnam in 2010 and Tanzawa forest in Japan in 2010

4.4. Conclusions

The successful use of ^{137}Cs and ^{210}Pb$_{ex}$ for estimating soil erosion rates on difference land-uses types has clearly demonstrated the validity of these methods in both the Northeast Vietnam and Tanzawa area. The results presented in Table 4.1 and Table 4.2 clearly confirms the potential for using ^{137}Cs and ^{210}Pb$_{ex}$ measurements to investigate the spatial pattern of soil redistribution in the study catchment. These results indicate that soil erosion are generally lower in which has more understory vegetation and litter cover. Higher erosion rates of 330 t ha^{-1} year^{-1} are found on the bare land in Vietnam. The ^{137}Cs technique has been successfully used to study the spatial distribution of soil redistribution within a study area and thus offers important advantages over other methods for documenting erosion rates. Moreover, fallout radionuclide measurements are particularly useful for the assessment of erosion rates in areas with limited monitoring data and the techniques may overcome many of the limitations associated with conventional monitoring methods.

CHAPTER 5SUMMARY, CONCLUSION AND MANAGEMENT APPLICATION

5.1. Main findings of the thesis

Soil erosion was known as an important factor that controlled soil quality, nutrient which directly influences the vegetation and soil cover condition as well as the dynamic of water, soil nutrient and pollutants and surface and subsurface soil. Serious soil erosion could result soil degradation and seriously affect to environment and human being. Erosion spans a wide range of spatial scales that includes the simple plot of specific site, the field observation in hillslope and catchment scale (Kirkby, Imeson et al. 1996). Numerous studies on water erosion from arable lands have indicated that soil erosion rate from field observation areas are much lower than those from plot areas, stressing the importance of the scale (Boardman and Favis-Mortlock 1993; Evans 1993). This study therefore combined the information about soil erosion and nutrient loss on different vegetation ground cover in plot scale and hillslope scale for land management. Statistically, soil erosion is a multivariate issue; it is influenced by many variables and factors such as vegetation, soil physical properties, chemicals, and metrological conditions, etc. Any field inventory will be suffered from two types of variations known as temporal variation and spatial variation in addition to measurement variation. The advantage of plot-scale study is that we can reduce spatial variation, thus we can expect to see clearly the correlation among variables and its real contribution to soil erosion. These correlations may reveal many interesting underlying mechanism and insightful interaction among variables, which is very important for management of soil erosion. On the other hand, there relationships may be seen only in plot-scale study, and it may not be seen in larger scale because of the interference of spatial variation of all variables. However, this is a real outcome from the interaction among variables and spatial variations. In this thesis I will address to above knowledge gaps through five chapters. Chapter 1 introduces the importance of ground cover condition and spatial scales on studying soil erosion and nutrient accumulation and the main objectives and structure of this thesis. Chapter 2 presents the characteristic of short- and long-term soil erosion and soil nutrient accumulation using soil pedestals and radionuclides at plot scale in northern Vietnam. We also evaluate the relationships and potential feedbacks between land use, macronutrient levels, physical soil properties, the amount of vegetation and litter, and soil erosion. Chapter 3 addresses the bigger-scale issue of the distribution of soil erosion and nutrient accumulation (influenced by the various ground covers) alters water land management of headwater catchment in Tanzawa prefecture, Japan. In particular, this chapter highlighted the functional roles of headwater systems and their linkages with downstream systems, furthermore I also discuss the possible effect of local deer activities on vegetation and soil erosion in study area. The objective of chapter 4 is to explore the potential for using ^{137}Cs and $^{210}Pb_{ex}$ measurements to investigate soil erosion rates in both Vietnam and Japan study sites. Such information is need to design and target effective soil and water conservation in forested headwater catchment. The chapter 5 is summary of important findings, the scale issue was also discussed along with conclusions and soil erosion management and application in Vietnam and Japan. The key findings of the five chapters are summarized in the flowing section.

5. 1.1. The importance of ground cover condition (chapter 1)

Soil erosion is a major and widespread challenging problem of soil conservation in the world today, because it seriously threatens agriculture and the natural environment (Dung et al., 2011). Soil erosion leads to loss of valuable topsoil (Logan, 1990; Troeh et al., 2004) and increases suspended sediment concentrations in streams and sedimentation in reservoirs and, with consequent effects on ecosystem health (Flügel et al., 2003).

Soil erosion depends not only on soil properties, climate, and slope, but also on land use and ground cover (Yarie, 1980), which have been known as an indicator of landform characteristics, disturbance history (Kamisako et al., 2007; Meilleur et al., 1992), nutrient cycling and soil fertility (Chapin Iii, 1983; Li et al., 2001; Matsushima and Chang, 2007; Yarie, 1980). Numerous studies have indicated that the extent of vegetation and litter cover reduces overland runoff and soil erosion (Castillo et al., 1997; Cerdan et al., 2002; Marston, 1952; Miyata et al., 2009).

Soil erosion due to decrease of vegetation ground cover is one of the major environmental concerns in steep mountainous watershed and produces excess sediment to downstreams. Reduction of vegetation and litter groundcover can induce severe degradation of both soil physical and geochemical properties (Montgomery, 2007). For instance, Fierer and Gabet (2002) showed that hillslope vegetation types had strong effects on the loss of carbon and nitrogen.

Although we realize the importance of vegetation and litter ground cover. On the other hand, the need to understand, describe, predict and quantify soil erosion at all scales, and accurately define the influence of local ecological factors is important for the adoption of suitable erosion control measures. Many of the problems associated with long-term monitoring of soil redistribution can be overcome by using methodology to trace soil movement (Belyaev et al., 2009; Li et al., 2009; Ritchie et al., 2007; Wakiyama et al., 2010; Walling, 1998; Zhang et al., 2006).

This study combined soil erosion and nutrient accumulation under various ground covers in both plot scale and watershed scale. The objective of this study were to understand the interaction between soil erosion and soil nutrients accumulation from plot scale to headwater catchments under various ground surface conditions.

5.1.2. Plot-scale study in the North of Vietnam (chapter 2)

The plot-scale study found clearly the interactions between understory biomass, litter, and soil properties. Understory biomass tended to be lower in agricultural land than most forest types, but both *P. massoniana and R. regia* had very low understory biomass. *R. regia* also had relatively little understory biomass and also very low litter amount, and this may be due to the fact that this was a relatively young stand. In contrast, the native forest *(E. dubius*) had the highest canopy cover, but still had a moderate amount of understory biomass and a high litter mass and ground cover. Shrubland tended to be intermediate with not only high canopy openness but also high understory and litter mass, resulting in more than 90% ground cover. This makes simple generalizations difficult, except for bare land having very little overstory, biomass, and percent cover.

Soil organic carbon and nitrogen were strongly related to the amount of understory biomass than the amount of litter, although there was a strong correlation between the amount of litter and understory biomass. The amount of ground cover was a complex function as this was positively but not significantly correlated with both understory biomass and litter amount, and inversely related to canopy openness. Soil organic carbon and nitrogen levels significantly declined with increasing bulk density, and this may be a reflection of both current and prior land use activities.

Soil pedestal heights indicated that short-term soil erosion was greatest in the four land use types with the least understory biomass. The correlation analysis showed that pedestal height was most strongly related to percent ground cover, as the four land uses with the highest pedestal heights did not have more than 63% ground cover, while none of the land uses with more than 76% cover had any soil pedestals

The $^{210}Pb_{ex}$ inventories for four of the forest types in our study and the shrubland ranged from 4280 to 5678 Bq m^{-2}, even though this was only measured in the top 5.35 cm. The very low value for *R. regia* can be attributed to the effect of terracing, while it is not clear why the $^{210}Pb_{ex}$ value for *Acacia spp.* is so low as there was no evidence of soil pedestals. For comparison, the $^{210}Pb_{ex}$ inventories for 0 to 30 cm at reference sites in Indonesia were nearly identical to most of our forest values at 4122 to 5322 Bq m^{-2}. Taken together, these results indicate that erosion rates for most of the forested areas on Luot Mountain have generally been low for much longer than the age of the current tree plantations and the replanted native forest.

The low $^{210}Pb_{ex}$ contents in agricultural and bare lands were attributed to erosion by rainsplash and overland flow, and this is supported by the observed pedestal heights in the cassava and bare lands. No pedestals were observed in the lemon grass plots, but previous agricultural activities may be responsible for the current low inventory of $^{210}Pb_{ex}$. Soil pedestal height was most closely related to the amount of surface cover, and surface cover also was the strongest explanatory variable for the amount of $^{210}Pb_{ex}$.

Forests did not necessarily have the highest amounts of litter or ground cover, or the lowest bulk densities. Hence they did not necessarily have the highest concentrations of soil organic carbon, nitrogen or phosphorus, or the lowest erosion rates. These results indicate that understory biomass, surface cover, and bulk density are the most important characteristics influencing soil nutrient status and erosion rates, and these three controlling factors are governed more by the specific characteristics of different types of forests or agricultural crops rather than the broad classification of land use (e.g., forest vs. agriculture).

Our findings suggest that the changes in land management and the associated changes in understory and ground cover can alter soil physical properties, macronutrient contents, and both short- and long-term soil erosion rates. The decrease in understory vegetation and ground cover is believed to be the primary cause of the increase in soil erosion and decrease in macronutrients. Similarly, soil chemical richness is strongly linked to understory biomass litter biomass, and possibly the degradation of soil physical properties as exemplified by bulk density.

The substantial differences in vegetation and soil physical properties among the specific land uses affect soil carbon and nutrient levels as well as erosion rates, indicating an important feedback loop between vegetation, soil conditions, and erosion rates. A simple characterization of forest or non-forest is not sufficient to calculate carbon and nutrient stocks, or to assess erosion risks. For these purposes, and for guiding land management in hilly areas such as North Vietnam, more specific information is needed on the local soils and vegetation characteristic

5.1.3. Headwater catchment scale in Tanzawa prefecture, Japan (chapter 3)

Statistical analysis showed that variables of vegetation, soil physical and chemical properties of surface soil Tanzawa forest can be characterized into two main components that explained 74.5 % of total variances. Component 1 (PC1) consisted most of vegetation and soil physical properties variable, explaining 44.3% of total variances, is represented for the contribution of variables in the ground to short-term soil erosion in study area. The main factor controlling soil erosion in the area are ground vegetation knows as ground biomass and canopy openness followed by soil moisture, gradient slope and soil hardness. Soil pedestal was very good indicator for short-term soil erosion in study areas. Component 2 (PC2) consisted of most of chemical parameters known as litter, SOC, and TN, explained 30.13% of total variance. The PC2 showed the source of soil nutrient of study area was mainly original from litter. SOC and TN were well correlated with ^{137}Cs showing that these chemical parameters were related to long-term soil erosion processes.

Soil pedestal and concentration of ^{137}Cs were good indicators for short-term soil erosion and long-term soil erosion, the migration of ^{137}Cs, however, associated with soil colloid and leaving plants such as lichens and mosses in several host plots should be considered and eliminated from long-term soil erosion prediction. Understory biomass has negatively correlated with soil pedestal, when the biomass was greater than 100 g m^{-2} there would be no soil pedestal or in other word, soil erosion could be negligible.

The activity of deer in forest significantly affected litter and the biomass at highly ground cover vegetation. The effects of deer activity on biomass at low ground cover vegetation were not significant. The effects of deer activity on soil nutrients were temporarily insignificant in a short-term (2 years). However a long-term affect are needed to be monitored for a bester assessment of deer activity on soil nutrients.

5.1.4. Estimation of soil erosion rate and nutrients accumulation (chapter 4)

In Vietnam, estimated soil erosion rates range between 14 t ha^{-1} yr^{-1} (1.2 mm yr^{-1}) and 330 t ha^{-1} yr^{-1} (32.4 mm yr^{-1}) with different land-use types. The highest erosion rate occurred on bare land, whereas the lowest value was found on Eucalyptus plantation. Mean estimated soil erosion rates were 52.3 t ha^{-1} yr^{-1} in the forested land ranging from 14 to 85 t ha^{-1} yr^{-1} (1.2 to 8.3 mm yr^{-1}). Soil erosion rate of agriculture land ranged from 135 to 140 t ha^{-1} yr^{-1} (11.5 to 14.0 mm yr^{-1}) with mean of 137.5 t ha^{-1} yr^{-1}. Erosion rate of shrub land was 174 t ha^{-1} yr^{-1} (13.3 mm yr^{-1}), while the reason rate of the bare land was 330 t ha^{-1} yr^{-1} (32.4 mm yr^{-1}).

In Japan, It is clear that the vegetation cover plays a very important role to control on soil erosion in headwater catchment. The highest average soil erosion rate of 18 t ha^{-1} yr^{-1} was found on cover class 1 without understory vegetation and litter cover. The soil erosion rates with litter cover class were a bit higher than the soil erosion rates with understory vegetation.

The successful use of ^{137}Cs and $^{210}Pb_{ex}$ for estimating soil erosion rates on difference land-uses types has clearly demonstrated the validity of these methods in both the Northeast Vietnam and Tanzawa area. The results confirm the potential for using ^{137}Cs and $^{210}Pb_{ex}$ measurements to investigate the spatial pattern of soil redistribution in the study catchment. These results indicate that soil erosion are generally higher in which has more understory vegetation and litter cover. Higher erosion rates of 330 t ha^{-1} yr^{-1} are found on the bare land in Vietnam. The ^{137}Cs technique has been successfully used to study the spatial distribution of soil redistribution within a study area and thus offers important advantages over other methods for documenting erosion rates. Moreover, fallout radionuclide measurements are particularly useful for the assessment of erosion rates in areas with limited monitoring data and the techniques may overcome many of the limitations associated with conventional monitoring methods.

5.2. Synthesis

As I mentioned in the beginning of this dissertation, the ultimate goal of this study is to understand the interaction between soil erosion and soil nutrients accumulation from plot scale to headwater catchments under various ground surface conditions. The evidences of relationships among these factors in a plot scale were thoroughly discussed in chapter 2, which represented for typical interaction among soil nutrients, vegetation and soil erosion in a tropical forest in Northern Vietnam. These evidences were re-captured in a larger scale known as headwater catchment in a temperate forest in Tanzawa prefecture, Japan. Each study site provided several individual characteristics that associated with site-specific conditions, moreover, a greater picture on soil erosion and interesting facts underlying these data can be drawn. The difference between the finddings of two studies is the relationship between vegetation ground cover and soil production process. This may associate with tropical and temperate climate in two of area. On the other hand, there is no related between soil nutrients and soil erosion. This is difference topography because Vietnam site is hilly, Japan site is steep mountain (Figure 5.1). Therefore, I summarized several main findings in this study as below.

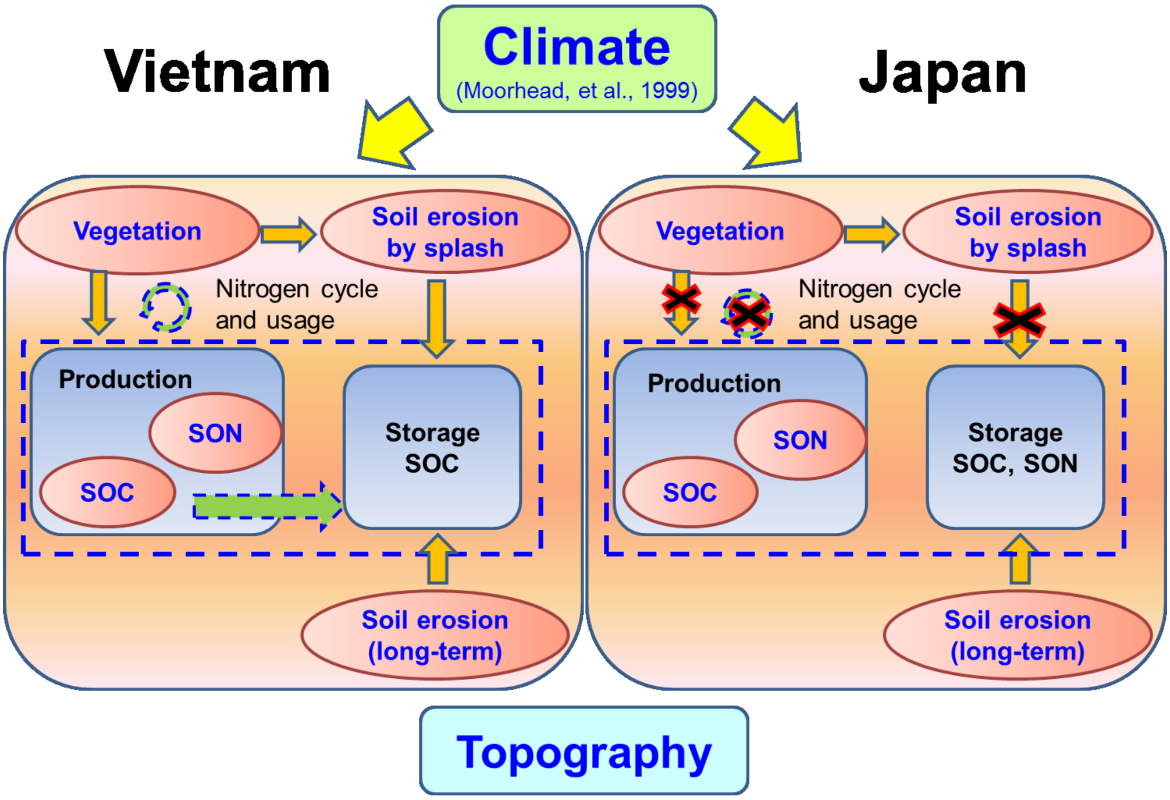

Figure 5.1. Comparison of finding in both Vietnam and Japan study

Because of tight relationships of soil pedestal and ^{137}Cs with other physical and chemical factors as well as vegetation observed in both tropical forest in Vietnam and temperate forest in Japan, this study supported that soil pedestal and ^{137}Cs are one of the good indicators for short-term and long-term soil erosion, respectively. Although, soil pedestal and concentration of ^{137}Cs were good indicators for short-term soil erosion and long-term soil erosion, the migration of ^{137}Cs, however, associated with soil colloid and leaving plants like lichens and mosses which may result in ^{137}Cs hotspots, should be considered during inventory, and the values should be eliminated from long-term soil erosion assessment. Furthermore, soil management practices such as the cultivation or other human activities in the cultivated area may disturb surface soil and affect the accuracy of ^{137}Cs as well as soil pedestal measurements that were then impacted soil erosion assessment.

Understory biomass was significantly depended on land-use types, and in general, biomass invented in the forest land had a larger variation as compared to that in agricultural land. Understory biomass highly correlated groundcover and openness and negatively correlated with soil pedestal, which indicated that understory biomass was an important factor that directly affects the short-term soil erosion. Depended on characteristics of each forest, when the understory biomass reached certain values, there would be no soil pedestal available in that region or in other word soil erosion would not occurred or negligible at such conditions. In northern Vietnam, when biomass was greater than 130 to 150 g m^{-2} then short-term soil erosion was negligible, whereas these biomass values found in Tanzawa, Japan was 100 g m^{-2}.

Soil organic carbons are strongly correlated with total nitrogen, and both were positively correlated to litter and strongly and inversely influenced by bulk density. Litter is placed in top surface soil layer, thus it is a main source supplying organic matter to the top soil layer. The transfer of organic matter from litter to organic carbon in surface soil is typical nutrient cycle in study area since the soil was very fertile, and contained relatively high organic carbon content. We observed high correlation between SOC and TN and understory biomass in Vietnam but these correlations were rather low in Japan. In fact, it required a longtime to degrade the fallen materials of living plans and dead understory vegetation knows as biomass to litter and then soil nutrients such as SOC and TN. In other word, there was time lag in the conversion from biomass to SOC and TN. The lag depended on environmental condition in each site. In tropical region with high temperature and humidity, we could expect a high decay rate of understory biomass as compared to that in temperate forest. In Vietnam, we expected the lag could be short thus we still observed a high correlation between SOC and TN with biomass, however, in Japan, the lag was expected to be longer, and that would be the reason why we saw a low correlation between SOC and TN with understory biomass at the time of measurement. Another possible reason was the effect of study scale. Plot study had less spatial variation than the headwater catchment, thus it the correlation in plot-scale study was also larger than that in the headwater catchment.

Land use activities may affect soil bulk density and then significantly affect soil organic carbon and nitrogen levels. Forests did not necessarily have the highest amounts of litter or ground cover, or the lowest bulk densities. Hence they did not necessarily have the highest concentrations of soil organic carbon, nitrogen or phosphorus, or the lowest erosion rates. These results indicate that understory biomass, surface cover, and bulk density are the most important characteristics influencing soil nutrient status and erosion rates, and these three controlling factors are governed more the specific characteristics of different types of forests or agricultural crops rather than the broad classification of land use (e.g., forest vs. agriculture).

Multivariate analysis among variables in Vietnam and Japan also present the difference in scale effect. In plot-scale, totally five principal ground were extracted such as (1) chemical status and physical degradation, (2) short-term soil erosion, (3) ground cover and vegetation, (4) clay content, and (5) phosphorus , which indicated the complication of the interaction among variables. Because of low spatial variation (noise), the correlations (signal) among variables were larger (clearer), thus a high resolution picture of the interaction among variable was observed. However, in catchment (in case of study site in Japan), only two principal components were extracted such as (1) short-term soil erosion and (2) long-term soil erosion, which evidenced that the noises were large thus the signal was getting weaker, and only strong signal can been seen. The short-term soil erosion group consists of vegetation such as ground cover, understory biomass, canopy openness and some physical parameters such as soil moisture, hardness and soil pedestal. These parameters are rapidly changed throughout a year. The long-term soil erosion group consists of SOC, TN ^{137}Cs, slope gradient. The typical characteristics of this parameter are that they quit stable in a short period and their change is require a lot of time. The analysis again supported that soil pedestal and ^{137}Cs are good indicator for short-term and long-term soil erosion, respectively.

The major difference between plot-scale study in northern Vietnam and headwater catchment in Tanzawa prefecture in Japan were the correlations among variables in Vietnam site were greater than theses in Japan. It indicated the effect of spatial variation and it is also the advantage of catchment-scale study where only true correlation or effective correlations were displayed.

In Tanzawa forest, the activity of deer in forest significantly affected litter and the understory biomass at highly ground cover vegetation. The effects of deer activity on understory biomass at low ground cover vegetation were not significant. The effects of deer activity on soil nutrients were temporarily insignificant in a short-term (2 years). However a long-term affect are needed to be monitored for a bester assessment of deer activity on soil nutrients.

The successful use of ^{137}Cs and ^{210}Pb$_{ex}$ for estimating soil erosion rates on difference land-uses types has clearly demonstrated the validity of these methods in both the Northeast Vietnam and Tanzawa area. The results confirm the potential for using ^{137}Cs and ^{210}Pb$_{ex}$ measurements to investigate the spatial pattern of soil redistribution in the study catchment. These results indicate that soil erosion are generally higher in which has more understory vegetation and litter cover.

5.3. Management and application in Vietnam and Japan

It is very difficult to attain a holistic understanding of short-term and long-term soil erosion under various spatial and temporal scales as well as the effects of management and disturbance regimes on soil erosion. This study provides snapshots about the vegetation and soil condition in Northern Vietnam and Japan. The data are useful for estimation and interpretation of soil erosion in these areas.

As I have mentioned in previous section, short-term soil erosion are depended on many factors related to vegetation and soil physical properties. The understory biomass was strongly correlated with short-term soil erosion in both Vietnam and Japan. 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. The simplest way to reduce soil erosion is to maintain understory biomass above 150 g m^{-2} in tropical region like Vietnam or above 100g m^{-2} in temperate region like Japan. Simpler indicator is ground cover rate to reduce soil erosion is to maintain up to 80% cover in both of study areas. It suggested that ground cover are very important factor controlling understory biomass, and it should be sufficient especially during rainy season to avoid soil erosion.

The relationships and potential feedbacks (cycle) between land use, macronutrient levels, physical soil properties and their resultant on the amount of vegetation and litter, and soil erosion suggested their important role in controlling soil nutrient and soil erosion. All management and exploratory activities should be aware of this issue and should not disturb the cycle. One the cycle is broken, soil nutrient and soil erosion will be severely affected.

The substantial differences in vegetation and soil physical properties among the specific land uses in Vietnam affect soil carbon and nutrient levels as well as erosion rates, indicating an important feedback loop between vegetation, soil conditions, and erosion rates. A simple characterization of forest or non-forest is not sufficient to calculate carbon and nutrient stocks, or to assess erosion risks. For these purposes, and for guiding land management in hilly areas such as North Vietnam, more specific information is needed on the local soils and vegetation characteristics.

These results indicate that understory biomass, surface cover, and bulk density are the most important characteristics influencing soil nutrient status and erosion rates, and these three controlling factors are governed more the specific characteristics of different types of forests or agricultural crops rather than the broad classification of land use (e.g., forest vs. agriculture). Soil pedestal and ^{137}Cs are good indicators for short-term and long-term soil erosion, thus monitoring of this parameter is essential for future estimation and management of soil erosion. The study showed that deer activities affected ground biomass in headwater catchment in Japan, and it tent to effect soil erosion therefore controlling the deer population in forest is very important factor to reduce soil erosion.

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