

## Research Article

# Assessing Soil Erosion by Agricultural and Forestry Production and Proposing Solutions to Mitigate: A Case Study in Son La Province, Vietnam

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Son La is a province in the Northwest region of Vietnam; this province has diverse terrains with elevation ranging from 100 m to 2,900 m. Due to lack of cultivating lands, farmers still cultivate lands with steep slope, even above 25°. Consequently, the soil erosion has occurred hugely and the time for productive cultivation has been shortened. Therefore, it is necessary to assess the actual soil erosion, analyzing causes and proposing solutions to mitigate soil loss in the Son La province. Application of GIS technology and the Universal Soil Loss Equation (USLE) to predict soil erosion showed that the soil eroded at a very low level (0–1 ton·ha<sup>-1</sup>·year<sup>-1</sup>) accounted for the largest proportion with 56.49% of the area. Low level (1–5 ton·ha<sup>-1</sup>·year<sup>-1</sup>), medium level (5–10 ton·ha<sup>-1</sup>·year<sup>-1</sup>), and high level (10–50 ton·ha<sup>-1</sup>·year<sup>-1</sup>) eroded areas account for 8.52%, 7.88%, and 1.41%, respectively, of the area. Soil is eroded in very high level (>50 ton·ha<sup>-1</sup>·year<sup>-1</sup>), accounting for 25.7% of the study area. Research on solutions to mitigate soil erosion in Mai Son district showed that, for the cultivation of perennial crops (coffee), when planting on following contour lines, the amount of soil lost annually due to erosion is 63.37 ton·ha<sup>-1</sup>, while the cultivation following level top bench terrace soil loss is 39.55 ton·ha<sup>-1</sup>. If more grass strips were planted, the amount of soil lost annually due to erosion was reduced by 71% compared to traditional solutions. For this solution, when intercropping soybean, the soil erosion was reduced by 63–76% compared to the traditional methods. For cultivation of annual crops (maize) where the traditional methods of cultivation, namely, burning, ploughing, and seeding, are followed, the average loss of soil annually is 64.06 ton·ha<sup>-1</sup>. This value was 45.04 ton·ha<sup>-1</sup> and 41.96 ton·ha<sup>-1</sup>, respectively, as the minimum soil tillage measure and no-tillage measure were used. When using the stems of maize after harvesting to cover lands following contour lines and terraces, soil erosion decreased by 38–59% compared to traditional solutions, while intercropping with legumes, soil loss due to erosion decreased 50–68% compared to traditional measures.

## 1. Introduction

The dominant factors influencing soil erosion in humid areas were reviewed, with an emphasis on the roles of precipitation, soil moisture, soil porosity, slope steepness and length, vegetation, and soil organisms [1]. In Vietnam, soil erosion by rainfall was considered as a main agent causing serious soil degradation in the hilly and mountainous north region [2, 3]. There are two approaches to study soil erosion, at the plot

scale and watershed scale. The soil erosion experiment was carried out at the plot scale to evaluate the effectiveness of erosion reduction of different cultivation practices. Under conditions of soil erosion experiment in field conditions, rainfall and soil types cannot be controlled. However, it is possible to control the vegetation cover, slope, and slope length by selecting the appropriate crop structure and creating a terrace on sloping land [4]. At watershed scale, soil erosion rates depend on the watershed size and other factors such as

topography, slope degree, and land use type (Mai, 2007 cited in [5]).

The research results of effects of slope on soil erosion at the tea (one year) planting soil in northern Vietnam (Ba Vi district) showed that the soil loss is  $96 \text{ ton}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$  at slope  $3^\circ$ ,  $211 \text{ ton}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$  at slope  $8^\circ$ , and  $305 \text{ ton}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$  at slope  $15^\circ$  [6]. A soil erosion experiment was conducted in Vinh Yen Township of Vinh Phuc Province over three rainy seasons to clarify the magnitude of soil loss and factors controlling water erosion. The plot had a low (8%) or medium (14.5%) slope with land cover of cassava or morning glory or being bare. Annual soil loss ( $177$  to  $2,361 \text{ g}\cdot\text{m}^{-2}$  equivalent to  $1.77$  to  $23.61 \text{ ton}\cdot\text{ha}^{-1}$ ) was a tolerable level in all low-slope plots but was not in some medium-slope plots. The effects of slope gradient and seasonal rainfall on the mean daily soil loss of the season were confirmed, but the effect of land cover was not, owing to the small canopy cover ratio or leaf area index during the season. The very high annual soil loss ( $2,200 \text{ g}\cdot\text{m}^{-2}$  equivalent to  $22 \text{ ton}\cdot\text{ha}^{-1}$ ) observed in the first year of some medium-slope plots was the site-specific effect from initial land preparation [4].

Other impacts of surface runoff and soil erosion were identified including eutrophication of water body, sedimentation of rivers and reservoirs, and muddy flooding of roads and residential areas [7]. In the study area, soil erosion affects not only the cultivated land but also sedimentation of the river, especially hydropower reservoirs.

There are many factors that affect the ability to resist the sediment of different vegetation covers in the watershed, including rainfall-flow, sediment source, texture, and flow density. It is very difficult to establish a synthetic model that includes all the factors. The actual soil erosion model can be based on Universal Soil Loss Equation (USLE); the results of the model should be validated and modified by erosion measurement in the field because the application of the model in different regions will require necessary modifications [8].

To assess soil erosion, in addition to the popular USLE (Universal Soil Loss Equation, 1965), there are several soil erosion models such as EPIC (Erosion/Productivity Impact Calculator, 1984), EUROSEM (European Soil Erosion Model, 1993), Rill Grow (a model for rill initiation and development, 1998), SEMMED (Soil Erosion Model for Mediterranean Regions, 1999), EGEM (Ephemeral Gully Erosion Model, 1999), and PESERA (Pan-European Soil Erosion Risk Assessment, 2003) [9]. With the development of GIS techniques, soil erosion models are greatly supported by spatial simulations with more factors and larger scales [10, 11].

Since 1999, the direct seeding mulch-based cropping system (DMC) is applied in Vietnam [12]. The practice restores the operation of natural forest ecosystems based on three fundamental principles: (1) mitigation of soil and land cover disturbance (no tillage), (2) maintenance of mulch, and (3) production and return organic matter into soils through intercropping systems/crop rotation [13]. By the application of DMC for corn planting with terraces and without mulch and with terraces and with mulch, the soil

loss reduced by 90.3% and 93.9%, respectively, compared to the traditional practices without terraces and mulch [12].

Son La is a province in the Northwest region of Vietnam. Its landform is very diversified with elevation ranging from 100 m to 2,900 m. The landform has steep slope and high intersection. The hilly and mountainous areas occupy 92%, in which the areas with slope above  $15^\circ$  occupy 67%. Additionally, the rain amount is high (annually precipitation of 1,426.6 mm) and concentrates from month 4 to 9 with 85.5% of total annual rain amount.

Due to lack of cultivating lands in the Vietnam hilly and mountainous regions, farmers still cultivate lands with steep slope, even above  $25^\circ$ . Consequently, the soil erosion has occurred hugely, soils have been degraded rapidly, and the land capability for cultivating has been shortened. With respect to annual food crops, the lands abandoned after two or three cultivation seasons and it is not long enough for soil fertility to be recovered and crop yields are generally low [14]. The aim of the study was to assess the potential of different soil erosion conservation measures which include different cultivation techniques for soil erosion reduction through field experiments in two extreme sloppy areas in the Son La province and to provide suitable recommendations for farmers for cultivation in sloppy areas under the study area.

## 2. Materials and Methods

**2.1. Study Area and Database.** The study area belongs to the Northwest region of Vietnam (Figure 1). The agricultural lands occupied 68.46% in 2015, in which cultivation areas are 25.47% and forestry ones are 42.78%. The nonagricultural areas are small (3.71%). The arable land areas are quite large (27.83%) [15].

The study used annual mean rainfall amount during 15 years (2001–2015) of eight meteorology stations in the Son La province [16] for calculating the rainfall erosivity factor ( $R$ ). Soil map of Son La province at scale 1:100,000 [17] was used to calculate the soil erodibility factor ( $K$ ). Son La topographic map at scale 1:50,000 [18] was used to calculate the topographic factor ( $LS$ ). Son La land use map in 2015 at scale 1:100,000 [15] was applied to make maps of cropping management factors ( $C$  and  $P$ ).

### 2.2. Methods

**2.2.1. Estimating Soil Erosion by Using the Universal Soil Loss Equation Based on Geographic Information System (GIS).** Annual soil loss amount was estimated based on the Universal Soil Loss Equation (USLE) [19] using the Raster Calculator technique in ArcGIS 10.2:

$$A = R \times K \times (L \times S) \times (C \times P), \quad (1)$$

where  $A$  = annual soil loss ( $\text{ton}\cdot\text{ha}^{-1}$ ),  $R$  = rainfall erosivity factor,  $K$  = soil erodibility factor,  $L$  = slope length erosivity factor,  $S$  = slope erosivity factor,  $C$  = cropping management factor, and  $P$  = conservation practices factor.

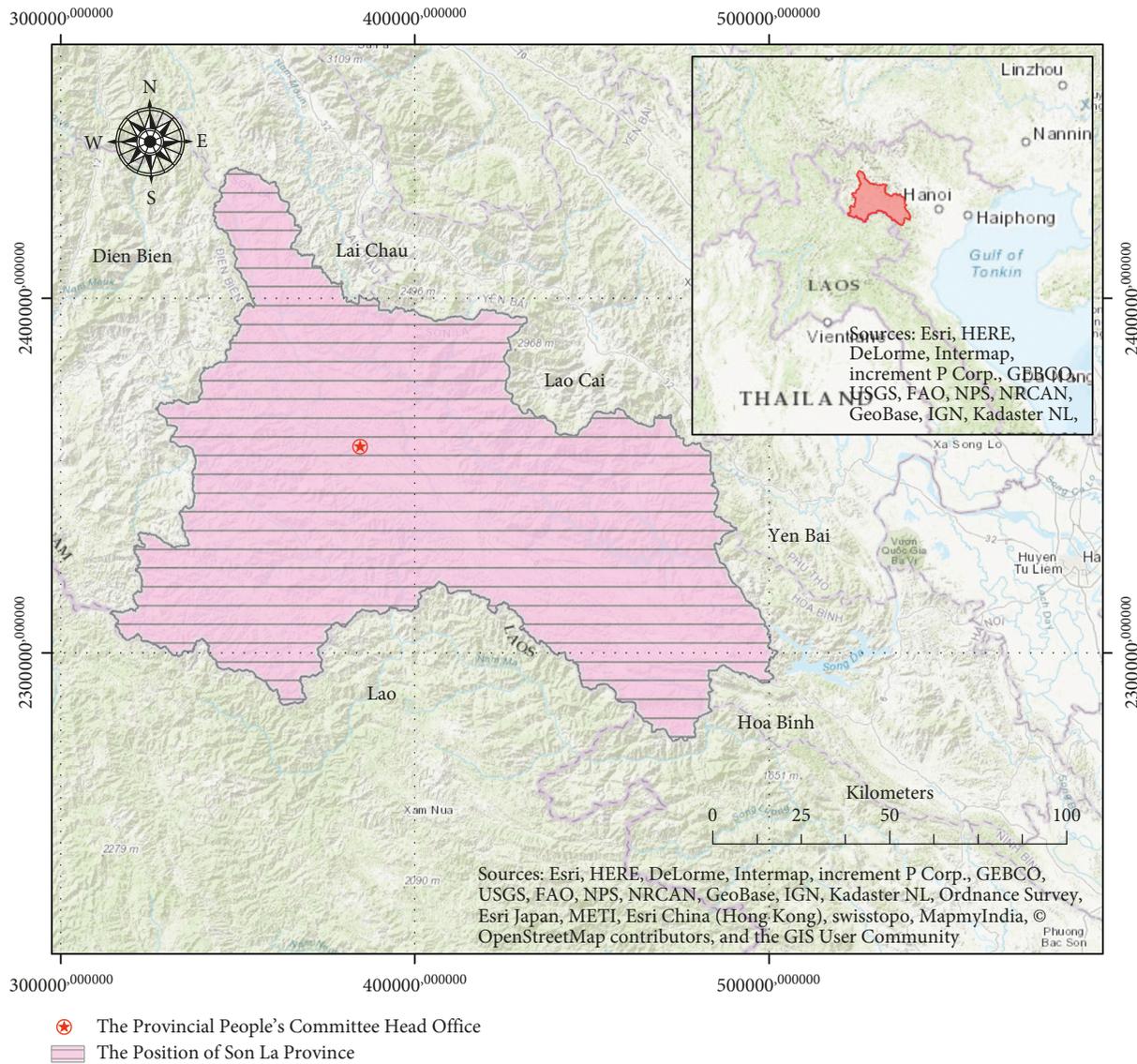


FIGURE 1: Location of Son La province.

2.2.2. *Rainfall Erosivity Factor (R)*. Annual mean rainfall was calculated by using Analyst Tools (which interpolates a raster surface from points using an inverse distance weight technique (IDW)) in ArcGIS 10.2 to build the rainfall erosivity factor (*R*) based on mean rainfall amount during 15 years (2001–2015) of eight meteorology stations in the Son La province [16]. After that, the rainfall erosivity factor was calculated by (2) (Nguyen, 1996 cited in [5]) based on the Raster Calculator tool:

$$R = 0.548257 \times P - 59.5, \quad (2)$$

where *R* = rainfall erosivity factor (J/m<sup>2</sup>) and *P* = annual mean rainfall (mm/year).

2.2.3. *Soil Erodibility Factor (K)*. Physical and hydraulic soil properties are the most important factors that determine soil erodibility (Pierzynski et al., 2005 cited in [1]). These soil properties include antecedent moisture, porosity, surface

roughness, texture, and aggregation [1]. The *K* factor expresses vulnerability of soils to erosion. The higher the *K* value is, the higher the erodibility is. *K* depends on stability of soil structure, soil texture, and soil organic matter; in this paper, *K* values were determined based on the value of soil texture.

The *K* factor was taken from the data of soil map at scale 1:100,000 [17]. The soil texture data were divided into six levels. Based on the levels and considering that the organic matter content is equal to 2%, the *K* values were defined (Table 1).

2.2.4. *Topographic Factor (LS)*. *LS* factor refers to the topographic and/or the relief factor. The slope length factor *L* computes the effect of slope length on erosion, and the slope steepness factor computes the effect of slope steepness on erosion [9].

TABLE 1: The  $K$  factor based on soil texture and organic matter content (after Stewart et al. 1975 cited in [29]).

Objects	Soil texture	$K$
Water bodies	—	0.00
Rocks	—	0.00
	Fine sand	0.14
	Loamy sand	0.10
Soils	Sandy loam	0.24
	Loam	0.34
	Clay loam	0.28
	Clay	0.20

3D Analyst Tools (with Create TIN technique) in ArcGIS 10.2 was used to create a triangulated irregular network (TIN) dataset based on Son La topographic map at scale 1 : 50.000 [18]. The conversion technique in ArcGIS 10.2 was then used to convert TIN to digital elevation model (DEM).

Slope ( $S$ ) and slope length ( $L$ ) values were calculated from DEM by using Spatial Analyst Tools in ArcGIS 10.2. After creating the slope and slope length data, Equations (3), (4), (5), and (6) were used to calculate  $LS$  factor by using Raster Calculator technique in ArcGIS 10.2.

With slope under 21%,  $LS$  was calculated using the Wischmeier and Smith formula [19]:

$$LS \text{ (factor 1)} = \left( \frac{L}{72.6} \right) \times (65.41 \times \sin(S) + 4.56 \times \sin(S) + 0.065), \quad (3)$$

where  $LS$  = topographic factor,  $L$  = length of slope (m), and  $S$  = slope angle (radians). With slope above 21%,  $LS$  was calculated using the Gaudasmita equation [20]:

$$LS \text{ (factor 2)} = \text{power}(L/22.1, 0.7) \times (6.432 \times \sin(\text{power}(S, 0.79)) \times \cos(S)), \quad (4)$$

The slope length ( $L$ ) was determined by using the Toxopeus equation [21]:

$$L = 0.4 \times S + 40, \quad (5)$$

where  $L$  = slope length (m) and  $S$  = slope angle (%). Combination of  $LS$  (factor1) and  $LS$  (factor2) was calculated by using the following equation:

$$LS \text{ factor} = \text{Con}(\text{slope} < 21\%, LS \text{ (factor 1)}, LS \text{ (factor 2)}). \quad (6)$$

### 2.2.5. Building the Cropping Management Factor ( $C$ ).

The  $C$  factor depends on plants' vegetative cover and the cropping management practices. Plants' vegetative cover in addition to crop residues reduces soil erosion potential, due to the fact that the vegetation cover protects and leads to slowing down surface runoff movement and enhancing surplus surface water infiltration [22]. The values reflect impacts of cover, productivity, length of cropping seasons, and farming practices.

The  $C$  factor values were calibrated by actual cover, length of cropping seasons, and farming practices. More specifically, the cropping system: paddy rice/paddy rice,  $C$  values are equal to 0.55; paddy rice/fallow,  $C$  values are equal to 0.4; and the cropping system: paddy rice/other annual crop,  $C$  values are equal to 0.55 [3]. With respect to shifting cultivation and annual industrial crops (corn, cassava, beans, and peanuts) and grassland crops,  $C$  values are equal to 0.21. With respect to perennial plant and forestlands,  $C$  values were defined based on the results published by authors [23, 24, 25]. In natural forest and conservation and protection plantation forestlands,  $C$  values are equal to 0.001; in production forestlands,  $C$  values are equal to 0.003, while in natural restoration forestlands,  $C$  values are equal to 0.027. The  $C$  values are equal to 0.83 for arable lands and 0.92 for hilly and mountainous shrub and grasslands (Table 2).

The  $C$  factor map was built by using Son La land use map in 2015 at scale 1:100.000 [15] and assigning the values of the  $C$  factor (Table 2) according to the type of land use in the map. After mapping the  $C$  value in vector form, use the Conversion Tool in ArcGIS 10.2 to convert to raster map.

2.2.6. *Building the Conservation Practices Factor ( $P$ ).* The  $P$  values reflect impacts of practices to reduce weights and velocity of water flows. The  $P$  shows ratio of soil loss by conservation practices such as technical methods, terrace farming practices, and intercropping systems. The  $P$  in the study was defined based on the  $P$  published by authors (Roose, 1977 cited in [2, 3, 25, 26]) (Table 3).

The  $P$  factor map was constructed by combining the land use map [15] and the slope map. The land use map [15] was converted to raster map by ArcGIS Conversion Tool in ArcGIS 10.2 after assigning land use types by numerical values. Use the Raster Calculator tool in ArcGIS 10.2 to calculate the  $P$  value map by combining the land use type value and the slope value in Table 3.

### 2.2.7. Method for Measuring Eroded Soil in Monitoring Plots.

Selecting the different farming practices and crops and evaluating soil erosion were based on the measurement of the actual soil loss. Each experiment grid with 5 m × 20 m size was designed to monitor soil erosion, and there is one trench with 5 m × 0.8 m × 1 m size at the ending part of the grid. The trench was covered by nylon layer to create a watertight bulkhead to keep eroded soil (Figure 2). Soils collected in the trench were weighted monthly. The annual soil loss was calculated based on (2).

$$A = \frac{(D \times k)}{10}, \quad (7)$$

where  $A$  = annual soil loss (ton·ha<sup>-1</sup>),  $D$  = total soils weighted in the trench during 12 months (kg), and  $k$  = conversion coefficient from wet soils (in the field) to dry soils (drying at 70°C in cabinet drier). The  $k$  value was determined by weighted kilogram soil in the field condition to dry in the cabinet drier at 70°C and then by weighted dry soil;  $k$  value is the weight of dry soil. In this study,  $k$  value is 0.7.

TABLE 2: The C factor assigned by land use types in the study area.

Lands	Land use types	C value
1. Rice	Paddy rice/paddy rice	0.55
	Paddy rice/fallow	0.40
	Shifting cultivation	0.21
2. Other annual crops	Annual food and industrial crops	0.21
	Meadow	0.21
3. Perennial plants	Fruit-tree, perennial industrial plants	0.05
	Natural forest (conservation, protection, production)	0.001
	Plantation forest (protection, conservation)	0.001
4. Forestry lands	Plantation forest (production)	0.003
	Natural restoration forest	0.027
5. Shrub and grass lands	Arable lands	0.83
	Hilly and mountainous shrub and grass lands	0.92

TABLE 3: The P value is based on land use types and farming practices.

Land use types	Farming practices	P
Paddy rice/fallow	Planting on beds, slope <8°	0.1
Paddy rice/annual food crop		
Shifting cultivation	Planting on terraces, slope > 15°	0.8
Annual food and industrial crops	Planting on terraces, slope ≤ 15°	0.6
Meadow	No conservation practices	1.0
Fruit-tree	Planting based on lines, terraces, and strips	0.35
Perennial industrial plants		
Plantation forest	Planting terraces, slope above 15°	0.9
Natural forest	No conservation practices	1.0
Natural restoration forest		
Arable lands	No conservation practices	1.0
Hilly and mountainous shrub and grass lands		

### 3. Results and Discussion

3.1. *Assessing Actual Soil Loss in the Study Area.* The results of calculated soil erosion by (1) are shown in Figure 3 and Table 4. The results were classified into five levels (very low, low, moderate, high, and very high).

The statistic results in the raster map (Figure 3) show that average eroded soil in the Son La province is 26.23 ton·ha<sup>-1</sup>·year<sup>-1</sup> (minimum value is 0 and maximum value is 105.9 ton·ha<sup>-1</sup>·year<sup>-1</sup>). Compared with the results of the study in the Asap catchment, an area located in central Vietnam with the same soil erosion calculator method showed that the results of this study were higher. The average annual soil erosion of this study was 26.23 ton·ha<sup>-1</sup>·year<sup>-1</sup>, compared to that of the study in the Asap basin which was 18 ton·ha<sup>-1</sup>·year<sup>-1</sup> [5]. The main reason is that the R value of this study is higher than that of the study in the Asap catchment (R in this study is 1,172–2,129 compared to 1,634.21–1,732.9).

Table 4 shows that the soil eroded at a very low level accounted for the largest proportion with 56.49% of the area.

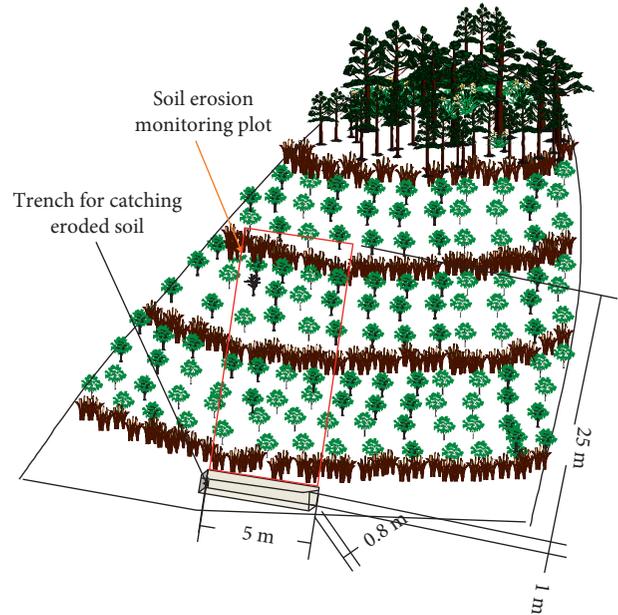


FIGURE 2: Designing a monitoring plot and caching eroded soil in the field.

Low, medium, and high level eroded areas account for 8.52%, 7.88%, and 1.41%, respectively, of the area. Soil is eroded in very high level, accounting for 25.7% of the study area. The very high level area accounts for a large proportion of the total land area due to hilly terrain and steep slopes. These erosion calculations were used to select sites for assessing effectiveness of measures to mitigate soil erosion in the study area.

#### 3.2. Evaluating the Possibility of Reducing Soil Erosion of Cultivation Measures

3.2.1. *Selecting Sites.* Although Son La natural lands are mainly the hilly and mountainous landforms with high slope, lands with slope above 15° have still used to cultivate, especially maize. The maize areas were 159,910 ha, which occupied 11.32% total areas and 44.95% agricultural lands, in which 30,710 ha concentrates on Song Ma district, 26,970 ha on Mai Son, 26,850 ha on Phu Yen, 17,840 ha on Muong La, 16,250 ha on Thuan Chau, 14,970 ha on Van Ho district; there are below 10,000 ha areas in other districts. Additionally, coffee trees have planted quite popularly in the Son La province due to pedological and climate conditions suitable for them, and their economic effectiveness is higher. In 2015, there were 11,793 ha of coffee areas in the province and concentrated on Son La city (4,418 ha), Mai Son district (3,524 ha), and Thuan Chau (3,240 ha) [27].

Two sites as shown in Figure 4 were selected to assess soil loss and evaluate effectiveness of measures to mitigate soil erosion in this study. The results showed that Mai Son district was highly affected by erosion with a high level of soil erosion area of 11.8% and very high level of 23.45% (Table 5).

The coordinates of the experiment site in Muong Bon commune are 21° 6' 59,4"–21° 7' 18,1" N and 104° 10'

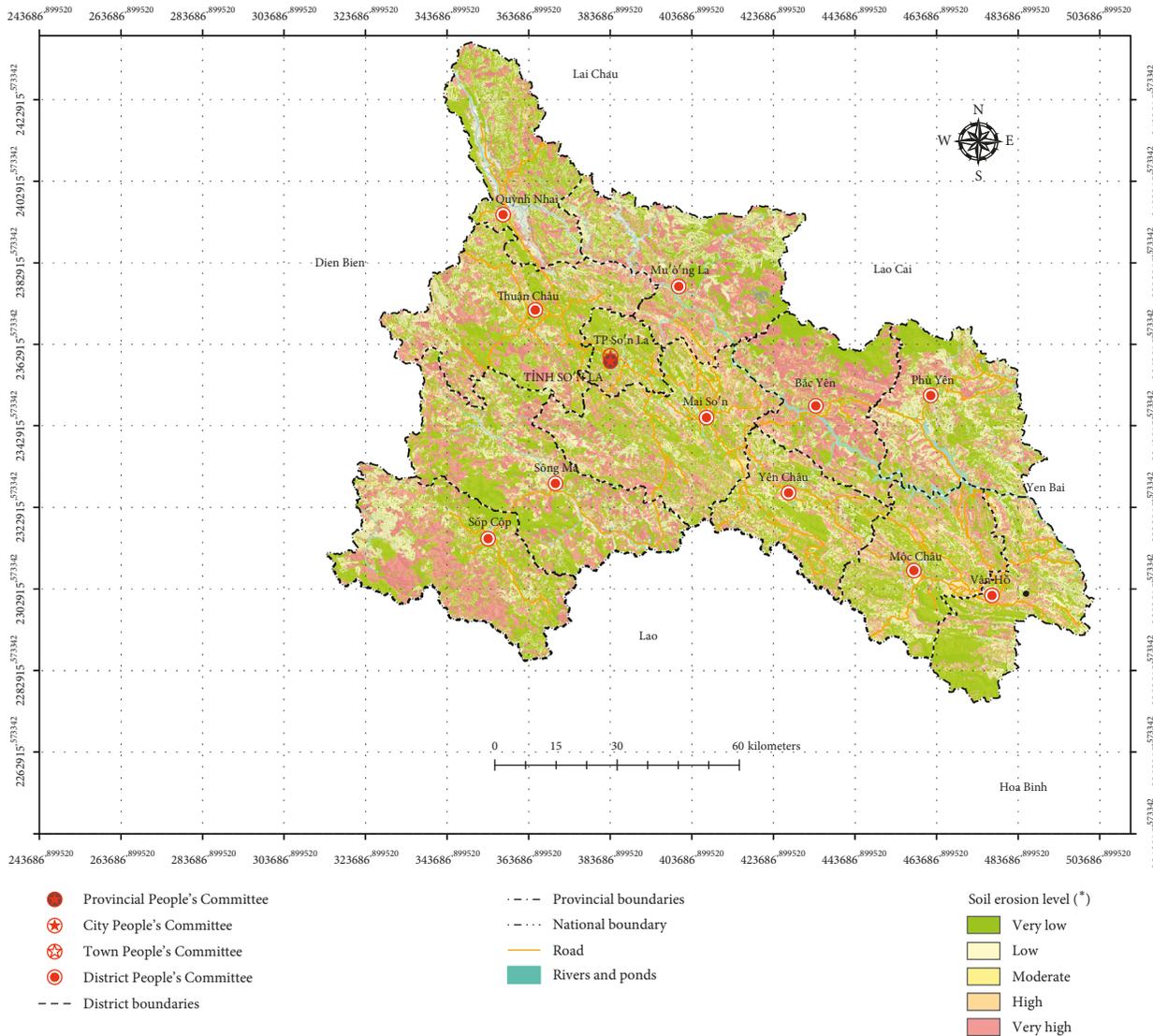


FIGURE 3: Soil erosion map in Son La.

TABLE 4: Soil loss levels and areas in the Son La province.

Soil erosion levels	Soil loss (ton·ha <sup>-1</sup> ·year <sup>-1</sup> )*	Total (ha)	(%)
Very low	0–1	74,683.30	56.49
Low	1–5	11,270.63	8.52
Moderate	5–10	10,419.30	7.88
High	10–50	1,868.08	1.41
Very high	>50	33,974.10	25.70
Total	132,215.41	100	

\*The value level is classified according to Vietnam TCVN 5299: 2009 Soil Quality—method for determination of soil erosion by rain.

44,2''–104° 11' 10,3'' E. Figure 4 indicates that the soil loss is mainly from high to very high levels of soil erosion. Main crops in the area are perennial such as coffee, fruit-trees, and forest on the top of the site.

At the remaining site in the Co Noi commune (its coordinates are 21°14'20,1''–21°14'32,5'' N and 104°4' 0,7''–104° 4' 16,9'' E). The results showed that the soil loss is

mainly also from high to very high levels of soil erosion. The status crops are maize, and the cultivation practices are burning/tillage/seeding.

3.2.2. *Evaluation Ability of Mitigating Soil Loss by Using Cultivation Measures.* There were many publications on soil loss solutions in the north mountainous regions of Vietnam. The solutions were already recommended as below.

(1) *Increasing Land Cover and Mitigating Tillage.* The solution was to reduce soil erosion and soil fertility loss [6, 28, 29, 30, 31]. Reducing tillage positively influences several aspects of the soil, whereas excessive and unnecessary tillage operations give rise to opposite phenomena that are harmful to soil. Therefore, currently there is a significant interest and emphasis on the shift from extreme tillage to conservation and no-tillage methods for the purpose of controlling erosion process [32]. It made good environment for microorganism and improved soil structure and fertility.

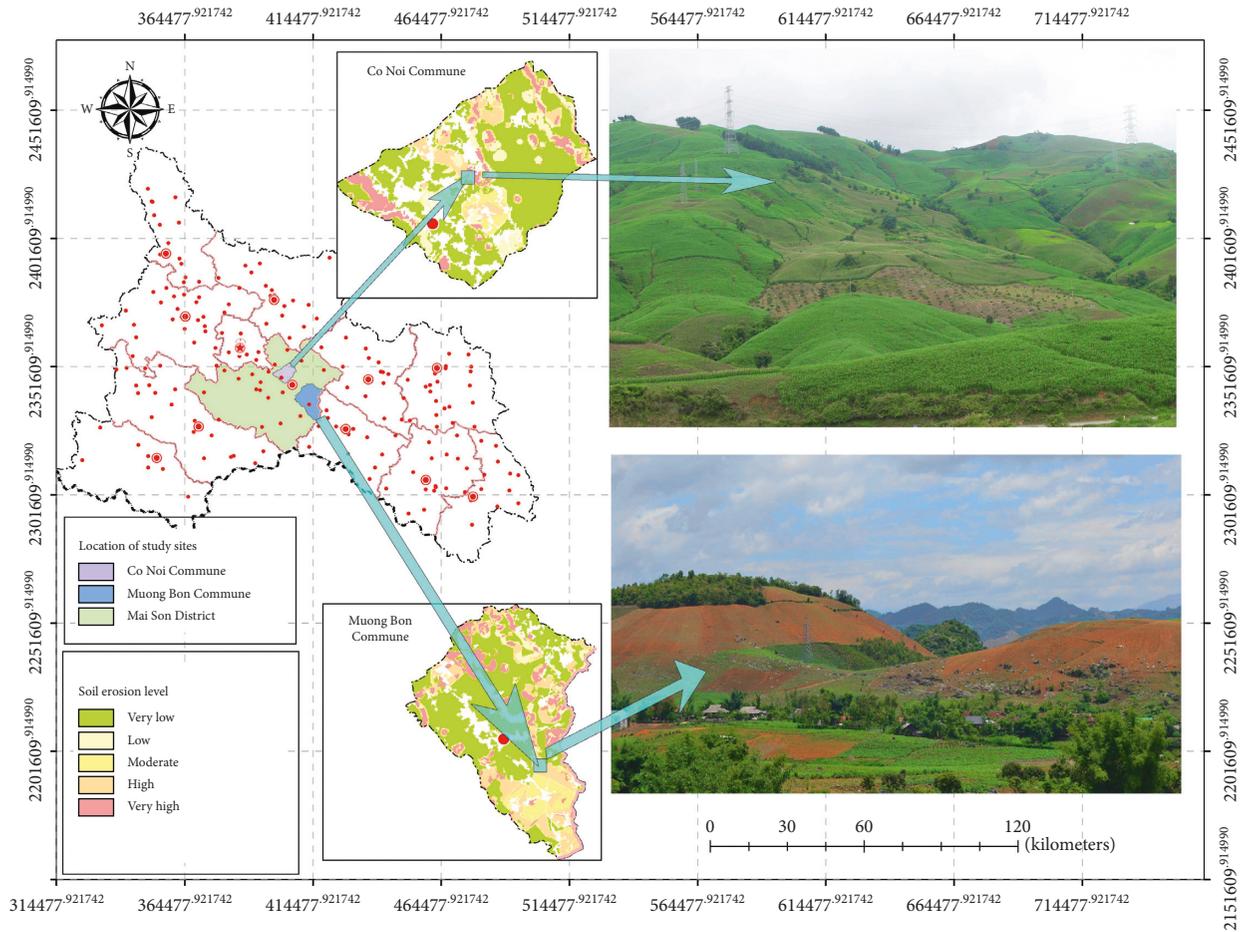


FIGURE 4: Sites monitoring, assessing soil erosion, and studying solutions to mitigate soil loss.

TABLE 5: Soil loss levels and areas in Mai Son district.

Levels of soil erosion	Soil loss ( $\text{ton}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ )	Total (ha)	(%)
Very low	0–1	7,222.20	54.38
Low	1–5	1,069.48	8.05
Moderate	5–10	299.88	2.26
High	10–50	1,575.28	11.86
Very high	>50	3,114.13	23.45
Total		13,280.95	100

Consequently, crops grew well, increasing productivity and economic effective. According to the traditional farming practices in the north mountainous regions of Vietnam, residues of crops are burned or cleaned before cultivating a next season. In contrast, as applying measures to increase the land cover and combining mitigation of soil tillage (it means that wild grasses and residues of crops are kept on the ground surface), the soil surface is not disturbed and finally the soil erosion is prevented.

(2) *Cultivation of Legumes*. They are black beans, green beans, grape-beans, and peanuts which are intercropped with maize, upland rice, cassava, fruit-tree, coffee, or tea in the study area. The legumes do not only make covers to

reduce soil erosion but also enhance soil nutrients due to their ability of fixing nitrogen. Legume crop residues contribute to organic N, and after decomposition by soil microbes, through mineralization, add available N for the next crop [33]. The effects of the measure as reducing soil loss and nutrient loss, improving soil structure and soil fertility, supporting good crops growth, and increasing productivity and economic effective [31].

(3) *Terracing*. The measure of terracing was suggested for lands with slope above  $15^\circ$  in the study area. The terraces should be made enough wide for planting a trip of crops at each terrace. The distance between terraces depends on the type of crops and often is equal to one between the crops as seeding following traditional farming practices. The measure could combine with increasing land cover or intercropping, and the effective of soil loss reduction was better [14]. In order to apply the terracing measure, it was necessary for using many labors in the beginning years to create terraces and maintain them [35]. The basic principle behind terracing is the management of runoff and sedimentation through gravity along hillsides or stream channels. The techniques are labor-intensive, based on hybrid knowledge, and accept knowledge-based innovation through time [36].

(4) *Planting Grasses following Strips to Prevent Soil Erosion and Provide Feeds for Animal Husbandry.* This is a good solution for cattle breeding [37].

Based on the mentioned studies, our research selected the different measures to assess ability of reducing soil erosion and recommendations.

(5) *At the Site in the Muong Bon Commune.* Although coffees are often cultivated on relatively flat lands (below 15°), they have been planted popularly in slope lands in Son La as the climate conditions and soil fertility are suitable for them. In the experimental area, terrain conditions have a slope of 15–20° and annual rainfall over 1,400 mm; people have applied the terracing measure for cultivating coffees. However, the measure has not gotten good effect. The study proposed the combination measure between terracing and making strips of grass and intercropping beans. Planting strips of grass following contour lines would reduce soil erosion and provide feeds for cows, and cultivating beans is to increase soil fertility and products are to increase incomes for people. The actual soil loss, which was measured in the sites with the selected reducing measurement, is shown in Table 6.

Table 6 shows that application of the measures of cultivating coffees following contour lines and terraces causes high soil loss. With respect to the cultivating coffees following contour lines, the average soil loss for 3 years was 63.37 ton·ha<sup>-1</sup>, while the cultivating coffees following terraces caused the average soil loss of 39.55 ton·ha<sup>-1</sup>. With respect to application of the cultivating coffees following terraces and planting strips of grass, the average soil loss was 18.23 ton·ha<sup>-1</sup>·year<sup>-1</sup> and the soil loss reduced by 54–71% compared to the traditional measure. While application of the measure of cultivating coffees following terraces, combining plantation of strips of grass and intercropping legumes (beans), the average soil loss was 14.53 ton·ha<sup>-1</sup>·year<sup>-1</sup> and reduced by 63–76% compared to the traditional measure.

(6) *At the Site in the Co Noi Commune.* In the experimental area, terrain conditions have a slope of 15–20° and annual rainfall over 1,400 mm; people uses the farming practices such as minimizing tillage (weeding) and no tillage (shifting cultivation) and burning residues of maize/ploughing/seeding. The study proposed measures of using stem of maize as strips following contour lines and intercropping legumes (beans) to reduce soil erosion and improve soils and diversity products.

Table 7 indicates that the average soil loss was 64.06 ton ha<sup>-1</sup>·year<sup>-1</sup> at the sites cultivating maize in Co Noi where the traditional cultivation measures (burning/ploughing/seeding) were applied. This value was 45.04 ton·ha<sup>-1</sup>·year<sup>-1</sup> and 41.96 ton·ha<sup>-1</sup>·year<sup>-1</sup>, respectively, as the minimizing soil tillage measure and no-tillage measure were used. The average soil loss was reduced by 38–59% compared to the traditional cultivation measures at the site where the stems of maize after harvesting to cover lands following contour lines and terraces were applied, while it was 50–68% at the site where the stems of maize after harvesting to cover lands following contour lines and terraces, intercropping legumes were applied.

TABLE 6: Soil loss caused by different cultivation measures in Muong Bo.

No	Measures	Soil loss (ton·ha <sup>-1</sup> )			
		2014**	2015	2016	Average
1	Cultivating based on contour lines	63.34	62.53	61.23	62.37
2	Cultivating following terraces	40.54	39.67	38.43	39.55
3	Cultivating terraces, planting strips of grass.	-	18.33	18.12	18.23
4	Cultivating terraces, combining plantation of strips of grass and intercropping legumes (beans).	-	14.43	14.63	14.53

\*\*2014 is year in which the measures began carrying out because the strips of grass have not grown stably.

TABLE 7: Soil loss caused by measures cultivating maize in Co Noi.

No	Measures	Soil loss (ton·ha <sup>-1</sup> )			
		2014	2015	2016	Average
1	Burning and plough	64.21	64.34	63.64	64.06
2	Minimizing soil tillage	45.34	44.32	45.45	45.04
3	No tillage	42.34	41.23	42.32	41.96
4	Using stems of maize after harvesting to cover lands following contour lines and terraces	25.34	24.34	24.67	24.78
5	Using stems of maize after harvesting to cover lands following contour lines and terraces, intercropping legumes	21.34	20.56	20.22	20.71

## 4. Conclusion

Son La is a province in the Northwest region of Vietnam with hilly terrain, and cultivation activities are affected by soil erosion. The results of the mapping of soil erosion showed that the soil eroded at a very low level accounted for the largest proportion with 56.49% of the area. Low, medium, and high level eroded areas account for 8.52%, 7.88%, and 1.41%, respectively, of the area. Soil is eroded in very high level, accounting for 25.7% of the study area.

The annual soil loss reduced by 54–71% at the slope sites cultivating coffees following the measures of using terraces and planting strips of grass compared to the traditional ones. The value was 63–76% at the slope sites cultivating coffees following the measures of using terraces combining plantation of strips of grass and intercropping legumes (beans). The annual soil loss reduced by 38–59% at the slope sites where are cultivating maize following measures of using stems of maize after harvesting to cover lands, while it was 50–68% at the site where are cultivating maize following measures of sing stems of maize after harvesting to cover lands and intercropping legumes compared to the traditional cultivation of maize.

In the study area, for coffee growing on high sloping land (over 15°), farmers should use cultivating terraces, combining plantation of strips of grass between 3 and 4 coffee rows and intercropping legumes (beans). For maize growing in high sloping areas (over 15°), farmers should incorporate measures making terraces, using stems of maize after harvesting to cover lands following contour lines and intercropping legumes. In lower sloping areas, the minimum soil tillage can be used, using stems of maize after harvesting to cover lands following contour lines and intercropping legumes. These cultivation measures not only reduce soil erosion and improve soil but also produce bean products and grass for livestock.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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### References

- [1] D. J. Holz, K. W. J. Williard, P. J. Edwards, and J. E. Schoonover, “Soil erosion in humid regions: a review,” *Journal of Contemporary Water Research and Education*, vol. 154, no. 1, pp. 48–59, 2015.
- [2] C. T. Trinh, *Soil Erosion in Vietnam (The Case of BuonYong Catchment)*, Scholars Press, 2015.
- [3] K. Vezina, F. Bonn, and P. V. Cu, “Agricultural land-use patterns and soil erosion vulnerability of watershed units in Vietnam’s Northern Highlands,” *Landscape Ecology*, vol. 21, no. 8, pp. 1311–1325, 2006.
- [4] K. Kurosawa, H. D. Nguyen, T. C. Nguyen, and K. Egashira, “Magnitude of annual soil loss from a hilly cultivated slope in Northern Vietnam and evaluation of factors controlling water erosion,” *Applied and Environmental Soil Science*, vol. 2009, Article ID 464767, 8 pages, 2009.
- [5] T.G. Pham, J. Degener, and M. Kappas, “Integrated universal soil loss equation (USLE) and geographical information system (GIS) for soil erosion estimation in A Sap basin: Central Vietnam,” *International Soil and Water Conservation Research*, vol. 6, no. 2, pp. 99–110, 2018.
- [6] N. Menzies, A. Verrell, and G. Kirchhof, “Can conservation farming practices ensure agricultural ecosystem stability?,” in *Proceedings of 3rd International Conference on Conservation Agriculture in Southeast Asia*, pp. 202–220, CIRAD, NOMAFSI, University of Queensland, Hanoi, Vietnam, December 2012, [http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings\\_Final\\_Web.pdf](http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings_Final_Web.pdf).
- [7] J. Boardman, M. L. Shepherd, E. Walker, and I. D. L. Foster, “Soil erosion and risk-assessment for on- and off-farm impacts: a test case using the Midhurst area, West Sussex, UK,” *Journal of Environmental Management*, vol. 90, no. 8, pp. 2578–2588, 2009.
- [8] B. Sude, N. Wu, J.-X. Gao, C. Zhang, J. Ge, and E. Driss, “New approach for evaluation of a watershed ecosystem service for avoiding reservoir sedimentation and its economic value: a case study from Ertan reservoir in Yalong River, China,” *Applied and Environmental Soil Science*, vol. 2011, Article ID 576947, 10 pages, 2011.
- [9] J. A. Bahrawi, M. Elhag, A. Y. Aldhebiani, H. K. Galal, A. K. Hegazy, and E. Alghailani, “Soil erosion estimation using remote sensing techniques in Wadi Yalamlam basin, Saudi Arabia,” *Advances in Materials Science and Engineering*, vol. 2016, Article ID 9585962, 8 pages, 2016.
- [10] E. G. Gregorich, K. J. Greer, D. W. Anderson, and B. C. Liang, “Carbon distribution and losses: erosion and deposition effects,” *Soil and Tillage Research*, vol. 47, no. 3–4, pp. 291–302, 1998.
- [11] C. J. Williams, F. B. Pierson, P. R. Robichaud, and J. Boll, “Hydrologic and erosion responses to wildfire along the rangeland-xeric forest continuum in the western US: a review and model of hydrologic vulnerability,” *International Journal of Wildland Fire*, vol. 23, no. 2, pp. 155–172, 2014.
- [12] J. C. Castella, A. Chabanne, D. D. Quang et al., *Towards Sustainable Agricultural Development in Mountain Areas of Northern Vietnam: Main Results from the Mountain Agrarian Systems (SAM) Program in Bac Kan province, 1998–2002*, Multimedia CD-Rom, Vietnam Agricultural Science Institute, Hanoi, Vietnam, 2003.
- [13] French Development Agency/French Global Environment Facility (AFD/FFEM), “Direct seeding mulch-based cropping systems (DMC), an alternative to conventional cropping systems in developing countries,” p. 68, Les Petites Affiches, Paris, France, 2007, [http://open-library.cirad.fr/files/2/231\\_1162708018.pdf](http://open-library.cirad.fr/files/2/231_1162708018.pdf).
- [14] L. Q. Doanh, H. D. Tuan, and A. Chabanne, “Upland agro-ecology research and development in Vietnam,” in *Proceedings of Building an Agro-Ecological Network through DMC in Southeast Asia*, Regional Workshop-Vientiane, Lao, December 2005, <http://open-library.cirad.fr/files/2/2411141426824.pdf>.
- [15] Center of Land Data and Information (CLDI), *Map and Data of Current Land Use Year 2015 of Son La province*, General Department of Land Management, Hanoi, Vietnam, 2015.
- [16] Center for Technology Responding to Climate Change (Cli-Tech), *Climate Database in Period 2001–2015 of Son La Province*, Department of Methodology and Climate Change, Hanoi, Vietnam, 2016.
- [17] National Institute of Agricultural Planning and Projection, *Soil Map (Scale 1/100,000) of Son La Province*, NIAPP, Hanoi, Vietnam, 2004.
- [18] Center of Survey and Mapping Data (CSMD), *Topographic Map (scale 1/50,000) of Son La province*, Department of Survey, Mapping and Geographic Information, Hanoi, Vietnam, 2006.
- [19] W. H. Wischmeier and D. D. Smith, “Predicting rainfall erosion losses: a guide to conservation planning,” in *Agriculture Handbook 537*, p. 58, U.S. Department of Agriculture, Washington, DC, USA, 1978.
- [20] K. Gaudasmita, “Contribution to geo-information system operation for prediction of erosion,” M.Sc. Thesis, ITC, The Netherlands, p. 130, 1987.
- [21] A. G. Toxopeus, “Cibodas: the erosion issue,” in *ILWIS 2.1 for Windows: Applications guide: the Integrated Land and Water Information System*, C. J. van Westen, A. Saldaña López,

- S. P. Uria cornejo, and G. Chavez Ardanza, Eds., pp. 307–321, ITC, Enschede, The Netherlands, 1997.
- [22] V. H. D. Zuazo, J. R. F. Martínez, C. R. R. Pleguezuelo, A. M. Raya, and B. C. Rodríguez, “Soil-erosion and runoff prevention by plant covers in a mountainous area (SE Spain): implications for sustainable agriculture,” *Environmentalist*, vol. 26, no. 4, pp. 309–319, 2006.
- [23] X. D. Bui and V. Q. Do, “Applying universal soil loss equation (USLE) to estimating soil erosion at Lam Son headwater catchment,” *Journal of Forestry Science and Technology*, vol. 5, 2017, <http://vnuf.edu.vn/documents/4400543/5135893/8.Bui.Xuan.Dung.pdf>.
- [24] Food and Agriculture Organization of the United Nations—the International Fund for Agricultural Development, Strategic Environmental Assessment, “An assessment of the impact of cassava production and processing on the environment and biodiversity,” in *Proceedings of the validation forum on the global cassava development strategy*, pp. 26–28, Rome, Italy, April 2000, <http://www.fao.org/docrep/007/y2413e/y2413e09.htm#bm09.1.1>.
- [25] K. Kuok, D. Mah, and P. Chiu, “Evaluation of C and P factors in universal soil loss equation on trapping sediment: case study of Santubong River,” *Journal of Water Resource and Protection*, vol. 5, no. 12, pp. 1149–1154, 2013.
- [26] Y. Glemarec, *Environmental Indicators For Tropical Areas: A Methodology Applied to Forest, Water and Soil Degradation in Thai Nguyen Province, Vietnam*, A research undertaken within the framework of project STD3-CT94-0310 of the European Union (DG X II) and coordinated by l’Institut de Recherche Pour le Développement, France, 1997, [http://www.cartographie.ird.fr/publi/Glemarec\\_ang.pdf](http://www.cartographie.ird.fr/publi/Glemarec_ang.pdf).
- [27] Department of Statistic Office (DSO), *Statistic year book of Son La Province*, Statistic Publishing house, Hanoi, Vietnam, 2015.
- [28] J. R. Benites, “Effect of no-till on conservation of the soil and soil fertility,” in *No-Till Farming Systems*, T. Goddard, M. Zebisch, Y. Gan et al., Eds., pp. 59–72, Special Publication No.3, World Association of Soil and Water Conservation, Funny Publishing, Bangkok, Thailand, 2008.
- [29] S. Boulakia, S. Chabierski, P. Kou et al., “Adaptation of direct-seeding mulch-based cropping systems for annual cash crop production in Cambodia rainfed uplands,” in *Proceedings of 3rd International Conference on Conservation Agriculture in Southeast Asia*, pp. 92–108, CIRAD, NOMAFSI, University of Queensland, Hanoi, Vietnam, December 2012, [http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings\\_Final\\_Web.pdf](http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings_Final_Web.pdf).
- [30] A. J. Mercado, V. B. Ella, and M. R. Reyes, “Yield, biomass and soil quality of conservation agriculture systems in the Philippines,” in *Proceedings of 3rd International Conference on Conservation Agriculture in Southeast Asia*, pp. 256–258, CIRAD, NOMAFSI, University of Queensland, Hanoi, Vietnam, December 2012, [http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings\\_Final\\_Web.pdf](http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings_Final_Web.pdf).
- [31] P. T. Sen, L. H. Huan, D. S. An et al., “Adaptive participatory research to develop innovations for sustainable intensification of maize-based farming systems in the northern uplands of Vietnam,” in *Proceedings of 3rd International Conference on Conservation Agriculture in Southeast Asia*, pp. 109–111, CIRAD, NOMAFSI, University of Queensland, Hanoi, Vietnam, December 2012, [http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings\\_Final\\_Web.pdf](http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings_Final_Web.pdf).
- [32] M. Iqbal, A. U. Hassan, A. Ali, and M. Rizwanullah, “Residual effect of tillage and farm manure on some soil physical properties and growth of wheat (*Triticum aestivum* L.),” *International Journal of Agriculture and Biology*, vol. 1, pp. 54–57, 2005, [http://www.fspublishers.org/published\\_papers/42622\\_pdf](http://www.fspublishers.org/published_papers/42622_pdf).
- [33] G. X. Chu, Q. R. Shen, and J. L. Cao, “Nitrogen fixation and N transfer from peanut to rice cultivated in aerobic soil in an intercropping system and its effect on soil N fertility,” *Plant and Soil*, vol. 263, no. 1–2, pp. 17–27, 2004.
- [34] J. Poesen, “Soil erosion in the anthropocene: research needs,” *Earth Surface Processes and Landforms*, vol. 43, no. 1, pp. 64–84, 2018.
- [35] O. Nicetic, A. Lugg, P. T. Sen, L. T. H. Nga, L. H. Huan, and E. V. D. Fliert, “Farmers’ perception of soil erosion as a risk to their livelihood—scenario analysis with farmers in the northern mountainous region of Vietnam,” in *Proceedings of 3rd International Conference on Conservation Agriculture in Southeast Asia*, pp. 53–55, CIRAD, NOMAFSI, University of Queensland, Hanoi, Vietnam, December 2012, [http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings\\_Final\\_Web.pdf](http://cansea.org.vn/wp-content/uploads/2017/06/Proceedings_Final_Web.pdf).
- [36] G. Bocco and B. M. Napoletano, “The prospects of terrace agriculture as an adaptation to climate change in Latin America,” *Geography Compass*, vol. 11, no. 10, 2017.
- [37] O. Husson, A. Chabanne, H. D. Tuan et al., “Integrating crops and livestock through direct seeding on vegetal cover in Vietnam,” in *Proceedings of II World Congress on Conservation Agriculture*, pp. 357–367, Ponta Grossa, Brazil, August 2003.

