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Impact of agroforestry on soil loss mitigation in the sloping land of Northwest Vietnam

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ABSTRACT

Impact of agroforestry on soil loss mitigation in the sloping land of Northwest Vietnam

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Soil erosion is one of the major threats to soil functions in many parts of the world. Today's challenge is to adapt agriculture practices in order to reduce soil erosion and at the same time consider local conditions. One solution that has been proposed for hilly regions is agroforestry, a land-use system in which woody perennials are grown on the same piece of land as agricultural crops and/or animals.

This Master thesis was conducted in two sites in Northwest Vietnam, in Son La and Dien Bien province. Northwest Vietnam is characterized by a mountainous landscape and agriculture is practiced in the hills, often as monoculture of sole crops. This type of land use in combination with seasonal large high-intensity rains aggravates soil erosion.

In this study, agroforestry (AF) practices' capacity for erosion control was evaluated, and compared to sole crops of the dominant species in the area. An Experimental Trial in form of replicated field plots of block design and a larger Exemplar Landscape were used. The Experimental Trials and the Exemplar Landscape had two treatments, one AF system and one control treatment with sole crops. The AF system included crops, fruit trees and grass strips with the aim to form terraces naturally.

To evaluate the AF's capacity for erosion control, average amount of lost soil was estimated in the Experimental Trials by three methods; erosion traps, erosion pins (both field methods) and a WEPP model. Another function of the erosion pins was to evaluate the movement of soil along the hillside. Soil texture, structure, color and signs of biological activity were analyzed from soil profiles. Soil samples were also taken for soil analyzes of parameters needed for calculations and the WEPP model. A method was also developed to assess the terrace formation over a longer a time scale.

Results of this study showed that agroforestry in combination with grass strips perform well in decreasing soil loss in the Son La study site. The soil loss in Son La was found to be 43% less two years after establishment compared to the sole maize system figuring as the control. The results also showed that grass strips have the ability to start forming terraces already one year after establishment of the Experimental Trial in both study sites. The terraces showed further development several years after the establishment at landscape level.

Keywords: Conservation agriculture, Erosion, Grass barriers, Upland cropping, Vietnam

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REFERAT
Jorderosion är i nuläget ett av de största hoten mot jordens funktionella kapacitet i många delar av världen. En stor utmaning är att anpassa odlingsmetoder i syfte att minska jorderosion och samtidigt ta hänsyn till lokala förhållanden. En lösning som ofta föreslås för odling i sluttande terräng är trädjordbruk, ett markanvändningssystem där perenner (ofta i form av träd eller buskar) odlas på samma areal som jordbruksgrödor och/eller boskapsdjur.

Detta examensarbete har utförts på två lokaler i Nordvästra Vietnam, i provinserna Son La och Dien Bien. Nordvästra Vietnam karaktäriseras av ett bergigt landskap och jordbruk bedrivs på sluttningarna, ofta i form av renbestånd. Denna typ av markanvändning i kombination med stora högintensiva regn förvärrar jorderosion.

I denna studie har trädjordbrukets förmåga att reducera erosion utvärderats, jämfört med monokulturer av den dominerande grödan i området. Detta gjordes genom ett fältförsök med replikerade fältrutor i blocksystem samt ett större landskapsförsök. Både fältförsöket och landskapsförsöket hade två behandlingar, trädjordbruk och en kontrollbehandling i form av renbestånd i monokultur. Trädjordbruket inkluderade annuella grödor, fruktträd och gräsremsor med syfte att ansamla jord och på så sätt bilda terrasser.

För att utvärdera trädjordbrukets kapacitet att reducera erosion i fältförsöket, skattades total mängd eroderad jord genom två fältmetoder; erosionsfällor och erosionspinnar. Därutöver gjordes en modellering i WEPP. Erosionspinnarna användes även för att skatta jordens rörelse längs sluttningen. Jordens textur, struktur, färg och biologisk aktivitet analyserades med hjälp av jordprofiler. Jordprover togs även för analys av parametrar som krävdes för beräkningar och modellering. Vidare utvecklades en metod för att skatta terrassformation över en längre tid.

Resultaten från denna studie visar att trädjordbruk i kombination med gräsremsor minskar mängden eroderad jord med 43% jämfört med kontrollbehandlingen två år efter etablering av fältförsöket i Son La. Resultaten från båda lokalerna visar även att gräsremsorna har en förmåga att skapa terrasser redan ett år efter fältförsökets etablering. Därefter kunde en vidare utveckling av terrasserna observeras i landskapsförsöket.

Nyckelord: Trädjordbruk, Erosion, Gräsbarriärer, Höglandsodling, Vietnam

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PREFACE

This Master thesis covers 2x30 ECTS and is the final project in the Master's Programme in Environmental and Water Engineering at Uppsala University and Swedish University of Agricultural Sciences (SLU). The master thesis is presented as one project, but was in reality divided between the authors in some parts. Birgitta Sjödell had more focus on the parts concerning the Experimental Trial while Hanna Thelberg had more focus on the parts concerning the Exemplar Landscape. More specific, Birgitta Sjödell was more responsible for the sections; 3.3.1, 3.3.3, 3.3.4 (erosion pins), 4.1, 4.3 and 4.4.2 while Hanna Thelberg was more responsible for the sections; 3.3.2, 3.3.5, 3.3.4 (erosion traps), 4.2, 4.4.1, 4.5.

The study was conducted at the Department of Soil and Environment at SLU and in cooperation with International Centre for Research in Agroforestry (ICRAF) in Hanoi, Vietnam. Professor Ingrid Öborn at the Department of Crop Production Ecology, SLU was supervisor. Associate professor Sigun Dahlin at the Department of Soil and Environment at SLU was the academic supervisor. This project is connected to the research within the ongoing AFLi project (lead by ICRAF) and some data from previous years were used.

First, we give our thanks to our supervisor professor Ingrid Öborn for the support and guidance through the whole project, and for assistance in find financial support. We also want to thank associate Prof. Sigrun Dahlin for guidance, especially in data processing. Furthermore, we would like to give thanks to our supervisors Hung Do Van and La Nguyen at ICRAF in Hanoi, Vietnam.

And of course, we would like to give thanks to all the people involved during the time in Vietnam. Especially, Dr. La Nguyen for supervising the soil profile and field supervisor Thach Nguyen Van for guidance in field and for making our stay in Vietnam easy and fun. Thanks to Rudolphe Martin for assisting us in field. This thesis would not have been possible without the help from Ph.D. Hung Do Van throughout the whole project.

Last but not least, we would like to give our big thanks to the farmer families in Son La and Dien Bien for their great hospitality and help in the field.

This project has been a great experience and has given us knowledge and memories that we will keep with us in the future.

Birgitta Sjödell and Hanna Thelberg
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POPULÄRVETENSKAPLIG SAMMANFATTNING

Trädjordbruks påverkan på jorderosion i de bergiga landskapen i nordvästra Vietnam

Birgitta Sjödell, Hanna Thelberg

Befolkningen på jorden ökar och det leder till att allt mer mat behöver produceras. Att öka den globala matproduktionen under klimatförändringen är en utmaning. Alla områden är inte lämpade för odling utan odlingsmetoderna behöver anpassas efter lokala förutsättningar.

Området i nordvästra Vietnam utgörs av en stor andel branta sluttningar och det krävande vädret med höga intensiva säsongsregn utgör särskilda utmaningar. I denna region bor etniska minoriteter som till en högre andel lever i fattigdom än resterande delar av landets befolkning. En ökad befolkningsmängd och små skördar leder till att även de branta sluttningarna odlas upp, vilket bidrar till att skogarna minskar och att jorden eroderar bort med tiden. När jorden utsätts för erosion påverkas marken kraftigt vilket kan leda till stora miljöproblem såsom översvämning och jordskred. Det finns en rad olika faktorer som påskyndar erosionen: lutningen, vegetationen och bearbetningen av marken. För att minska erosionen i de branta sluttningarna där projektet ägde rum har det införts trädjordbruk, ett odlingssystem som inkluderar gräsremsor, grödor och träd, vilka planteras horisontellt längs sluttningarna. Ett av målen med detta system är att det skapar naturliga terrasser med åren. Systemet ökar även jordbrukets produktivitet vilket leder till att landsbygdsbefolkningen får en säkrare livsmedels- och näringstillgång.

I detta arbete har data används från befintligt fältförsök som etablerades 2017 i två olika lokaler i nordvästra Vietnam. Utifrån befintlig och insamlad data har skillnaden mellan trädjordbruk och monokultur (enbart en gröda som odlas) jämförts. För att undersöka den långsiktiga utvecklingen av trädjordbruk har landskapsförsök gjorts på ett område som har etablerats 2015.

Resultatet från en av lokalerna i fältförsöket visar att trädjordbruk minskar den totala mängd jord som eroderar bort i jämförelse med monokulturen. Resultaten från båda fältförsöken visar även att störst andel eroderad jord ansamlar sig ovanför gräsremsorna i trädjordbruket. Samma trend i fördelning av eroderad jord förekommer i landskapsförsöket.

Detta arbete har bidragit till att fylla några av de kunskapsluckor som finns inom ämnesområdet. Metoder som inte har funnits i tidigare litteratur har skapats för att kunna analysera naturlig bildning av terrasser.

CONTENTS

1 INTRODUCTION

Despite decades of research within the field, soil erosion still remains one of the major threats to soil functioning in many parts of the world (FAO, 2019). Along with the world's increasing population and the changing climate, the challenges due to soil erosion are more important today than ever before. Agricultural practices must adapt to climate change in order to generate food security today and in the future (Hilger et al., 2013).

The upland areas of Mekong in northwest Vietnam are characterized by steep sloping landscapes and the weather conditions are harsh with seasonal large high-intensity rains. Simultaneously, 80% of the population in the Northwest are dependent on agriculture for their livelihoods (Hoang et al., 2017). These conditions result in severe soil erosion which cause huge environmental problems and jeopardize income opportunities from agriculture and forestry activity within the landscape.

Additionally, farmers of many ethnic minorities living in Northwestern Vietnam are limited by low income as well as low level of education. The number of people living in poor conditions is higher in the mountainous parts of Vietnam than in other areas of the country, thus they are strongly dependent on local resources for their livelihoods. An increasing population in combination with decreasing yields result in cultivation of even the steepest slopes which causes soil erosion (Nguyen et al., 2019a, Zimmer et al., 2017).

The present agricultural practices in the area are dominated by maize monoculture in combination with burning of the crop residues after harvest (Ha et al., 2004, Kiel et al., 2008, Hoang et al., 2013, Zimmer et al., 2017). This type of land use causes severe problems of erosion as the steep slopes lack continuous vegetation cover. The soil erosion does in turn lead to decreasing soil fertility and crop yields as well as threats like floods and landslides. These environmental impacts are emerging as major economic problems in northern Vietnam (Zimmer et al., 2017).

A solution that has been proposed to reduce soil erosion and land degradation is agroforestry, "a land-use system in which woody perennials (trees, shrubs etc.) are deliberately grown on the same piece of land as agricultural crops and/or animals" (Lundgren & Raintree, 1982). In sloping landscapes, agroforestry can also be combined with contour farming techniques in form of grass strips (Bhattacharyya et al., 2015), which is the practice evaluated in this study. The grass strips benefit local farmers through reduced labor for fodder collection (Hilger et al., 2013). In addition, fruit trees together with annual crop in the agroforestry system contributes to safe income for the farmers (Hilger et al., 2013). Today there is a political interest in agroforestry implementation on a larger scale in northwestern Vietnam. At the same time, there is a lack of knowledge when it comes to the connection between vegetation cover, reduction of erosion and soil fertility, especially in a long-term perspective (Zimmer et al., 2017). This study will contribute to fill this knowledge gap by investigating the effects of some agroforestry practices established in ongoing research for development projects in relation to soil erosion control.

1.1 MAIN OBJECTIVE AND RESEARCH QUESTIONS

The main objective of this study was to evaluate agroforestry systems' capacity for erosion control, compared to sole crops of the dominant species in the area. The study was conducted in two sites, one in Son La province and one in Dien Bien province, both in Northwest Vietnam. In the two sites, fieldwork was conducted to evaluate the movement of soil along the slope in the agroforestry system as compared to the control with sole crop. In addition, terrace formation was evaluated in the exemplar landscape in Son La. The following research questions were formulated;

1. How much soil is lost by erosion in the two agroforestry systems, as compared to sole crops (the controls)? Can this be quantified by a method with erosion pins?

2. The contour planted grass strips will serve as starting points for terrace formation in both sites. How is the movement of soil developing one and two years after the grass strips are planted?

3. How can terrace formation by contour planted grass strips in an agroforestry system be evaluated at landscape level?

4. How does the erosion pattern develop over the years, from the year of establishing the agroforestry practices and the consecutive years?

5. Can the erosion model WEPP be use to simulate the soil loss as compared to the measured values? Which calibrations are needed?

Research question 1, 3 and 4 will be addressed at both sites, and number 2 and 5 only in Son La.

1.2 DELIMITATION

This study was designed in order to build on and cooperate with the ongoing "Agroforestry for livelihoods of smallholder farmers in Northwest Vietnam" (AFLi) project. This was beneficial because already implemented methods could be used to save us time. In addition, our results would be useful in the AFLi project since the same trial area and experimental set-up was used. On the other hand, this leads to limitations, such as the choice of study area and adjustments to ongoing fieldwork. We also had to adapt to the local farmers and their work in the fields. For example, the field work was paused for a few days when it was time for maize harvest in the experimental trial in Son La.

Furthermore, this study do not cover of soil organic matter content investigations and nutrient losses in the field due to soil erosion, even though this could have been an interesting connection to make. Other sub-projects within AFLi are focusing more on nutrient dynamics studies.

The modelling part of this study was chosen to be applied in the Son La study site. The reason was that the software that was used within this study had data of maize parameters preinstalled (maize is the grown crop in the experiment in Son La but not Dien Bien where coffee is the main crop). This made the modelling work possible since there was no time for determining the required coffee parameters in the field. Another aspect was that the budget could only cover climate data from one weather station, which made us choose one of the two study sites for the modelling work.

1.3 NORTHWEST VIETNAM AND PREVIOUS STUDIES

In five of seven regions in the world (Africa, Asia, Latin America, Near East and North Africa, and North America), problems caused by soil erosion one of the major threats to soil functions. According to the report Status of the World's Soil Resources from 2015, there have not been any improvements in decreasing soil erosion in four of the regions Africa, Asia, Latin America, Near East and North Africa (FAO & ITPS, 2015). In the international literature, there are many articles in soil erosion that have provided a base for further research about soil erosion. However, there are still some research gaps that need to be filled, such as off-site impacts of erosion involving several interest groups (FAO, 2019).

There have also been reported problems due to soil erosion in the mountainous Northwest (NW) Vietnam. Therefore, several research projects have been carried out in this area, for example the Uplands Program (SFB 564) "Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia" through the German Research Foundation (Vu Dinh et al., 2014).

In NW Vietnam there is an ongoing project called AFLi led by World Agroforestry (ICRAF) and partners. The project has operated in two phases, the first AFLi 1 conducted in 2011-2016 and the following AFLi 2 starting in 2017 with a slightly broader scope and renamed to 'Developing and promoting market-based agroforestry and forest rehabilitation options for northwest Vietnam'. The aim of the AFLi 1 project was to increase productivity of smallholder farming systems in the region using agroforestry, while simultaneously conserving the natural resource base (Nguyen et al., 2016). Afli 2 aims to proceed with the results of AFLi 1 by developing and promoting market based agroforestry options adapted to the local conditions. AFLi 2 also has the ambition to include the aspects of soil erosion, which is the reason why this MSc thesis project was established. Funding for the AFLi project mainly originate from Australian Centre of International Agricultural Research (ACIAR) and the Global agricultural innovation network (CGIAR) Research program on Forests, Trees and Agroforestry (FTA) (Nguyen et al., 2016).

When the AFLi project was introduced, some of the farmers in the study sites in the NW had never heard of agroforestry (AF) before, while farmers at some of the sites were already practicing AF, but in a very small scale (Hoang et al., 2013). The project presented in this report is strongly connected to the research within the AFLi project and existing study sites and field experiments have been used. Some methods used in this work had already been established in the AFLi project, although some methods were introduced or developed for the first time within this master thesis study. The AFLi project already had cooperating farmers and institutions in the study sites and in the provinces, which made the fieldwork of this study possible.

2 THEORY

This section contains relevant theory that is necessary in order to understand the study. Firstly, this section includes information about issues and threats due to soil erosion. Secondly, soil erosion processes and soil conservation techniques are presented. Lastly, the section includes theory about soil erosion models.

2.1 ISSUES AND THREATS DUE TO EROSION

87% of NW Vietnam have hillslopes steeper than 25%, the weather condition in this area are harsh and seasonal and include large high-intensity rains. When these steep areas are cultivated the soil can be left bare, during tillage operations and under the establishment phase of the crops (e.g. maize). This can cause severe soil degradation (Hoang et al., 2017, Vu Dinh et al., 2014). The Food and Agriculture Organization (FAO, 2019) reports that even though soil erosion is an issue that have been known for almost a century, still in 2019, it is the greatest threat to soil health and soil ecosystem services in many parts of the world. A threat directly connected to erosion is landslides which increases the mortality risk in the affected regions (Vu Dinh et al., 2014, Forbes & Broadhead, 2011).

Shifting cultivation with cassava, maize, or upland rice is the traditional practice in the fields in NW Vietnam (Vu Dinh et al., 2014). Shifting cultivation can be described as an agricultural system where a piece of land is used for some seasons only to be abandoned a few years later, often because the land has become inadequate for crop production (FAO et al., 2015). The soil loss from this practices have been recorded to 124 t ha^{-1} yr^{-1} (Khiet, 2014). Fields with seasonal crops have a soil loss between 40-100 t ha^{-1} yr^{-1} (Phien & Siem, 1999). Soil erosion leads to negative impacts both on- and off-site, such as declining soil fertility and crop productivity and pollution of streams through the process of nutrients being attached to eroded sediments (Clemens et al., 2010, Wezel et al., 2002, Schmitter et al., 2010, Vu Dinh et al., 2014).

2.2 EROSION

Soil loss by erosion is a two-phase process. Firstly, individual soil particles are detached from the soil mass. The detachment become easier if the soil is disturbed for example by tillage operations and by trampling of people and livestock. Running water and wind are additional contributors to the detachment of soil particles. The second phase is the displacement of particle by erosive agent such as water and wind. Deposition of the soil particles occur when sufficient energy is no longer available for the erosive agent (Morgan, 2005).

Soil particles' resistance to erosion mainly depends on three factors: Particle density, size and plasticity. Particles that are larger than 0.1 mm in diameter have higher resistance to displacement by wind or rain splash erosion and are not easily transported in runoff water. Soil with larger particle sizes have a higher porosity which increases the soil´s capacity to infiltrate water, minimizing the effects of storm runoff. On the other hand particles smaller than 0.1 mm in diameter have an inter-particle cohesion. Plasticity depends on the water ratio in the soil. Therefore, a higher force is required to displace and transport soils with small particles (Charman, 2000).

Previous studies in NW Vietnam show that most common erosion in the sloping land is caused by water such as raindrop/splash, sheet, rill, and gully erosion (Vu Dinh et al., 2014, Turkelboom et al., 2008).

2.2.1 Water Erosion

Raindrops are the most important detaching agent and occur when drops hit bare soil. The force from the rain drop can break soil aggregates into single soil particles and lift them as high as 60 cm above the ground and transport them 1.5 m from the point of impact. The characteristics of the rainfall such as drop mass and size, intensity, direction and terminal velocity is directly linked to the movement of a single particle. Soil characteristics such as particle size and type of binding between individual particles inside the aggregate also have an impact on the movement on a single particle (Charman, 2000, Morgan, 2005).

Sheet erosion (overland flow), occurs when the infiltration capacity in the soil is reached and the finest soil particles are suspended in the surface water runoff. The rate of infiltration depends on the soil texture, structure, moisture and vegetation cover. If the slope has a high gradient and the water have a long way of an unimpeded flow the runoff velocity will become faster which increases the erosion capacity of the runoff water. Rain with a high intensity can compact the soil (surface sealing) and form a surface crust that has low infiltration capacity. The smooth surface increases the velocity of the water runoff. If the slope has a gradient greater than 3%, the thin crust becomes eroded by the runoff. The overall effect of sheet erosion is notable, although not in a short time (Charman, 2000, Morgan, 2005).

Water flow can be concentrated to channels in the surface and then the capacity to carry larger soil particles is increasing. The sediment that moves inside the channel erodes the channel so it becomes wider and deeper. The amount of soil that is eroded is proportional to the square of the velocity. Capacity to transport the lost soil in the channels increases in proportion to the fifth power of the velocity. If the channel is shallower than 30 cm and can be removed by tilling operation it is called a rill. If the channel is deeper and a more permanent feature, it is a gully (Charman, 2000, Morgan, 2005).

2.3 SOIL CONSERVATION TECHNIQUES

Soil conservation technique (SCT) are used for controlling soil loss and runoff in agricultural lands. There are many SCT:s that can be used both in the landscape and at field level. Different techniques aim to decrease different negative factors that cause soil erosion. Techniques such as grass barriers, natural vegetative strips and alley cropping (rows of trees with companion crops growing in between) aim to reduce slope length. Some other methods decrease the direct impact of raindrops on the soil surface such as cover crops, relay cropping, mulching and bio or synthetic geo-textiles that are placed on the soil's surface. Minimum or zero tillage is a SCT that aims to minimize the negative effect of tillage on the soil structure. One larger scale, contour terracing is an effective SCT (Hilger et al., 2013).

2.3.1 Contour-Based Cropping System

Contour-based cropping systems are SCT:s that are mostly preferred and likely to be adopted by farmers (Hilger et al., 2013). To create the system, the tillage practice is carried out by following the natural contour line when cultivating the soil. There are many methods for laying out contour lines. A simple one, already available for farmers, is to follow a buffalo or cow who prefers to walk along contour line (Nguyen et al., 2016, FAO, 2008). Contour-based cropping systems aim to collect surface runoff, increase water infiltration and prevent soil erosion (Bhattacharyya et al., 2015). There are many different contour-based systems that can be applied to reduce soil loss. Contour bund is such a technique, that can be both mechanically or vegetatively applied on steep slopes (Bhattacharyya et al., 2015). Contour-based cropping is often combined with strip cropping to protect the soil surface at high intensity rainfalls (Morgan, 2005).

2.3.2 Terrace Formation

There are different ways of creating terraces; they can be constructed by hands, by a machine or created over time by grass strips planted in natural contours lines in a hilly landscape (Bhattacharyya et al., 2015). Common types of terraces are bench terraces and half-moon terraces. They are suitable where soil depth is deeper than 1.0 m (Bhattacharyya et al., 2015).

Grass strips are known for their ability to create terraces, due to their root systems ability to bind soil particles, increasing shear strength and surface roughness (Welle et al., 2006, Shi et al., 2011). The efficiency of grass forming terraces have been examined in previous studies. Welle et al. (2006) investigated 16 plots on an average slope of 9% located in Ethiopia. Four treatments were studied, one control system without grass strips and three with different grass species (Desho, Setaria and Vetiver) planted with a row spacing of 15 cm. The grass strips ability to cause terracing was measured by erosion pins. Welle et al. (2006) determined that the grass was forming terraces, but the efficiency differed remarkably among the three species. Of the three species, the performance in terrace formation was defined as $Vetiver > Desho > Setaria$.

2.3.3 Conservation Agriculture

Conservation agriculture (CA) is one soil conservation techniques which aims to minimize the negative effect that tillage has on soil structure. Conservation agriculture include three important key principles (Hilger et al., 2013). The first principle is to minimize tillage operations with the method of direct seeding. This means growing crops without mechanical seedbed preparation. This reduces soil erosion and preserves soil organic matter. Second principle is to have at least a 30% permanent protective layer of vegetation on the soil surface with cover crops and/or crop residues. This layer protects the soil from the impact of extreme weather patterns, helps to preserve soil moisture, avoids compaction of the soil and suppresses weeds. The third principle is to practice diverse crop rotations or crop interaction. This improves the soil structure and nutrient cycling and prevents pests and diseases (FAO, 2017, Hilger et al., 2013).

In a study in north-eastern Thailand, with slope characteristics similar to NW Vietnam, maize was grown with minimum tillage operations and relay cropping. This was done with a legume cover crop on a moderate hillside with slope gradient between 21–28%. The results from the study showed that minimum tillage and legume relay cropping practices reduced the amount of lost soil from 24.5 t ha^{-1} the year of establishment to 1.6-2.5 t ha^{-1} three years after establishment (Pansak et al., 2013).

2.3.4 Agroforestry

Agroforestry is a farming method that combines crop and/or livestock agriculture with trees. The practice includes the agricultural use of the trees, in addition to the crops and/or livestock (Lundgren & Raintree, 1982). The cycle of an AF system is always longer than 1-year (Nguyen et al., 2016). The practice is particularly suitable for erosion mitigation in steep sloping lands of 25° and above (Hoang et al., 2017), indicating that it could be a successful SCT in NW Vietnam. Agroforestry implies numerous benefits at different scales. On a field scale, a combination of crops and trees can increase soil fertility, create shadow and reduce soil erosion. On a farm scale trees can provide fodder for livestock, shelter, fuel, food, timber and income products. On a landscape level, agroforestry can play a role of providing ecosystem services and increase the resilience of the agricultural landscape (ICRAF, 2019). One of the challenges is to motivate the implementation of these systems since some of the benefits emerges a few years after the establishment, when the trees starts to bear fruit. Lack of knowledge can many times be a reason for negative attitude among the farmers (Hoang et al., 2017). A long-term thinking is essential in order to achieve a successful conversion to agroforestry land use systems. Also, it is important to adapt the agroforestry systems to local conditions in order to increase the acceptability among the farmers. A strong governmental support helps to contribute a successful implementation (Hoang et al., 2017). Agroforestry can be combined with other soil conservation measures, e.g bunding, contour ploughing and the use of strips and terraces (Bhattacharyya et al., 2015).

2.3.5 Crops and Vegetation Cover Used in Soil Conservation

Vegetation plays an important role in erosion control. The part of the vegetation that is above ground such as leaves and stems take up some of the energy from the raindrops. Crops that cover the surface are increasing the roughness on the surface and therefore decreasing the speed of water flow. Cover crops also protect the soil from the direct effect of raindrops (Morgan, 2005). Trees contribute to improvements in numerous soil parameters and can be compared with the soil under a natural forest. That type of soil is fertile, well structured, has a good water holding capacity and has a storage of nutrients in the organic matter. Both carbon and nutrients are mainly recycling in the soil with low inputs and outputs (Young, 2002). Furthermore, tree roots generate less runoff by keeping a high infiltration rate and water-holding capacity. A dense and uniform ground cover of vegetation is the most effective way of controlling erosion (Morgan, 2005).

Crops and vegetation that are commonly used in NW Vietnam for soil conservation and agroforestry practices are introduced in the following section. They are also the crops grown in the field trials used in this project.

Longan
Longan (*Dimocarpus longan*) is a fruit tree of the soapberry family that can reach a height of 20 m (Slaven, 2018). The fruit´s peel is yellow and the meat is white with a red-brown to black seed in the middle (Choo, 2000, Nguyen et al., 2019c). Longan is found in many tropical and subtropical countries, but is only commercially exploited in few countries and Vietnam is one of them (Choo, 2000).

Longan is suitable in sloping landscapes, although preferable at altitudes below 800 masl (Nguyen et al., 2019c). The plant requires generous soil humidity from fruit set until maturity, although it is sensitive to waterlogging (Choo, 2000, Nguyen et al., 2019c). Thus Longan prefers porous soil. Favorable annual precipitation is about 1500 mm. Longan grows in tropical climates but requires a period of colder climate before flowering and blooming (Nguyen et al., 2019c). Harvest occurs after 5-7 months. Excessive rainfall as well as droughts during the flowering and fruit set period can reduce fruit productivity. Examples of suitable soils for Longan is rich sandy loams or heavy alluvial soils with access to the water table. The root depth is 2-4 m (Choo, 2000).

Mango
Mango (*Mangifera indica L.*) is a fruit tree of the cashew family. The fruits are grown in clusters on long steams. There are numerous varieties with fruits varying in size, color and maturity period (Nguyen et al., 2019b). In NW Vietnam the mango fruits are ready for harvest in June [1]. The yield increases with the age of the trees. The Mango tree prefer a temperature of 24-26 °C and a minimum annual rainfall of 1000-1200 mm (Nguyen et al., 2019b).

Son Tra
Son Tra (*Docynia indica*) is a fruit tree of the rosaceae family. The tree is growing at high elevations and can reach a height of 4 m. The Son Tra fruit is a small apple with a light green color. The tree only bears fruit when it grows above 800 masl. The fruits can be harvested once a year around October. Son Tra bears fruits in the second year and the yield increases until the fifth year (Nguyen et al., 2019d). Son Tra can grow in various soils such as light (sandy), medium (loamy) and heavy (clay) soils and prefers well-drained soil conditions (Pfaf, 2012).

Forage Grass
Forage grass (e.g. mulato or guinea or other species) is planted along the contour lines in agroforestry systems mainly for soil conservation purposes, but is also used as fodder at the farm. The forage grass is harvested when it reaches a height of 60-70 cm, which occurs about three months after planting. Replanting might be necessary after a couple of years, due to competition with other species in the agroforestry system (Nguyen et al., 2019d).

Coffee
The coffee bush planted in the area is Arabica coffee (*Coffea arabica*) which belongs to the Rubiaceae family. It can reach a height of 4–5 m. The three is adopted to a temperature

[1] Hung Do Van, researcher at ICRAF. Hanoi, 2019

between 20 to 25 °C and the lowest temperature should not go below 0 °C. Favorable precipitation is about 1200-1900 mm per year and with an even distribution. An ideal relative humidity should be around 70% (La et al., 2019).

2.4 EROSION MODELS

In the literature, over 50 models are presented that can be used for studying soil erosion. The models vary in many terms, for example regarding capability and complexity, representation of processes, input requirements and what types of output they can provide. Soil erosion models can be divided into three different groups depending on how they are constructed; empirical, conceptual and physical based models (Pandey et al., 2016).

Empirical models are based on observations and data response characterization (Wheater et al., 1993). These kind of models do not take into account that the analyzed catchments appears the same. The main sources of uncertainty within empirical models come from physical assumptions and simplifications, which can contribute to significant differences between the actual scenario and the modeled scenario. The amount of data and computational requirements for empirical models are few, therefore the model is capable of working with coarser measurements and limited data (Pandey et al., 2016).

Conceptual based models represent a catchment area as a number of internal storages. The model describes the catchment in general and does not include specific details about the process interactions. The parameters that are included in the models have limited physical interpretability (Pandey et al., 2016).

Physical based models use equations for describing the essential mechanisms that control erosion in a catchment. Two of the equations that are used describe conservation of mass and momentum for flow, and conservation of mass equation for sediment. The models can also include physical characteristics, such as topography, geology, land use, climate, plant growth and river flow. Physical models require more input data then empirical and conceptual models (Pandey et al., 2016).

2.4.1 Models for Soil loss Prediction

The most common models for soil loss prediction around the world are the universal soil loss equation (USLE) (Wischmeier & Smith., 1978) and its revised version RUSLE (Kinnell, 2017), both empirical models. These models were developed in the middle of the twentieth century and are often referred to as the traditional erosion models (Kinnell et al., 2018). USLE and RUSLE are suitable for modeling long-term erosion at locations all over the world (Kinnell, 2017).

Because the traditional models USLE and RUSLE are suitable for predicting long-term ($>$ 20 years) average annual soil loss due to rainfall, there was a need of a model that could predict soil loss over a shorter time scale (annual or event based) (Kinnell et al., 2018). Another weakness of USLE is that it can only take into account of larger regions of a hillslope, and not model sediment transports from fields to off-site channels or streams. Furthermore, USLE cannot estimate parameters such as runoff, spatial locations of soil loss on a hillslope profile or recurrence probabilities of erosion events (Flanagan et al., 2017). The idea was to develop a model that could cover these needs and that was the birth of the Water Erosion Prediction Project, WEPP (Flanagan et al., 2001) and USLE-M (Kinnell & Risse, 1998). These are process based models, which are able to make soil loss predictions caused by individual rainfall events. Advantages of a model that has the capacity to make predictions over a shorter time scale is that it can take short-term variations in vegetation and climate into account, which the traditional models are incapable of (Flanagan et al., 2017). These models are supposed to perform better than the traditional models when runoff is known or predicted well (Kinnell et al., 2018).

2.4.2 WEPP

The Water Erosion Prediction Project (WEPP) was developed by the Agricultural Research Service of the U.S Department of Agriculture (USDA-ARS) and introduced in 1985, but it was not until 1995 that the first release was delivered to users (Flanagan et al., 2017). The WEPP model is a physical based model, in contrast to the traditional empirical erosions models USLE and RUSLE. The WEPP model is suitable for common hillslope applications and small catchments (Flanagan et al., 2017). WEPP calculates runoff accurately, while USLE and RUSLE do not (Kinnell, 2017).

Modelling a hillslope scenario with WEPP requires four different input files (Dennis et al., 1995). Those are 1) a climate file, 2) a slope file, 3) a soil file, 4) a plant/management file.

3 MATERIALS AND METHODS

This section contains information about the study area, experimental design and method descriptions used in this project. The statistical analysis used in the study is introduced and the modelling process is presented.

3.1 STUDY AREA

The NW of Vietnam consists of six provinces, totally covering an area of 5.64 million ha. The area is characterized by sloping landscapes with 87% of the land having a slope of 25 degrees or greater (Hoang et al., 2017).

3.1.1 Study Sites

Within the project there are two study sites, one is located in Son La province and the other one in Dien Bien province (Figure 1).

The study site in Son La (N 21°10.970', E 104°06.404') is located in Na Ban village, Hat Lot commune, Mai Son district, Son La province. The study site in Son La consist of 50 ha of Exemplar Landscape (EL) where farmers are practicing agroforestry and an Experimental Trial where a field experiment is replicated. The area where the study site is situated is characterised by a hilly landscape (Figure 2).

The study site in Dien Bien (N 21°033.611', E 103°030.335') is located in Hang Tau village, Toa Tinh commune, Tuan Giao district, Dien Bien province. The study site includes an Experimental Trial where a field experiment is replicated. The area where the study site is located has a mountainous landscape (Figure 3).

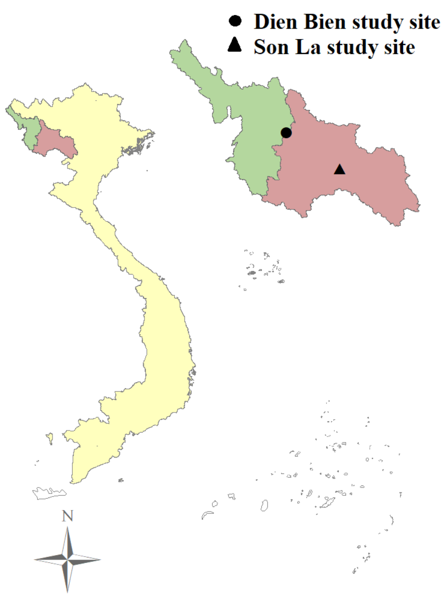

Figure 1. Map of Northwest Vietnam showing the location of the two study sites, Dien Bien (N 21°033.611', E 103°030.335') and Son La (N 21°10.970', E 104°06.404').

Figure 2. The hilly landscape in Son La study site.

Figure 3. The mountainous landscape in Dien Bien study site.

3.1.2 Climate

NW have subtropical climate the rainfall is seasonal and most frequent in June to September. The annual rainfall ranges from 1200 to 2800 mm (Zimmer et al., 2017). Data of precipitation from years 1989-2018 from a weather station (code 48806) located in Son La (N 21°20', E 103°54') shows the same pattern as the literature in annual and monthly frequent precipitation (Figure 4). The mean annual temperature is 21.5 °C and the monthly mean temperatures range from a minimum of 15.3 °C in January to a maximum of 25.5 °C in June (Figure 4).

The field work was accomplished during the dry season 2019, 16 October - 3 November in Son La study site and 4 - 8 November in Dien Bien study site. The weather was in general hot, dry, sunny or partly cloudy. One rain event occurred during the fieldwork in both sites.

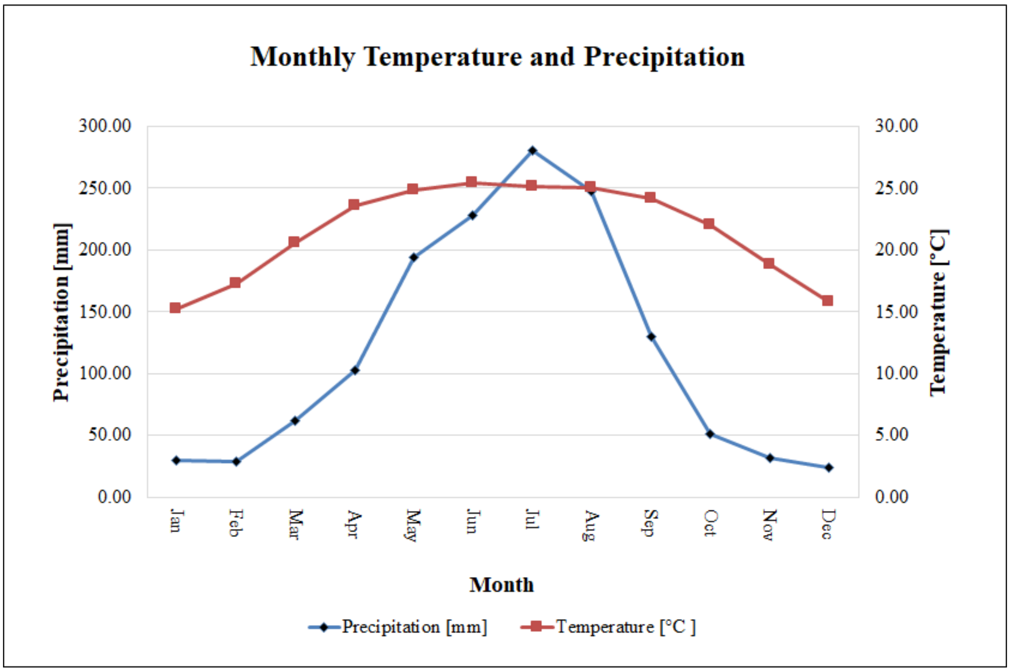

Figure 4. Graph of monthly average temperature [°C] and precipitation [mm] at Son La weather station between years 1989-2018.

3.1.3 Geology and Soil Properties

The dominant rock types in the locations of the two study sites are rocks formed in the Paleozoic Era (541-252 million years ago) and Proterozoic Eon (2500-541 million years ago) and also younger sedimentary rock from Permian-Triassic (299-201 million years ago) (Roger et al., 2012). The Paleozoic and Proterozoic rocks are either sedimentary rocks or a transformed foliated metamorphic rock (Roger et al., 2012).

According to previous studies, the dominant soil type in NW Vietnam is Ferralsols with medium fertility (Hai et al., 2018). Ferralsols are classical tropical soils characterized by its yellow to red color, strongly weathered condition and diffuse horizon boundaries (ISRIC, n.d). The diffuse horizon boundaries can partly be caused by intense termite activity. Since they destroy rock structure by increasing the depth of the solum and increasing the permeability of the soil by their nets, tunnels and ventilation shafts. Ferralsols have low pH and high content of sesquioxides, weathering products of Fe/Al-rich silicates (ISRIC, n.d).

In an agricultural context, Ferralsols have a number of limitations. According to World Soil Information (ISRIC) those limitations are mostly connected to the soil's chemical poorness. Ferralsols have, in general, low natural fertility. In natural systems, the plant nutrients tends to circulate with most nutrients contained in the biomass. Nutrients available for the plants are concentrated in the upper 10 to 50 cm of the soil profile. Therefore, it is particularly important to minimize the surface erosion since the majority of the nutrients are concentrated in the upper part of the soil profile. In order to maintain good soil fertility, manuring and mulching are required soil treatments. In addition, both liming (increases pH, minimizes risk of aluminum toxicity and raises cation exchange capacity (CEC)) and fertilization are needed if Ferralsols should be successfully used for crop production. Since Ferralsols in NW Vietnam have slightly better fertility (medium instead of low), all the mentioned soil fertility treatments are usually not applied. Treatments used in the study sites are manuring, mulching and fertilization. Lastly, Ferralsols have limited water-holding capacity (ISRIC, n.d). That is an issue of the water supply in times of droughts and is especially problematic in sloping landscapes, as is the case in NW Vietnam.

3.1.4 Local History and Demography

The farmers living in NW are mostly minorities of the ethnic groups Tay, Thai, Muong, Khmer, H'mong and Dao. Within this project, cooperation occurred mainly with White Thai in Son La and H'mong in Dien Bien. The local history differs between the two sites and they are therefore described separately.

Most of the farmers managing the agricultural land within Son La study site lives in the small village Na Ban. Paddy rice is grown in the valleys, while maize, upland rice and sugar cane are grown on the steep hillsides. The village land also includes limited areas of forest. Each farmer family has about 1-2 ha of agricultural land divided into subareas located in different parts of the village, so called farmers' plots. This is a consequence of the government distributing the land equally between each farmer in 2007. Before 2007 less farmers were living in Na Ban and each farmer family had about 6-7 ha of agricultural land. In 2007, new families were relocated to Na Ban because the government decided to build a hydropower plant in their former home area. The government wanted to divide the land fairly between the already living farmers and the newcomers. Since different locations varied in quality, the government split the land so that each farmer family obtained subareas at different elevation. Today there are three ethnic groups living in Na Ban, Kinh and the minorities black and white Thai. The farmer families are generally self-sufficient, but can buy complementary local products from other farmers in the village or at the local market [2].

The people living in the village Hang Tau within Dien Bien study site belong to the ethnic group H'mong. Before the establishment of the experimental plots the farmers were planting maize and upland rice with rotation of 3 years. This agricultural practice was used for about 10 years. Before there was open grass land in the area.[3]. The farmer families in the village are generally self-sufficient.

[2]Information obtained by interviews with local fieldworkers (Thach Nguyen Van, Hung Do Van) and researchers of ICRAF together with conversations with local farmers: Son La, 2019.

[3]Lau A Vang, local farmer, Hang Tau 2019

3.2 EXPERIMENTAL DESIGN

The experimental set-up in this study emanates from two already existing experimental designs in the AFLi project. Those are replicated Experimental Trials established in June 2017 in both Son La and Dien Bien study sites and one Exemplar Landscape (EL) established in 2015 in Son La study site.

3.2.1 Experimental Trials

The trials consist of replicated plots of block design. All plots in the trial are equal in size and placed on one hillside. The plots are delimited by a metal barrier of about 2 dm height at all sides except the bottom where an erosion trap is located. Both trials consist of two treatments, one agroforestry practice (AF) and one sole crop figuring as the control. The present agriculture methods and the most commonly used crops in the area were the starting points when designing the trials. Local adaptions were necessary in order to make the experiment sustainable over time and also in order to reach a favorable collaboration with the local farmers. It was also important to choose economically strong crops, to ensure the farmers' income. Based on these criteria two AF practices were selected for the trials and compared with two sole crops. In Son La the most commonly grown crop was maize and there was an emerging interest in growing fruit trees, which led to the selection of Longan and Mango that were considered to be suitable species for the area. Forage grass was selected to benefit the local farmers in form of reduced labor for fodder collection and for its ability to create terraces. That led to an AF system composed of Longan-Mango-Maize-Forage Grass and a monoculture of sole maize (SM), figuring as the control. In Dien Bien, the most commonly grown crop at the time of the establishment was coffee. That lead to an AF system composed of Sontra-Coffee-Forage Grass with monoculture of sole coffee (SC) as the control. Sontra is a tree suitable for the high elevation in Dien Bien study site. In addition, the tillage methods that the farmers were using in the area where considered when designing the management of the trials. The intention was that the tillage methods used in the experimental plots should simulate the tillage methods that the farmers use on the other fields in the area, although in smaller scale in the trial. The general tillage method used by the farmers was buffalo ploughing, and in the trials the ploughing was done by hand using a hoe.

The Son La trial is located on a homogeneous hillside with an elevation of 565 masl [4]. The trial consists of 9 equal sized plots (5 AF plots and 4 SM plots) placed according to Figure 5. The plots are replicated four times, thus forms four blocks; block 1 (plot 1 and 2), block 2 (plot 3, 4 and 5), block 3 (plot 6 and 7), block 4 (plot 8 and 9). Block 2 has an extra AF plot.

[4] Measured value (October 2019) in the middle part of the hill, next to plot 7

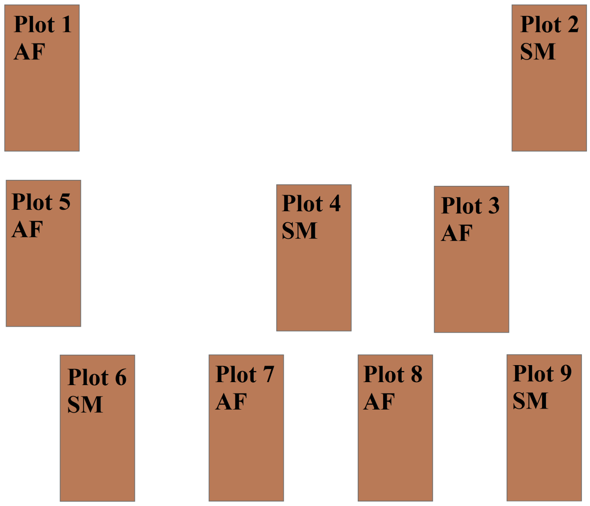

Figure 5. Figure illustrating the experimental design with the treatment plots in the Son La trial. The trial consists of two treatments and four replicates (plus an extra plot), in total 9 plots forming 4 blocks. Number 1, 3, 5, 7 and 8 are agroforestry (AF) plots while number 2, 4, 6 and 9 are control plots with sole maize (SM).

The Dien Bien trial is located on a homogeneous hillside with an elevation of 1115 masl [5]. The trial consist of two treatments and four replicates, in total 8 experimental plots (4 AF plots and 4 SC plots) placed in two rows, as illustrated in Figure 6. The plots are organized in four, thus forms four blocks; block 1 (plot 1 and 2), block 2 (plot 3 and 4), block 3 (plot 5 and 6), block 4 (plot 7 and 8).

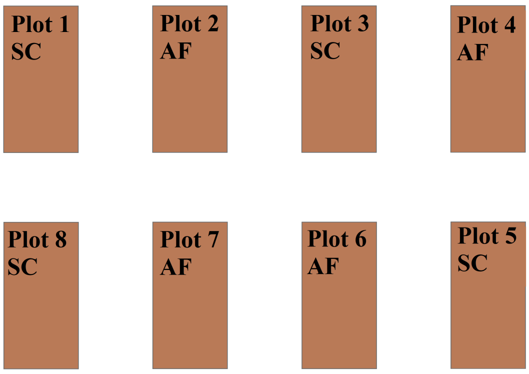

Figure 6. Figure illustrating the experimental plots in the Dien Bien trial. The trial consists of two treatments and four replicates, in total 8 plots forming 4 blocks. Plot number 2, 4, 6 and 7 are agroforestry (AF) treatment while number 1, 3, 5 and 8 are control plots with sole coffee (SC).

[5] Measured value (October 2019) in the middle part of the hill, between plot 2 and 3

3.2.2 Exemplar Landscape

The Exemplar Landscape in Son La covers an area of total 50 ha. The subareas in the Exemplar Landscape are spread out on many hillsides. The aim of the Exemplar Landscape is to study the AF systems on a larger scale and over a longer time frame. The 50 ha are fragmented in different subareas belonging to and managed by different farmers. In total, 29 farmers are managing the Exemplar Landscape by taking care of their own fields plots. The area of the farmers' plots varies in size depending on how large land they have. At the start of the experiment (2015), the co-operating farmers agreed to replace some of their maize fields by AF practices including fruit trees and grass strips. Thus, the Exemplar Landscape now includes both fields with sole maize (or other crop) and fields with AF practice. The details of the AF systems, such as tree species or type of sole crop, can vary among different farmers' plots and they manage their fields individually. For example, the distances between the grass strips and trees can vary. Due to this, the systems are not as perfectly set up and managed for research purposes such as in the Experimental Trials, which lead to some difficulties in the study design. The main tillage method used by the farmers within the Exemplar Landscape is buffalo ploughing. The contour lines in the AF areas were created with the buffalo method (mention in section 2.3.1 in Theory).

3.3 METHOD DESCRIPTIONS

In this section, the methods that were used in the study are described.

3.3.1 Soil Profile Description

Soil profile pits were dug to the depth of 1 meter by hand to characterize the soil at the sites. In this study, the purpose was to understand the characteristics of the soils in the area, by determining the soil texture, structure, color and signs of biological activity and take samples for soil analysis.
The profiles were placed within the area of the field trial but outside the treatment plots in the experimental set-up in order not to cause any disturbances. Firstly, the soil horizons (layers with distinct morphology) in the profile was determined by observing the color, structure and texture by scratching the vertical soil surface gently with a knife. The characteristics of the top layer (Ap horizon - plough layer) in the soil profile in Son La was later used in the identification and measurements of the A-horizon in the Exemplar Landscape (see section 3.3.5). The characteristics of each horizon were observed following the FAO guidelines for soil description (FAO, 2006), but did not include all soil characteristics. The parameters determined in the field are presented in Table 1.

In addition, soil samples were taken in each horizon with the aim to analyze bulk density (BD), soil texture, percent organic carbon (org. C), total amount of nutrients (nitrogen - N, phosphorous - P, potassium - K), pH-value and cation exchange capacity (CEC). For bulk density, the samples were taken by pressing down a metal ring from the top of each horizon to obtain an intact core of undisturbed soil of a given volume. In the layers below the A-horizon a horizontal surface had to be dug (somewhere within the horizon) in order to press down the metal ring from the top of the surface. The soil samples were analyzed in the laboratory of the Soils and Fertilizers Research Institute (SFRI) in Hanoi, Vietnam, in December 2019. Measurements of pH were done in both water (H_2O) and in a salt solution (KCl). The soil texture, BD, organic matter content and CEC were parameters of interest as input data for the modelling. The depth of each soil layer was also required soil parameters in the model (section 3.5.1). The soil profile in Son La was dug on the right side of plot 7 (Figure 5) and the soil profile in Dien Bien was located between plot 2 and 3 (Figure 6).

Table 1. The soil parameters and methods for determination in the field used for the soil profile descriptions in the Son La and Dien Bien experimental trials.

Parameter	**Method for determination in field**
Depth of layer	Observing the appearance (mostly color) and scratching the soil with a knife to estimate the change in consistence between the layers
Color	An undisturbed soil sample was compared with a soil color map of international standards (Munsell, 2009)
Clay content	A soil sample was taken and mixed with water in the hand until soft and smooth consistence. Then the soil was formed to a string and then rolled to a circle. The clay content was estimated from the number of cracks on the string.
Cracks	Number of cracks were counted in an area of 10x10 cm. The width of the smallest and largest crack were measured with a ruler.
Pores	Number of pores were counted in an area of 10x10 cm. The diameter of the smallest and largest hole was measured with a ruler
Mottles	Number of mottles (having different color then the matrix) within the layer was counted in an area of 10x10 cm. The diameters of the smallest and largest mottle were measured with a ruler and then the average radius was calculated. The total surface that the mottles covered was calculated and determined as a percentage of the total observed area (10x10cm). The color of the mottles was compared with Munsells color chart (Munsell, 2009)
Rock fragments	Number of rock fragments (<2mm) within the layer was counted in an area of 10x10 cm. The diameter of the smallest and largest rock fragment was measured with a ruler and then the average radius was calculated. The total surface that the rock fragments covered was calculated and determined in percentage of the total observed area (10x10cm). The colors of the rock fragments were compared with Munsell color chart (Munsell, 2009)
Roots	Number of roots were counted in an area of 10x10 cm. The diameters of the smallest and largest root were measured with a ruler.

3.3.2 Slope Gradient

To measure the slope gradient, a tube filled with water was used (Figure 7). One end of the tube, *A*, was placed along a vertical straight stick that was located in the lowest part of the slope, point *1*. The other end of the tube, *B*, was placed a bit up the slope over point *2*. Between the two points, the tube was placed close to the surface.

The two ends of the tube were then opened and the water levels in both ends were set against the atmospheric pressure. The height of the water level in the tube ends *A* and *B* were then at the same elevation. The end *A* of the tube was moved along the vertical stick to regulate the water level at *B*. When the water level at *B* was equal to the surface level (y_1) the height of water level at *A* (y_2) of the tube was measured with an yardstick. The distance between point 1 and 2 (L) was calculated. To calculate the slope gradient in degrees Eq. 1 was used.

$$S = \arcsin \frac{\Delta y}{L} \qquad \text{(Eq. 1)}$$

L = The distance between point 1 and 2
S = Slope gradient in degrees
Δy = y_2 - y_1

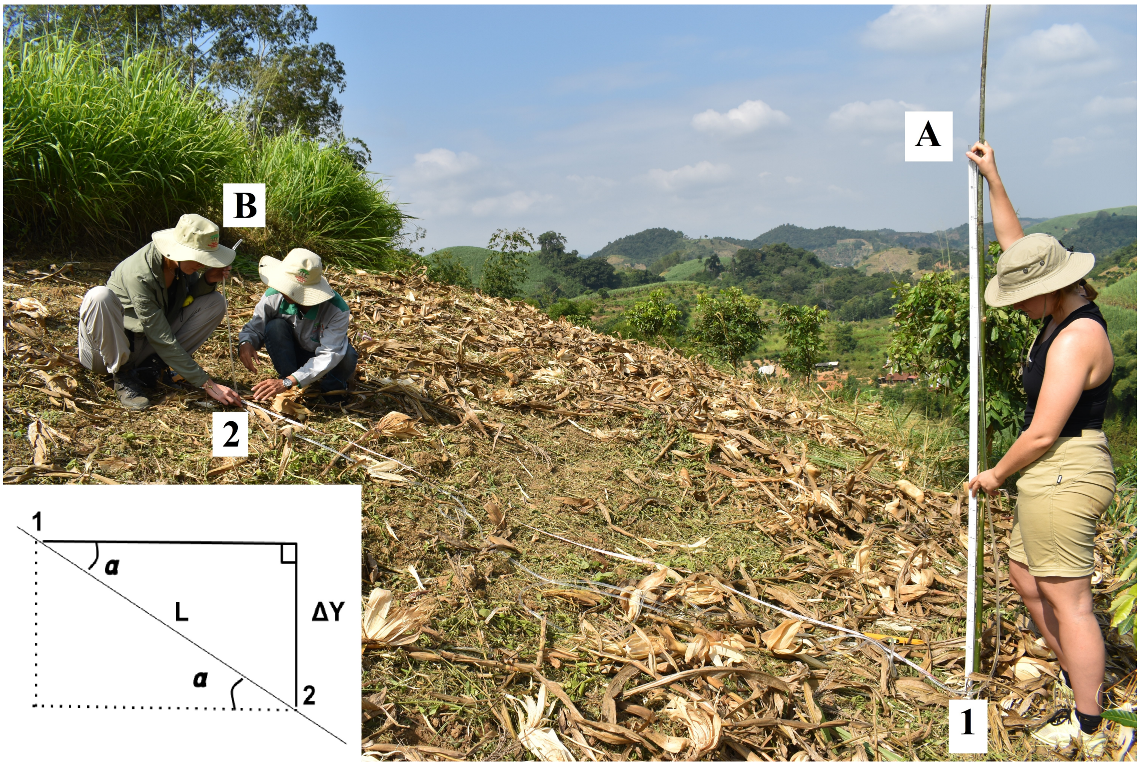

Figure 7. Demonstration of the method set up to evaluate the slope gradient.

Measurements of the slope gradient were carried out in the both Experimental Trials in the two study sites. In the Son La Experimental Trial, measurements of the slope gradient were carried out in three positions; the upper, middle and lower part of each plot. In the Dien Bien Experimental Trial, the measurements were carried out in two positions; the upper and lower part of each plot. An average was calculated for each plot and for the two treatments. Measurements of the slope gradient were also carried out in the Exemplar Landscape and an average gradient were calculated for each treatment.

3.3.3 Evaluation of Movement of Lost Soil Along a Hillside

The movement of lost soil along a hillside was evaluated by using erosion pins. An erosion pin is a 30 cm long two-colored metal stick (Figure 8). It is installed by being pushed down 15 cm into the soil (to the midpoint of the pin). The pins were fitted at the start of the field experiments in 2017. The function of the erosion pin is to indicate the amount of added or lost soil at different points in the experimental plots.

The pins were placed in rows of four as illustrated in Figures 9 and 10. In the AF experimental plots in both sites, the pin rows were placed in four different positions related to the grass strips; 'Below' (row 1), 'Middle' (row 2), 'Upper above' (row 3) and 'Above' (row 4). These four positions were called one section and were replicated three times in the Son La trial (12 rows in total) and two times in the Dien Bien trial (8 rows in total), because the difference in length. The control plots had fewer rows of erosion pins, located in the height of the grass strips in the corresponding AF treatment. In the control plots in Son La, the pin rows were located with equal distance between the rows in four different positions; the 'upper', 'upper middle', 'lower middle' and 'lower' part of the plot. In Dien Bien there were only three rows of pins due to the smaller size of the experimental plots. The positions of the rows were in the 'upper', 'middle' and 'lower' part of the plot.

The total length of each plot was 30 m in Son La and 20 m in Dien Bien. The width of the plot was 4 m in both sites. The distance between the grass strips was also equal in the sites, 10 m. The rows of erosion pins with the position 'below' were located 0.7 m beneath each grass strip. The rows with the position 'middle' were located 5 m below the grass strips (exactly in the middle of the two strips). The rows with position 'upper above' were located 0.5 m above the lower grass strip and the rows with position 'above' are located 0.2 m above the grass. The positions are marked with b, m, ua and a in Figure 8 where the different row positions are illustrated. The distance between the tree and the underlaying grass strip was 1 m. In both treatments in Son La (AF and SM), maize was sown with 0.65 m row spacing and 0.3 m between the plants. In Dien Bien, the coffee was planted with 2 m row spacing and 1.4 m between the plants in both treatments (in both AF and SC).

All pins were measured with a caliper from the top of the pin to the soil surface. The amount of added or lost soil in each point was calculated by subtracting the measured pin height from the initial pin height of 15 cm. Then an average was calculated for each pin row.

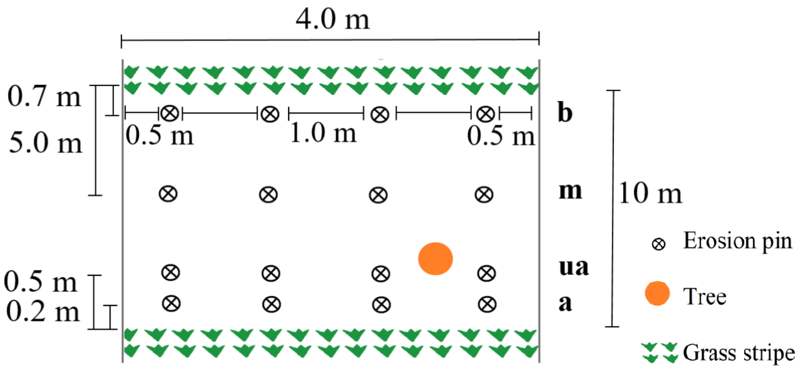

Figure 8. Figure (to the left) illustrating the positions of the erosion pins in one section in the AF experimental plots in both sites. The four positions in one section are below the grass strip (b), in the middle of two grass strips (m), upper above the grass strip (ua) and above the grass strip (a). Photo of an erosion pin (to the right).

Son La

Erosion pins were measured in all 9 plots in Son La. The AF plots had 12 rows of 4 pins, 48 pins and three sections in total, while SM plots had 4 rows of 4 pins, 16 pins in total. The rows were placed in the plots according to Figure 9.

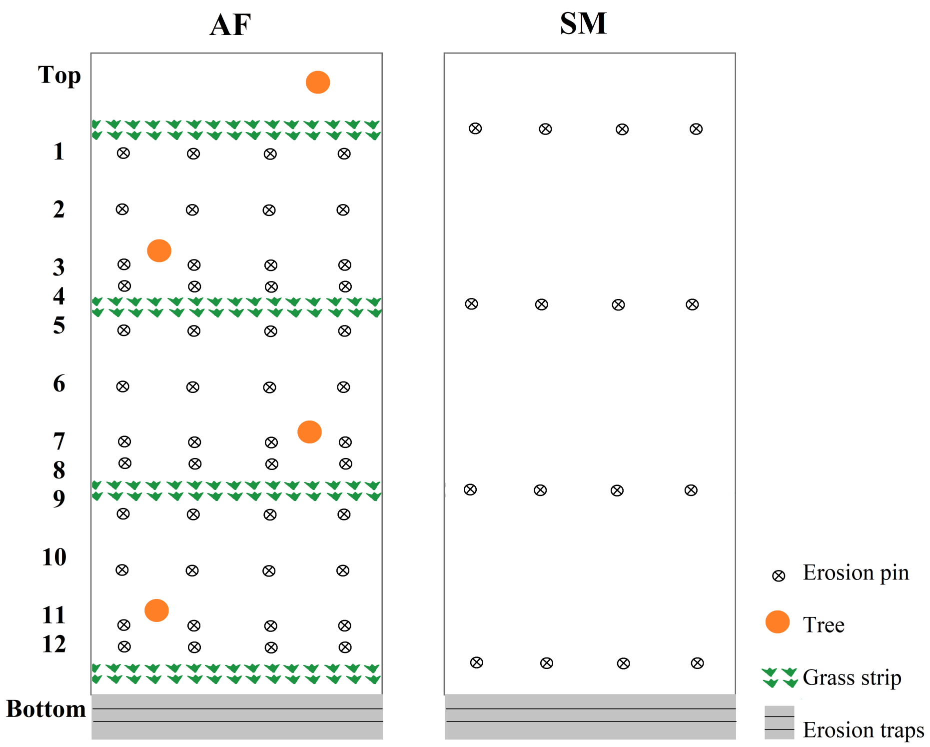

Figure 9. Illustration of the plot design in the Son La trial. The AF plot was designed with four grass strips and twelve rows of erosion pins with four pins in each row. The AF plots also had four trees, placed above each grass strip. The species were Longan and Mango, alternating between the rows with Longan placed in the top of the plot. The SM plot was designed with four rows of erosion pins, located in the height of the grass strips in the AF plot.

Dien Bien

The erosion pins were measured in all 8 plots in Dien Bien. AF plots had 8 rows of 4 pins, 32 pins and two sections in total, while SC plots had 3 rows of 4 pins, 12 pins in total. The rows were placed in the plots according to Figure 10.

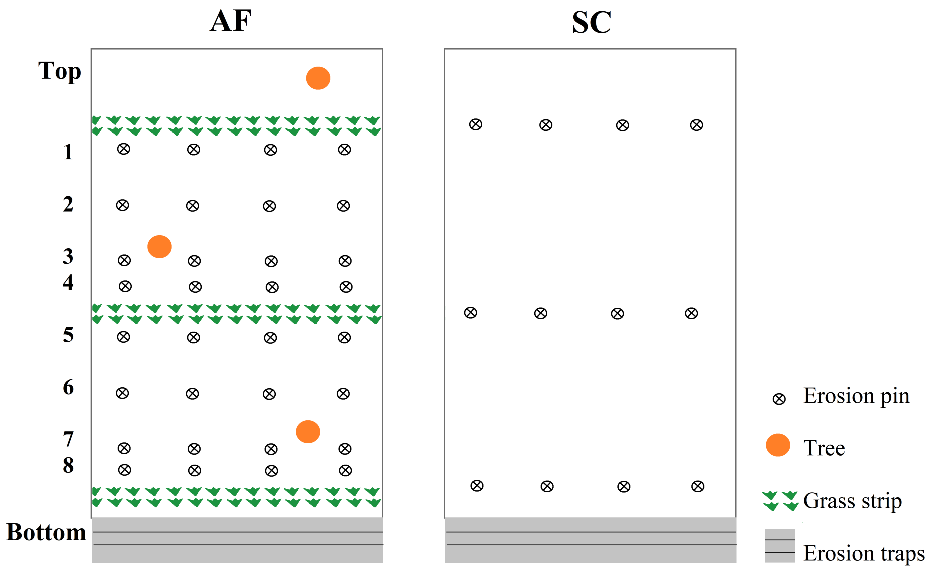

Figure 10. Illustration of the plot design in the Dien Bien trial. The AF plot was designed with three rows of grass strips and eight rows of erosion pins, with four pins in each row. There were also three Son tra trees, one above each grass strip. The SC plot was designed with three rows of erosion pins, located in the height of the grass strips in the AF plots.

3.3.4 Soil loss in Experimental Trials

Soil loss in the Experimental Trials was estimated in both sites by two field methods, erosion traps and erosion pins. Erosion traps gave directly the mass of lost soil, while the measurements of erosion pins had to be converted from a height to a mass.

Soil Loss Determined by Erosion Trap

At the bottom of each experimental plot there was an erosion trap (Figure 11). The erosion traps were formed as pits with the same width as the experimental plots. They were covered with a permeable fabric with the aim to allow infiltration and at the same time prevent soil from outside the experimental plot to enter the trap. The purpose of the erosion trap was to collect eroded soil from the plot. The eroded soil was quantified during the months when the rain was most frequent. The measurements were done when there was a sufficient amount of soil collected in the trap, which occurred 2-3 times per year. After measuring the mass of the total amount eroded soil (m_{tot}) one sample was taken out and weighted (m_{fresh}). The soil sample was then air-dried in 25 degrees and weighed again (m_{dry}). Equations 2 and 3 were used to calculate the total amount of dried soil (m_{totdry}) in each plot.

$$frac_{water} = \frac{m_{dry}}{m_{fresh}} \quad \text{(Eq. 2)}$$

$$m_{totdry} = frac_{water} \cdot m_{tot} \quad \text{(Eq. 3)}$$

m_{dry}	=	Mass of dry sample
$frac_{water}$	=	Fraction water
m_{fresh}	=	Mass of fresh sample
m_{tot}	=	Total fresh mass
m_{totdry}	=	Total dry mass

Figure 11. Photo of an erosion trap. The erosion trap in the photo is located in a AF plot.

Soil Loss Estimated using Erosion Pins

Soil loss was also estimated with data from the erosion pin measurements. The strategy was to calculate the volume of lost or accumulated soil and convert it to a mass by using the bulk density [g cm^{-3}] obtained from the analysis of soil profile samples. The volume segments for each pin were first calculated. The volume for one pin (V_{pin}) was defined as the difference in pin height (Δh_{pin}) (from the start of the experiment to sampling time) multiplied by a calculated area for that pin (Eq 4). For some erosion pins, height observations were missing due to loose, skew or missing pins most likely caused by human activity in the plots. In those cases, the average height of the other pins on the same row were assigned as a value for the missing pin.

In the AF system, an area was defined for each pin position because they were not evenly distributed in the plot. The area for one position was defined as 1 m wide because the total width of one plot was 4 m and there were 4 pins in one row. The length of the pin area was initially defined as the sum of half the distance to the upper laying pin and half the distance to the pin located below. Weighted values of the area for each pin position were then obtained (Table 2). Note that the length equals the area since the width was 1 m.

When using this strategy, the pin with position 'upper above' obtained an unrealistically large area. Therefore, the area for the position 'upper above' was redefined. Photos of the experimental plots and observations in field were used to identify the point where soil had started to accumulate and the slope decreased compared to the ground above. The area considered for soil accumulation or depletion around the pin located in the upper part of the plot ('upper above') was estimated to begin 1.25 m above the pin. Due to this redefinition, the area for the position 'middle' became larger than the initial definition. In the control treatments (SM and SC) the pin area was defined as the total plot area divided by the number of pins. This could be done since the pins were evenly distributed across the control plots. The defined areas after the correction can be seen in Table 2.

When the areas for pin positions were defined the total volume lost or accumulated soil could be calculated (Eq 4-5) and the result could be converted to a mass (Eq 6). The bulk density of the A-horizon was used in the calculation.

$$V_{pin} = \Delta h_{pin} \cdot A_{pin} \quad \text{(Eq. 4)}$$

$$V_{plot} = \sum_{n=1}^{x} V_{pin} \quad \text{(Eq. 5)}$$

$$m_{plot} = V_{plot} \cdot BD \quad \text{(Eq. 6)}$$

Δh_{pin}	=	Original pin height - measured pin height [m]
A_{pin}	=	Area for each pin [m^2]
V_{pin}	=	Volume lost or added soil for each pin [m^3]
x	=	Number of pins in the plot
V_{plot}	=	Total volume lost or added soil in plot [m^3]
m_{plot}	=	Total mass lost or added soil in plot [kg]
BD	=	Bulk density of the A-horizon in the study site [g cm^3]

Table 2. Defined areas for different pin positions in AF, SM and SC treatments. The areas were used in the method for calculating total mass lost or accumulated soil using erosion pin measurements.

Treatment	**Pin position**	**Area (per pin)** [m^2]
AF	Below	2.85
	Middle	5.40
	Upper above	1.40
	Above	0.35
SM	All positions	7.5
SC	All positions	6.7

3.3.5 Evaluate Terrace Formation in Exemplar Landscape

To evaluate the terrace formation in the Exemplar Landscape six of the farmers' plots were analyzed, three with AF and three controls with sole maize (SM). The three AF systems were chosen to represent the AF practices in the Exemplar Landscape. Factors that were required when choosing the AF plots were, tillage using by buffalo, a slope gradient that was representative for the area, double rows of grass strips, 10 m distance between grass strips and that the farmers were willing to collaborate. The three control plots (SM) were chosen if the tillage management was done by buffalo and the farmers were willing to collaborate.

Homogeneous areas containing 3-4 grass strips were chosen within the AF treatment in the farmers' fields, called a "farmers plot". Every grass strips consisted of double rows of grass, in conjunction to the grass strip the terraces were formed. The area between the grass strips were called sections and the sections from the top to the bottom in the AF plot were called upper (*U*), middle (*M*) and lower (*L*) section (Figure 12). The control plots consisted of sole maize these were also divided into three sections representing the upper, middle and lower part of the plot. The distance between every section was 10 m.

The method that was developed for evaluating the terraces in the Exemplar Landscape included measurements of the slope gradient, a method to estimates the movement of topsoil and a method to estimate the volume of the formed terrace. Measurements of the slope gradient (see section 3.3.2) were carried out in three replicates, with an interval of 10 m in every section both in the AF and control treatment (SM).

To estimate the long-term movement (five years after the establishment) of topsoil, the depth of the A-horizon was measured from an undisturbed soil sample taken with a soil corer. The soil corer was driven down into the soil with a hammer. From the soil sample the depth of the A-horizon could be identified using the color identified in the soil profile dug in the Experimental Trial in Son La (see section 3.3.1). The measurements were carried out in both AF and control (SM) treatments in the farmers' plots selected for this study.

Nine soil samples were taken with the soil corer in every section in the farmers' plots in the AF treatment. Three of the samples were taken with different distance related to the grass strips. The first sample with the soil corer was taken 0.5 m below the upper grass strip (*b*), the second soil sample was taken in the middle of the section (*m*), and the third soil corer sample was taken 0.5 m above the lower grass strip (*a*) (Figure 12). All the three distance were measured in three replicate with an interval of 10 m and an average depth of topsoil for each position related to the grass strip was calculated. In the control plot (SM), the slope gradient measurement and one soil core sample was taken in three replicates with an interval of 10 m in the upper, middle and lower section. An average depth of topsoil for each section was calculated.

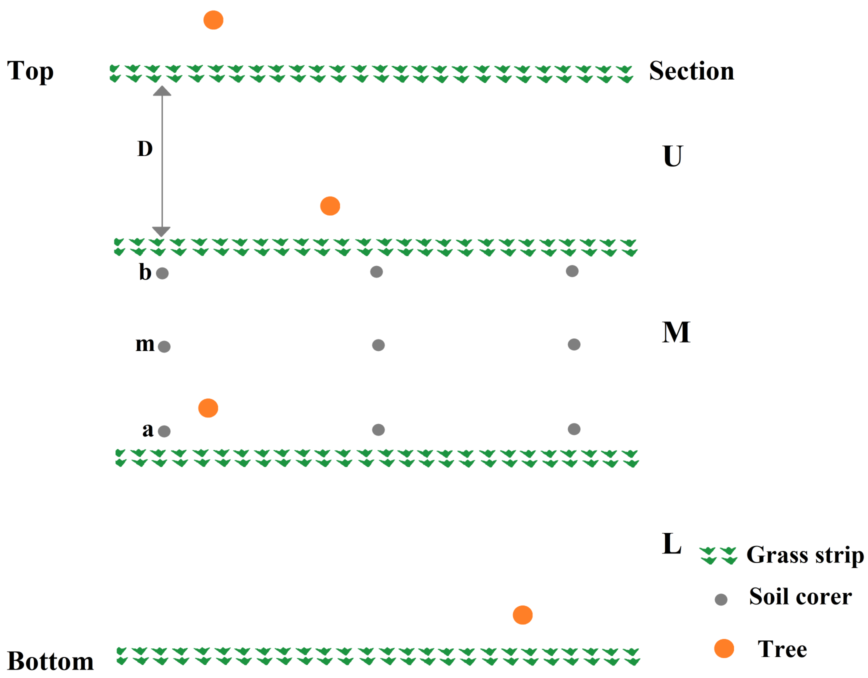

Figure 12. Illustration of the measurement setup in one of the AF plots in the Example Landscape. One AF plot had in total 9 soil corer measurements in every section.

To estimate the volume of the formed terrace in the AF treatment, three distances were measured, the width of the double row of grass (w) and two different heights of the terrace (h_1 and (h_2) (Figure 13). To measure the height of the terrace, a straight object was horizontally placed (water house was used) with a starting point of 0.5 m above the grass strips point (a) (Figure 13). The specific distance was chosen due to the recommendation for this Exemplar Landscape was that the farmers should plant the trees in the AF systems 0.5 m from the first row of grass strip. This position was located in the same place as one of the soil core samples (see (a), in Figure 12). The height from the bottom of the terrace to the horizontal object was measured (h_1). The height from the second grass strip to the same position was also measured (h_2). All the three distance were measured in three replicates with an interval of 10 m.

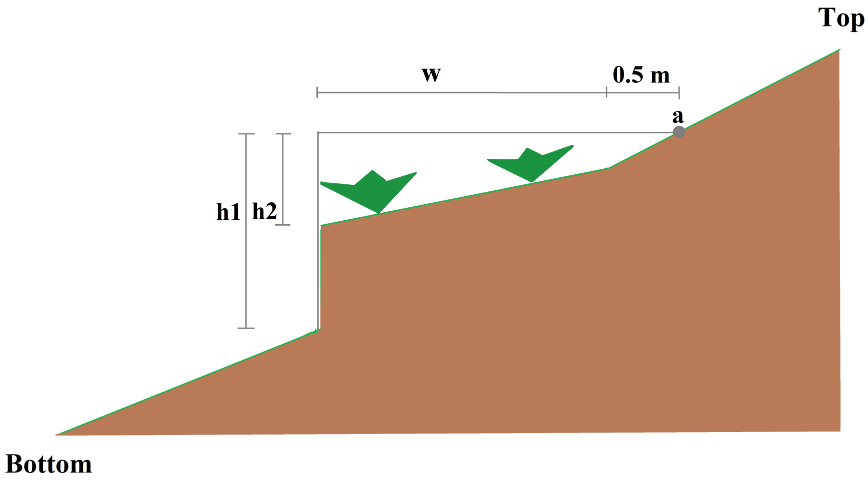

Figure 13. Illustration of the measurement setup to evaluate the terrace volume in the Example Landscape in Son La.

In order to calculate the total soil volume of a terrace, two triangles of 90 degrees, but different height (h_1 and h_2 respectively) were constructed. The slope of the terrace was assumed to be perfectly straight from point a to the bottom of h_2. The volume was calculated per meter terrace. The following equations were used to estimate the total terrace volume (Eq. 7 - 9). An average volume of formed terrace was calculated for each section in the AF treatment.

$$V_1 = \frac{h_1 \cdot (w + 0.5)}{2} \cdot 1 \qquad \text{(Eq. 7)}$$

$$V_2 = \frac{h_2 \cdot (w + 0.5)}{2} \cdot 1 \qquad \text{(Eq. 8)}$$

$$V_{tot} = V_1 - V_2 \qquad \text{(Eq. 9)}$$

h_1 = Height from the bottom of the terrace to the horizontal object.
h_2 = Height from the second grass strip to the horizontal object.
V_1 = Volume of soil.
V_2 = Volume of no soil.
V_{tot} = Total volume terrace.
w = Width of the double row of grass strip.

3.4 STATISTICAL ANALYSIS

The statistical software JMP© was used (JMP, 2199) for the statistical analysis. Statistical analysis, described in this section, was carried out for the data of soil movement along the hillside in both the Experimental Trial and the Exemplar Landscape. Statistical analysis was also carried out for the data of soil loss determined from erosion traps and estimated from erosion pins. Also, the data for estimating terrace volume in the Exemplar Landscape was analyzed statistically.

First, the distribution of all data sets were analyzed and if the data followed a normal distribution, an analysis of variance (ANOVA) was carried out. When doing the ANOVA, the p-value from the effect test was firstly noted. The confidence interval was chosen to 95%, thus if the p-value was less than 0.05 there was a significant difference among the studied variable.

The data from the Experimental Trial in Son La had a nonsymmetrical block design, since block 2 in the field consisted of three plots instead of two. Plot number 5 was located further away from the other two plots in the same block (Figure 5). To create a symmetrical block design of four blocks of two, it was investigated if block 5 could be removed without any negative effects due to loss of observations. This was carried out by two equal one-way ANOVAs, one including plot 5 and the other excluding plot 5. If both ANOVAs showed similar results it was considered that the loss of observations had little impact.

3.4.1 Movement of Soil

The same statistical analysis was carried out for the data of movement of soil in both the Experimental Trials and the Exemplar Landscape.

First an one-way ANOVA was carried out for both data sets. For the Experimental Trial, the average value calculated for each row was analyzed according to position to grass/position in plot by treatment and site and for randomized block design. For the Exemplar Landscape, the average value calculated for each row was analyzed according to position to grass/position along the hillside in a farmer's plot by treatment.

Also, a two-way ANOVA was carried out for both the Experimental Trial and the Exemplar Landscape to analyse the interaction between the position to grass and the sections. This was carried out by the same set-up as the one-way ANOVA but by adding a cross between the parameters position to grass and section.

3.4.2 Soil Loss

The data of soil loss was analyzed by an one-way ANOVA. The soil loss for each plot was analyzed by treatment and for randomized block design. If there was a difference of soil loss between the two treatments ($p<0.05$) Student's test was carried out.

3.4.3 Terraces Volume

The data set of the average volume of the terraces formed in the Exemplar Landscape had not a normal distribution, therefore a logarithmic transformation was carried out. The average volume for each section was analysed by an one-way ANOVA according to position along the hillside in the farmers' plots with AF treatment.

3.5 THE WEPP MODELLING

Modelling a hillslope scenario with WEPP requires four different input files (Dennis et al., 1995) and those are 1) climate, 2) slope, 3) soil characteristics, and 4) plant management data.

The climate required data were minimum and maximum monthly average temperature and monthly average precipitation. To obtain a more accurate model, one can also use local data of rain intensity (for each rain event), wind velocity and wind direction. When the scenario of interest is located outside the U.S the climate file must be produced manually or must be modified from the already existing U.S weather data files (Dennis et al., 1995, Elliot, 2015). The method applied in this study was to modify U.S weather data in the WEPP online application (Elliot, 2015).

3.5.1 Modelling Process

A model was designed in WEPP with the aim to estimate annual soil loss for a sole maize (SM) plot in Son La. The modelling strategy was to create a model of an average SM plot in the Experimental Trial. The starting point was defined to January 2018, and two simulations were carried out, for 1 and 10 years respectively. The required modelling parameters were obtained as described below.

The climate file was constructed by modifying an existing U.S climate station (Florida Avon Park) in the WEPP online application (FSWEPP interfaces). Climate data from a weather station (code 48806) located in Son La (N 21°20', E 103°54') (elevation: 675 m) were used to calculate the required climate parameters. The data included daily values for temperature and precipitation for a period of 30 years (1989-2018). Calculated monthly mean maximum and mean minimum temperatures (C), mean precipitation (mm) and number of wet days are presented in Figure 14. . Monthly data for all the 30 years are presented in Appendix D

Climate parameters for Son La station +

27.60°N 81.50°W; 675 m elevation
62 years of record

Month	Mean Maximum Temperature (°C)	Mean Minimum Temperature (°C)	Mean Precipitation (mm)	Number of wet days
January	17.7	11.7	31.00	8.1
February	21.0	11.0	28.07	11.1
March	23.3	16.4	60.96	15.0
April	25.3	21.6	103.08	13.1
May	27.5	23.4	196.85	14.1
June	26.5	24.3	228.60	15.0
July	26.1	24.3	282.24	16.1
August	25.9	24.0	248.17	17.1
September	25.2	22.4	131.04	13.9
October	24.1	19.7	49.87	8.9
November	21.3	16.7	31.35	6.9
December	17.6	12.7	24.00	5.9
Annual			1415.23	145.2

Figure 14. Climate parameters calculated from data of a 30-year period (1989 - 2018) from a local weather station in Son La (code 48806, N 21°20', E 103°54').

The gradient of the slope was determined from measurements in the field (section 3.3.2). A slope of 32% was used as the gradient in WEPP.

The required soil parameters (depth of soil layer, and for each soil layer percent of sand, clay, organic matter and rock, as well as CEC) were obtained from the soil profile in Son La. The depth of each soil layer was determined in field. The remaining parameters were obtained from analyzes of soil samples taken in each soil horizon in the soil profile (section 3.3.1). WEPP only includes sand and clay for texture parameters and defines the amount of sand as 100-%CLAY. Thus, amount of sand was calculated by the amount of presented clay (Table 3). Soil albedo, could be calculated from the amount of organic carbon (Table 3) and were set to 0.29. The parameters interrill erodability (erodability between rills), rill erodability, critical shear and effective hydraulic conductivity was set to "have model calculate".

Table 3. Parameters as defined in the soil file in WEPP based on data from the soil profile in Son La.

Horizon	**Depth** [mm]	**Clay** [%]	**Sand** [%]	**Org. C** [%]	**Rock** [%]	**CEC** [me/100g]
A	170	36.9	64.1	1.8	9.5	15.2
B1	190	32.3	67.7	1.0	2.1	11.4
B2	200	30.7	69.3	0.8	6.5	15.8

The plant, management and operation parameters were estimated by interviews with local researchers that were familiar with the study site [6]. One parameter, the root depth of maize, was measured in field. This was done by digging a soil pit (30x30x50 cm) in front of a maize plant and then observing how deep from the soil surface that the roots could be distinguished. This was replicated three times for different elevations and slope gradients of the trial area. The average root depth was calculated to 43 cm and used as the root depth parameter for WEPP. Lastly, the date for every operation was set to;

Initial conditions:	1st of January 2018
Tillage:	1st of January
Plant:	1st of April
Harvest:	1st of September

[6]Information obtained by interviews with Thach Nguyen Van (local fieldworker and researcher of ICRAF): Son La, 2019.

4 RESULTS

In this section, the results that describe the study sites are presented, both soil characteristics and slope gradients, along with results from the Experimental Trials and the Exemplar Landscape.

4.1 SOIL CHARACTERISTICS

The soil profile in Son La had one A-horizon and two B-horizons, while the soil profile in Dien Bien had one additional B-horizon. Both sites had diffuse transitions between the B and the unaffected C horizons which were therefore defined as BC horizons (Tables 4-5 and Figures 15-16). The Son La soil had mainly a yellowish matrix color, while the Dien Bien soil had a larger depth of a more distinct brown matrix color. Both soil profiles had mottles and their abundance increased in the BC horizons. The mottles were distinct in the Dien Bien soil because their lighter color. Rock fragments were not observed in any of the soil profiles.

Table 4. Soil profile description for the Son La study site.

Horizon	**Description**
A, 0-17 cm	Light yellowish brown (10 YR 6/4), few red (2.5 YR 4/6) and reddish yellow (7.5 YR 7/8) mottles, no rock fragments; light clay; plastic; common very fine roots; clear broken boundary.
B1, 17-36 cm	Yellowish red (5 YR 4/6), very few red (2.5 YR 4/6) and yellowish (5 YR 5/8) mottles, no rock fragments; heavy clay; very plastic; few very fine roots; clear wavy boundary.
B2, 36-56 cm	Yellowish red (5 YR 4/6), very few yellowish red (5 YR 4/6) and yellow (10 YR 7/8) mottles, no rock fragments; heavy clay; very plastic; very few very fine roots; diffuse wavy boundary.
BC, 56- cm	Yellowish red (5 YR 5/8), abundant mottled with 90% light red (2.5 YR 6/6) and 10% brownish yellow (10 YR 6/8) aggregates, no rock fragments; light clay; plastic; no cracks, no roots; no boundary observed.

Figure 15. The soil profile in the Son La Experimental Trial.

Table 5. Soil profile description for the Dien Bien study site.

Horizon	Description
A, 0-23 cm	Brown (7.5 YR 4/3), very few fine light bluish grey (grey 2-7/5 PB) mottles, no rock fragments; clay loam; slightly plastic; common fine roots; clear wavy boundary.
B1, 23-44 cm	Brown (7.5 YR 5/4), no mottles, no rock fragments, light clay; plastic; few very fine roots; clear wavy boundary.
B2, 44-63 cm	Yellowish red (5 YR 5/6), very few medium pale yellow (5Y 8/4) mottles, no rock fragments; light clay; plastic, few very fine roots; diffuse wavy boundary.
B3, 63-96 cm	Yellowish red (5 YR 5/8), few medium very pale brown (10 YR 7/3) mottles, no rock fragments, light clay; plastic; very few fine roots; diffuse wavy boundary.
BC, 96- cm	Yellowish red (5 YR 5/8), abundant coarse mottles with 60% light greenish grey (grey 1-8/10Y) and 40% reddish brown (2.5 YR 4/4); no rock fragments; light clay; plastic; very few fine roots; no boundary observed.

Figure 16. The soil profile in the Dien Bien Experimental Trial.

The texture of both profiles were light loams in the topsoil, but the clay content increased in the B horizons and especially in Son La (Tables 6-7). The soils were also rather acidic, with lowest pH values in the Dien Bien soil. One difference between the two sites was that Son La soil profile had a higher content of clay (<0.002 mm) in all horizons compared to Dien Bien (Table 6). The Son La profile was also slightly stony, while the Dien Bien soil had no stones. Both the bulk density and the CEC were higher in the Son La soil than in Dien Bien. The nutrient concentrations were not remarkably different between the two sites.

Table 6. Soil texture, stone content (SC) and bulk density (BD) for each horizon in soil profiles from both study sites.

Site	**Horizon**	**Depth**	**Texture (%)**				**SC**	**BD**
		[cm]	2-0.2 mm	0.2-0.02 mm	0.02-0.002 mm	<0.002 mm	%	[g cm^{-3}]
Son La	A	0-17	6.66	35.94	39.54	17.86	9.51	1.37
	B1	17-36	4.33	32.33	27.72	35.62	2.09	1.35
	B2	36-56	5.20	30.68	21.50	42.62	6.48	1.32
	BC	56-	24.13	35.91	14.70	25.26	8.89	1.56
Dien Bien	A	0-23	3.73	40.21	39.12	16.94	0	1.15
	B1	23-44	3.23	38.97	33.60	24.20	0	1.27
	B2	44-63	2.84	32.70	36.42	28.04	0	1.16
	B3	63-96	2.93	34.41	32.24	30.42	0	1.21
	BC	96-	4.54	34.66	39.16	21.64	0	1.26

Table 7. Amount organic carbon (org. C), nitrogen (N), phosphorus (P), potassium (K), pH in water (pH(H_2O)) and cation capacity (CEC).

Site	Horizon	Depth	Total content of				pH	CEC
			org. C	N	P	K	(H_2O)	
		[cm]	[%]	[%]	[%]	[%]		[me/100g]
Son La	A	0-17	1.78	0.15	0.08	0.37	5.46	15.2
	B1	17-36	0.97	0.13	0.05	0.35	5.01	11.4
	B2	36-56	0.81	0.14	0.06	0.41	4.88	15.8
	BC	56-	0.38	0.09	0.04	0.35	5.10	11.0
Dien Bien	A	0-23	2.21	0.16	0.09	0.76	3.97	11.8
	B1	23-44	2.02	0.14	0.07	0.77	4.02	9.4
	B2	44-63	1.17	0.09	0.06	0.83	4.10	9.4
	B3	63-96	0.79	0.07	0.05	1.00	4.70	9.6
	BC	96-	0.50	0.05	0.05	0.97	4.00	10.0

4.2 SLOPE GRADIENT

It is clear that the total average slope gradient of all experimental plots in Dien Bien were steeper than the plots in Son La (see Table 8). The average slope gradient also differed between the plots within one study site. In the Exemplar Landscape in Son La, the total average gradient for both treatments is quite similar to each other (see Table 9).

Table 8. Table of average gradients [°] and standard errors [°] for each plot in the Experimental Trial at both sites.

Site	Plot	Block	Treatment	Average gradient [°]	Std. error [°]
Son La	1	1	AF	15	± 3
	2	1	SM	20	± 1
	3	2	AF	22	± 1
	4	2	SM	22	± 2
	5	2	AF	23	± 3
	6	3	SM	26	± 3
	7	3	AF	22	± 1
	8	4	AF	21	± 1
	9	4	SM	19	± 1
Tot. average				21	± 3
Dien Bien	1	1	SC	29	± 2
	2	1	AF	32	± 2
	3	2	SC	27	± 2
	4	2	AF	24	± 2
	5	3	SC	25	± 1
	6	3	AF	31	± 0
	7	4	AF	32	± 1
	8	4	SC	34	± 3
Tot. average				29	± 4

Table 9. Total average gradient of all AF and SM (control) farmer plots included in the study in the Exemplar Landscape in Son La.

Treatment n=30 (AF) / n=27 (SM)	**Average gradient** [°]	**Std. error** [°]
AF	24	± 3
SM (control)	21	± 3

4.3 MOVEMENT OF SOIL ALONG THE HILLSIDE IN THE EXPERIMENTAL TRIALS

Evaluated erosion pin measurements from the experimental plots (section 3.3.3) provided an overview of the movement of eroded soil along the hillside (Figures 17-20 and in appendix Tables A.1-A.4). In general, the results showed an accumulation of eroded soil in the two positions above the the grass strips, in both study sites. The accumulation increased the second year after the establishment (2017-2019). For both study sites and both periods (2017-2018 and 2017-2019), there were no difference of added or lost soil among the sections within the AF plots ($p>0.05$). Also, for both study sites and both periods, the two-way ANOVA showed that there were no significant interaction between the variable 'position to grass' and the sections in the AF plots ($p>0.05$).

In the AF plots in Son La, there was already one year after the establishment (2017-2018) a difference between the soil accumulation or loss in different positions to the grass strips (Figure 17). In the control plots, there were no difference of added or lost soil between the positions ($p>0.05$).

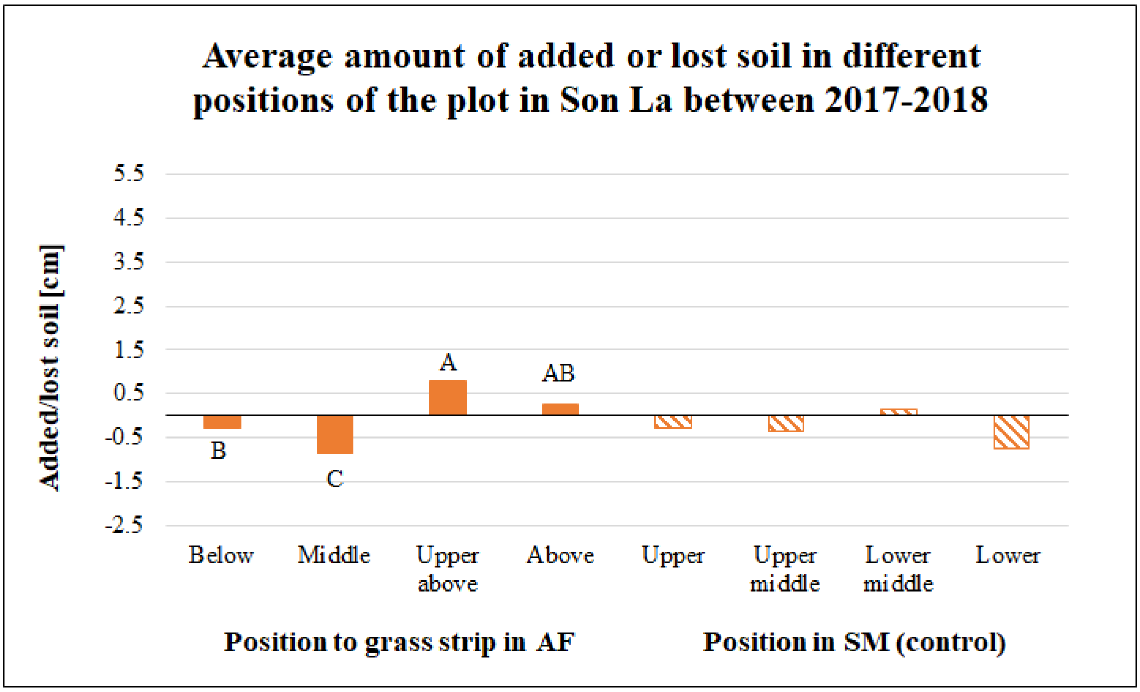

Figure 17. Graph illustrating added (positive value) or lost soil (negative value) in different positions of the plots in Son La Experimental Trial between the years 2017-2018. In AF plots (filled bars) the positions are located below the grass strip, in the middle of two grass strips, upper above and above the grass strip. In the SM plots (striped bars) the positions are located in the upper, upper middle, lower middle and lower part of the plot. The letter system shows which positions that are significantly different from each other. If two bars do not share the same letter, there is a significant difference ($p<0.05$).

The results from Son La AF system of the period 2017-2019 (Figure 18) showed a more distinct pattern of soil accumulation above the grass strips (both in ’upper above’ and ’above’) in comparison to the results from the first year of the experiment (Figure 17). The positions ’below’ and in the ’middle’ of two grass strips had average soil accumulation or loss around zero. The pattern of soil accumulation or loss in ’upper above’ and ’above’ the grass strips were significantly different compared to the positions ’below’ and in the ’middle’ of two grass strips. In the control plots, the average added or lost soil did not differ between the four positions ($p>0.05$).

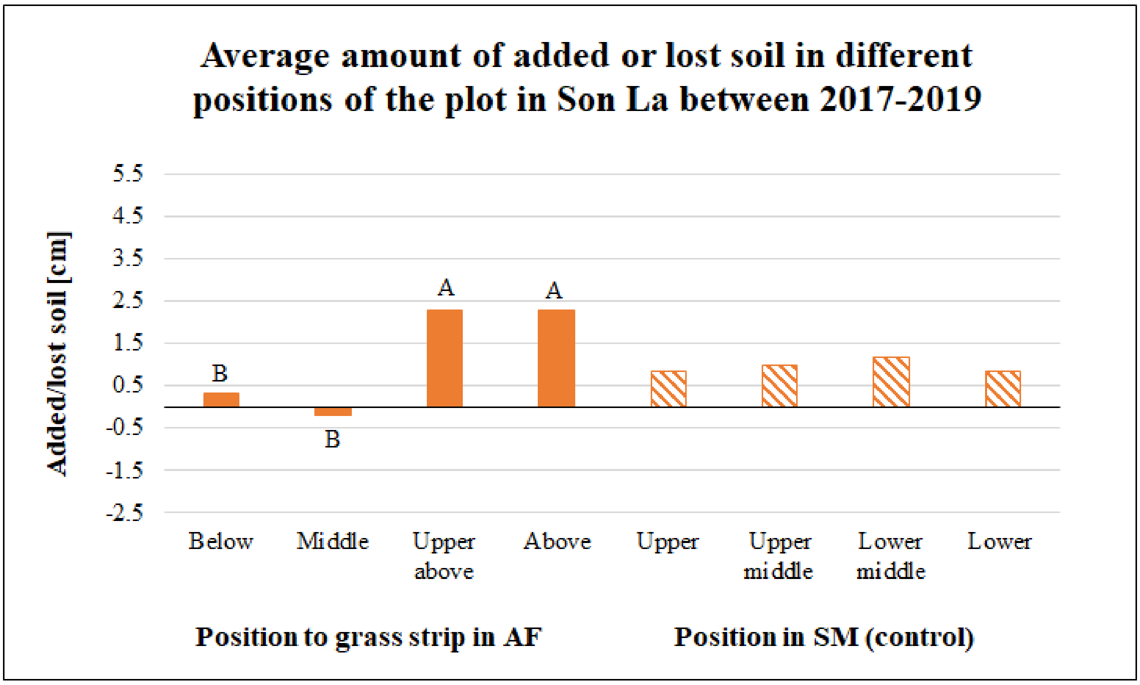

Figure 18. Graph illustrating added (positive value) or lost soil (negative value) in different positions of the plots in Son La Experimental Trial between the years 2017-2019. In AF plots (filled bars) the positions are located below the grass strip, in the middle of two grass strips, upper above and above the grass strips. In the SM plots (striped bars) the positions are located in the upper, upper middle, lower middle and lower part of the plot. The lettering system shows which positions that are significantly different from each other. If two bars do not share the same letter, there is a significant difference.

One year after the start of the experiment in Dien Bien (Figure 19), there was a soil accumulation in all positions, both in the AF system and in the control (SC). However, there was a significantly larger accumulation above the grass strips (both in 'upper above' and 'above') than 'below' and in the 'middle' of the grass strips. In the control plots, the average added or lost soil did not differ between the three positions ($p>0.05$).

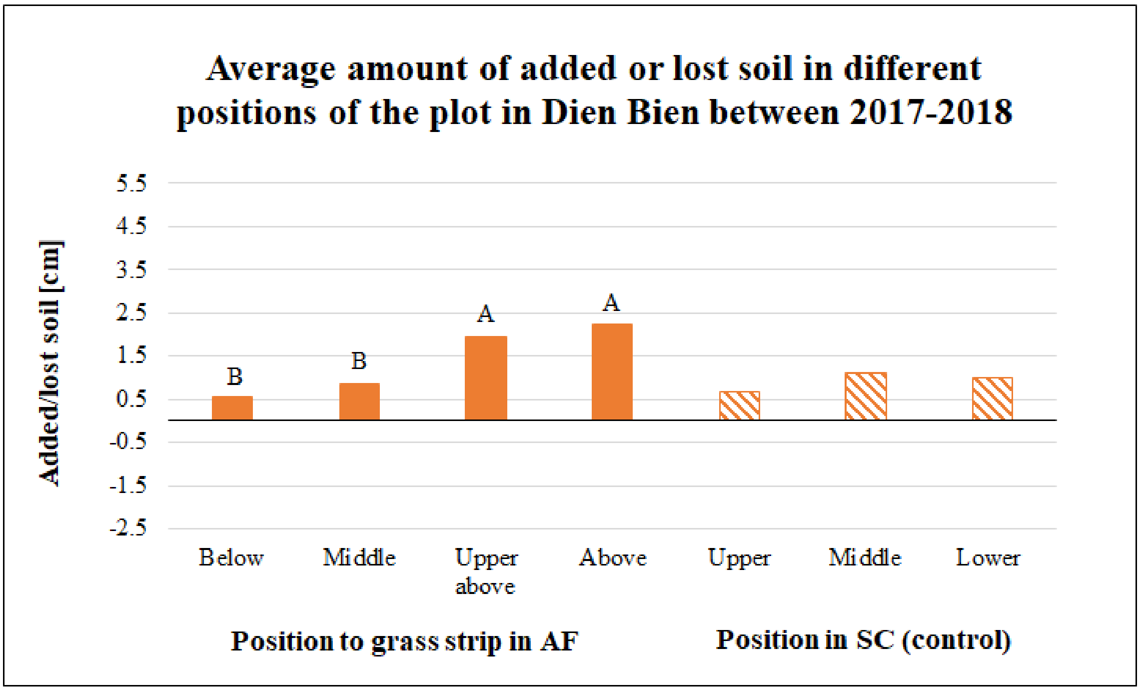

Figure 19. Graph illustrating added (positive value) or lost soil (negative value) in different positions of the plots in the Dien Bien Trial between the years 2017-2018. In the AF plots (filled bars) the positions are located below the grass strip, in the middle of two grass strips, upper above and above the grass strip. In the SC plots (striped bars) the positions are located in the upper, middle and lower part of the plot. The letter system shows which positions that are significantly different from each other. If two bars do not share the same letter, they are significantly different from each other.

Likewise the Son La site, the soil movement along the hillside in Dien Bien was more distinct after two years compared to one year after establishment of the experiment (Figure 20). A large accumulation of soil was observed above the grass strips (both 'upper above' and 'above') in the AF system. The result is significant different from the other two positions where the added/lost soil were around zero. The control plots (SC) showed either an average soil loss around zero or an accumulation, but the average added or lost soil did not differ between the three positions ($p>0.05$).

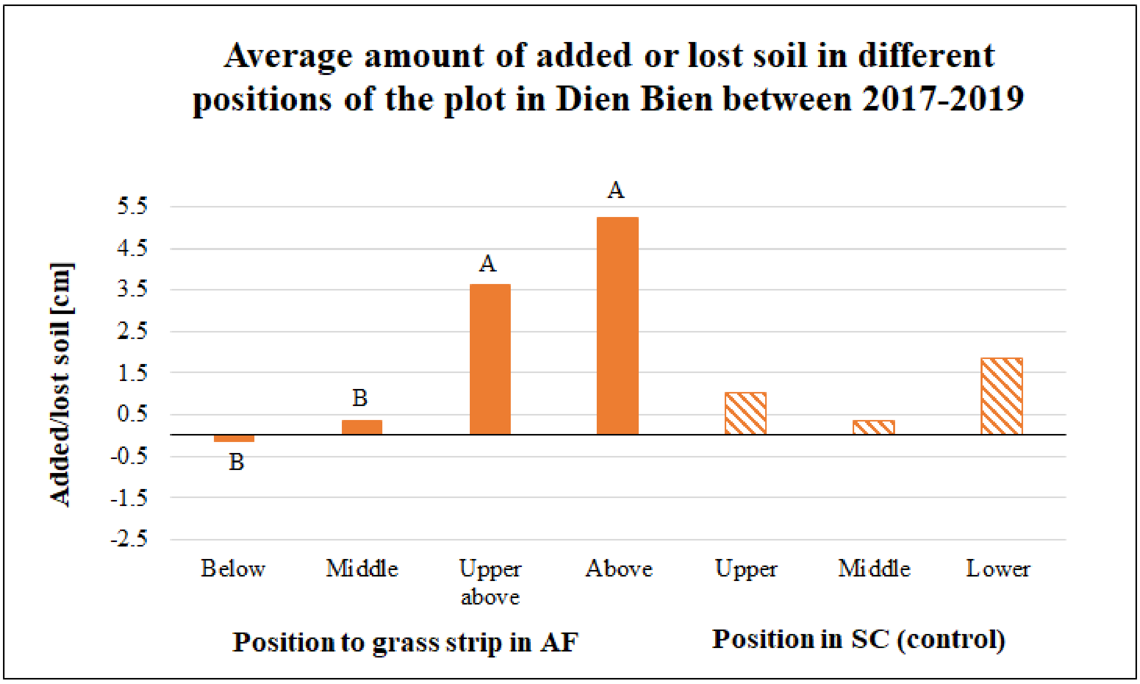

Figure 20. Graph illustrating added (positive value) or lost soil (negative value) in different positions of the plots in the Dien Bien Trial between the years 2017-2019. In the AF plots (filled bars) the positions are located below the grass strip, in the middle of two grass strips, upper above and above the grass strip. In the SC plots (striped bars) the positions are located in the upper, middle and lower part of the plot. The letter system shows which positions that are significantly different from each other. If two bars do not share the same letter, they are significantly different from each other.

4.4 SOIL LOSS IN EXPERIMENTAL TRIALS

Soil loss in the Experimental Trial is presented both determined from the erosion traps and estimated from the measurements of the erosion pins.

4.4.1 Soil Loss from Erosion Trap

The Experimental trial in Son La has data of soil loss collected in erosion traps from 2017, 2018 and 2019 and the Experimental Trial in Dien Bien had soil loss data from 2017 and 2018, see appendix B. It is clear that the annual average soil loss in both treatments in Dien Bien study site were higher than the soil loss in Son La (see Figures 21-22 and Table 10). In Son La, the annual average soil loss in the AF treatment was lower than the control treatment (SM) for all three years. The largest average amount of soil loss from the AF treatment in Son La was collected in 2017 when the trial was established. In 2019, the soil loss in AF treatment had decreased by a factor of ten compared to the average lost soil the year before (2018). In the Dien Bien Experimental trial, the average soil loss was higher for both treatments in 2018 compared to soil loss in 2017. In 2018, the soil loss in the control treatment was higher than the AF treatment. The average soil loss in both sites is not significantly different between the two treatments in any of the years of analyzed soil loss in the erosion traps.

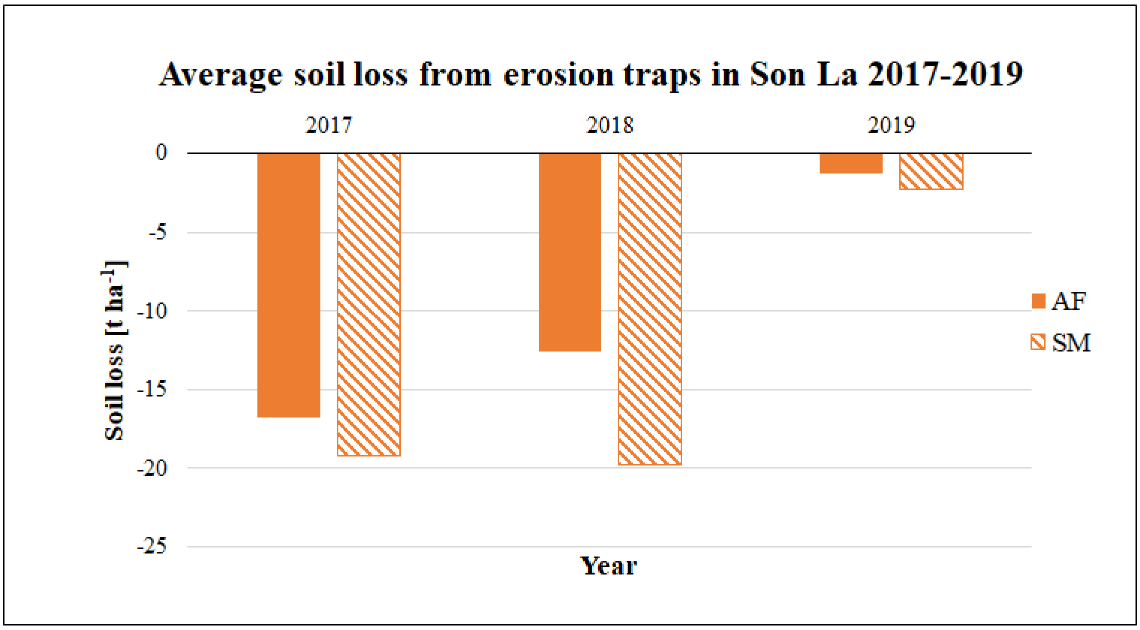

Figure 21. Average soil loss [t ha^{-1}] in AF and SM treatments, determined from erosion traps in the Experimental Trial in Son La study site. The soil loss in AF and SM treatment are not significantly different.

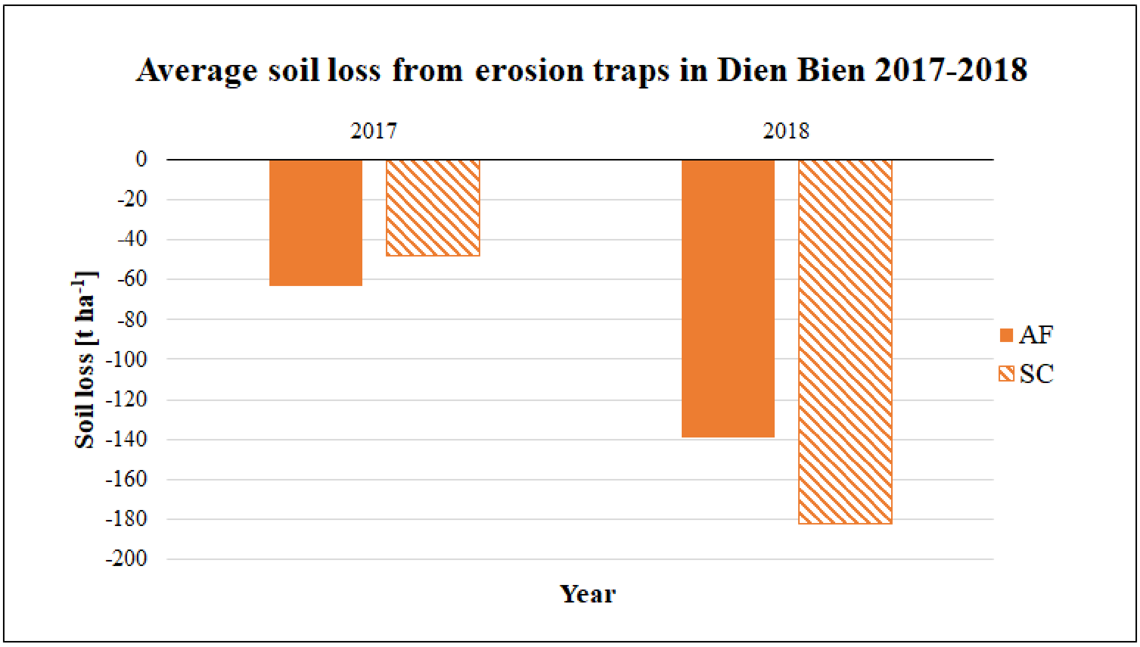

Figure 22. Average soil loss [t ha^{-1}] in AF and SC, determined from erosion traps in the Experimental Trial in Dien Bien study site. The soil loss in AF and SM treatment are not significantly different.

Table 10. Least square mean values and standard errors for yearly average soil loss [t ha^{-1}] in AF and SM/SC treatments, obtained from erosion traps in the Experimental Trial both in Son La and Dien Bien study site.

Site n=8	**Year**	**Treatment** [t ha^{-1}]	**Average soil loss** [t ha^{-1}]	**Std. error**
Son La p-value=0.82	2017	AF SM	-16.8 -19.2	±8.1 ±8.1
Son La p-value=0.08	2018	AF SM	-12.6 -19.8	±4.1 ±4.1
Son La p-value=0.29	2019	AF SM	-1.3 -2.3	±0.7 ±0.7
Dien Bien p-value=0.48	2017	AF SC	-63.2 -48.0	±17.4 ±17.4
Dien Bien p-value=0.47	2018	AF SC	-139.2 -182.2	±32.1 ±32.1

4.4.2 Soil Loss from Erosion Pins

Soil loss estimated from erosion pin measurements showed an actual soil loss only the first year after the establishment of the Experimental Trial in Son La (Figure 23 and table C in appendix). The soil loss was greater in the AF treatment than the control (SM). Two years after the establishment of the Experimental Trial in Son La the estimation instead showed a soil accumulation. The same results of an accumulation were observed in Dien Bien, both one and two years after the establishment of the Experimental Trial (Figure 24). There was no difference between the two treatments for all periods where an soil accumulation was observed instead of a soil loss (Table 11).

Soil losses are presented in periods from the establishment of the trials to one year after (2017-2018) and from the establishment to two years after (2017-2019). These periods were chosen (instead of one-year periods) since the estimation of soil loss is based on the measurements of the erosion pins.

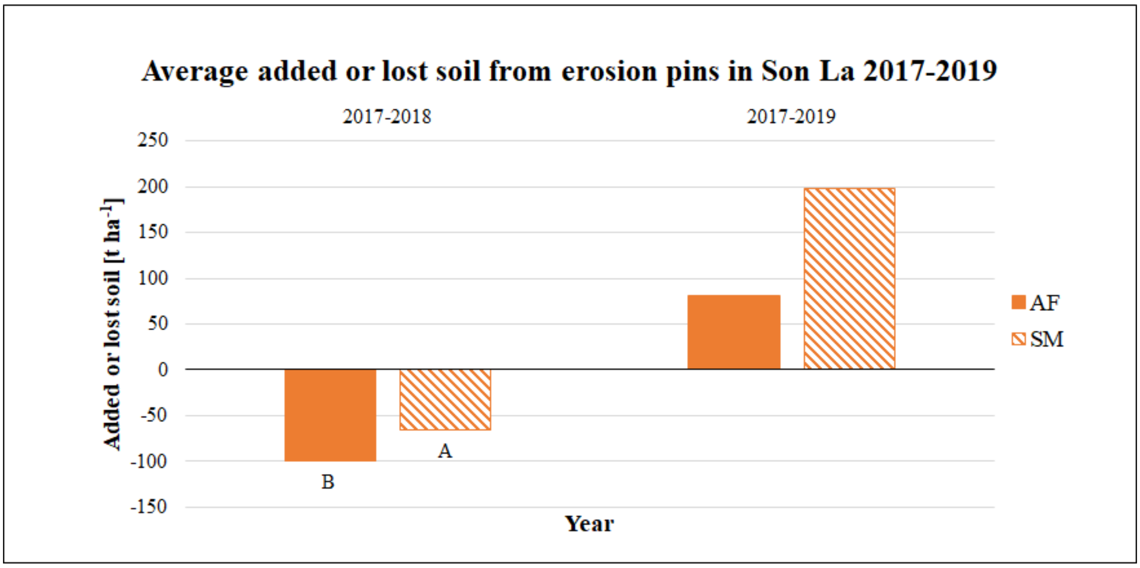

Figure 23. Average added or lost soil [t ha^{-1}] in AF and SM treatments, obtained from erosion pins in the Experimental Trial in Son La study site. The letter system shows which positions that are significantly different from each other. If two bars do not share the same letter, they are significantly different from each other.

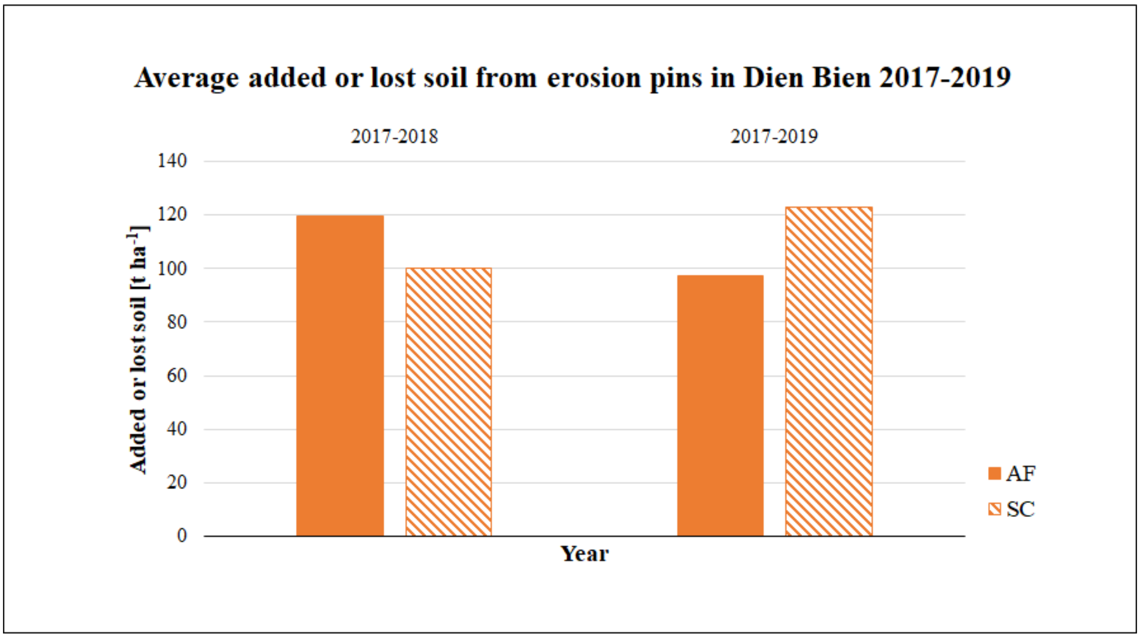

Figure 24. Average added or lost soil [t ha^{-1}] in AF and SC treatments, obtained from erosion pins in the Experimental Trial in Dien Bien study site. The soil loss in AF and SC treatment are not significantly different.

Table 11. Least square mean values and standard errors for yearly average added or lost soil [t ha^{-1}] in AF and SM/SC treatments, obtained from erosion pins in the Experimental Trial both in Son La and Dien Bien study site.

Site n=8	**Year**	**Treatment** [t ha^{-1}]	**Average soil loss** [t ha^{-1}]	**Std. error**
Son La	2017-2018	AF	-99.6	±24.8
p-value=0.03		SM	-66.3±24.8	
Son La	2017-2019	AF	+80.6	±52.0
p-value=0.17		SM	+197.4	±52.0
Dien Bien	2017-2018	AF	+119.5	±16.5
p-value=0.36		SM	+100.0	±16.5
Dien Bien	2017-2019	AF	+97.4	±34.8
p-value=0.66		SM	+123.1	±34.8

4.5 EVALUATION TERRACE FORMATION IN EXEMPLAR LANDSCAPE

Results from six farmers' plots (three with AF and three controls with sole maize (SM)) in the Experimental Landscape in Son La are presented in this section. The results include slope gradients, movement of topsoil in the AF and the control (SM) farmers' plots and results of the estimated terrace volume.

4.5.1 Movement of Topsoil

Five years after the establishment of the Exemplar Landscape the depth of topsoil in the AF treatment differed between all three positions, by increased depth towards the grass strips at the bottom of each section (Figure 25 and Table 12). The farmers that were managing the Experimental Landscape used a plowing depth of approximately 0.1 m. Thus, the minimum depth of the A-horizon was around 0.1 m. This must be considered for the position below the grass strip, where the average depth of topsoil was 0.11 m. The plowing depth did not affect the positions 'middle' and 'above'. A clear accumulation of topsoil was observed above the grass strips. In the control treatment, there was no difference between the depth of topsoil along the hillside in a farmer's plot. Also, there was no difference in the depth of topsoil in the three sections in the farmers' plots in the AF treatment. No interaction between the sections and the positions to grass could been observed in the AF treatment.

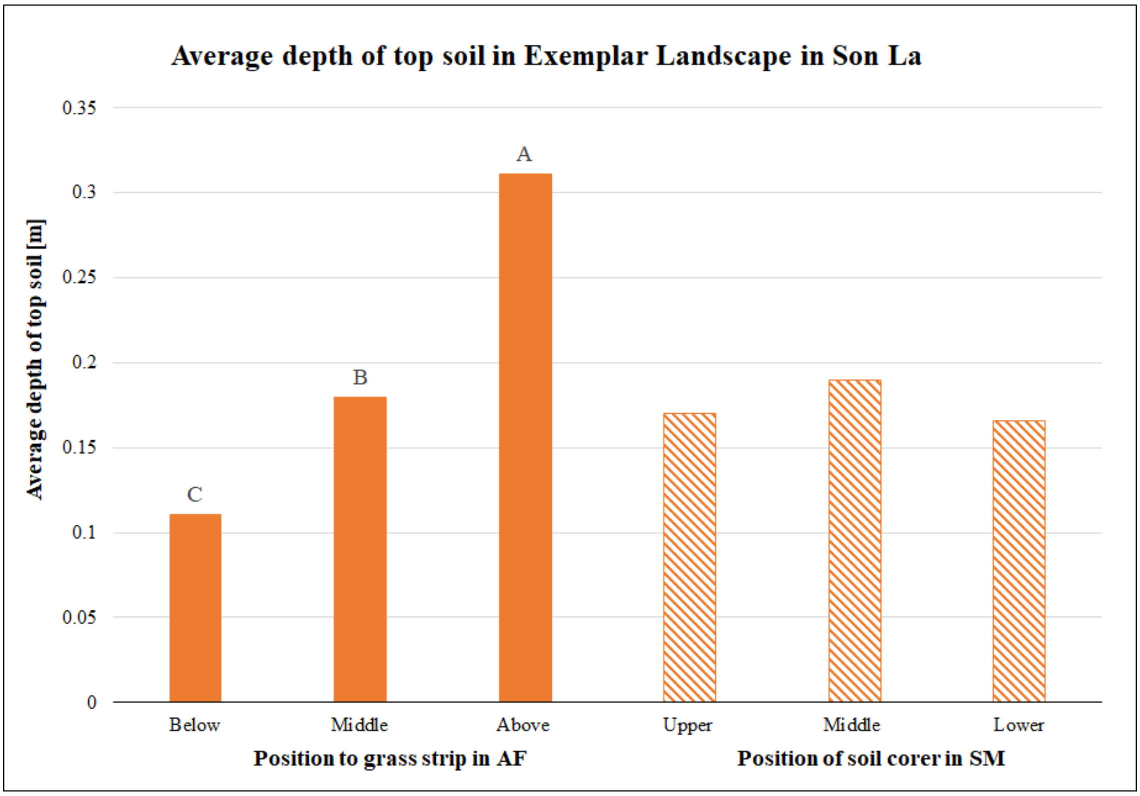

Figure 25. Graph illustrating average depth of topsoil (A-horizon) in the AF plots (filled) and in the control (SM) plots (striped) in the Exemplar Landscape. Positions of the soil corer measurements in the AF system were located, below the grass strip, in middle of two grass strips and above grass strip. Positions of the soil corer samples in the SM plots were located in the upper, middle and lower part of the plots. The letter system shows which positions that are significantly different from each other. If two bars do not share the same letter, they are significantly different from each other.

Table 12. Least square mean values and standard errors for average depth of top soil [m] in each position in AF and SM (control) plots in the Exemplar Landscape. The least Sq. mean values can also be observed in Figure 25.

Position to grass strip in AF p-value$<$ 0.0001 n=90	**Average depth of top soil** [m]	**Std. error** [m]
Below Middle Above	0.11 0.18 0.31	$\pm$ 0.02 $\pm$ 0.02 $\pm$ 0.02
Position in SM (control) p-value=0.85 n=27	**Average depth of top soil** [m]	**Std. error** [m]
Upper Middle Lower	0.17 0.19 0.17	$\pm$ 0.03 $\pm$ 0.03 $\pm$ 0.03

4.5.2 Estimation of Volume of Formed Terraces

The estimated terrace volume along a hillside in the farmers' plots did not differ in the three positions in the AF treatment in the Exemplar Landscape (Figure 26 and Table 13). Since the control treatment (SM) do not form terraces, the two treatments could not be compared.

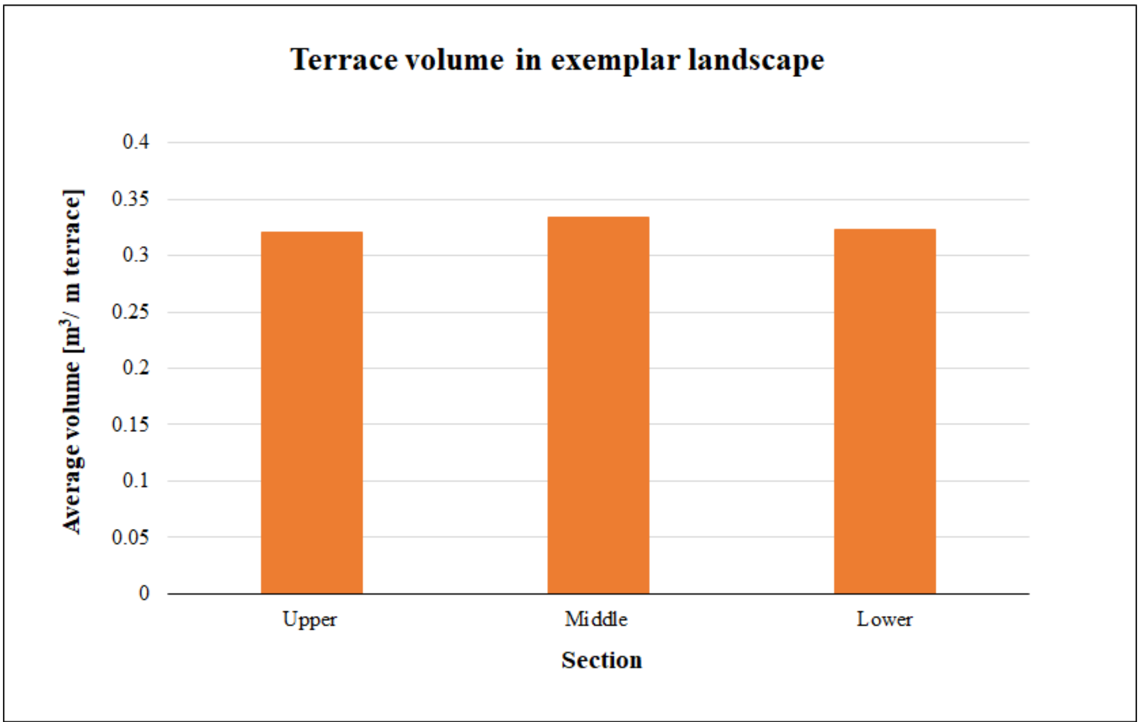

Figure 26. Graph illustrating average volume [m^3/ m terrace] in upper, middle and lower section in the AF plot in the Exemplar Landscape in Son La.

Table 13. Average volume [m^3/ m terrace] in upper, middle and lower section in the AF plot in the Exemplar Landscape in Son La. The least Sq. mean values can be observed in Figure 26.

Position to grass strip in AF p-value = 0.98 n = 9	**Average volume** [m^3/ m terrace]	**Std. error** [m^3/ m terrace]
Upper	0.32	± 0.17
Middle	0.33	± 0.17
Lower	0.32	± 0.17

4.6 SOIL LOSS ESTIMATED BY THE WEPP MODEL

The simulation of 1 year gave an annual soil loss 422 t ha^{-1}, while the simulation of 10 years gave a lower annual soil loss of 317 t ha^{-1} (Figure 27) showing decreasing soil loss over time.

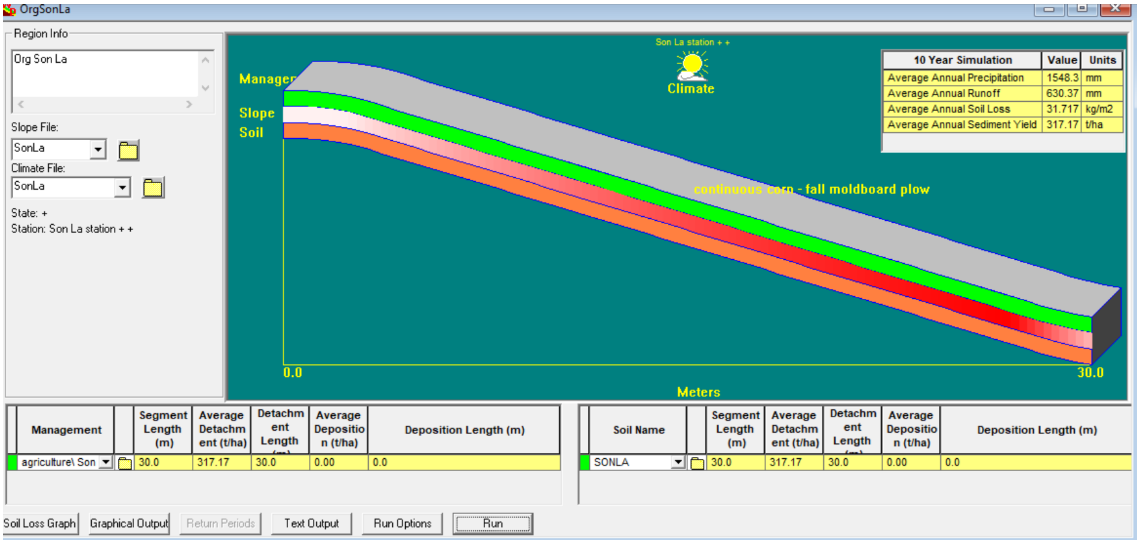

Figure 27. The result screen in WEPP for a simulation of a SM plot in Son La over a period of 10 years. Total soil loss is 317 t ha^{-1}.

The same result from a simulation of 10 years is presented in Figure 28. The red line represent the hillslope surface and the green line represent the detachment of soil in each point along the slope. The y-axis displays the relative elevation and the x-axis the horizontal distance. Note that the y-axis changes units so that the grey area represents the estimated soil accumulation/loss [kg m^2] for each point along the profile. Grey area beneath zero represent detachment, while any grey area above zero instead implies deposition of soil. It is clear that the soil loss increases down the slope. The actual erosion follows the same pattern in both simulations (1 and 10 years), with most erosion occurring in the lower part of the slope, except for the very end of the slope. The model acts as the hill ends after 30 m (as the x-axis was defined) and that might explain why the the soil loss suddenly decreases in the last three meters of the horizontal distance.

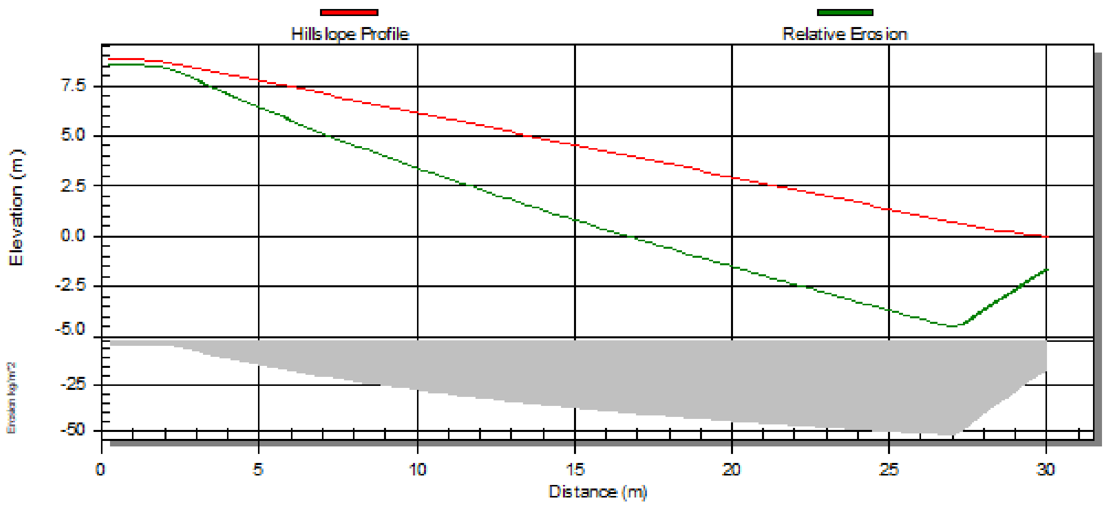

Figure 28. Output graph from WEPP showing the actual slope surface (red), the soil detachment (green) and the actual erosion [kg m^2] (grey area). A 10 year-simulation with the WEPP model gave a total soil loss of 317 t ha^{-1}.

5 DISCUSSION

In this section, the results are discussed in terms of soil characteristics, soil loss and movement of soil along the hillside. Soil loss was mainly determined using erosion traps, and the results are compared to other studies. Erosion pins were used as a method to estimate both the movement of soil along the hillside but also for determining the total amount of lost soil. The results of the two methods are discussed as well as the methods themselves. Finally, the output, difficulties and possibilities of the modelling are discussed.

5.1 SOIL CHARACTERISTICS

Vu Dinh et al. (2014) explains that less organic matter would increase soil erosion risks due to lower aggregate stability and more surface sealing. The results of this study shows the opposite, the Son La site containing less organic matter than Dien Bien (Table 6) but less soil loss. The soil loss is larger in Dien Bien than Son La study site (Figures 21-22 and Table 10). This could though be explained by several other factors. Firstly, by the steeper slopes in Dien Bien. In a similar erosion study to this project, Vu Dinh et al. (2014) found that between their two study sites, which differed only 3 ° in slope gradient, the soil loss was significantly higher in the steeper site. In this study, the difference in slope gradient between the sites was 9°, thus the greater soil loss in Dien Bien compared to Son La could be justified. Secondly, the difference in soil loss can be explained by the lower ground cover in Dien Bien. Two years after the establishment of the experiment the ground cover was observed to be more dense among the maize plants in Son La than among the coffee plants in Dien Bien.

5.2 MOVEMENT OF SOIL ALONG THE HILLSIDE

In this study, grass strips showed ability of causing terracing as expected and consistent with a similar erosion study located in Ethiopia carried out by Shi et al. (2011). Terraces started to form already one year after the establishment (2018), due to soil accumulation above the grass strips (Figures 17-20 in Results), but is even more apparent the following year (2019). In the AF plots in Son La (2017-2019) and Dien Bien (2017-2018 and 2017-2019), the positions 'upper above' and 'above' were significantly different from the other positions concerning added or lost soil. In the control plots at both sites, there are no significant differences (p-values$>$0.05) in added or lost soil along the slope.

The results from the AF farmer plots in the Exemplar Landscape shows the same pattern in movement of lost soil as the results from the Experimental Trial AF plots two years after establishment (Figures 18, 20 and 25). The Exemplar Landscape is not as monitored as closely as the Experimental Trial since it is managed by the local farmers. Despite this, the depth of the top soil in all the positions between the grass strips are significantly different from each other. In the control plots in farmers sole maize, there are no significant difference (p-values$>$0.05) in depth of the top soil, as in the Experimental Trial. One issue with this method is that the plowing can in some cases mix the topsoil with the first B horizon, depending on the depth of the topsoil and the plowing depth at the site. An improvement of the method could be to measure the amount of organic C in the identified topsoil and compare with the analysis from the soil profile carried out in the same site. This improvement could be appropriate as a future study in Son La Experimental Landscape.

Using erosion pins to evaluate sediment deposition along a slope involves numerous uncertainties (Shi et al., 2011, Ghimire et al., 2013), which was also discovered during the fieldwork of this study. Ghimire et al. (2013) mention that the soil around the pin may become loose when it is inserted and cause misleading erosion. In addition, it was likely that pins are disturbed by humans, especially in experiments located in areas with agricultural activities, as was the case at the Son La and Dien Bien study sites.

5.3 SOIL LOSS

5.3.1 Soil Loss from Erosion Trap

Results of this study show that AF in combination with grass strips decrease the average soil loss compared to the control system with solo maize in the Experimental Trails in Son La (Figure 21 and Table 10). Kagabo et al. (2013) found that grass strips alone decreased soil loss by 43% compared to the control system with monoculture of annual crops. Kagabo et al. (2013) was made in moderate to steep sloping lands in Buberuka, Rwanda. Within this study, the soil loss from the soil traps in AF at the Son La site, was found to be 12% less 2017, 37% less 2018 and 43% less 2019 compared to the sole maize system figuring as the control. This implies that grass strips alone perform as well as a combination of grass strips and trees in erosion mitigation, which could speak against investments in AF systems. It should be taken into consideration that benefits from trees increase when they start to bear fruit and berries or reach maturity if they are timber trees, which has not yet occurred within this study. Trees also provides other ecosystem services (Nguyen et al., 2016).

The effect of AF is not obvious from the results of soil loss in Dien Bien (Figure 22 and Table 10). The year when Dien Bien trial was established (2017), the average soil loss in AF plots was greater than in plots with sole coffee. On the other hand, the AF system causes a smaller average lost soil than the control one year after establishment (2018). Furthermore, the average lost soil for AF and SC, in both years are considerably greater than the average soil loss in Son La (Figures 21-22 and Table 10). Data from a longer time series would be required to evaluate AF as compared to sole crop, in particular in Dien Bien where coffee is the main crop taking time to get established.

The average soil loss at the Son La study site was lower two years after the establishment of the trial (2019) in both treatments (Figure 21 and Table 10). The first year after establishment (2018), there was a slight decrease in average soil loss in the AF system, and even an increase of soil loss in the SM system. That the erosion do not decrease directly, but two years after establishment is also a result found in an erosion study with grass barriers by Pansak et al. (2013).

This pattern was not possible to evaluate at the Dien Bien study site since there only data until one year after establishment (2018) was available. Therefore, it was not known if the erosion increases or decrease in 2019, two years after establishment.

Future studies connected to the soil loss could be to establish precipitation measuring instruments at the Experimental Trials. That would make it possible to compare the determined soil loss with the precipitation for certain years. That is not possible within this study, since the climate data is obtained from a weather station which is not located at the Experimental Trial.

5.3.2 Soil Loss from Erosion Pins

Erosion pins were not only used to evaluate the movement of soil along the hillside, but also to determine average lost soil. The result of average lost soil obtained by erosion pin measurements show an accumulation in most of the cases, which is surprising. The numerous sources of errors mentioned could be one explanation of the unexpected result and does not correspond with the erosion of soil shown by the soil traps. It should also be mentioned that using erosion pins to calculate soil loss has not been found to be a common method according to the literature. Results from this study indicate that erosion pins were not an accurate method for determining soil loss but it gives interesting information about the soil movement within a slope.

5.4 METHOD TO EVALUATE TERRACE FORMATION

In section 3.3.5 we described a method to evaluate naturally formed terrace over a longer time scale. The method is not commonly known and not taken from the literature. Instead, it was developed within this project. It was designed for the conditions in Son La, but the methodology is general and can be applied to other locations. The distance from the first row of grass strip to the point where the measurements for the terrace volume started was in this project fixed to 0.5 m. In that point soil corer samples were also taken. This distance is based on recommendations for the farmers when planting the trees. The distance between the grass strip and the tree can vary in other location and therefor the parameter a must be adapted to the recommendations for that specific site.

5.5 MODELLING SOIL LOSS

Modelling can require a lot of work in order to be accurate, in particular when the model is applied in a different environmental setting from where it was developed (and the default values originates from). The main source of uncertainties in the model originates from the parameters used as input data in WEPP. Only the parameters of soil characteristics were analyzed properly in laboratory, from soil samples taken in field. The plant and management parameters were estimated based on the already existing default values for the same crop (maize) and an interview with local researchers. The model would be more accurate if even the plant and management parameters were measured and/or analyzed. The climate file was constructed by modifying an already existing US climate station with local weather data. Although the parameters of rain intensity, wind velocity and wind direction could not be obtained from the local weather data and were instead set to default according to the modified U.S weather station. This contributes to uncertainties in the model outcome, especially since rainfall is one of the main factors for causing soil erosion. To improve the study an climate station could be installed at the study site to measure rainfall and rain intensity at the location of the field experiment. The time for different tillage operations over the year depends on several factors, for example the weather conditions and the farmers' working plan. This is a challenge when constructing a general model especially in combination with a changing climate since that might lead to even more variations of time for different tillage operations.

The model acts as if the hillside starts at x=0 and ends at x=30, which could be a problem in some cases. However, in this study it is reasonable since the plots are clearly delimited with metal barriers and erosion traps in the end of the plots.

Even though there are many uncertainties in the WEPP model constructed in this study, the output value of lost soil was realistic when compared to the soil loss estimated by erosion traps (Tables 10). This indicates that using a WEPP model for soil loss estimations could be a suitable method if the model was calibrated properly, although it might be very time consuming.

The modelling performed in this study can only briefly evaluate the limitations and possibilities of a WEPP-model for determining soil loss in Son La Experimental Trial. The outcome of the model shows a soil loss that is realistic.

6 CONCLUSIONS

The main objective of this study was to evaluate agroforestry practices' capacity for erosion control compared to solo crops, in two study sites in NW Vietnam. By this study the research questions could be answered as follow;

- In Son La experimental Trial, the soil loss caused by erosion, one year after the establishment (2018), was estimated to 12.63 ton ha^{-1} in the AF treatment, and 19.80 ton ha^{-1} in the control plots with sole maize. The soil loss in Son La two years after establishment, had decreased, with estimations of 1.30 ton ha^{-1} in the AF treatment, and 2.28 ha^{-1} in the control plots. In Dien Bien Experimental Trial, the amount of soil loss was higher, estimated to 139.21 ton ha^{-1} in the AF treatment and 182.16 ton ha^{-1} in the control plots with sole coffee. The soil loss caused by erosion could not be quantified by the method of erosion pins in this study. More studies must be done in order to evaluate if erosion pins can be a method for estimating soil loss

- The contour planted grass strips in the Experimental Trials served as starting points for terrace formation in both sites. Both one and two years after the establishment, eroded soil was accumulating above the grass strips and thus contributing to the terrace formation. Soil was lost below and/or in the middle of two grass strips in some of the measured years, but not all

- Terrace formation by contour planted grass strips in an agroforestry system can be evaluated at landscape level by a method developed in this study. The method is based on identifying the topsoil in the area, followed by measurements of the depth of topsoil in different positions to the grass strips in the AF treatment. The aim of this procedure is to evaluate the movement of topsoil along the hillside. In addition, the method includes estimations of formed terrace volume

- The erosion pattern in the agroforestry practices in the Exemplar Landscape created terraces over the years. Eroded topsoil accumulated above the grass strips

- To use the WEPP model for simulating the soil loss in Son La there need to be more work carried out. The parameters used as input data must be better adapted to the local conditions of the modelled scenario. The modelling performed in this study can only briefly evaluate the limitations and possibilities of a WEPP-model for determining soil loss in Son La Experimental Trial.

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APPENDICES

APPENDIX A MOVEMENT OF SOIL ALONG THE HILLSIDE IN THE EXPERIMENTAL TRIALS

Table A.1. Least square mean values and standard errors for average added or lost soil [cm] in each position in both AF and SM (control) plots in the Son La Experimental Trial, during the years 2017-2018. The least square mean values can also be observed in Figure 17.

Position to grass strip in AF p-value=0.0003 n=48	**Average added or lost soil** [cm]	**Std. error** [cm]
Below	-0.27	± 0.27
Middle	-0.86	± 0.27
Upper Above	0.79	± 0.27
Above	0.26	± 0.27
Position in SM (control) p-value=0.33 n=16	**Average added or lost soil** [cm]	**Std. error** [cm]
Upper	-0.28	± 0.28
Upper middle	-0.35	± 0.28
Lower middle	0.14	± 0.35
Lower	-0.76	± 0.28

Table A.2. Least square mean values and standard errors for average added or lost soil [cm] in each position in both AF and SM (control) plots in the Son La Experimental Trial during the years 2017-2019. The least square mean values can also be observed in Figure A.2.

Position to grass strip in AF p-value<0.0001 n=48	**Average added or lost soil** [cm]	**Std. error** [cm]
Below	0.33	± 0.30
Middle	- 0.19	± 0.30
Upper Above	2.28	± 0.30
Above	2.26	± 0.30
Position in SM (control) p-value=0.92 n=16	**Average added or lost soil** [cm]	**Std. error** [cm]
Upper	0.85	± 0.45
Upper middle	0.98	± 0.45
Lower middle	1.17	± 0.45
Lower	0.85	± 0.45

Table A.3. Least square mean values and standard errors for average added or lost soil [cm] in each position in both AF and SC (control) plots in the Dien Bien Experimental Trial during the years 2017-2018. The least square mean values can also be observed in Figure 19.

Position to grass strip in AF p-value<0.0001 n=32	**Average added or lost soil** [cm]	**Std. error** [cm]
Below	0.57	± 0.29
Middle	0.86	± 0.29
Upper Above	1.95	± 0.29
Above	2.22	± 0.29
Position in SC (control) p-value=0.26 n=12	**Average added or lost soil** [cm]	**Std. error** [cm]
Upper	0.68	± 0.16
Middle	1.11	± 0.16
Lower	1.00	± 0.16

Table A.4. Least square mean values and standard errors for average added or lost soil [cm] in each position in both AF and SM (control) plots in the Dien Bien Experimental Trial, during the years 2017-2019. The least square mean values can also be observed in Figure A.4.

Position to grass strip in AF p-value<0.0001 n=32	**Average added or lost soil** [cm]	**Std. error** [cm]
Below	-0.13	± 0.60
Middle	0.36	± 0.60
Upper Above	3.61	± 0.60
Above	5.25	± 0.60
Position in SC (control) p-value=0.22 n=12	**Average added or lost soil** [cm]	**Std. error** [cm]
Upper	1.01	± 0.50
Middle	0.36	± 0.50
Lower	1.84	± 0.50

APPENDIX B SOIL LOSS FROM EROSION TRAP

Table B.1. Table of lost (negative value) soil [ton ha^{-1}] obtained from erosion traps in Son La. The soil loss is presented plot wise and yearly average for AF and SM/SC (control), from the years 2017, 2018 and 2019.

Site/Year	**Plot**	**Block**	**Treatment**	**Soil loss** [ton ha^{-1}]
Son La 2017	1	1	AF	-1.6
	2	1	SM	-5.0
	3	2	AF	-10.5
	4	2	SM	-10.3
	6	3	SM	-22.4
	7	3	AF	-41.8
	8	4	AF	-13.3
	9	4	SM	-39
Average, n=8			AF	-16.8±8.1
p-value< 0.82			SM	-19.16±8.1
Son La 2018	1	1	AF	-0.1
	2	1	SM	-13.1
	3	2	AF	-11.2
	4	2	SM	-21.9
	6	3	SM	-27.1
	7	3	AF	-23.9
	8	4	AF	-15.3
	9	4	SM	-17.1
Average, n=8			AF	-12.6±4.1
p-value< 0.08			SM	-19.8±4.1
Son La 2019	1	1	AF	0.0
	2	1	SM	-2.3
	3	2	AF	-0.5
	4	2	SM	-1.3
	6	3	SM	-3.1
	7	3	AF	-4.2
	8	4	AF	-0.5
	9	4	SM	-2.4
Average, n=8			AF	-1.3±0.7
p-value< 0.29			SM	-2.3±0.7

Table B.2. Table of lost (negative value) soil [ton ha^{-1}] obtained from erosion traps in Dien Bien. The soil loss is presented plot wise and yearly average in AF and SM/SC (control), from the years 2017 and 2018.

Site/Year	**Plot**	**Block**	**Treatment**	**Soil loss** [ton ha^{-1}]
Dien Bien 2017	1	1	SC	-92.3
	2	1	AF	-86.0
	3	2	SC	-40.7
	4	2	AF	-17.0
	5	3	SC	-18.3
	6	3	AF	-48.1
	7	4	AF	-101.6
	8	4	SC	-40.6
Average, n=8			AF	-63.2±17.4
p-value< 0.48			SC	-48.0±17.4
Dien Bien 2018	1	1	SC	-252.9
	2	1	AF	-101.2
	3	2	SC	-140.3
	4	2	AF	-77.6
	5	3	SC	-111.7
	6	3	AF	-213.1
	7	4	AF	-164.9
	8	4	SC	-223.6
Average, n=8			AF	-139.2±32.1
p-value< 0.47			SC	-182.2±32.1

APPENDIX C SOIL LOSS FROM EROSION PINS

Table C.1. Table of lost (negative value) or added (positive value) soil calculated by data of erosion pin measurements. Soil loss is presented plot wise and as an average with its standard error for each treatment in both sites for the period 2017-2018 and 2017-2019. Note that the soil loss is not presented per year since the two periods vary in length.

Site	**Plot**	**Block**	**Treatment**	**Soil loss** [ton ha^{-1}]
Son La	1	1	AF	-103.3
2017-2018	2	1	SM	-49.7
	3	2	AF	-74.0
	4	2	SM	-62.8
	6	3	SM	-16.7
	7	3	AF	-55.0
	8	4	AF	-166.2
	9	4	SM	-136.0
Average, n=8			AF	-99.6±24.8
p-value<0.033			SM	-66.3±24.8
Son La	1	1	AF	+134.3
2017-2019	2	1	SM	+59.2
	3	2	AF	+10.4
	4	2	SM	+194.0
	6	3	SM	+365.7
	7	3	AF	+155.3
	8	4	AF	+22.6
	9	4	SM	+170.7
Average, n=8			AF	+80.6±52.0
p-value<0.17			SM	+197.4±52.0
Dien Bien	1	1	SC	+93.9
2017-2018	2	1	AF	+122.0
	3	2	SC	+100.6
	4	2	AF	+44.9
	5	3	SC	+131.3
	6	3	AF	+145.7
	7	4	AF	+137.6
	8	4	SC	+101.6
Average, n=8			AF	+119.5±16.5
p-value<0.36			SM	+100.0±16.5
Dien Bien	1	1	SC	+63.8
2017-2019	2	1	AF	+115.7
	3	2	SC	+131.9
	4	2	AF	-16.6
	5	3	SC	+99.4
	6	3	AF	+172.8
	7	4	AF	+117.6
	8	4	SC	+197.1
Average, n=8			AF	+97.4±34.8
p-value<0.66			SM	+123.1±34.8

APPENDIX D CLIMATE DATA

Table D.1. Information about the climate station.

Code of station	48806
Name	Son La
Longitude	103°54'
Latitude	21°20'
Commune	Chieng Le
District	Son La city
Province	Son La
Elevation	675.342 m
Established	1960-01-12
Units precipitation	mm
Units temperature	°C

Precipitation [mm]

Month	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Year													
1989	52.3	12.6	164.3	47.9	140.6	212.7	333.5	86.2	97.2	31.5	0.0	3.3	1182.1
1990	19.8	59.2	110.2	76.6	380.4	414.1	289.3	94.4	111.9	19.9	64.9	10.5	1651.2
1991	6.8	1.4	62.2	116.5	124.1	375.5	406.3	93.5	83.0	25.6	10.5	5.3	1310.7
1992	36.3	70.7	1.8	33.8	191.9	220.5	412.8	92.3	179.6	43.0	1.2	64.2	1348.1
1993	4.8	25.6	73.0	147.8	246.2	247.1	136.6	317.3	195.2	2.3	2.4	6.0	1404.3
1994	0.4	9.0	68.7	67.1	205.4	310.7	521.1	213.6	148.9	119.0	5.2	48.6	1717.7
1995	5.5	18.8	49.2	36.8	225.8	346.5	319.8	434.8	42.1	26.1	109.3	0.0	1614.7
1996	0.0	213.0	100.2	67.4	325.3	207.7	234.8	397.8	141.1	39.3	39.7	21.9	1788.2
1997	8.8	10.3	162.4	97.1	103.4	310.3	241.9	268.4	150.8	30.5	3.9	11.8	1399.6
1998	0.0	3.2	46.6	96.5	235.3	192.7	164.7	102.7	98.2	5.5	64.5	4.3	1014.2
1999	21.3	0.1	26.1	130.6	253.8	222.1	246.1	353.8	103.9	77.4	38.3	0.0	1473.5
2000	8.9	87.3	22.4	70.3	259.4	175.2	266.3	200.8	60.8	118.2	0.0	7.6	1277.2
2001	18.4	1.8	107.7	82.1	290.9	194.3	291.3	92.0	105.8	106.3	4.8	0.4	1295.8
2002	61.1	21.9	54.6	64.6	322.8	283.8	257.7	240.3	36.4	94.4	51.6	70.3	1559.5
2003	26.1	51.2	29.2	181.5	151.5	140.2	283.8	161.6	50.1	14.3	0.2	1.1	1090.8
2004	11.8	7.4	48.0	278.9	186.7	105.3	208.7	294.5	141.6	0.0	47.9	0.0	1330.8
2005	10.4	9.3	75.6	63.9	65.4	150.4	266.6	403.1	147.4	57.8	21.1	20.2	1291.2
2006	0.0	36.3	36.7	87.3	152.2	222.7	260.5	305.3	57.6	39.0	12.1	0.7	1210.4
2007	4.0	17.0	9.2	166.1	266.9	176.4	290.0	175.4	168.5	69.3	11.2	1.3	1355.3
2008	24.2	65.2	31.5	71.7	132.6	337.2	409.8	246.0	448.7	166.9	136.2	11.8	2081.8
2009	0.0	0.1	41.0	114.7	111.2	153.0	228.5	231.7	98.8	17.1	0.4	5.9	1002.4
2010	79.1	18.0	68.9	150.8	140.7	98.1	174.0	190.6	178.7	19.0	1.5	90.4	1209.8
2011	11.1	13.3	108.5	106.5	136.3	190.9	215.4	167.8	88.8	47.0	5.7	2.1	1093.4
2012	90.5	6.0	48.7	114.0	180.6	122.3	299.9	344.9	153.3	48.7	44.9	26.2	1480.0
2013	42.9	13.6	33.4	89.2	183.9	201.4	369.4	353.6	120.4	22.4	0.5	109.3	1540.0
2014	1.4	21.4	36.5	75.1	129.6	252.1	299.8	311.5	114.6	29.0	143.6	0.0	1414.6
2015	76.3	1.6	61.3	75.1	42.6	359.8	429.5	258.9	266.2	86.0	44.9	101.2	1803.4
2016	100.8	32.8	19.1	160.1	347.3	166.0	154.5	286.1	129.4	32.0	42.3	1.9	1472.3
2017	150.8	19.5	83.9	112.2	81.1	136.2	227.5	319.5	105.4	76.4	10.2	59.3	1382.0
2018	32.4	2.8	84.0	95.1	208.2	313.0	179.7	399.2	78.7	63.9	45.6	37.0	1539.6
Monthly Mean	30.2	28.3	62.2	102.6	194.1	227.9	280.7	247.9	130.1	50.9	32.2	24.1	
Monthly Mean	117.6									**Annual Mean**			1411.2
Monthly Mean Min	24.1									**Annual Min**			2081.8
Monthly Mean Max	280.7									**Annual Max**			1002.4

Temperature ^{o}C

Month	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
Year													
1989	13.7	15.8	18.3	23.6	24.6	25.4	25.4	24.9	24.3	21.5	18.7	15.8	21.0
1990	16.5	16.4	18.9	23.3	23.4	24.6	24.3	25.9	24.5	21.8	19.6	15.9	21.3
1991	17.7	18.0	23.3	23.7	24.9	24.9	25.0	25.3	24.9	22.1	18.4	16.4	22.0
1992	14.0	16.2	21.1	24.4	25.9	25.8	24.6	25.7	24.4	19.7	16.9	16.0	21.2
1993	13.6	18.3	20.1	22.9	24.4	25.8	25.4	24.8	23.8	20.8	18.4	15.1	21.1
1994	16.6	20.4	18.0	25.0	25.0	24.9	24.6	24.7	23.7	20.6	18.1	16.7	21.5
1995	15.0	15.6	20.3	25.0	25.2	25.1	24.9	24.0	23.8	22.7	17.9	14.8	21.2
1996	15.9	14.0	21.8	21.6	24.7	25.2	24.8	24.5	23.8	21.4	19.1	14.7	21.0
1997	15.8	16.2	20.9	21.8	25.7	25.8	24.6	24.6	22.4	22.9	19.6	17.6	21.5
1998	17.4	18.1	22.2	23.8	24.8	25.9	25.4	25.4	24.0	22.4	19.1	17.2	22.1
1999	15.5	18.6	21.7	24.3	23.6	25.6	25.5	24.7	23.8	21.9	18.5	12.7	21.4
2000	15.8	16.1	20.8	23.7	23.7	24.3	25.2	25.1	23.5	22.1	17.8	16.8	21.2
2001	16.6	16.9	20.5	24.6	23.5	25.3	24.9	25.3	24.2	22.3	16.9	16.2	21.4
2002	14.5	18.1	21.2	24.3	23.6	25.0	24.6	24.4	23.8	21.6	17.9	16.1	21.2
2003	14.4	18.8	19.9	24.6	25.2	25.5	25.6	25.6	24.2	22.7	19.8	16.0	21.9
2004	15.7	17.2	20.5	22.8	23.9	24.9	24.9	25.4	23.9	21.4	18.9	15.0	21.2
2005	15.4	19.7	19.1	23.1	26.2	25.7	25.5	24.4	24.3	22.0	19.5	14.4	21.6
2006	15.4	18.4	20.4	23.9	24.1	25.8	25.4	24.7	23.7	23.1	20.5	15.9	21.8
2007	14.8	19.6	21.9	22.1	24.1	25.8	25.1	24.9	23.6	21.5	16.7	17.4	21.5
2008	15.0	11.0	20.2	23.9	24.5	24.6	24.6	25.1	24.5	22.3	17.5	14.6	20.7
2009	13.5	21.0	21.3	23.0	24.9	25.6	25.5	25.6	25.0	23.3	18.0	16.2	21.9
2010	17.4	18.6	20.6	23.6	26.3	26.1	26.1	24.9	24.8	21.7	18.4	16.9	22.1
2011	11.7	16.7	16.4	22.1	24.1	25.5	25.5	25.1	24.5	21.7	18.7	14.7	20.6
2012	14.2	16.7	20.1	24.3	26.1	25.9	25.4	25.2	23.6	22.8	20.7	17.4	21.9
2013	14.7	19.6	22.3	23.1	25.1	25.1	24.6	25.0	23.7	21.1	19.6	13.0	21.4
2014	14.4	16.9	21.4	25.3	25.8	25.8	25.5	24.8	25.1	22.0	19.8	14.5	21.8
2015	14.8	17.7	22.5	23.5	27.5	26.5	25.4	25.6	24.9	22.7	21.3	15.8	22.4
2016	15.2	13.9	19.8	25.2	25.6	26.3	25.6	25.6	24.7	24.1	20.0	17.1	21.9
2017	17.1	17.0	21.1	23.1	24.6	26.2	25.2	25.1	25.2	22.0	18.6	15.0	21.7
2018	15.8	16.3	20.2	22.7	24.7	25.1	25.5	25.0	24.9	22.6	20.1	17.0	21.7
Monthly Mean	15.3	17.3	20.6	23.6	24.9	25.5	25.2	25.0	24.2	22.0	18.8	15.8	
									Annual Mean Mean				21.5
Monthly Mean Min	15.3								**Annual Mean Min**				20.6