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Soil conservation methods and their impact on nitrogen cycling and competition in maize cropping systems on steep slopes in Northwest Vietnam

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To my son Vu Dinh Quang

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List of abbreviations

AGB: Above ground biomass

ARS: Agricultural Research Service

CH: Chieng Hac

CK: Chieng Khoi

CIAT: International Center for Tropical Agriculture

°C: Degree Celsius

DAS: Days after sowing

DM: Dry matter

GLM: Generalized linear model

HI: Harvest Index

IRMS: Isotope Ratio Mass Spectrometry

ISRIC: International Soil Reference and Information Centre

LAI: Leaf area index

LSD: Least Significant Difference

LSMEANS: Least squares means

MJ ha^{-1}: Mega joule per ha

MT: Minimum tillage

NS: Not significant

NW: Northwest

OC: Organic carbon

OM: Organic matter

PDB: Pee Dee Belemnite

WaNuLCAS: Water, Nutrient and Light Capture in Agroforestry Systems Model

Chapter 1

General introduction

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1 GENERAL INTRODUCTION

1.1 Soil erosion, its driver and consequences

Thousands of years are required to form a few centimeters of soil in moist and warm climates, even longer in cold or dry climates. Technically soil is a renewable resource, but its slow rate of formation makes it practically irreplaceable (Kelley 1983). Erosion on the other hand, can quickly truncate the depth of the soil by 1-3 cm yr^{-1} (Vogel 1988). Worldwide, erosion affects around 2 billion hectares of land (Lal 2007). On-site effects of erosion include loss of soil from the field, breakdown of soil structure and decline of organic matter and nutrients results in a reduction of cultivable soil depth and decline in soil fertility (Morgan 2005). In the area of variable rainfall distribution and shallow soil, available moisture for crop can be reduced. All these impacts restrict crop growth and their selection, and increase expenditure on fertilizer to maintain yields. These changes in soil with time will reduce crop yield and food security, eventually negatively impacting the livelihood of the upland users. This in turn forces farmers to encroach more marginal land of forest for their food and income if no alternative off-farm jobs are offered. The off-site effect is sedimentation downstream, which reduces the capacity of rivers, reservoirs and drainage ditches, enhances the risk of flooding, blocks irrigation channels and shortens the designs of reservoirs (Morgan 2005). Sediment deposited on roads also obstructs traffic, or even causes ‘mud flooding or land slide’. Sediment and agricultural chemical transport in the long term may increase nitrogen and phosphorus in water bodies resulting to eutrophication.

Vietnam, a country located in Southeast Asia, has a total surface area of 33 million hectares of which three quarter of the land area is hilly and mountainous. Because of such a complex topography and high rainfall intensity concentrated in a few months, much of her lands, particularly the Northern mountainous region, are erosion-prone areas (MONRE 2011). Currently, about one fifth of Vietnam’s upland area is considered ‘barren lands’ (Nikolic et al. 2008), originating from former forested area and featuring an extremely low level of productivity.

Land degradation, as consequence of soil erosion, is driven largely by socio-economic factors (Saint-Macary et al. 2010; Valentin et al. 2008). Vietnam’s remarkable economic growth started since the comprehensive reform/renovation policies in 1986 known as Doi Moi of the Communist Party in which the nation embarked on a transformation from central planning towards a ‘socialist market economy under state guidance’ (Bich 2007). Among the other changes in policy reform, a landmark of the agricultural sector dated back to 1981 with the Directive 100 CT/TW and was followed by the Resolution 10 of the Party Politburo, in which rural households became new elementary units of agricultural production encouraging individual initiatives, free circulation and exchange of farm products. More recently, rapid economic growth and urbanization in Vietnam have led to improved and diversified diets, and consequently increased demand for meat, eggs, and dairy products (Minot et al. 2006). Maize (*Zea mays*) is a major source of animal feed for Vietnam's rapidly growing livestock and poultry industry. The market demand caused a maize boom in the country, and is expected to further increase in the future (Keil et al. 2009). Increase in maize production has been achieved by the combined effects of higher-yielding varieties and area expansion. Further expansion of agricultural cultivation into fragile hillsides, and intensifying maize monocropping based on intensive tillage combined with slash and burn as occurred in North Vietnam led to severe erosion (Dung et al. 2008; Valentin et al. 2008; Toan et al. 2005; Stahr et al. 2013), enhanced soil organic matter decomposition (Wezel et al. 2002; Stahr et al. 2013; Häring et al. 2013) and as consequence lead to long-term degradation (Clemens et al. 2010; Hilger et al. 2013). Major form of soil degradation in upland areas in Vietnam is characterized by low organic and nitrogen content, reduced exchangeable calcium and magnesium, low pH (Siem and Phien 1992), or physical deterioration such as lowering clay content due to erosion and leaching losses (Phien and Vinh 2002). Crop yield reduction induced by soil degradation, among other things, drove farmers to clear forest areas to compensate for the yield loss. Moreover, in order to get higher yields, farmers increased fertilizer application associated with high yielding varieties which mitigate the negative impacts of cropping activities on soil nutrient depletion in the short-term (Neef et al. 2000). This practice, however, increases production costs for farms and environmental risk as lower fertilizer use efficiency is expected (Stevens et al. 2005).

The northern mountainous region (NMR) of Vietnam is considered as a poor region in Vietnam where the average incidence of poverty is 29.4%, being much higher than the national average of 14.2% (GSO Vietnam 2010). The high level of poverty reflects the constrains such as a poor physical environment limiting agricultural development and restricted access to infrastructure, market and social services (World Bank 2004). Crops grown in the region are diverse, including paddy rice, upland rice, cassava, maize, sugar cane, grass, orchards, fruits, tea, coffee and vegetables. Most of households have their own garden where some vegetables, herbs or medicinal plants are grown. The common species planted in 'production forest' areas include Acacia (*Acacia mangium* and *Acacia auriculiformis*), Teak (*Tectona grandis L.f.)*, bamboo, and Eucalyptus (*Eucalyptus camaldulensis*). In the context of a market orientated land use, and increasing demand of livelihood for their population, traditional swiden cultivation has been shifted to intensive agricultural systems in the region. By the mid-1990s, the area devoted to maize (*Zea mays*) production in Northwest Vietnam has strongly increased, mainly by expanding crop production into forested uplands where more than half of the surface area has slopes of over 20 degrees (Jamieson et al. 1998). This permanent cropping (often with hybrid varieties) adds to the susceptibility of sloping lands to degradation by erosion, leaching and nutrient depletion. To tackle erosion problems of the region, a project funded by the EnBW Rainforest Foundation was initiated by Hohenheim University, Germany in cooperation with Hanoi Agriculture University, Vietnam. The overall goal of this project was to foster sustained and enhanced livelihoods and environmental quality in the uplands of Northwest Vietnam. In the framework of the project, extended studies, including erosion assessments, nitrogen use efficiency and nitrogen competition in various maize based cropping systems, were carried out.

1.2 Soil conservation measures

Strategies for soil conservation should be based on: covering the soil to protect it from raindrop impact; increasing the infiltration capacity of the soil to reduce runoff; improving the aggregate stability of the soil; and increasing surface roughness to reduce the velocity of runoff (Morgan 2005). Conservation techniques can be classed into agronomic measures and mechanical methods. Agronomic measures utilize the role of vegetation to protect the soil against erosion. Soil management is concerned with the ways of preparing the soil to promote plant growth and improves its structure to be more resistant to erosion. Mechanical or physical methods on the other hand, often involve engineering structures, which manipulate surface topography to control flow of water. In practice, distinction between methods is not always clear, as a system usually involves more than one technique, and preference is always given to agronomic measures. Often, agronomic techniques are less expensive and deal directly with reducing raindrop impact, increasing infiltration, reducing runoff volume and decreasing water velocity. Additionally, they are more easily to fit into existing farming systems and more relevant to maintaining or restoring biodiversity of plant communities.

Contour ploughing or contour farming is probably the most common method, in which the farmer practices of ploughing and/or planting across a slope following its elevation contour lines. These contour lines, formed by dense vegetation, create a water break, which reduces the formation of rills and gullies during times of heavy water run-off; which is a major cause of top soil loss and soil erosion. The water flow break also allows more time for the water to settle into the soil, allowing higher infiltration. In contour ploughing, the furrows run perpendicular rather than parallel to slopes which also prevent tillage erosion (Van Oost et al. 2006). A similar practice is contour bunding where stones are placed around the contours of slopes. In the contour ditches, the channels are excavated along contour line to break the surface runoff and accumulate water before spreading flow along its length. The practices however are effective only on slopes of between 2% and 10% gradients and when rainfall does not exceed a certain amount within a certain period. On steeper slopes and areas with greater rainfall, a procedure known as strip cropping is used with contour farming to provide additional protection (NRCS 2007). Contour farming is most effective when used with other soil conservation methods like strip cropping, terrace (agriculture) farming, and the use of a cover crop. The proper combination of such farming methods can be determined by various climatic and soil conditions of that given area.

Contour hedgerow is a line of closely spaced shrubs and tree species, planted along contour lines. Multipurpose, fast growing tree legumes which can quickly form natural terraces for soil erosion control are usually species of choice. However, competition for resource limits the adoption of hedgerow systems. When fertilizer is applied to offset any nutrient competition from the trees (of hedgerows), light becomes a constraint for crop growth in alleys (Friday and Fownes 2002). In contrast, when light and water supply are not limited, nitrogen can be a constraint (Pansak et al. 2007). Another method is called terracing, which is an area of sloped plane that has been cut into a series of successively receding flat surfaces or platforms, which resemble steps, for the purposes of more effective farming. This type of landscaping, therefore, is called terracing. Graduated terrace steps are commonly used to farm on hilly or mountainous terrain. Terraced fields both decrease erosion and surface runoff, and may be used to support growing crops that require irrigation, such as rice.

Mulching is a measure, which usually uses plant residues or any organic materials to protect the soil against rain splash and to maintain a favorable soil microclimate such as higher moisture or reduced heat (Bergsma et al. 1996). A layer of mulch also can reduce weed growth and sometimes uses enhance visual appeal of the area. Mulching practice, however, appears easier at sites where biomass production is greater than the demand for animal feed and fuel (Valbuena et al. 2012). Synthetic foils or biological geo-textiles also aim to reduce the direct rainfall impact of the soil by increasing soil cover.

A cover crop is a crop planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agroecosystem (Lu et al. 2000). Cover crops are also effective in erosion control and of interest in sustainable agriculture. Dense cover crop stands physically slow down the velocity of rainfall before it contacts the soil surface, preventing soil splashing and erosive surface runoff (Romkens et al. 1990). Additionally, vast cover crop root networks help anchor the soil in place and increase soil porosity, creating suitable habitat networks for soil macrofauna (Tomlin et al. 1995).

Widespread scientific recognition of agroforestry in nurturing, conserving ecosystems and controlling erosion emerged since 1970s (Young 1989). Agroforestry refers to land use practices in which trees or shrubs are grown in spatial or temporal association with crops or pastures, and in which there are both ecological and economic interactions between the tree and non-tree components. There is enough evidence that agroforestry controls erosion, maintains organic matter and physical properties and promotes efficient nutrient cycling (Young 1989).

Minimum tillage or zero tillage is part of conservation agriculture. The measure is usually combined with mulching residues, cover crops and rotating primary crops. Minimum tillage systems combined with a legume cover effectively control erosion in tropical regions. Additionally, in the long term these measures improve soil fertility, structure and infiltration (Hilger et al., 2013). Recently, minimum tillage and legume relay crops in maize fields were tested on moderate slopes (22 degrees) showing positive impact on crop yield and reduced erosion (Pansak et al., 2008). These practices were considered as viable alternatives for tropical mountainous regions. However, suggested technologies still need to be tested under various conditions (i.e. slope, soil type, soil fertility, weed pressure) before their widespread application can be recommended. The reasons for not adopting soil conservation methods are varied, such as being economically unattractive and a failure to meet farmers' needs (El-Swaify, 1997; Neef et al., 2000). Other concerns include decreased yields, rat and pest remaining under residues (Erenstein 1999), increased labor requirements when herbicides are not used, and in particular instable socio-economic conditions of land users such as reallocation threats (Giller et al., 2009; Saint-Macary et al., 2010) (see also chapter 2).

1.3 Resource competition associated with soil conservation measures

Soil conservation systems involving more than one crop, such as contour hedgerows, grass barriers, cover crops, or agroforestry, usually exhibit complex interactions. On one hand, mixed species systems may enhance their growth through complementary resource acquisition strategies or better exploiting underutilized resources or exploiting new resource niches (Cadisch et al. 2004). On the other hand, competition refers to a negative effect (growth or mortality) that one exerts on the other (Vandermeer 1992). Competition belowground can be stronger and involve many more neighbors than aboveground competition. Belowground competitive ability is correlated with factors such as root density, surface area, and plasticity either in root growth or in the properties of enzymes involved in nutrient uptake (Casper and Jackson 1997). Many authors reported crop yield decline due to competition for nutrients, light and water between main crops and associated plants in mixed systems (Pansak et al. 2007; Dercon et al. 2006b; Smeltekop et al. 2002; Clay et al. 2009). To quantify the impact of environmental factors responsible for competition-induced yield loss, ^{13}C discrimination can be used as a useful tool in understanding abiotic stresses (e.g. water, nutrient or light) (Dercon et al. 2006a; Clay et al. 2005).

For C_4 plants, photosynthesis starts with the diffusion of CO_2 from atmosphere into the leaf via stomata. This first step occurs on stomatal pores with an apparent fractionation of 4.4‰ due to slower motion of the heavier ^{13}C-containing molecules. The absorbed CO_2 then is catalyzed by enzymes namely phosphoenolpyruvate (PEP) carboxylase which has an approximate discrimination of -6‰ for the fixation of CO_2 (Farquhar et al. 1989). If these enzymatic fractionations were fully and exclusively expressed relatively to atmospheric CO_2, they would yield tissue values of around -2‰. Further discrimination occurs in bundle sheaths of the leaf where C_4 compounds produced by PEP carboxylase are transported into. Inside the bundle sheath, the C_4 compounds are catabolized to C_3 compounds, releasing CO_2 which accumulates at high concentration. The released CO_2 is then fixed by Rubisco, the same enzyme used by C_3 photosynthesis. There is slowly leaking of enriched CO_2 from the pool as Rubisco prefers the lighter isotope ^{12}C. This process leaves leaf tissue more depleted in ^{13}C, resulting in measured values of ^{13}C for C_4 plant clustering around -14‰ (Marshall et al. 2007). Variation of ^{13}C in C_4 plants is less than in C_3 plants (Farquhar et al. 1989), because potential large effect of fractionation by Rubisco is suppressed in the semi-closed bundle sheath. It is, therefore, change of environmental condition results to variation in bundle sheath leakiness to CO_2 (ϕ) which can damp or amplify the effect of Ci/Ca (ratio of intercellular to ambient CO_2 concentrations) on ^{13}C discrimination (Δ). Interpreting variation in Δ, however, is challenging because it cannot attributable to a single factor. Even in the simplest case, Δ depends on both Ci/Ca and ϕ (Cernusak et al. 2013).

Light is reported to influence largest variation in Δ of C_4 plants. An increase of 3‰ was observed in maize from high to low radiation, as large as 8‰ in *Flaveria bidentis* (Ubierna et al. 2013). Much of works relate Δ with water use efficiency (Dercon et al. 2006a; Clay et al. 2001). For instance, Bowman et al. (1989) observed a negative correlation between bundle sheath leakiness in C_4 grasses and soil moisture availability. Dercon et al. (2006a) observed the changes in ^{13}C in maize were related to water at three N supply doses. In the field conditions when water supply was sufficient, Pansak et al. (2007) observed a significant increase in ^{13}C values in maize close to barriers or hedges, with a change in ^{13}C of 0.74 ‰.

In contrast to ^{13}C, information about the effects of environmental variables on ^{15}N natural abundance is still limited (Peri et al. 2011). Under similar environmental conditions, variation of natural ^{15}N abundance varies according to the ratio contributed from different nitrogen sources, though this is not correct when plant N demand is low compared with N supply (Högberg 1997). Both enzymes catalyzing nitrogen (nitrate reductase and glutamine synthetase-glutamate synthetase) discriminate against ^{15}N, but this discrimination will only be possible if there is an abundant inorganic N pool leaking from plant roots after uptake, which is unlikely if plant N demand is high relative to N supply (Evans et al. 1996).

During decomposition, mineralization and denitrification processes, microbes in the soil discriminate against the heavier isotope, leading to more enriched in soil-^{15}N than its original source, e.g. litter or mulch (Wang et al. 2011; Nadelhoffer et al. 1996). A plant relying much more on N from inorganic fertilizer or symbiotic fixation should probably be depleted in ^{15}N in the biomass than the one obtaining N mainly from the soil organic N-pool (Valles De La Mora and Cadisch 2010; Wang et al. 2011). The difference in ^{15}N values from different sources can be used to estimate their relative contribution to the crop N uptake (Dalal et al. 2013).

1.4 Nitrogen use efficiency of tropical crops

Nitrogen use efficiency (NUE) for a cropping system is broadly defined as the proportion of all N inputs that are removed in harvested crop biomass, contained in recycled crop residues, and incorporated into soil organic matter and inorganic N pools (Cassman et al. 2002). To a lesser extent, NUE is defined as mass of N within the crop plant per mass of N applied (Rowe et al. 2005).

In tropical farming systems, nitrogen uptake from fertilizer by the crop in the first growing season is around 30%, whereas the recovery rate during subsequent crop seasons accounted for just 3-6% (Pilbeam et al. 2002; Dourado-Neto et al. 2010). In Vietnam, fertilizer use efficiency was estimated to be 35-45% for N-fertilizers (Van Bo and Mutert 2003). For example, maize grown on Acrisols under experimental conditions had a N fertilizer recovery of 36-46% (Cong et al. 2001). Low nitrogen use efficiency in Vietnam was attributed to several factors. Firstly, imbalanced fertilization are practiced to a large extend, where N fertilizer is intensively used without combining with others (Van Bo and Mutert 2003). Under very well managed paddy systems in Northern Vietnam (optimum water supply, well-incorporated fertilizers into soil), balanced fertilization of N-P-K results in N recoveries of 43-56%, while single N fertilization resulted in a recovery rate below 30% (Ha and Tuan 2006). Secondly, the temporal synchrony between N supply and uptake is often not met. Farmers' practices typically relied on a large N fertilizer application early in the season, when the capacity for crop uptake was small, and one additional N topdressing (Cassman et al. 2002). Thirdly, the application methods also impactson potential N losses, e.g. surface applied methods increase N volatilization, hence reduce N recovery rates (Blaise et al. 1996).

Pathways of N-losses are votalization, denitrification and leaching. Additionally, farming on slopping land in tropical conditions provokes N-losses by erosion. For instance, Pansak et al. (2008) measured nitrogen losses induced by runoff, soil loss, and leaching of 12-15 kg N $ha^{-1} yr^{-1}$ under maize monocropping in Northwest Thailand, being nearly one fourth of fertilizer applied 60 kg N $ha^{-1}yr^{-1}$. The eroded N observed in upland rice fields in Northwest Vietnam reached 150 kg N $ha^{-1}yr^{-1}$, accounting for 72% of total N-export (Hoang Fagerström et al. 2002). Such N-losses induced by erosion need to be taken into account when designing crop cultivation in the uplands. While N-losses from soils in the upland cause on-site soil nitrogen depletion, fertility of lowland receiving eroded materials can be enhanced or degraded depending on quality of the delivered sediment. Therefore, understanding N-transportation and N-budgets in uplands should provide more information on lowland management.

1.5 Overview of the relevant techniques

1.5.1 Field measurement of soil erosion and runoff

Bounded plots

The method requires a setup with bounded plots representing experimental factors, and being replicated. Number of replicates depends upon the purpose and feasibility of experiment. Standard plot is 22 m long and 1.8 m wide, although other plot sizes are used. Plots edges are made of sheet metal, wood or any material that prevents leaking and overland flow into and out and vice versa. A collecting system is installed at the bottom of each plot. The collecting system should include a collecting trough, a divisor/collecting tank which splits flow into equal parts and passes one part into second collecting tank. Sometimes, prior to passing into the first collecting tank, the flow is channeled through a flume where the discharge is automatically measured. There will always be considerable amounts of debris in the runoff, and this must be caught on screens if any type of divisor or sampler is used. Sometimes a wire mesh screen is placed over the collecting trough, or alternatively one or more screens may be placed in the collecting tanks (Morgan 2005). The method is supposed to monitor rill and interrill erosion (Stroosnijder 2005) and gives probably most reliable data on soil loss at small plot scale (Morgan 2005). Errors involved with the method include silting of collecting trough and pipes leading to the tanks, particularly silt and fine debris which pass the mesh screen deposited in the pipes. During extreme events, overflowing would occur if monitoring system is not properly designed and managed. Other problems are that runoff may occur along the boundaries of the plot and form rills which would not otherwise develop, and that the bounded plot is a partial closed system, cut off from input of sediment and runoff from the upslope. It also neglects the redistribution of soil within a field or along slope.

Gerlach troughs

Gerlach troughs are simple metal or PVC gutter 0.5 m long and 0.1 m broad closed at the sides and fitted with a movable lid. An outlet pipe runs from the base of the gutter to a collecting device (bottle or tank). A set of Gerlach troughs (2-3) is usually placed side by side across the slope and group of such sets are installed at different slope lengths, arranged *echelon* in plan to ensure a clear run to each gutter from the slope crest (Morgan 2005). The method avoids edge effects as no boundaries are used. It relies on the assumption that the contributing area is equal to the width of the gutter times the length of the slope. A further assumption is that any loss of water and sediment from this area during its running downslope is balanced by inputs from adjacent area. This assumption is only reasonable if the slope is straight in plain (Morgan 2005). Recent studies suggest that the method doesn't quantify well erosion in tropical conditions. Major problems are rills formed during intense storms that could lead runoff out of the gutter collection area, thereby underestimating soil erosion (Boll 2008). Particularly, in tropical fields and steep slopes, assumptions of the method are often not met (e.g. contributing area, straight slope), and hence lead to unreasonable results (Suwimon Wicharuck, personal communication). Further, as size of the trough and pipe is much smaller than that of a bounded plot, debris and silt depositions easier block the pipe.

Soil pins

The method uses sharpened steel rods about 25-50 cm long, ~8-12 mm diameter, driven into soil, leaving a head of 5-10 cm out of the soil. Periodic measurements of the distance between the head of the rod and surface allow estimation of the depth of the soil layer eroded or deposited. A large number of pins, usually installed on a grid system, is needed to obtain representative data over a large area (Hudson 1993). The disadvantage of this method is that the pins can be easily disturbed by livestock and wildlife or stolen by local people. Additionally, the installed sites can be difficult to relocate in subsequent surveys. The method is considered 'semi-quantitative', as a direct measurement of the level of the soil surface is a very crude estimate. For example, if the lowering of the soil surface was measured to the nearest millimeter corresponding with an estimate of the soil loss to the nearest 15 ton (assume a bulk density of 1.5).

Erosion bridge or profile meter

A network of metal pegs is set unobtrusively in concrete at ground level so that their positions remain stable over time. A portable girder is placed across any two adjacent pegs from which vertical reading of the depth to the soil surface can be taken at regular intervals. In principle, this method is very similar to the soil pin one, but increases number of measurements, hence accuracy.

Splash erosion measurement

The method is designed to measure the amount of soil splashed from the soil surface to a target, including splash boards, field splash cups (Morgan 1978), and slash boxes (Moore and Singer 1990). Geissler et al. (2012) developed splash cups to measure erodibility of the rain drops under various field conditions.

Rill and gully erosion measurement

To assess rill erosion, a series of transects across the slope are established, which are positioned one above the other. Cross sectional area of the rills is determined along two successive transects. The average of the two areas, multiplied by the distance between the transects, gives the volume of material removed. The volume is converted into the weight of soil loss by multiplying with bulk density, and this weight is divided by surveyed area to get erosion rates. For small gullies, erosion rates can be assessed using the manner identical to the approach used for rills. For larger gullies, sequential surveys using aerial photography are more suitable. A three dimensional model of the terrain is built using a stereo plotter. The plotting machine then reads off heights, cross sections of the gully at intervals down slope. The information generates gully head wall, sidewall at different dates, which allow calculating volume of material removed from the gully (Morgan 2005).

Sediment fence

Originally, silt fences or sediment fences were used for the purpose to study the impact of soil conservation measures, which aim at slowing down the rate of both wind and water erosion. They were also able to filter out sediments that were transported with runoff, by allowing running water to pass through, but trap sediments behind (Leopold 1953). Later the fences were also used in quantifying sediment or erosion. The method is applicable in convergent, zero-order hillslopes (swale) without bordering, which usually being a small catchment with size of few hundreds to few thousands m^2 (Larsen et al. 2009; Tuan et al. 2014). The contributing area for a silt fence needs to be designed so that it does not overwhelm or overtop the silt fence. It is sometime difficult to determine the extent of the contributing area to a particular silt fence (Robichaud and Brown 2002). If fences are properly installed, they can capture over 90% of eroded sediment (MacDonald et al.

2006). Generally, the method requires relatively cheap materials for installation. The time interval to remove and weigh sediment depends on the capacity of the fences and resolution of data needs to be obtained. Usually, high potential erosion areas require sediment removal on a storm basis.

Reservoir survey

Sedimentation rates in lakes and reservoirs can be an indicator of erosion that has occurred in a catchment upstream, provided the efficiency of the reservoir as a sediment trap is known. Repeated surveys of designated transects across the reservoir are needed to set the benchmark. An ultrasound system can be used to measure the volume of reservoir (Margaritescu et al. 2011) which is then compared with the initial volume. The reduction in volume represents sediment accumulation in the reservoir. An additional survey on the characteristic of sediments (bulk density), and potential contributing area allow calculating erosion rates.

Potential errors are high during the reservoir survey, in which trap efficiency of reservoir is estimated which requires knowledge of frequency and sediment concentration of flow carried over the spillway, and errors in calculating the capacity of the reservoir (Morgan 2005). Estimates of sediment originating from another source to the reservoir are uncertain as a large part of the sediment may come from pathway or trampling by animal, which should be excluded from erosion.

Tracer

The method relies on the globally distributed radioactive isotope ^{137}Cs which was produced in the fall-out of atmospheric testing nuclear weapons during 1950s-1970s. Regionally, the amount of deposition varies with the amount of rain, but within a small area, the amount of deposition in reasonably uniform (Morgan 2005). Patterns of erosion or deposition are indicated by comparing of the ^{137}Cs inventories for a sampling point with a reference inventory. The reference site presents the local input fallout, which is where neither erosion nor deposition occurred. The method provides qualitative information of the patterns of soil erosion and deposition in the landscape over a period of 30-50 years, as ^{137}Cs has a half-life of about 30.17 years. A mass balance model can be developed, based on the accumulation depletion of ^{137}Cs through time as a result of erosion and deposition. The mass balance of an eroding site can be described by:

$$\frac{dA(t)}{dt} = I(t) - \left(\lambda \frac{R}{dm}\right) A(t)$$

where A(t) is the cumulative ^{137}Cs activity per unit area (Bqm^{-2})

t is the time (year) since ^{137}Cs fallout began

I(t) is the annual deposition flux of ^{137}Cs from fallout at time t ($Bqm^{-2}\ yr^{-1}$)

λ is the decay constant for ^{137}Cs ($=0.023y^{-1}$)

R is erosion rate ($kg\ m^{-2}\ yr^{-1}$)

d_m is the average plough depth represented as a cumulative mass depth (kg m^{-2})

The key assumption of the model is that radionuclide loss is directly proportional to soil loss. The method has advantages, e.g. by a single sampling an average erosion rate over a long term period 30-50 years can be obtained. However, the method has some disadvantages, for example sometimes is difficult to find a reference place for the study site; calculation of soil erosion and deposition strongly depends on the model used, which is sensitive to the parameter choice (Poreba 2006). Recently, the model was improved, which includes correction factors e.g. grain size of eroded sediment (Porto and Walling 2012). Alternatively, other potential tracers such as ^{219}Pb or ^{7}Be being used in erosion determination are investigated (Wallbrink and Murray 1993).

Nutrient distribution at landscape level

The method characterizes spatial-temporal variations of water quality at landscape or catchment level, which integrates various biochemical processes. The water quality and its magnitude flow (C, N concentration or particle size) quantify erosion occurred in the catchment (Valentin et al. 2008; Mai et al. 2013). Water quality is determined by either direct or indirect methods. Direct measurements include manual (e.g. grasp sample) or automatic (automatic water sampler) sampling while indirect measurements use a proxy such as turbidity sensor to monitor suspended sediment concentrations in channels or outlets of watersheds. The manual sampling refers to as taken samples at irregular time intervals throughout the year or a survey designed for a storm event where the time interval is shortened between samples (Schmitter 2011). When an automatic sampler is used, labor saving for field work can be achieved. To further reduce number of analysis, a flow proportional-composite sampling strategy was suggested by Schmitter et al. (2012). Turbidity sensors on other hand can continuously monitor suspended sediment concentrations, given appropriated calibration is carried out. Among other predictor variables (discharge and rainfall), turbidity is one of the most important predictors for sediment concentration. Usually, successful predictions have relatively homogeneous sediment loads (only small differences in texture and organic matter). This is usually associated with catchments with homogeneous geology, topography and land use, and for very high total suspended sediment concentrations (Slaets et al. 2014).

1.5.2 Field measurement of soil cover

Point transect method

The method is also called line-intercept transect. The principle of the method is similar at any scale, where number of transects and number of points for each transect are set, so that the desired points for the whole plot are met. Depending on the surface characteristic and size of plot, the hit point may include live vegetation, litter, rock or anything that can intercept rains and protect soil from rains. The method is simple, easy to carry out but requires intensive labor and causes large trampling damage on the monitored plots.

Digital image combined with software

Combining digital photography with the image analysis software, for example 'SamplePoint', to assess ground cover, is an alternative to the point transect method. The approach requires a camera hanging over the ground cover at desired height for photo taking. Supported tools can be a L-stick for small plots, and a remote controlled drone for a big plot or at the landscape scale. The method permits a high frequency of sampling with minimized trampling in monitored plots.

1.5.3 Isotope labelling techniques for studying soil-plant interaction in the field

There are several types of tracers which are commonly used in studying soil-plant interaction: radioisotopes (e.g. ^{32}P, ^{33}P, ^{35}S), and stable isotopes (e.g. ^{15}N, ^{34}S, ^{18}O). The technique uses the difference in the relative abundance of an isotope measured as a concentration (atom excess %) or radioactivity. The labeling material is applied into a system via soil, atmospheric feeding, foliar spray, split root and shoot feeding. Uptake can be followed by measuring its abundance in the source, in the plant, and in the soil compartments. The only basic assumption made when utilizing isotopically labelled fertilizer is that the behavior of the isotope and the carrier is identical in the soil-plant system. In other words, there should not be any isotope effect, or the effect can be negligible (see more in Chapter 3).

1.5.4 Application of natural ^{15}N and ^{13}C abundance in agriculture research

Natural abundance measurements of stable N isotopes in plants or calculated ^{15}N enrichment factors are used as indicators of ecosystem N cycling and/or site N status. The first possible mechanism is that the product of nitrification is ^{15}N-depleted nitrate-N (Fry 2006). High rates of net soil nitrification and elevated levels of nitrate-N leaching can contribute to a gradual enrichment in ^{15}N abundance in forests with open and leaky N cycles due to the loss of ^{15}N-depleted nitrate (Högberg 1997). Secondly, if soil is highly prone to nitrification, the consecutive denitrification process which is characterized by a relatively large isotopic fractionation leaves the remaining soil nitrate isotopically enriched in ^{15}N. For instance, N-rich forests (particularly sites with elevated net soil nitrification) have higher foliar ^{15}N values than that in N-poor forests (Garten 1993; Pardo et al. 2002).

Using the natural ^{15}N abundance method, the proportion of nitrogen fixed from air can be measured (Unkovich et al. 2008). The technique is based on a two-source mixing model. In principle, it should include three 'experiments' employing N_2-fixing plant growing in a medium free of mineral N, non- and N_2-fixing plants growing in soil. The N_2-fixing plant growing in a medium free of mineral N is completely reliant upon N_2 fixation for growth. The isotopic composition of this plant will be similar to that of atmospheric N_2. Conversely, the non-N_2-fixing plants growing in soil is having similar ^{15}N enrichment level of available soil-N. The third plant assimilating both atmospheric N_2 and soil-N is expected to have a value of ^{15}N in between the two former plants. The values of ^{15}N of the third plant will gradually decline as atmospheric N_2 of lower ^{15}N abundance is progressively fixed (Unkovich et al. 2008).

Plant tissue contains less ^{13}C than in air, a so-called depletion. This depletion is caused by enzymatic and physical processes that discriminate against ^{13}C in favor of ^{12}C. Discrimination varies among plants using different photosynthetic pathways: the Calvin cycle (C3), Hatch–Slack cycle (C4) and Crassulacean acid metabolism (CAM) in which they differ so profoundly and so consistently that ecologists have used isotopic signatures to distinguish them in large-scale surveys of plant species. Abiotic factors influence ^{13}C discrimination, for example increase in ^{13}C values can be an indicator of lacking water supply in C4 plants, but would indicate abundance of water availability for C3 plants (see more in section 1.3 of Chapter 1).

1.6 Justification

Maize monocropping grown on hillside and steep slopes are commonly found in the study area. During 2000-2010 maize production in Son La province of Vietnam has tripled, as results of area expansion (2.6 times), and yield increase (1.50). By 2012, the province planted 134,000 ha, accounting for 12% maize area of whole country, being the largest share among 63 provinces (GSO Vietnam 2014). This monocropping based on intensive tillage combined with slash and burn led to severe erosion, and soil degradation in the long term. Although farmers are well aware of soil erosion, effective soil conservation measures for the region are rarely practiced (Keil et al. 2009). Various reasons were identified including non-economically attractive and not meeting farmers' needs (El-Swaify 1997; Neef et al. 2000). Additionally, increased labor requirements, fear of pest disease retained in residues also hamper the acceptance. Therefore, there is a need for assessing potentially acceptance soil conservation measures on such steep slopes for their effectiveness and adoptability. The conservation measures tested in this thesis were selected based on the discussion with farmers and the local extension service. The species were chosen for the experiment because of their potential values as fodder (*Panicum maximum, Arachis pintoi*) (Ly 1992) or bean seeds (*Phaseolus calcaratus*) (Thang et al. 2004), and as soil erosion controls (Le Doanh and Tuan 2004). As the magnitude of erosion in different scales can be very different (Mai et al. 2013; Valentin et al. 2008), there is also need to monitor sediment yield and erosion pattern under farmers' practice at both catchment and plot levels. The sediment fence approach was chosen for catchment level as complementary for the bounded plots, as it avoids interference of bordering on monitored area.

Current and future growth of intensification still occurs in the development course of Northwest Vietnam or similar condition elsewhere, where a higher fertilizer use is predicted. Concomitantly, government promoted higher-yielding hybrid varieties (Pasuquin et al. 2012) requiring increased nutrients. When fertilizer in general, and particularly nitrogen fertilizer rate is increased, lower nutrient or N use efficiency is predicted (Cassman et al. 2002). As consequence, increased N-losses and lower N use efficiency negatively impact on the environment and reduce net profit of the system. To date, in many studies, ^{15}N labelled fertilizer using micro-plots has been employed to trace N flows in the system. However, not much research on N fates has been conducted on steep land under tropical rainfall conditions, particularly none without micro-plots. The present study used ^{15}N fertilizer in 'open' plots, attempting to bridge the gap of scientific knowledge on nitrogen recovery and spatial translocation downslope on steep lands (Chapter 3).

Nitrogen recovery in plant may be determined using unlabelled and labelled methods, but the measurement of N recovery in the soil and soil-plant system can only made by using ^{15}N-labelled fertilizer (Hood-Nowotny et al. 2008; Powlson et al. 1992). In many tested conservation systems, competition for nutrients or water is a driver for yield decline (Pansak et al. 2007; Dercon et al. 2006a). The carbon isotope discrimination method has been intensively used in assessing the cause for competition, and it is suggested to extend and intensify plant sampling to further evaluate temporal and spatial variations in ^{13}C values in crop samples, and relate their responses to competition for water and N (Pansak et al. 2007). Most studies on natural abundance of ^{15}N focused on discrimination and fractionation processes occurring in the soil and plant (Fry 2006). In the presented study, using both isotopes ^{13}C and ^{15}N in combination with standard methods that determine N availability and uptake is expected to explore alternative approach for assessing resource competition in soil conservation measures.

1.7 Hypotheses

The main hypotheses addressed in this thesis are:

- Soil conservation measures reduce erosion which positively affects maize yield with time as compared to the farmers' practice. Grass barrier may reduce maize yield in the first few years after establishment due to the reduction in maize cropping area (23%) but they provide animal fodder which may compensate for yield loss.
- Ground cover rate is the most important indicator relating to erosion under the same condition. The critical period for erosion is at time with lowest cover rate. When high cover rate is obtained, storms with high rainfall intensity probably just produce minor erosion.
- Soil conservation measures reduce erosion, and hence a mixed cropping system has more chance to intercept N-fertilizer added before it is eroded or leached. As consequence, maize N-uptake and nitrogen fertilizer use efficiency are increased in soil conservation systems.
- Sustainability of soil nitrogen may be achieved with minimum tillage with a legume through reducing N-losses induced by erosion and providing N input through N_2 fixation.
- *Panicum maximum* is a competitive grass, which may reduce growth rate and yield of maize rows closeby, and its impact is stronger for maize rows at lower position than at upper position.

- *Arachis pintoi*, a N_2-fixing legume, is not a competitive cover crop because its canopy is below that of maize. *Phaseolus calcaratus,* a N_2-fixing legume, as a relay crop does not compete with the main crop as it is planted later than maize by about a month.
- ^{13}C isotopic discrimination and ^{15}N natural abundance techniques in combination with data on N availability and uptake can be used to examine if competition for N occurred in the conservation systems.

1.8 Objectives

The overall objective of this thesis was to better understand the impact of different soil conservation methods on erosion, crop performance, nitrogen use efficiency and nitrogen translocation. Competition for nitrogen between maize and associated crops in the conservation systems was studied as well.

Specific objectives of the study were:

- To assess the effect of soil conservation methods *vs.* current farmers' practices on runoff and soil loss, soil cover, and maize yields and identify economically viable soil conservation options.
- To use ^{15}N labelled fertilizer for assessing N fate on steep slopes, and assess effect of soil conservation methods on N uptake and recoveries in different plant and soil compartments.
- To employ ^{13}C isotopic discrimination and ^{15}N natural abundance techniques in combination with standard methods in identifying causes for competition.

1.9 Outline of the study

This thesis comprises of three manuscripts, covering topics on soil losses, nitrogen fertilizer use efficiency and translocation, and nitrogen competition in the conservation measures on steep slopes. The study employs two experiments with bounded plots established in two communes, i.e. Chieng Hac (260 m a.s.l., 21.02° N and 104.37° E, slope 53%) and Chieng Khoi (520 m a.s.l., 21.02° N and 104.32° E, slope 59%). The experiments with bounded plots were conducted in three years (2009-2911). Besides that, at Chieng Khoi, soil loss was investigated in 2010 and 2011 under farmers' field using the sediment fence method (unbounded plots).

Chapter 2 of this thesis presents results of soil loss in both bounded and unbounded plots, runoff in bounded plots. Soil conservation in relation to soil loss, runoff and relationship between soil loss, rainfall kinetic energy and ground cover rate were intensively discussed. Given crop performance and yield between farmers' practice and conservation measure, their pros and cons, advantage and disadvantage were discussed, and improvements for each conservation measure are suggested.

The effect of maize monocropping and conservation measure on N recovery and translocation is discussed in Chapter 3. Uptake of ^{15}N fertilizer was determined at maize, associated crop, soil, and sediment.

Chapter 4 highlights the method, where ^{13}C isotopic discrimination in combination with data on N-uptake, and crop performance were used to elucidate cause of resource competition. Particularly, ^{15}N natural abundance technique was employed to assist in identifying the underlying reason of the competition.

The thesis is completed by general discussions and a summary.

Chapter 2

Mitigation potential of soil conservation in maize cropping on steep slopes

2 MITIGATION POTENTIAL OF SOIL CONSERVATION IN MAIZE CROPPING ON STEEP SLOPES[1]

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2.1 Abstract

Maize (*Zea mays*) cropping has greatly increased in Southeast Asia since the mid-1990s, mainly by expanding its production into steep forested uplands. This led to severe erosion, soil degradation, and strong environmental impacts. This study aimed at assessing the magnitude of erosion in maize and the mitigation potentiality of soil conservation measures in such environments. Bounded experimental plots established in two catchments of the Son La province of Northwest Vietnam were monitored during 2009-2011. Three soil conservation measures represented by Guinea grass (*Panicum maximum*) barriers, minimum tillage with Pinto peanut (*Arachis pintoi*) as a cover crop, and minimum tillage with relay cropping of Adzuki beans (*Phaseolus calcaratus*) were compared against the current farmers' maize cropping practice based on slashing, burning, and ploughing. Additional on-farm measurements of soil loss on maize fields

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were made using sediment fences on six convergent unbounded fields in 2010 and 2011. Under farmers' practice, annual soil losses of experimental plots reached up to 174 t ha^{-1}, being higher than those from sediment-fence plots (up to 111 t ha^{-1}). The pattern of erosion events, however, was similar in both methods. Most of the soil loss occurred in the first weeks after sowing or under maize mono cropping when high rainfall intensities coincided with a low percent ground cover of fields. Under the prevailing conditions (1270 mm rainfall, inclination 53-59%), a very high ground cover is required to keep erosion rates low which is hardly achievable by maize mono-cropping. Conservation measures had no effect on soil loss in the year of trial establishment as rainfall was low and erosive rains fell only when ground cover by plants was already high. From the second year after establishment of soil conservation measures, erosion was reduced by 39-84% in grass barriers or by 93-100% in simultaneous cover crop treatments. Maize yields, however, decreased by 26% in grass barriers or up to 35% in cover crop plots if Pinto peanuts were not cut on time. Both of these options provided animal feed, up to 5.5 t ha^{-1} yr^{-1} dry grass or 1.8 t ha^{-1} yr^{-1} dry biomass of Pinto peanuts. Guinea grass even yielded higher in 2010, a dry year with erratic rainfall distribution. Minimum tillage with relay cropping reduced soil loss by 94%, while providing similar maize yields as the controls. This latter practice is a win-win situation and, hence, attractive to farmers fostering its acceptance.

Keywords: Erosion; maize; mountain watersheds; soil conservation; upland cropping; Vietnam

2.2 Introduction

In Asia, farming systems have undergone significant changes in the past decades. Increased population pressure, rapid expansion of cereal and vegetable production, improved infrastructure, migration, and 'market forces' have contributed to this development resulting in a widespread land degradation (Pingali and Shah, 2001; Valentin et al., 2008). Traditional shifting cultivation with long fallow periods contributing to sustainability has been gradually replaced by systems with short or no fallow periods (Dung et al. 2008). With land use intensification, mountainous landscapes in Southeast Asia became dominated by less diverse rainfed upland fields, wetland rice terraces, small areas of fallow vegetation, and patches of secondary forest (Fox and Vogler, 2005; Turkelboom et al., 2008). Land use change, local people's knowledge, and economic realities, as well as natural conditions were main drivers for land degradation (Binh et al., 2008). In addition, agricultural commercialization, restrictions to use old fallows, and both, deforestation and reforestation of upper catchments have strongly modified mountainous landscapes with strong environmental impact in Southeast Asia mainland (Bruun et al. 2009; Ziegler et al., 2009).

Vien et al. (2006) stressed that the improvement of traditional systems combined with adoption of new ventures may achieve greater success than replacing them by completely new farming systems. Tomich et al. (2004) found that land use planning and other regulatory approaches had little success in Asia in the past. They concluded that further research and experimentation needs to incorporate strategic consideration of processes and spatial scales of environmental impacts and resource governance. Awareness of the importance of the link between land use change and environmental services in Southeast Asia has grown among scientists, policymakers and society. It has also been increasingly recognised that an integrated approach is required to assess the impact of new technologies and/or systems on productivity, ecosystems functions, farmers' livelihoods, markets, and potential feedback loops, necessitating the involvement of all stakeholders. Farmers' decisions about how much land to use where and for what purpose and the related consequences, however, are still poorly understood (Heistermann et al., 2006).

As in many areas of Southeast Asia, the maize (*Zea mays*) production area of Northwest Vietnam has strongly increased since the mid-1990s, mainly by expanding crop production into steep forested mountain watersheds. After weeding and burning, farmers usually plough their fields to prepare them for the next cropping season. At the onset of the monsoon rains, the tilled fields are bare and exposed to potentially large high-intensity rains. This often results in severe erosion and longer-term degradation with declining crop production on-site and strong environmental impacts off-site (Wezel et al., 2002a; Clemens et al., 2010; Schmitter et al., 2010). Turkelboom et al. (2008) attributed these adverse effects to a combination of runoff-generating areas, runoff-concentrating features, and their connectivity and interaction at landscape level. As a consequence, landslides are common. This poses a serious threat to long-term sustainability in general and may even be accelerated by the ongoing shift to produce maize for biofuels in the near future.

Despite these problems, past soil and water conservation projects have had only a limited impact on farming practices in tropical environments. Often, the suggested technologies were not economically attractive and failed to meet farmers' needs (El-Swaify, 1997; Neef et al., 2000). Other concerns include decreased yields, increased labor requirements if herbicides are not used, and the unstable socio-economic conditions of land users due to external factors such possible land reallocation (Douglas , 2006; Saint-Macary et al., 2010).

Soil cover plays an important role in erosion processes as erosion will increase with decreasing soil cover (Dung et al., 2008; Pansak et al., 2008; Chaplot et al., 2005; Podwojewski et al., 2008; Valentin et al., 2008). Effective soil conservation measures for controlling water induced erosion in tropical regions are, hence, grass barriers or minimum tillage systems combined with a legume cover (Hilger et al., 2013). These practices can greatly reduce erosion and associated nutrient losses on sloping lands, provide soil cover, and improve soil structure and infiltration. However, the use of hedgerows or other vegetative barriers are hindered by farmers' concerns over the reduction in cropping area and competition between species. These views are supported by studies showing that crop yields in rows adjacent to barriers or hedgerows are reduced due to competition for light, water, and nutrients (De Costa and Surenthran, 2005; Dercon et al., 2006b; Pansak et al., 2007). However, minimum tillage and legume relay cropping in maize fields on moderate slopes in Northeast Thailand had a positive yield response and control of soil loss (Pansak et al., 2008). Such soil conservation measures are considered as viable alternatives for tropical mountainous regions. The application domain (i.e. slope, soil type, soil fertility, weed pressure) still needs to be determined before their widespread application can be recommended.

The objectives of this study were to: (i) measure runoff and soil losses from maize cultivated on steep slopes under intensive field preparation (representing current farmers' practices); (ii) evaluate the effect of grass barriers and minimum tillage associated with cover crops, or relay cropping on soil cover, soil erosion, and maize yields; and (iii) identify economically viable soil conservation options.

2.3 Materials and methods

2.3.1 Site description

This study was carried out in two small catchments of Son La province in Northwest Vietnam. The two catchments were Chieng Hac (CH; 260 m a.s.l., 21.02° N and 104.37° E) and Chieng Khoi (CK; 520 m a.s.l., 21.02° N and 104.32° E) (Fig 2.1). The climate at both sites is characterized by tropical monsoon rains, with a rainy season from May to October and a relatively dry cool season from November to March. The mean annual temperature is 21°C and the monthly mean temperatures range from a minimum of 16°C in February to a maximum of 27°C in August (Thao, 1997). Mean annual rainfall is approximately 1200 mm (Schmitter et al., 2010). The mean slope of the plots at CH (53%) was slightly less steep than the mean slope at CK (59%). Soils at CH were classified as Alisols to Luvisols, depending on their clay content; while the soils at CK were classified as Luvisols to Calcisols depending on their carbonate content (Reinhardt, 2009; Breunig, 2011). The soil textures were clay loam at CH and clay at CK (Table 2.2). Both the percent organic matter (OM) and total N of the top soils at CH tended to be higher than at CK (OM: 2.3% and 1.9%; N: 0.14% and 0.11%, respectively). Exchangeable cations were dominated by Ca^{2+}, being lower at CH (Table 2.1).

Maize is grown on the uplands during the rainy season, followed by cassava (*Manihot esculenta*) when soil fertility decreases and fertilizer is not available. The valleys are cropped with paddy rice (*Oryza sativa*), but severe erosion after heavy rains from surrounding upland fields can result in large sediment depositions and heavy damage in paddy rice (Schad et al., 2012; Schmitter et al., 2012).

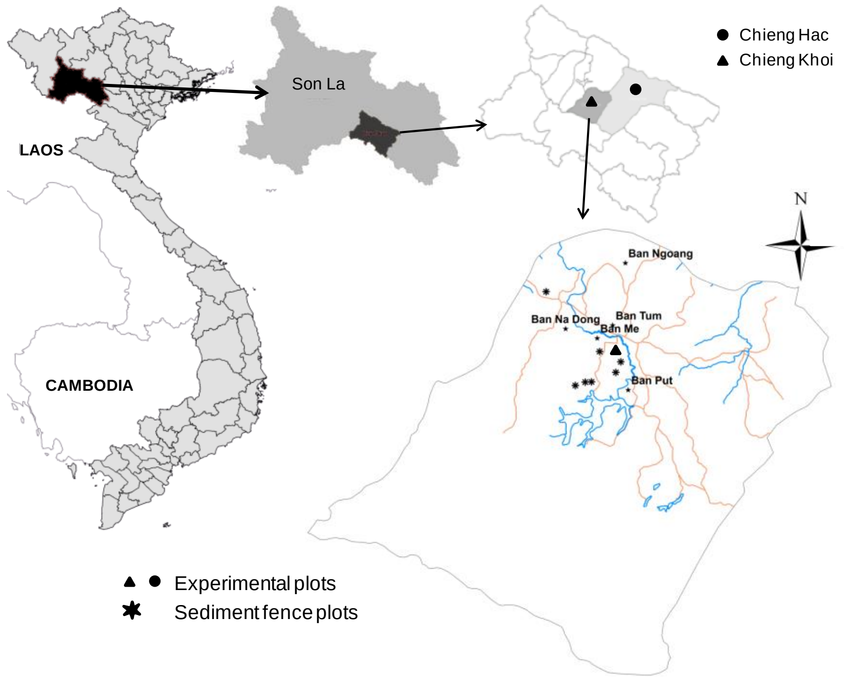

Fig 2.1. Localization of study sites in Son La province, Northwest Vietnam

Table 2.1. Top soil characteristics at Chieng Hac (CH, from Breunig, 2011) and Chieng Khoi (CK, from Reinhardt, 2009).

	Topsoil depth	Bulk density	pH_{KCl}	Texture (%)			Exchangeable cations ($mmol_c$/kg)				Organic matter	N
	(cm)	(g/cm^3)		Sand	Silt	Clay	Na	K	Ca	Mg	(%)	(%)
CH (n=3)	0-15	1.4	5.0	42.4	24.4	33.2	0.2	5.6	100	22	2.3	0.14
CK (n= 3)	0-30	1.5	6.5	33.7	19.2	47.1	0.3	4.9	225	18	1.9	0.11

2.3.2 Field experiments and experimental layout

An experiment with twelve bounded plots (hereafter referred to as experimental plots) was established in 2009 at each site using a randomized complete block design with three replicates of four treatments. Additionally, at Chieng Hac next to the experimental plots, four similar plots but unbounded and managed by famers (size 270 m² each) were established. The aim of these farmer-managed plots was to monitor bean yield after maize harvest, which was not possible on experimental plots due to destructive sampling for maize biomass yield. In Chieng Khoi, six sediment-fence plots were installed in unbounded fields as well to monitor soil loss only and to compare with bounded plot results. This resulted in three types of plots: experimental plots, farmer-managed plots and sediment-fence plots. The four treatments of the experimental and farmer-managed plots were: (i) maize under current farmers' practice based on slashing, burning and ploughing (T1, control); (ii) maize with Guinea grass (*Panicum maximum*) barriers (T2);

(iii) maize under minimum tillage with Pinto peanuts (*Arachis pintoi*) as a cover crop (T3); and (iv) maize under minimum tillage and relay cropped with Adzuki beans (*Phaseolus calcaratus*) (T4). Treatments were selected as a result of discussions during a participatory workshop with farmers, the local extension service, and researchers.

Experimental plots were 18 m long and 4 m wide (72 m^2) and bounded. At the bottom of each plot the surface runoff was directed into a plastic tank with a storage capacity of 200 L and 16 outlet hoses at the same height near the top of the tank. One of these hoses was connected to a second 200 L tank, receiving 1/16 of the overflow from the first tank.

A local hybrid variety of maize (cv. LVN-10) was planted in rows along the contour with spacing of 24 cm in the row and 75 cm between rows. All treatments received 158 kg ha^{-1} of N, 17.5 kg ha^{-1} of P, and 58.6 kg ha^{-1} of K per year. Nitrogen was split-applied with a small basal dressing at sowing (3.2%), a second one month after sowing (49.3%), and a third two months after sowing (47.5%). Further details on crop management are provided in Table 2.2.

At CK soil loss was measured in 2010 and 2011 using sets of sediment fences placed at the base of six convergent unbounded maize fields under farmers' practice (Ramos-Scharron and MacDonald, 2007). The location of sediment-fence plots is shown in Fig. 2.1. At each field, a set of two sequential fences captured eroded soil from a given contributing area. Overtop flow when receiving larger water amounts than the volume of the first fence was caught by the second fence. Sediment fences, however, only monitor soil loss but not runoff. Plot areas (S1 to S6) ranged from 420 to 1590 m^2, slope lengths from 25 to 47 m, and slope gradients from 27 to 74% (Table 2.3).

Table 2.2 Detailed description of the crop management practices for each of the four treatments.

Treatment	Details
Maize under farmer's practice (T1)	Maize residues from the previous season and weeds were piled and burnt after drying, followed by a second weeding and burning just before planting. Contour furrows were established by ploughing to a depth of 15 cm Depending on rainfall pattern and locality, ploughing was repeated, followed by furrows preparation and hand-seeding using a hoe. Maize seeds were put in furrows and covered with soil. Weeds were removed by hand hoeing. In 2011 a herbicide was applied before sowing.
Maize with *Panicum maximum* grass barrier (T2)	Tillage, planting and weeding was done in the same way as in T1. Four 1m wide *Panicum maximum* barriers were transplanted at intervals of 6m on June 6th and 9th of 2009 at Chieng Khoi (CK) and Chieng Hac (CH), respectively. The area reserved for barriers was 23%. Grass barriers were regularly cut: in CK 2, 5 and 4 times and in CH 2, 6, and 4 times in 2009, 2010, and 2011, respectively.

	Grass was used as fodder in a-cut-and-carry system.
Maize under minimum tillage with *Arachis pintoi* (T3)	Crop residues from the previous season and slashed weeds were left as mulch. Contour furrows were established by hoeing, followed by hand-seeding. Weeds were removed by hand hoeing at the same time as in T1. *Arachis pintoi* was transplanted on June 10^{th} and 13^{rd} of 2009 at CH and CK, respectively. In 2010 and 2011 *A. pintoi* was cut in early season when its growth was considered proliferate (twice in 2010 for CK, three times for both sites in 2011). The cut materials were used as fodder.
Maize under minimum tillage with relay cropping of *Phaseolus calcaratus* (T4)	Minimum tillage and weed control was done in the same way as in T3 except in 2011 when an herbicide was applied before ploughing. *Phaseolus calcaratus* was always sown between maize rows one month after maize sowing. *P. calcaratus* yield was assessed from farmers managed plot at CH.

Table 2.3 Site characteristics, soil loss rates from the six sediment-fence plots for 2010 and 2011 at Chieng Khoi.

Sediment fence ID	Area	Slope length	Slope gradient	2010 soil loss	2011 soil loss
	(m^2)	(m)	(%)	(t ha^{-1})	(t ha^{-1})
S1	1,590	47	55	18	22
S2	490	40	37	49	30
S3	1,410	41	27	33	10
S4	420	41	43	103	29
S5	730	30	41	50	14
S6	590	28	74	111	55

2.3.3 Data collection and analyses

Rainfall: In each catchment, rainfall was measured with a set of tipping bucket rain gauges (MD532-HOBO, UP GmbH, Germany) (0.24 mm/tip) connected to a logger (HOBO-UA 003-64 Pendant, Onset Computer corp., USA). Storm kinetic energy (EI_{30}) was calculated using the rainfall intensity summarization tool (RIST) version 3.6 (Dabley and Justice, 2012), and the following equation (McGregor et al., 1995):

$$EI_{30} = 1099[1-0.72\exp(-1.27i)] \quad (1)$$

where, *i* is maximum intensity of 30 minutes. The kinetic energy of the rainstorms occurring on each day was summed to obtain a daily kinetic energy *E*. Sigmaplot version 11.0 (Systat Software Inc., 2008) was used to select graphs fitting the relationship between kinetic energy, percent ground cover and soil loss data monitored over three years (2009-2010).

Runoff and sediment collection: Runoff from experimental plots was measured after every rainfall that produced runoff by using a tape adhered to a stick. The overlying water was siphoned off and the deposited sediment was collected from the bottom of the tanks, that was weighed and subsampled. Sediment sampling in sediment-fence plots was done in a manner identical to that of experimental plots. Subsamples were dried at 60°C until constant weight was reached to measure percent water content. The measured weights in the field were corrected for moisture content, divided by the contributing area, and summed to obtain an annual soil loss in metric tons per hectare. In April 2009, one or two times, depending on the site, runoff was not collected due to plot establishment.

Plant sampling: At physiological maturity the maize cobs and above-ground biomass were harvested row-wise excluding border plants and weighed in the field to determine their fresh weight. Fresh subsamples of these materials were weighed, air-dried, oven dried at 60°C until constant weight was reached, and weighed again to determine fresh/dry weight ratios. These ratios were used to convert the field-measured fresh weights to dry weights. In all cases, the measured maize yields were divided by the total plot area, including the areas devoted to grass barriers.

Ground cover measurements: In the experimental plots, soil cover was monitored in the first two years at 88-100 points in each plot using a transect method (Benavides-Solorio and MacDonald, 2001). In the third year, ground cover was determined by taking photos from 3.5m above the ground using a digital camera Canon IXY 910 IS. An L-shaped aluminum stick was used to place the camera 3.5m high above and perpendicular to the ground. A rope with a metal cone at its end and connected to the top of the L-shaped stick controlled the upright position of the stick during image taking. Six images were taken on each plot, covering about half of the plot area. These images were visually evaluated by 'SamplePoint', free available image analysis software for natural resources (ARS-USDA, 2011). Comparisons of these two methods for four of the experimental plots in Chieng Khoi showed no significant ($p<0.05$) differences. At both sites, ground cover was assessed four times in 2009, three times in 2010, and seven times in 2011. In 2009 and 2010 ground cover at the time of sowing was assumed to be zero in the controls (T1) and 23% in T2 (equal to grass barrier area) due to tillage operations. Percent ground cover at the time of sowing for 2009 and 2010 in the minimum tillage plots (T3, T4) was interpolated by the ratio of residues in 2009 and 2010 to that in 2011 when cover rate was measured. Between measurements ground cover was estimated using linear interpolation.

Experimental plot data sets on soil loss and percent ground cover were grouped into four periods. The first period started from tillage till two weeks before sowing, when unsaturated soil could absorb early rainfalls ('infiltration period' lasting about 1 month). The second period was supposed to be susceptible to erosion, from two weeks before sowing until about one month after sowing ('early season', approximately 1.5 month at low ground cover <30%). The third period ('mid-season') with a medium cover rate of 30-70% occurred during rapid maize growth. The fourth period ('late growing season') was characterized by a high ground cover rate of more than 70%. Time spans of the last three periods refer to T1, the control; whereas, ground cover rate classes apply for the conservation treatments T2-T4, where higher rates may have reached threshold levels earlier than in the control. These periods were used to assess the relationship between kinetic energy of the rain (rain erosivity) and soil loss.

Data analysis: For the experimental plots, the effect of the different soil conservation measures on soil loss, maize yields, and above-ground maize biomass were assessed over three years and across the two sites by the PROC MIXED model of SAS ver. 9.0. A square root transformation was used to normalize the soil loss data. When the *F*-test was significant, LSMEANS was used to identify the significant ($p<0.05$) differences among means. This procedure was also applied for the Guinea grass and Pinto peanut yield analysis.

2.4 Results

2.4.1 Rainfall, runoff, and soil loss by time and soil conservation treatment

At CH the annual rainfall increased each year, as there was 930 mm in 2009, 1305 mm in 2010, and 1529 mm in 2011. At CK the annual rainfall was higher in 2009 at 1035 mm and again in 2010 at 1488mm. However, in 2011, the rainfall at CK dropped to 1299 mm. The rainfalls of the second and third year were higher than the 10-year average of 1200 mm (Schmitter et al., 2010), while being lower in the first year. The total number of rains was higher at CH as compared to CK and dominated by small rains (<10 mm) at both sites (Table 2.4). The number of rains with higher intensities (50-100 mm) was similar at both sites.

In the first year, soil conservation did not influence runoff due to establishment of the barriers or cover crop after critical period of erosion at middle of season (Table 2.2). Moreover, in the first year, annual rainfall was lowest among all monitored years and rains with high intensity came after maize canopy closure which in combination with weeds well protected soils against runoff (Fig. 2.2). Soil conservation significantly reduced runoff in the following years. In 2010, runoff in soil conservation treatments was significantly lower at both sites than that in the controls, except for the relay cropping treatment (T4) at CK. In the final year of observation, significantly reduced runoff was observed in relay cropping at CH; while in CK, T3 had the lowest runoff.

In the year of trial establishment (2009) the soil loss in the plots with farmers' practices (T1) ranged from 3 to 7.0 t ha^{-1} in CH and from 25 to 42 t ha^{-1} in CK (Fig. 2.2). In 2010, the mean soil loss from the farmers' practices (T1) increased by more than an order of magnitude at CH to 87 t ha^{-1}, and by about a factor of five at CH to 174 t ha^{-1} CK. In 2011, the mean soil loss dropped to 37 t ha^{-1} at CH and 120 t ha^{-1} at CK. Fluctuation in soil loss over three years was partly attributed to high variations in total annual rainfall and number of erosive rains. In 2009, the number of rains with intensities of 10-20 mm and 20-30 mm day^{-1} was higher at CK (Table 2.4). In the second year, at CK there were again a higher number of days in the rainfall categories 20-30 mm and 30-50 mm compared to CH. The third year was characterized by a higher number of rains in categories 10-20 mm and 50-100 mm at CK, while CH had a higher number in the categories 20-30 mm and 30-50 mm.

Table 2.4 Rainfall, number of days with rainfall in various categories at study sites.

Rainfall	**-------- Chieng Hac -------**			**-------- Chieng Khoi-------**		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**
Total amount (mm)	930	1337	1529	1035	1488	1299
< 10 mm	101	118	115	46	81	91
10-20 mm	9	19	14	17	17	21
20-30 mm	4	11	10	6	15	7
30-50 mm	5	8	11	5	10	6
50-100 mm	5	4	6	4	4	6
Total days	124	160	156	78	127	131

Table 2.5 Change (%) in annual soil loss and runoff for each treatment and each year relative to the controls (farmers' practice). Negative or positive values indicate percent reduction or increase.

Runoff		2009	2010	2011
Chieng Hac	T2: Grass barrier	-7	-56	-21
	T3: Min. tillage + cover crop	9	-90	-48
	T4: Min. tillage + relay crop	57	-90	-56
Chieng Khoi	T2: Grass barrier	-58	-61	26
	T3: Min. tillage + cover crop	-49	-92	-54
	T4: Min. tillage + relay crop	1	-26	-22
Soil loss		2009	2010	2011
Chieng Hac	T2: Grass barrier	17	-84	-60
	T3: Min. tillage + cover crop	-50	-99	-93
	T4: Min. tillage + relay crop	35	-94	-82
Chieng Khoi	T2: Grass barrier	-27	-39	-48
	T3: Min. tillage + cover crop	-39	-100	-94
	T4: Min. tillage + relay crop	-25	-52	-79

Soil conservation had no effect on soil loss during the establishment phase in 2009 but significantly reduced erosion in the second and third year when there were much higher erosion rates in the controls (Table 2.5, Fig. 2.2). More specifically, the grass barriers (T2) reduced erosion at CH to just 16% of the controls in 2010 and 40% in 2011. At CK, the grass barriers reduced erosion to 61% of the controls in 2010 and 52% of the controls in 2011.

Minimum tillage with either simultaneous cover crops (T3) or relay cropping (T4) caused an even stronger reduction in soil loss. Soil loss under T3 was only 0-1% of the controls in 2010 and 4-7% in 2011 (Table 2.5). At CH, relay cropping (T4) had a similar impact with a soil loss of only 6% of the controls in 2010 and 18% in 2011. Relay cropping was not as effective at CK, as the measured erosion rates were 48 and 21% of the controls in 2010 and 2011, respectively. In 2011, minimum tillage with a cover crop yielded a significantly lower soil loss relative to the controls and the grass barriers at CH. At CK, each of the soil conservation treatments significantly differed from each other (T3 < T4 < T2 < T1) (Fig. 2.2).

The ratio of annual soil loss to annual runoff decreased over time when soil conservation was applied (Fig. 2.3), indicating an increase in efficiency of the tested measures against surface flow of the same amount with ongoing treatment time.

Annual soil loss from sediment-fence plots ranged from 18 to 111 t ha^{-1} in 2010 and from 10 to 55 t ha^{-1} in 2011 (Table 2.3). The lower soil loss in the second year was attributed to a lower number of days with rains exceeding 20 mm (29 days in 2010 *vs.* 19 days in 2011). The highest soil loss in each year was from plot S6, and this had the steepest slope at almost 74% (Table 2.3). Both the absolute and the relative erosion rates between years are consistent with the measured values from the farmer's practices in the experimental plots, and this suggests that the measured erosion rates are more broadly applicable.

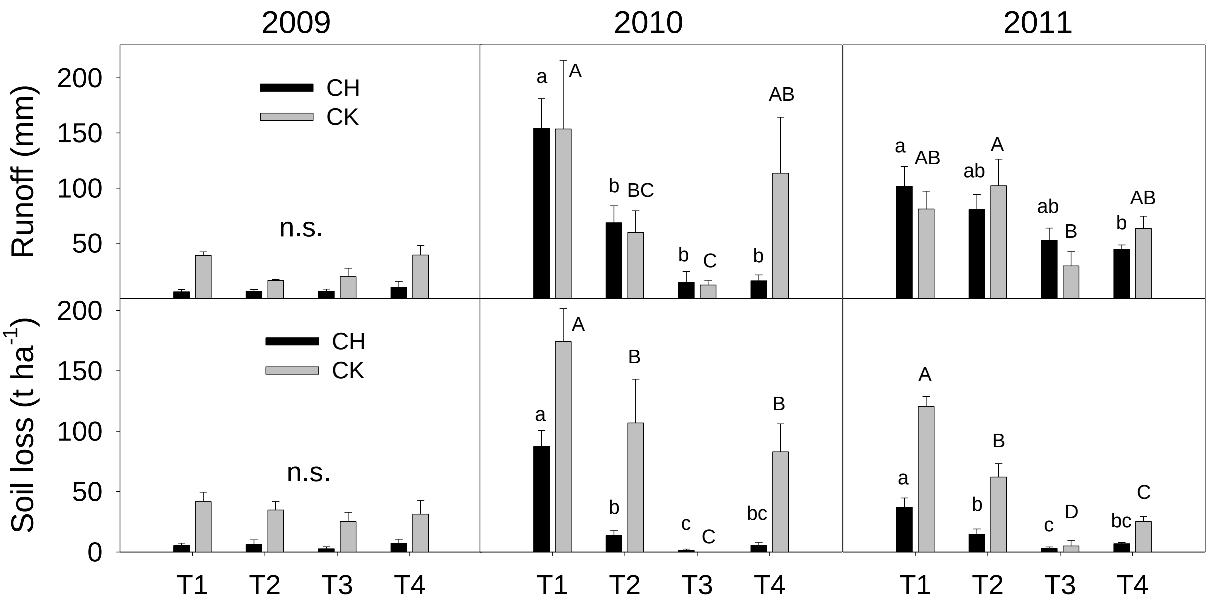

Fig. 2.2 Annual runoff (mm) and soil loss (t/ha) from experimental plots for each treatment and year expressed as means and standard errors. CH: Chieng Hac; CK:

Chieng Khoi; T1: control; T2: grass barrier; T3: minimum tillage + cover crop; T4: minimum tillage + relay crop. Bars with different letters indicate significant ($p<0.05$) differences within a site; n.s. = non-significant.

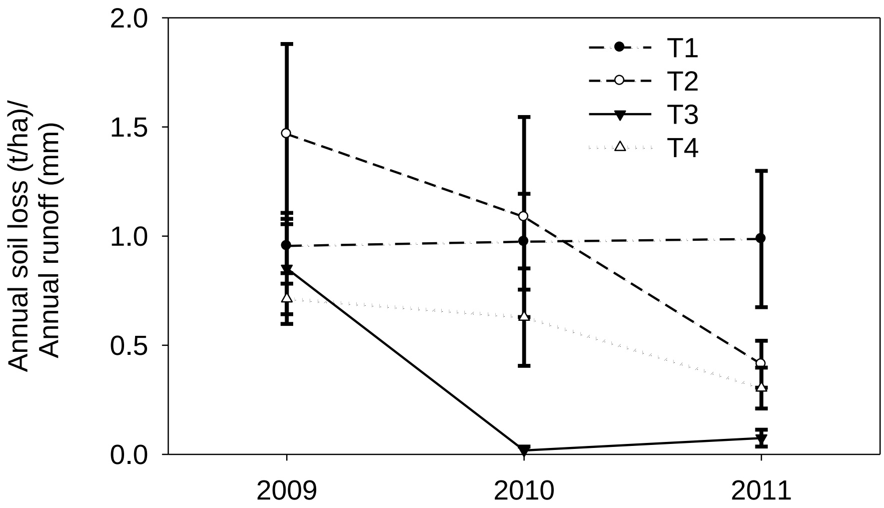

Fig. 2.3 Ratio of annual soil loss and runoff from experimental plots over three years (2009-2011). Each symbol represents the mean of six values (two sites, three replicates per site). The bars indicate one standard error. T1: control; T2: grass barrier; T3: minimum tillage + cover crop; T4: minimum tillage + relay crop.

2.4.2 Impact of rainfall and ground cover on soil loss

The timing and amount of soil loss was similar between the farmers' practice treatment in the experimental plots and in the sediment fences. In both cases, most of the erosion occurred around the time of planting when the soil surface was bare due to tillage operations or low plant cover (Figure 4). After this period, even high rains did not automatically lead to soil loss. At planting, the mean ground cover for T1 was usually less than 10%. By the third year of the experiment, the grass barrier treatment (T2) averaged 29% ground cover at both sites. Highest ground cover was observed in the minimum tillage with cover crop plots, averaging >93 for both, CH and CK. By the same time, minimum tillage with a relay crop treatment achieved only 66% and 63% ground cover respectively (Figures 4A and 4B). Soil covers before planting were given by weeds in T1, and by planted species and weeds in other treatments.

Before sowing when soil was unsaturated, rainfall with low to moderate rainfall intensity at that time did not cause significant soil loss, mostly less than 0.2 t ha^{-1} per storm (Fig. 2.5). During 'early season' period, considered as susceptible to erosion, high rainfall erosivity significantly increased soil loss of T1, T2, and T4, represented by linear relationship with slopes of 0.025, 0.014, and 0.008, respectively; but not for T3, explaining the reason for the very low cumulative erosion in this treatment. During the next period when ground cover rates of 30-70% in T1, T2, and T3 were not enough to protect the soil from erosion, increasing erosivity resulted in linear increases of soil loss with magnitude of slope in order of 0.021, 0.009, 0.005, and 0.001 for T1, T2, T4, and T3, respectively. The pattern of this relationship at high cover rate period was again at the same order but with lower slopes. By that time, some heavy storms just produced only runoff with very small or even zero soil loss, which further highlighted the importance of ground cover provided by maize after canopy closure, and by weeds in intercepting rains and reducing their kinetic energy. The grass barriers appeared to reduce erosion per unit rainfall erosivity, as the regression had a lower slope and lower *y* intercept. Minimum tillage with a simultaneous cover crop (T3) showed the lowest soil loss per unit erosivity as this had the lowest regression slopes (Fig. 2.5). Minimum tillage with a relay cover crop (T4) also tended to reduce soil loss, represented by lower regression slopes than T1 and T2 but higher compared to T3.

Since most of the soil loss occurred early in the cropping period when there was less cover, ground cover at the onset of the cropping season was plotted against annual soil loss in experimental plots for two sites (Fig. 2.6). The data showed a significant decline in annual soil loss as percent ground cover increased (R^2=0.29, p<0.001).

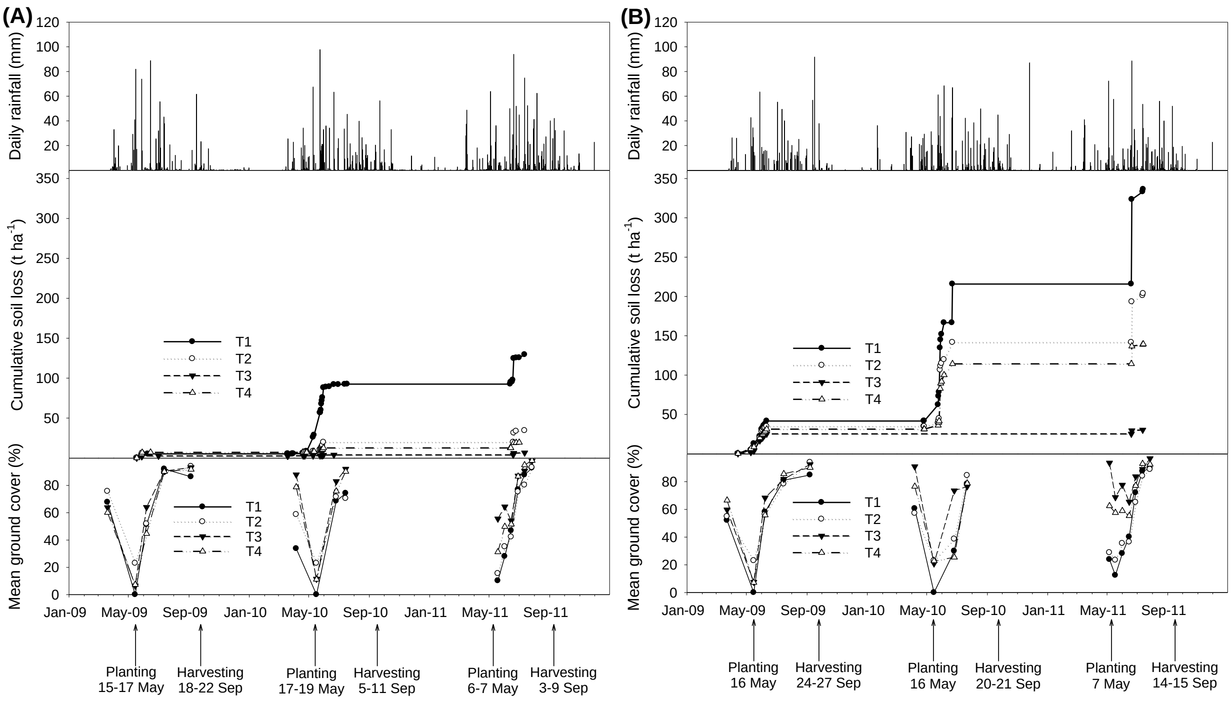

Fig. 2.4 Cumulative soil loss, daily rainfall and mean percent ground cover with time as affected by soil conservation for the observation period 2009-2011 from experimental plots at (A) Chieng Hac and (B) Chieng Khoi. T1: control; T2: grass barrier; T3: minimum tillage + cover crop; T4: minimum tillage + relay crop.

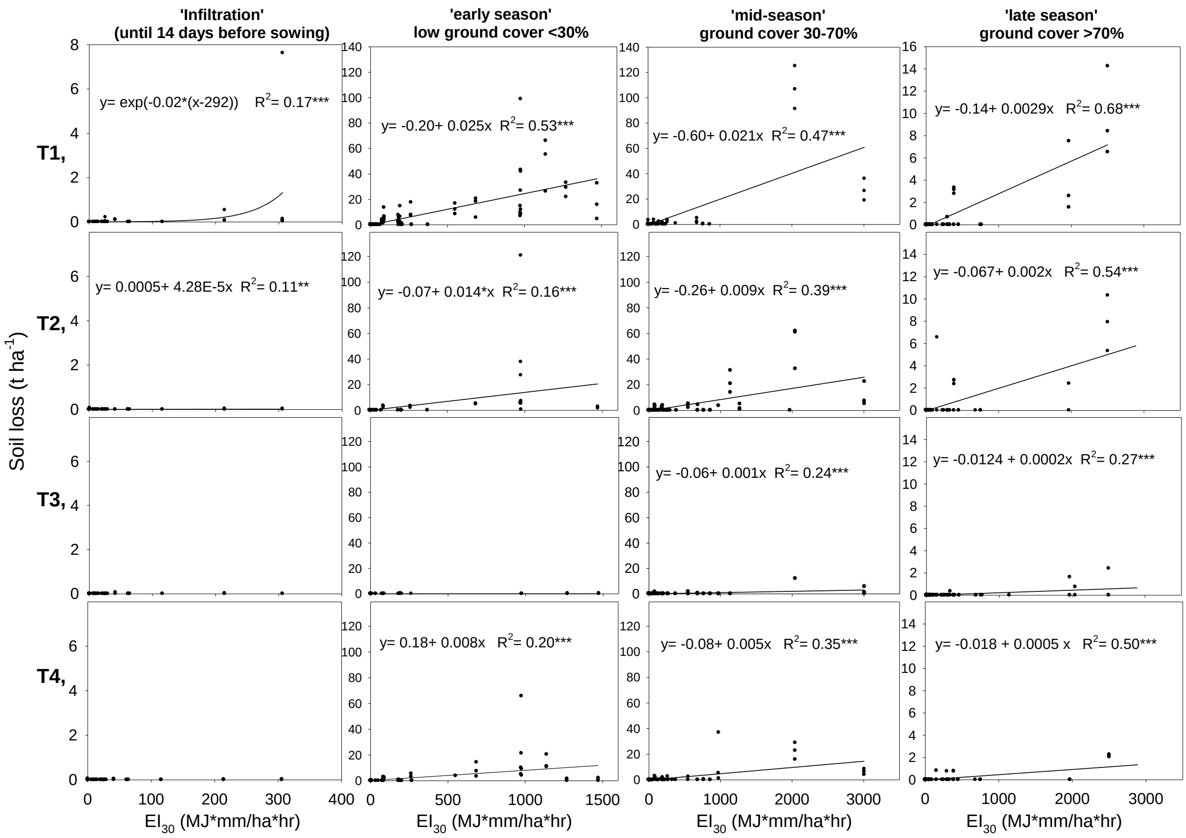

Fig. 2.5 Relationship between rainfall erosivity (EI_{30}) and event-based soil loss for four periods ("infiltration", "early season", "mid-season", "late growing season") for each of the four treatments from experimental plots in 2009-2011. T1: control; T2: grass barrier; T3: minimum tillage + cover crop; T4: minimum tillage + relay crop.

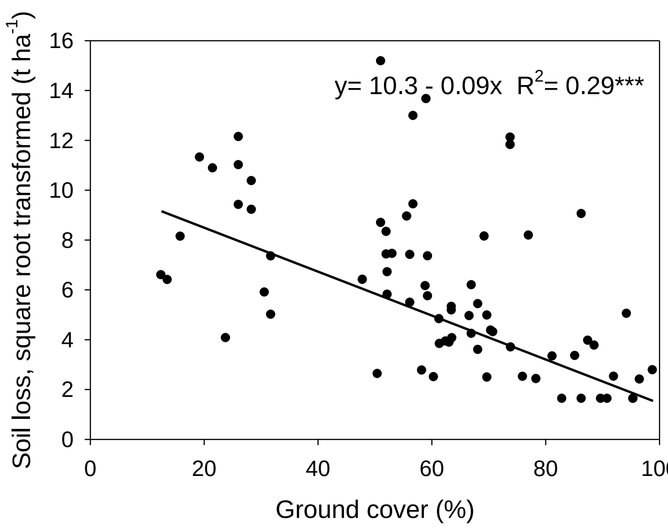

Fig. 2.6 Relationship between percent ground cover and annual soil loss from experimental plots over three years (2009-2011). Ground cover was measured during the erosive period at the onset of the cropping season, and annual soil loss was summed up from all events each year. Soil loss data were square root transformed.

2.4.3 Yields and above ground biomass of maize, cover crops and grass barriers

At both sites, yields declined from the first to second year (2010) but tended to increase again in the third year (Table 2.6). In 2010 maize suffered from a drought period, coinciding with the flowering stage of maize, a very sensitive period for maize yields, and causing strong maize yield losses all over the region (Yen Chau Dept. Agriculture, 2010, 2011).

In the first year, the soil conservation measures had no significant effect on maize yields (Table 2.6). In the second and third years the maize yields for T2 were significantly lower than the controls at CH, while at CK the maize yields were only significantly lower in 2011. At Chieng Hac, grass barriers (T2) reduced maize yields by 34% in the second and third year, respectively. For Chieng Khoi, the yield losses induced by grass barriers were less strong, reaching 18%. Both minimum tillage treatments (T3, T4) had often similar or sometimes even higher yields as the controls (T1), except in 2010 in CK when the yield for T3 was even lower than T2. Severe reduction of maize yield of T3 at CK due to proliferate growth of Pinto peanuts at early season in 2010 was eliminated by cutting them on time in the following year. Maize yields of T4 did not differ significantly as compared to T1 but showed even higher yields than the control in 2010, indicating no competition between the main and the relay crops.

Maize above ground biomass production showed a similar pattern as that of grain yield. Overall, conservation measure and year significantly affected above ground biomass (Table 2.6). The use of grass barriers significantly reduced above ground biomass in the second and third year as compared to the control at CH. At Chieng Khoi, above ground biomass of T2 was significantly lower as compared to T4 but showed no significant differences to those of T1 and T3 in 2010. The above ground biomass of T3 compared to T4 was also significantly lower. In the third year, at CK, above ground biomass of all treatments were not significantly different.

In all years, grass biomass production was significantly ($p<0.05$) higher at CH. Guinea grass grew well and made cutting possible even in the first season already soon after its establishment (1.4 t ha^{-1} and 0.4 t ha^{-1} at CH, and at CK, respectively). In the second year, grass biomass yield was highest with 5.5 tons at CH and 3.6 t ha^{-1} at CK despite dry spells which limited maize growth in this year. However, grass biomass decreased to 3.8 and 2.7 t ha^{-1} in the third year at CH and CK, respectively.

At CH, slow development allowed cutting of Pinto peanuts only in the third year (0.5 t ha^{-1}) but at CK, this was done already the second year (2010: 1.2 t ha^{-1}; 2011: 1.8 t ha^{-1}). Adzuki bean yield can amount to 1.2 t ha^{-1} as observed in farmer-managed plots at CH in 2010 (data not shown). Labor shortage in 2011 led to a delay of Adzuki bean harvest. Therefore, most pods dropped to the ground so there are no data on bean yields.

Table 2.6 Yield and above ground biomass of maize (t ha^{-1}) at harvest for each treatment and each year expressed as absolute values and percent of the controls (farmer's practices). Values are means and standard errors, and different letters indicate significant differences ($p<0.05$).

Maize yield		**2009**	**%**	**2010**	**%**	**2011**	**%**
Chieng Hac	T1:Farmers' practice	5.7±0.4 a	100	4.1±0.1 a	100	5.2±0.1 a	100
	T2: Grass barrier	5.0±0.2 a	86	2.7±0.1 b	66	3.5±0.3 b	66
	T3: Min. tillage + cover crop	5.1±0.5 a	89	4.7±0.2 a	115	4.5±0.4 a	86
	T4: Min. tillage + relay crop	5.4±0.5 a	94	4.5±0.3 a	111	5.1±0.1 a	98
Chieng Khoi	T1:Farmers' practice	5.8±0.4 a	100	3.4±0.6 b	100	5.3±0.1 a	100
	T2: Grass barrier	5.8±0.6 a	100	2.8±0.3 bc	82	4.4±0.4 b	82
	T3: Min. tillage + cover crop	5.9±0.1 a	109	2.2±0.3 c	65	4.5±0.2 ab	84
	T4: Min. tillage + relay crop	5.4±0.2 a	93	4.5±0.2 a	132	5.4±0.3 a	101
Maize above ground biomass		**2009**	**%**	**2010**	**%**	**2011**	**%**
Chieng Hac	T1:Farmers' practice	12.4±0.8 a	100	8.6±0.1 a	100	10.5±0.3 a	100
	T2: Grass barrier	10.8±0.4 a	87	5.7±0.1 b	66	6.9±0.6 b	66
	T3: Min. tillage + cover crop	10.8±1.0 a	87	9.5±0.5 a	111	9.5±0.7 a	90
	T4: Min. tillage + relay crop	12.5±0.9 a	101	9.1±0.7 a	105	10.4±0.1 a	99
Chieng Khoi	T1:Farmers' practice	11.7±0.8 a	100	6.7±1.1 ab	100	10.5±0.2 a	100
	T2: Grass barrier	11.7±1.2 a	100	5.7±0.6 b	85	8.6±0.8 a	82
	T3: Min. tillage + cover crop	12.8±0.7 a	109	5.0±0.7 b	74	9.2±0.6 a	88
	T4: Min. tillage + relay crop	10.9±0.2 a	93	8.6±0.3 a	127	10.3±0.6 a	98

2.5 Discussion

2.5.1 Site effects on soil loss

A significantly higher soil loss (Table 2.3, Fig. 2.2) at Chieng Khoi relative to Chieng Hac, despite similar runoff (P=0.08), suggests that Chieng Khoi may have a higher erodibility which can be attributed to several factors. First, the mean slope was steeper at CK (59%) as compared to CH (53%). The slope effect is often considered to be a positive exponential function and to be stronger in the tropics where rainfall is heavier (Morgan, 2005). Second, the soil at CK had higher sodium content. Sodium tends to disperse soil aggregates, which would make the soils more susceptible to erosion (Mills and Fey, 2004). The sandier and less clayey texture at CH may have fostered water infiltration and, hence, decreased surface runoff (Mamedov et al., 2001). Finally, the soils at CK tend to have less organic matter and higher calcium than at CH, and this again would lead to a lower aggregate stability as well as more surface sealing (Le Bissonnais and Arrouays, 1997). No significant differences were observed for percent ground cover between the two sites ($p<0.05$).

Soil loss under current farmers' practice was unsustainably high, averaging 43 and 112 t ha-^{1} yr^{-1} for the experimental plots at CH and CK, respectively, and 44 t ha^{-1} yr^{-1} for the sediment-fence plots at CK. These high losses occurred even though the farmers use contour ploughing and cropping instead of up-and-down slope cultivation, usually a suitable measure to reduce erosion (Morgan, 2005). Repeated tilling and cropping, as done by most farmers in the study area, break down soil aggregates and decrease surface cover by crop residues, accelerating the erosion risk (Engel et al., 2009). The breakdown of soil aggregates also facilitates surface sealing that reduces infiltration (Cogo et al., 1983).

The multiple tillage operations are probably part of the problem. After harvesting maize, the farmers usually slash and burn their fields in December and again in March to remove weeds. The fields are then deep-ploughed at the onset of the rainy season, followed by a second finer ploughing. Seedbed preparation and planting is carried out when soil moisture has sufficiently increased to allow germination. Altogether, these operations greatly increase the erodibility of the soil, and the low soil cover at the beginning of the rainy season or after weeding fosters soil crusting. The resulting surface runoff helps promote surface erosion, and rills commonly form in the early part of the rainy season before canopy closure (Podwojewski et al., 2008). Our erosion rates are very similar to the 43 t ha^{-1} yr^{-1} measured under cassava in the same region (Phien and Loan, 2005), but slightly higher with a soil loss of 7-22 t ha^{-1} yr^{-1} under mono cropped cassava or upland rice as observed on another northwest Vietnamese site under similar conditions but less steep slopes (Dung et al., 2008). A study of Phong (1995) on steep slopes in Northwest Vietnam measured soil losses of 175-260 t ha^{-1} yr^{-1}. We also measured a mean annual erosion rate of 174 t ha^{-1} in 2010 at CK, indicating that the erosion rates measured in this study were consistent with other studies. It is important to recognize that erosion rates under farmer's practices were only 5.2 t ha^{-1} at CH in 2009. This indicates that erosion rates under farmer's practices can vary quite substantially from year to year and from site to site (Fig. 2.2).

2.5.2 Comparison of soil loss between experimental and sediment-fence plots

In sediment-fence plots erosion was slightly lower compared to experimental plots. Higher infiltration rates or gentler slopes at the bottom of the plot due to sediment deposition are possible reasons of this decrease (Morgan, 2005). Soil loss in the sediment-fence plots also was highly variable between years and sites, although the range of 10 to 110 t ha^{-1} yr^{-1} was less than the variability in the experimental plots (Table 2.3). The high values from S6 could be at least partially explained by the steeper slope, while the relatively high values from S4 might be attributed to past land use history. The latter site was cleared from secondary forest and planted with upland rice from 1986-1999 followed by cassava as the soil fertility declined (Balagopalan et al., 1988). In 2007, this site returned to maize cultivation which was possible due to fertilizer application. While plot S1 had a steeper slope and longer slope length than plot S4, here cassava was planted from 1980 to 2003 before being converted to maize. The soil in S1 was observed to have a better maize growth (4.3-5.5 t ha^{-1} at S1, 2.8-3.0 t ha^{-1} at S4 in two monitored years, data not shown) associated with a higher level of soil fertility and probably better structure, which would reduce both the propensity for soil sealing and soil erodibility. In addition the better maize growth may have contributed soil cover during early growth stages leading to a faster canopy closure making S1 plot less susceptible to erosion (Pansak et al. 2010). Land use history is a potentially important control on soil properties and can affect both erosion and crop yields, but the data presented here suggest that the variations in rainfall and topography are generally more important controls, at least at the spatial scale of this study.

2.5.3 Ground cover rate, rainfall kinetic energy and erosion

The highest soil loss of 108 t ha^{-1} per day for the control treatment (T1) occurred on June 20^{th}, 2011 in Chieng Khoi. This severe erosion was caused by a rainfall with a kinetic energy of 2044 MJ ha^{-1} mm h^{-1}, whereas a storm event with an even higher energy of 2504 MJ ha^{-1} mm h^{-1} 22 days later caused a soil loss of just 9.7 t ha^{-1}. The first storm occurred when there was 60% ground cover, while the second occurred when the ground cover was at 87%. A field trial with similar treatments but much gentler slope gradients (21-28%) found that soil loss was negligible under minimum tillage and Jack bean (*Canavalia ensiformis*) relay cropping when the ground cover was greater than 60% (Pansak et al., 2008). Other studies under widely different conditions found similar results (Larsen et al., 2009). In our study, a site with a steep slope gradient and high rainfall erosivity, a higher percent ground cover was required to protect the soil fully. The temporal pattern of soil loss at both sites showed that the most critical period was just a few weeks after sowing when percent ground cover was <30%, and again this threshold is consistent with studies under different conditions (Benavides-Solorio and MacDonald, 2001; Duran and Rodriguez, 2008). As the ground cover increased as a result of the growth of the maize, weeds, and cover crops, the risk of soil loss was greatly reduced. The differences in ground cover can explain why minimum tillage combined with cover crops (T3) or relay crops (T4) decreased soil loss significantly compared to conventional cropping. Crop residue mulch in combination with minimum tillage (T3, T4) effectively reduces soil erosion by providing a protective layer to the soil surface, increasing resistance against rain splash, soil sealing and crusting, and overland water flow. Enhancing soil surface aggregate stability and permeability through mulch combined physical and biological effects, resulting increased pore volume lead to improved infiltration and water storage (Roth et al., 1988; Erenstein, 2002; Thierfelder and Wall, 2009). Under tropical conditions, this can be achieved within three years (Pansak et al. 2010), which is a time frame being acceptable for famers.

When assessing cover, it is important to distinguish between ground cover, which might be considered as litter, mulch, and rocks that are in direct contact with the soil, and cover provided by the plant canopy, which is not in direct contact with the soil. According to Wischmeier (1975), cited in Morgan (2005) and Laflen and Colvin (1981), there is an exponential decrease of soil loss with increasing ground cover; and this relationship has been repeatedly demonstrated (Duran and Rodriguez, 2008; Larsen et al., 2009). In contrast, the percent cover provided by the plant canopy has a more linear relationship with soil loss (Wischmeier and Smith, 1978).

Our measurements of 'ground cover' included both the ground cover in contact with the soil and the plant canopy, and we found power relationship between annual soil losses and cover (Fig. 2.6). Based on this regression, y= 10.3-0.09x, where *y* is square root transformed soil loss and *x* is ground cover rate, a minimum ground cover of 95% was calculated to reduce erosion to values that are below the 3 t ha^{-1} yr^{-1} considered as a tolerable soil loss under tropical conditions by Valentin et al., 2008. It is very difficult to obtain such a high cover early in the cropping season when the primary crop is a monoculture. There also is a methodological question of how to assess cover, and what type of cover should be used to relate cover and soil loss. We had trouble finding a standard method to measure ground cover (Booth et al., 2006; Duran and Rodriguez, 2008; Ha et al., 2012), but we found that the point transect method and digital photo interpretation yielded similar results, and both of these methods included both types of cover. Finally, combining digital photography with the image analysis software 'SamplePoint' to assess ground cover is an alternative to the transect method and can also be attractive for more detailed assessments of ground cover regarding spatial distribution and time. The L-shaped stick used to support a camera at a desired height is relatively cheap, mobile and simple to operate, permitting a higher frequency of sampling with a minimized trampling in monitored plots, and reducing labor requirement.

2.5.4 Potential use of soil conservation measures

Well-established grass barriers reduced soil loss, provided fodder for ruminants but significantly decreased maize yields by an average of 26% in experimental plots. The yield reduction can be attributed to competition and the reduction in maize cropping area. Though many researchers observed crop growth suppression on rows adjacent to grass strips or hedges (Garrity et al., 1995; Dercon et al., 2006b; Pansak et al., 2007), there are a number of possible causes. Some studies have suggested that fertile topsoil is displaced downhill by erosion within alley (Garrity et al., 1995) or by tillage (Thapa et al., 1999; Dercon et al., 2006b), exposing less fertile subsoil in the alley. Pansak et al. (2007) concluded that the combination of reduced cropping area and reduced soil nitrogen availability accounts for the yield depression. In the same region, a *Tephrosia candida* hedgerow system resulted in a 10% reduction in cropping area and a yield decline in the first few years after establishment; thereafter, soil fertility improved and crop yields increased to the level before hedges were established (Phien and Loan, 2005).

In contrast to maize, grass biomass production was much higher in 2010 than in 2011, the latter being a year with an even rainfall distribution. Guinea grass is a relatively drought tolerant grass (Wilson et al., 1980) and hence performed well in the drier year of 2010. Thereby, grass barriers may increase farmers' acceptance as it mitigates risks associated with erratic rainfall patterns. Grass is suitable for the grazing livestock and also is used for feeding fish (Cook et al., 2005). In economic terms, the cumulative three years reduction in maize yields for the T2 treatment was 3.8 t ha^{-1} at CH and 1.5 t ha^{-1} at CK (Table 2.6). The corresponding returns from grass production for the two sites, assuming a food conversion ratio of 18.4 kg dry matter per 1 kg grass carp (Shireman et al., 1978), were 580 and 365 kg ha^{-1} of grass carp, respectively. Without counting the labor costs for maintenance, the potential net returns over three year were 1013 and 801 US $ per ha maize with grass barriers for CH and CK, respectively (data not shown). Although, adoption decisions heavily rely on the returns if grass was used for feeding grass carp in fish pond, it is not the only factor that farmers consider (Erenstein, 1999). Setup and maintenance of the grass strips is relatively easy, although in the first year, the farmer needs to transplant the grass seedlings along the contour lines. After that, the grass strips are a cut-and-carry operation without any special techniques.

However, labor (30% increase; data not shown) needed for grass strip establishment and management may compete with other farm activities such as weeding and fertilizing, and also requires initial investment for planting material. Further, other 'free' fodder sources such as weeds, banana, and tree leaves are rather easy to collect in the home garden and fields close to the homestead. All these factors hinder farmers' adaptability; thereby, soil conservation seldom appears near the top of their priority list, even where impact of erosion becomes evident (Shaxson, 1993).

Proper use of soil conservation techniques help to sustain main crop yield, particularly in drastic condition. In 2010, a year with a drought period during maize tasseling, yield of minimum tillage with a relay crop at both sites or cover crop at CH tended to be higher compared to the farmers' practice. This yield increase may point to a positive mulch effect provided by cover and relay crops in the minimum tillage treatments (Erenstein, 2002). However, when Pinto peanuts were not cut on time they also had a strongly negative influence on maize yield as observed in the second year at CK. This yield reduction was attributed to the late pruning of the vigorously growing Pinto peanut at the onset of the season. More frequent cutting of the cover crop during the third year reduced the competition between the maize and the cover crop, resulting in a lower depression in maize yields.

The main constraints on the use of cover crops are the reduction in yield and the fear of pests, and fungal diseases resulting from leaving crop residues in the field (Morgan, 2005; Giller et al., 2009; Thierfelder and Wall, 2012). Strong and highly competitive natural weeds suppressed Pinto peanut if weeding was not done in a timely manner like the one that happened at CH. The slow establishment of Pinto peanut means that this conservation measure requires even more labor to remove weeds by hand (CH) and to control them from proliferating main crop (CK). This cover crop therefore contradicted farmers' expectation because weed suppression is their major concern in the area (Wezel et al., 2002b). On the other hand, this measure provided protein-rich fodder, which may replace some of the alfalfa being brought in from the US and used for the dairy farms in the neighboring Moc Chau district. To attract farmers' adoption, cover crop systems either have to suppress weeds or its benefit has to outweigh the additional labor demand.

Minimum tillage combined with an Adzuki bean relay cropping appeared to be the best method to control erosion, especially in the third year and at Chieng Khoi where the slope is steeper than at Chieng Hac. Competition was not an issue in this treatment, but the market for Adzuki beans is an important question once planted at a larger scale as raised by a local extension worker in the study area. In a farmer managed trial at Chieng Hac, the vigorous climbing Adzuki beans created a dense vegetation and the farmers claimed access was difficult to collect the maize cobs. Such a constraint can be negligible on small farms, where sufficient family labor is capable to harvest maize in difficult condition. The effort to promote adoption of conservation agriculture therefore needs to be tailored to local conditions and adjusted to site-specification based on bio-physical and socio-economic environments (Erenstein, 2002). In Yen Chau and surrounding regions with their steep, erodible environment, the desire to diversify out of agriculture likely opts for a conservation measure providing short-term returns and reducing economic risk (Reardon and Vosti, 1992; Erenstein, 1999).

2.6 Conclusions

The current wide use of maize mono cropping on steep slopes in Vietnam leads to severe erosion, with most of this occurring at the beginning of the cropping season when heavy rains coincide with a poor ground cover. After juvenile growth the maize, together with weeds, provided a better soil cover and greatly reduced soil loss, even during highly erosive rains.

The different soil conservation measures in this study each effectively controlled soil loss after establishment. Grass barriers strongly reduced soil loss as compared to farmers' practice and provided fodder for ruminants, but significantly decreased maize yields (26%) due to both reduction in cropping area and competition. If farmers are interested in animal keeping, this measure can be a useful option, particularly when drought tolerant grass species are used to mitigate the risks associated with below average or erratic rainfall. Minimum tillage with either simultaneous or relay cropping of cover crops also strongly reduced soil loss. Simultaneously established cover crops reduced maize yields due to competition if pruning was not done in time. A cut-and-carry system using Pinto peanut provided substantial amounts of protein-rich fodder that can compensate for the reduction in maize yields.

The most promising option was maize under minimum tillage with relay cropping. In this treatment maize yields were similar to conventional practices while soil loss was very low. The Adzuki bean relay crop provided grains that could be sold in the market, and this may be a viable farming option if sufficient labor is available to harvest beans on time. As farmers in Southeast Asia usually perceive erosion as a common problem such additional benefits may make them more willing to adopt such soil conservation techniques, generating a win-win situation for farmers in fragile environments and decreasing both on- and off-site hazards.

Acknowledgements

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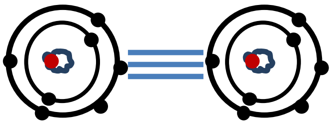
Chapter 3

Nitrogen recovery and downslope translocation in maize hillside cropping as affected by soil conservation



3 NITROGEN RECOVERY AND TRANSLOCATION IN MAIZE HILLSIDE CROPPING AS AFFECTED BY SOIL CONSERVATION[2]

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3.1 Abstract

We conducted a field experiment on a 53%-slope in Northwest Vietnam using ^{15}N-labelled urea to trace its fate in maize (*Zea mays*) under intensive tillage and fertilization (T1, control) *vs.* maize with *Panicum maximum* grass barriers (T2), under minimum tillage (MT) with *Arachis pintoi* as cover crop (T3) or relay cropped with *Phaseolus calcaratus* (T4). ^{15}N-labelled urea was applied to one maize row at the top of each plot one year after trial establishment. At harvest, 21.6% of the labelled ^{15}N were recovered by maize in T1, 8.9% in T2, 29% in T3, and 30.9% in T4. In T2, maize and *P. maximum* competed heavily for N with a total 38.1% of ^{15}N recovered in barriers. Less than 6% of ^{15}N applied was found in maize rows along the slope regardless of the treatment. MT reduced ^{15}N translocation to deeper soil layers (40-80 cm), indicating a safety net function. Less than 0.1 kg N ha^{-1} of applied ^{15}N reached the collection devices at the bottom of plots; the majority of added ^{15}N was intercepted by plants along the slope. Current farming practice (T1) induced a negative N balance of -142 kg N ha^{-1} in which residue burning and erosion were major pathways for N losses. Reduced N losses by erosion in T2 contributed to a less negative N balance as compared to T1. Positive N balances of MT treatments were associated with strongly reduced N losses by erosion and abandonment of burning residues, indicating a viable option for hillside cropping.

Key words: Maize, N fertilizer use efficiency, ^{15}N labelled urea, soil conservation, translocation, Vietnam

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3.2 Introduction

A strong demand for animal feedstuff to feed a growing affluent population is inducing an increasing expansion of maize mono-cropping on steep slopes in many countries of Southeast Asia. This often leads to accelerated erosion and soil degradation under heavy rainfall (Valentin et al. 2008; Turkelboom et al. 2008). To maintain high crop yields, farmers usually rely on increasing fertilization to compensate for the decreasing soil fertility. As more fertilizer is applied, lower fertilizer use efficiencies are expected (Stevens et al. 2005), contributing to both increased production costs and environmental risks, particularly in hillside agriculture under heavy rainfall (Zhao et al. 2011).

In tropical farming systems, crop nitrogen uptake from fertilizer in the season of application was commonly found to be around 30% with smaller proportions (3-6%) of the applied N fertilizer being recovered in subsequent cropping seasons (Dourado-Neto et al. 2010; Pilbeam et al. 2002). Improving nitrogen fertilizer use efficiency (NFUE) relates to controllable and uncontrollable factors. The three main controllable factors that adversely affect fertilizer use efficiency are (i) unbalanced fertilization (20–50% reduction in NFUE), (ii) inappropriate crop variety (20–40%), and (iii) untimely sowing (20–40%) while the main uncontrollable factor is climate (Hood-Nowotny et al. 2008). To minimize a potential surplus of nitrogen being subject to losses, optimum use rates have to be identified and exercised. However, this does not seem easily feasible in most agro-ecosystems due to variability in rainfall and temperature, both strongly affecting N losses. In general, higher mean annual rainfall and temperature lead to higher losses (Dourado-Neto et al. 2010). To a greater extend, locally prevailing climate conditions influence pathways and magnitude of fertilizer N losses, i.e. leaching and gaseous emissions (Hood-Nowotny et al. 2008). Several studies emphasized the loss of fertilizer N by leaching (Stevens et al. 2005; Sogbedji et al. 2000; Blevins et al. 1996), while other pathways such as NH_3 volatilization may induce substantial N losses if the fertilizer is applied on the surface (Stevens et al. 1989). Although there are a number of factors influencing N losses, rainfall intensity largely affecting ‘residence time’ of a nutrient in the rooted soil layers is the prime factor to be considered in tropical agro-ecosystems (van Noordwijk and Cadisch 2002). On the other hand, inefficient utilization in space and time of N released from plant residues often cause low recovery rates (Bergstrom and Kirchmann 1999; Giller and Cadisch 1995) due to regulating residue quality attributes (e.g. C/N ratios and lignin contents) and asynchrony with plant N demands (Vanlauwe et al. 1998). Hence, applying the right fertilizer source (form), at the right rate and the right place, at the right time or the so-called 4Rs has to be implemented to improve NFUE (The Fertilizer Institute 2014).

Agricultural activities on slopping land also provoke N losses associated with erosion. Under maize mono-cropping in Northwest Thailand, 12-15 kg N $ha^{-1}yr^{-1}$ losses via runoff, soil loss and leaching were reported by Pansak et al. (2008), representing almost one fourth of the fertilizer applied. Such N losses were reduced by three to five times when *Brachiaria ruziziensis* barriers or *Leucaena leucocephala* hedges were integrated into maize cropping. In Northwest Vietnam, the integration of *Tephrosia candida* hedgerows in upland rice (*Oryza sativa*) reduced erosion N losses by 50% (Hoang Fagerström et al. 2002). Similar N loss reductions (21 kg $ha^{-1}yr^{-1}$ under farmers' practice *vs.* 15 kg N ha^{-1} yr^{-1} in a hedgerow system) were observed by Loc et al. (1998), working in the same area. Such reductions are associated with a shorter runoff area, better soil cover, and positive impacts on soil structure and infiltration provided by hedgerows, grass barriers or minimum tillage (Hilger et al. 2013).

To combat erosion on hilly terrain used for crop production in tropical Northwest Vietnam, a participatory experiment with soil conservation techniques revealed reduced erosion of up to 94% but also decreased maize yields (Tuan et al. 2014). Furthermore, labour requirement, weeds suppression by minimum tillage, and returns based on additional benefits such as animal feeds are crucial issues for adoption (Tuan et al. 2014). Understanding the NFUE in soil conservation based cropping systems may increase the likelihood of adoption, provided it is associated with better or improved productivity.

Two methods for quantifying NFUE are commonly used: (i) N difference and (ii) isotopic dilution. The first method is based on differences in N uptake between fertilized and non-fertilized crops. It is based on the assumption that N uptake from control plots measures the amount of N available from the soil, whereas that of N fertilized treatments represents the amount made available by both soil and fertilizer. It also assumes that mineralization, immobilization, nitrification, de-nitrification, and other N transformation processes are the same in fertilized and unfertilized soils. In most cases, the assumptions are not met, (i) due to priming effects defined as stimulation of soil organic matter decomposition by N addition into the soil and (ii) due to altered N cycling associated with changes in crop N uptake patterns and rooting depth. The second method assesses NFUE based on uptake of ^{15}N labelled fertilizer. This method relies on the assumptions that plants and soil microbial populations do not distinguish between ^{15}N and ^{14}N and that the chemical identity of those isotopes is maintained in the biochemical system (Rao et al. 1992). Possible problems are isotopic pool substitutions, e.g. when added labelled ^{15}N displaces native unlabelled ^{14}N from bounded pools, which can lead to apparent lower estimated fertilizer uptake efficiencies as compared to the difference method when only assessing plant isotope recoveries. To date, little is known about how much of the applied nitrogen is translocated from its point of application downslope and how far. In a small catchment with conifers, Kjønass and Wright (2007) detected a N loss of 3.9% as dissolved inorganic N and 1.1% as dissolved organic N over a 10-year-period. However, in the year of the ^{15}N addition the ^{15}N level in runoff largely reflected the level in incoming N. At plot scale, Catchpoole (1975) reported plant ^{15}N recoveries were below 20% for pastures on gentle slopes of 5-8 degrees, while the total recovery of the soil-plant system was below 50%. This study also implied that surface runoff and leachates could have contributed to ^{15}N losses, even though they were not traced. Very few ^{15}N studies were done on steep slopes as they usually involve micro-plots to monitor the ^{15}N tracer. Such micro-plots neglect the impact of lateral flows in hillside cropping which particularly matters on steep lands under tropical rainfall conditions (Xu et al. 1993; Stevens et al. 2005; Rowe et al. 2005).

Our hypothesis was that soil conservation technologies improve NFUE in maize cropping and simultaneously reduce N fertilizer losses due to an increased interception of the applied N-fertilizer by companion crops before it is eroded or leached, and thereby improving the plant available N pool for crop uptake. Yield estimates from ^{15}N experiments are often unreliable due to the small size of the micro-plots typically used or just missing (Gardner and Drinkwater 2009). We, therefore, used plots of 72 m^2 and applied ^{15}N tracer to one row at the top of each plot. This allows assessing crop N recovery on slopes as well as downslope movements of N under field conditions as affected by soil conservation.

The objectives of this study, thus, were to (i) trace the fate of ^{15}N in four maize based cropping systems on steep slopes; (ii) assess total and proportional recoveries from different soil-plant compartments of the studied systems; and (iii) evaluate the impact of soil conservation techniques on soil-plant N recovery and N translocation along the slope.

3.3 Materials and methods

3.3.1 Study site and experimental setup

This study was carried out during 2010 at Chieng Hac commune (260 m a.m.s.l., 21.02° N and 104.37° E) in the Son La Province, Northwest Vietnam, one year after trial establishment. The site has a tropical monsoon climate with an average temperature of 25 °C. In 2010, the annual rainfall was 1305 mm, falling from end of March until mid of October (Fig. 3.1). The site was under secondary forest before 1992, being converted to four seasons of upland rice and followed by soybean till 1998 and thereafter maize monocropping. The soil at the study site was classified as Luvisols with a silty clay texture (Table 3.1). The top soil was rather acid (pH_{KCl}: 4.6-5.0), soil organic matter (SOM) and total N of the top soil were low to moderate with a C/N ratio just below 10, while available phosphorus (Bray I) before fertilizer application was 14 mg kg^{-1}.

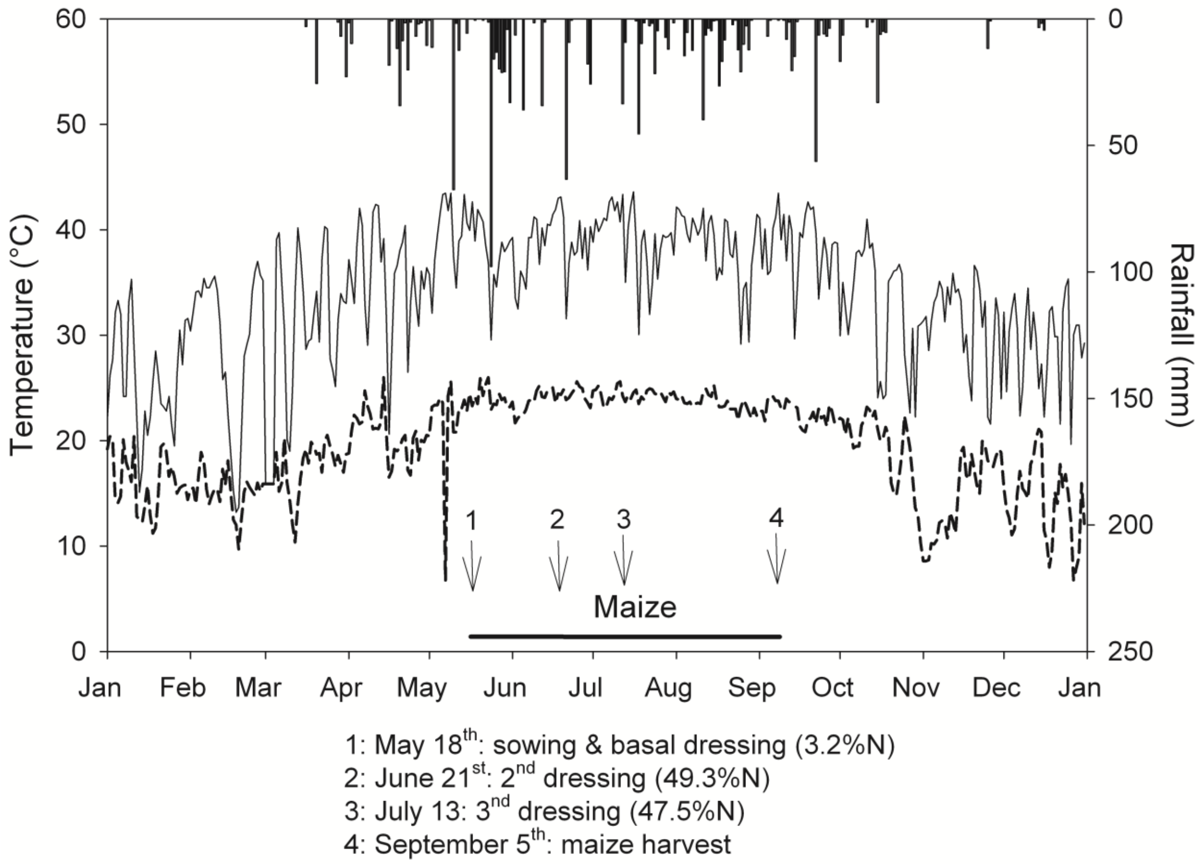

Fig. 3.1 Daily rainfall distribution (vertical bars), maximum (solid line) and minimum (dashed line) temperature for 2010 at Chieng Hac, Son La province, NW Vietnam. Arrows indicate sowing, fertilization, and harvest dates. 1 – May 18th: sowing and basal dressing (3.2% N); 2 – June 21st: 2nd dressing (49% N); 3 – July 13th: 3rd dressing (47.5% N); 4 – September 5th: maize harvest.

Table 3.1 Soil properties of the experimental site at Chieng Hac, NW Vietnam, after Breunig (2011).

Depth (cm)	pH_{KCl}	----- Texture (%)-----			Exchangeable cations ------- ($mmol_c$/kg) -------				OM	N	P Bray-1	C/N
		Sand	Silt	Clay	Ca^{2+}	Mg^{2+}	K^+	Na^+	%	%	mg kg^{-1}	
0-14	5.0	42	24	33	100	22	5.6	0.2	2.25	0.14	14.0	9.6
14-36	4.6	30	26	44	104	28	4.0	0.3	1.57	0.12	0.9	8.4
36-54	4.1	24	22	54	97	28	3.7	0.4	1.14	0.11	0.3	6.5
54-90	4.2	24	20	56	111	28	3.1	0.6	0.84	0.09	0.2	5.9
90-120	4.6	31	24	44	134	27	3.5	0.7	0.60	0.08	0.2	3.1

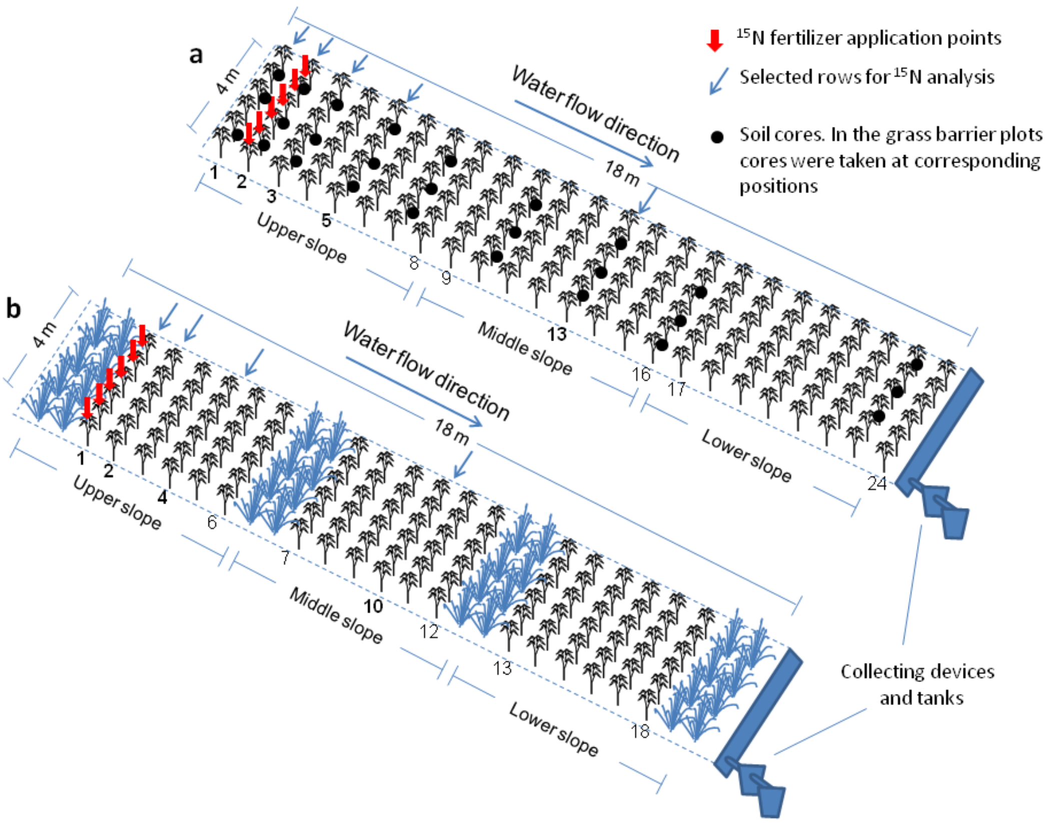

Fig. 3.2 Layout of field trial plots at Chieng Hac, Son La province, NW Vietnam (a) without grass barriers representing T1 - farmers' practice (control), T3 - minimum tillage + cover crop, and T4 - minimum tillage + relay crop; and (b) with grass barriers - T2.

The trial layout was a randomized complete block design with three replicates. Plots were 18 m long and 4 m wide, giving 72 m^2. The mean slope gradient of the plots was 53±3.1%.

Three soil conservation measures consisting of maize with Guinea grass (*Panicum maximum*) barrier (T2), maize under minimum tillage (MT) with Pinto peanut (*Arachis pintoi*) as cover crop (T3), and maize under MT and relay cropping with Adzuki beans (*Phaseolus calcaratus*) (T4) were tested against the current farmers' 'slash and burn' practice followed by double ploughing and furrow preparation along the contour lines (T1; control). In T2, tillage was done in the same way as in T1, while in MT light hand hoeing was done once to form contour furrows. In all treatments, weeding was done by hand hoeing and at the same time. A local hybrid maize variety LVN 10 was sown by hand in rows along the contour with a spacing of 24 cm in the row and 75 cm between rows on May 18, 2010. In T1, T3, and T4 maize occupied 100% of the cultivable area with 24 rows per plot (Fig. 3.2a). In T2, maize occupied 77% of the area with 18 rows (Fig. 3.2b); the remaining area was covered by four rows of Guinea grass, representing 23% of the plot area. Guinea grass barriers were planted on June 9th, 2009 and regularly cut back to a height of approximately 30 cm to avoid shading of maize. The cut material was used as fodder in a cut-and-carry system. The perennial cover crop *A. pintoi* was established on June 10th, 2009 within T3; and maize seeds were hand sown into small contour furrows (minimum tillage) in 2010. Weeding was done in early season and together with cut *A. pintoi* (at the end of the season; December 1, 2010) material were removed and used as fodder. Minimum tillage and weed control of the T4 was done in the same way as in T3. Adzuki beans were sown between maize rows one month after maize sowing. Adzuki beans were harvested two months after maize harvest. Crop residues of the previous season and slashed weeds were always left as mulch on the soil surface in MT treatments. More details on the crop management are given by Tuan et al. (2014).

All treatments received 158 kg of N, 17.5 kg of P, and 58.6 kg of K per hectare and year. N was split-applied according to the local recommendation: 3.2% as basal dressing on May 18th, 49.3% at the 4-5-leaf-stage on June 21st as second dressing, and 47.5% at the anthesis stage on July 13th as third dressing (Table 3.2). In order to trace the pathway of N fertilizer, ^{15}N-labelled urea with an equal N amount completely replaced the N fertilizer applied to the second maize row from the top of each plot in non-grass barrier treatments (T1, T3, and T4) and to the first maize row in the grass barrier treatment (T2). To achieve uniform application, ^{15}N-enriched urea (103.0 g, 5.1835% ^{15}N) was mixed with 100 g air-dried soil taken from the experimental site before the cropping season and applied to the designated row in each plot (corresponding to 3 m^2). At basal dressing, the mixture of ^{15}N urea and maize seeds were placed into prepared furrows before covering them with soil. For the 2nd and 3rd dressings, the mixture of ^{15}N urea and soil was placed as dollops in wholes (5-10 cm diameter) on the upper side to each maize plant in the ^{15}N application row of each plot and covered by soil thereafter as recommended by the local extension service.

To assess recovery of labelled fertilizer the following compartments of the system were analyzed for total N and ^{15}N contents: runoff water and eroded sediments, maize grain and stover, Guinea grass, weeds including Adzuki bean or Pinto peanut residues, and soil samples (up to a soil depth of 80 cm) after maize harvest.

Table 3.2 Source, timing, and rate of fertilizer applications in each treatment.

Timing	Compound NPK fertilizer [1]	Urea[2]	KCl	------- N -------		------- P -------		------- K -------	
	---------------- kg ha^{-1}----------------			kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
Basal dressing (May 18)	100			5.0	3.1	4.4	25.0	1.6	2.6
Second dressing at 4-5 leaf stage (June 21)	180	150	50	78.0	49.4	7.9	45.0	29.0	49.5
Third dressing at anthesis stage (July 13)	120	150	50	75.0	47.5	5.2	30.0	28.1	47.9
Total				158.0	100.0	17.5	100.0	58.7	100.0

1) 5% N, 10% P_2O_5, 3% K_2O

2) ^{15}N labelled urea substituted N fertilizer in the second maize row from the top of each plot in T1, T3, and T4 and the first maize row in T2. In these rows, equal amounts of P and K were added as superphosphate and muriate of potash.

3.3.2 Maize growth and dynamics of nitrogen uptake

Leaf area index (LAI) was measured by a LAI-2000 plant canopy analyser (LI-COR Biosciences, USA) 38, 53, 63, and 79 days after sowing (DAS). Samples of the third youngest leaf from three randomly selected maize plants were taken at ^{15}N application rows by using a hole-puncher 36, 43, 57, 64, and 74 DAS. Samples were air-dried and then oven dried at 60 °C to constant weight for $^{15}N/^{14}N$ analysis to determine dynamics of N uptake.

3.3.3 Maize sampling

Maize was harvested row-wise at physiological maturity by manually cutting plants at ground level excluding border plants. The plants were separated into grains, husks, cobs, leaves, and stems. A subsample of each row was taken, weighed, air-dried before oven drying at 60°C to constant weight to determine moisture content, used to convert field measured fresh weights into dry weights. In T2, maize yields were calculated based on the total plot area, including the areas devoted to grass barriers.

To reduce number of stable isotope analyses, husk, cob, leaf and stem were bulked (stover) based on weight proportions. To assess downward movement along the slope and subsequent uptake of labelled fertilizer N plots were harvested row wise. For isotopic recovery assessments five maize rows (1, 2, 3, 5, 13 counted from the top) in non-grass barrier plots and four rows (1, 2, 4, 10 counted from the top) in grass barrier plots were selected for total N and ^{15}N and ^{13}C analysis (Fig. 3.2). A pre-test showed that these rows were representative to capture the spatial translocation of enriched ^{15}N labelled material.

3.3.4 Grass barrier sampling

In 2010, grass barriers were cut six times at intervals of approximately one month, starting just before maize sowing. The one taken before ^{15}N-urea application served as background isotopic enrichment. A subsample from each grass barrier strip was processed in a manner identical to that of maize samples.

3.3.5 Weed/legume sampling

After maize harvest, weeds together with *P. calcaratus* or *A. pintoi* residues were collected at nine positions within each plot by using a quadratic frame of 0.25 m^2 (0.5*0.5 m). As legumes in T3 and T4 yielded only small amounts they were included into the weed dry matter. Closer to the ^{15}N-urea application row, shorter intervals between sampling points were used. At each quadrate, total fresh biomass was weighed and subsamples were taken to determine dry weight and processed in the same way as maize samples.

3.3.6 Soil sampling

After maize harvest, soil samples were taken at eight maize row positions in non-grass barrier plots (Fig. 3.2). In T2, samples were collected at corresponding positions. Initially, at each position three cores within the maize row were taken and bulked up to a depth of 80 cm, divided into 0-10, 10-20, 20-40, and 40-80 cm. After pre-tests (see above), subsamples at five positions at rows 1, 2, 3, 5, and 13 from the top (as for maize plants above) (Fig. 3.2) were used for further analyses and processed in a manner identical to that of sediments.

3.3.7 Runoff water and eroded sediments

The experimental plots were part of an erosion experiment and hence bounded by metal sheets (Tuan et al. 2014). At the bottom of each plot the surface runoff was directed by a collecting device into a plastic tank with a storage capacity of 200 L and 16 outlet hoses. One of these hoses was connected to a second 200-L tank. So the second tank received 1/16 of the overflow from the first tank. The overlaying water in the tanks was measured after each erosive event. After measuring the water level, two subsamples of 200 ml were taken, and stored in a deep freezer (-20 °C) until analysis. One subsample was filtered

(SARTORIUS, Grade 293, particle retention: 1 – 2 µm) and mineral N in the clear water diffused, and then trapped on acidified glass fibre paper discs and subsequently analyzed for $^{15}N/^{14}N$ ratio (Brooks et al. 1989, modified). The second subsample was analyzed for total N, and total OC analyses using a LiquiTOC II analyzer (Elementar Analysensysteme GmbH, Germany). After water sampling, runoff was siphoned off to collect deposited sediments at the bottom of each tank. Sediments were collected, weighed and sampled after each storm that produced soil loss. The samples were oven-dried at 60 °C until constant weight was reached. Subsamples were taken and finely ball-milled for total N and $^{15}N/^{14}N$ analyses.

3.3.8 ^{15}N and ^{13}C analysis and calculation

Weights of plant, soil and sediment samples were determined based on expected enrichment levels and nitrogen concentration so that an adequate amount of N (about 50 µg N) allowing reliable N isotope analysis being obtained. Samples were finely ball-milled before packing into tin-capsules for total N, ^{15}N and ^{13}C (maize samples) analyses by using an Euro Elemental Analyzer coupled to a Finnigan Delta IRMS (Thermo Scientific, Germany). The glass fibre paper that absorbed the diffused nitrogen in runoff was also packed into tin-capsules for ^{15}N analysis.

Nitrogen yield and N recovery of each component was calculated row wise by the following steps adapted from (IAEA 2001):

$$N\ yield\ (g\ m^{-2}) = \frac{Yield\ (g\ m^{-2})*N\ (\%)}{100} \quad (1)$$

$$Ndff\ (\%) = \frac{atom\%\ ^{15}N\ excess\ in\ sample}{atom\%\ ^{15}N\ excess\ in\ fertilizer} \quad (2)$$

where *Ndff* is plant N derived from fertilizer.

$$Fertilizer\ N\ yield\ (g\ m^{-2}) = \frac{N\ yield\ (g\ m^{-2})*Ndff\ (\%)}{100} \quad (3)$$

$$N\ recovery\ or\ N\ fertilizer\ use\ efficiency\ (\%) = \frac{Fertilizer\ N\ yield\ (g\ m^{-2})}{Rate\ of\ N\ application\ (g\ m^{-2})}*100 \quad (4)$$

N derived from soil (*Ndfs*) was calculated as difference:

$$Ndfs\ (\%) = 100\% - Ndff\ (\%) \quad (5)$$

Excess ^{15}N values were determined by subtracting background ^{15}N values of respective samples from non-fertilizer plots of the corresponding block. Mean values of ^{15}N atom%

in background samples for maize grain and stover, Guinea grass, weeds, and soil were 0.3712, 0.3724, 0.3688, 0.3718, and 0.3688 atom %, respectively.

Values of ^{15}N in between measured positions were estimated using linear interpolation for maize rows (n=5), and weed quadrates (n=8).

N recoveries over the whole plot were then summed up as follows:

$$Total\ N recovery\ (\%) = \sum_{i=1}^{m} N\ recovery_i\ (\%) \tag{6}$$

where m is the total number of rows, or quadrates in each plot, $N\ recovery_i$ is ^{15}N recovery (% of applied N) at row i or quadrate i.

N recovery rates were up-scaled as follows:

Row-based N yields and fertilizer N yields of non-grass barrier treatments were converted from g m^{-2} to kg ha^{-1} by multiplying with the factor 10. In T2, values were area corrected due to the area dedicated for the grass barriers. Up-scaling of N-recovery rate of T2 relied further on the assumptions that N recovery rates for rows close to barrier were the same as measured in T2 and N recoveries for rows distant to barrier would be similar to those observed in T1. The maize recovery rate of T2 was, therefore, calculated based on the fact that one third of maize rows were close to the barrier, and two thirds distant to the barrier:

$$Estimated\ N\ recovery\ in maize\ of\ T2\ (\%) = \frac{Measured\ N\ recovery\ \ in maize\ at\ T1(\%)*2 + Measured\ N\ recovery\ \ in maize\ at\ T2(\%)}{3} \tag{7}$$

The estimated N recovery by Guinea grass was proportioned one and two thirds of values obtained in current study for N recovery at barriers down slope and application row according to results of this study, respectively:

$$Estimated\ N\ recovery\ in\ grass\ of\ T2(\%) = \frac{N\ recovery\ \ in\ barier\ downslope(\%)*2 + N\ recovery\ \ in\ barrier\ next\ \ to\ {}^{15}N\ application\ (\%)}{3} \tag{8}$$

3.3.9 Statistical analysis

Data were analysed by one-way ANOVA using SAS 9.0 (SAS Institute 2002). Different treatment means were separated by using LSD test ($p<0.05$) unless otherwise indicated.

3.4 Results

3.4.1 Crop performance and N uptake

Maize grain yield of the control (T1) was 4.1 Mg ha^{-1}, statistically similar to the grain yields of minimum tillage treatments (T3 and T4) (Table 3.3). The area corrected maize grain yield of the grass barriers treatment (T2) was significantly reduced by 34% compared to the control and additionally lower by another 6-10% compared to MT treatments. Maize stover yields showed the same trends and magnitude as those of grain yields. Amounts of weeds and/or legume residues ranged from 2.5 to 3.3 Mg ha^{-1} but did not differ significantly between treatments. *Panicum maximum* yielded 5.5 Mg ha^{-1} cumulatively over the season, based on six cuttings. In treatments without grass barriers, row based grain and stover yields varied only slightly among rows within treatments, without showing significant trends (Fig. 3.3). In T2, maize grain yield per row strongly decreased towards the grass barriers but was similar to non-grass barrier treatments in rows away from the barriers. Nitrogen concentrations of maize grain and stover, weeds and legume residues varied slightly between treatments but without showing statistically significant differences.

At harvest, maize in the grass barrier treatment revealed a significantly lower total N uptake (52 kg N ha^{-1}) than in all other treatments (Table 3.4). However, there were no significant differences in N accumulation in maize among MT treatments (89-95 kg N ha^{-1}) and the control (82 kg N ha^{-1}). Nitrogen accumulated in weeds varied from 31 to 36 kg N ha^{-1}, without showing significant differences among treatments. In non-barrier plots, the soil provided about half of the N uptake of maize (45-51%), whereas in the grass barrier treatment almost three quarters of maize N originated from the soil (73%). However, the absolute amounts of N derived from soil were not statistically different between treatments (38-49 kg N ha^{-1}). Fertilizer-N, on the other hand, contributed least to the maize N uptake in the grass barrier treatment (14 kg N ha^{-1}) compared to those without grass barriers (44-49 kg N ha^{-1}). Furthermore, the fertilizer-N uptake of grass barriers was four times higher than that of maize.

Table 3.3 Aboveground dry matter (DM) and N concentration of maize, weeds and/or legumes, *Panicum maximum* in 2010 at Chieng Hac, NW Vietnam. Maize yields were determined at harvest, weeds and/or legume residues dry matter after maize harvest and *P. maximum* dry matter were based on six cumulative cuttings. Values are means of three replicates. Means followed by different letters within the same column indicate significant differences (LSD test, $p<0.05$).

Treat-ment	DM (Mg ha^{-1})							N concentration (%)						
	Maize grain		Maize stover		Weeds and/or legumes		*P. maximum*	Maize grain		Maize stover		Weeds and/or legumes		*P. maximum*
T1	4.1	a	4.5	a	2.5	a		1.44	a	0.51	a	1.22	a	
T2	2.7	b	3.0	b	2.9	a	5.5	1.46	a	0.54	a	1.16	a	1.43
T3	4.7	a	4.8	a	3.3	a		1.52	a	0.48	a	1.08	a	
T4	4.5	a	4.5	a	3.0	a		1.39	a	0.58	a	1.19	a	

T1: Farmers' practice (control); T2: Grass barrier; T3: MT + cover crop; T4: MT + relay crop.

Table 3.4 Total above-ground N yield, contribution of fertilizer-N, soil-N for maize, weeds and/or legumes residues, *Panicum maximum* for each treatment in 2010 at Chieng Hac, NW Vietnam. Values are means of three replicates and different letters indicate significant differences in the same row within each parameter (LSD test, $p<0.05$).

	N-yield				N derived from fertilizer				N derived from soil			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
Maize (kg ha^{-1})	82[a]	52[b]	95[a]	89[a]	44[a]	14[b]	46[a]	49[a]	38[a]	38[a]	49[a]	41[a]
(%)					54	27	49	55	46	73	51	45
P. maximum (kg ha^{-1})		78				60				18		
(%)						74				26		
Weeds[1] (kg ha^{-1})	31[a]	33[a]	36[a]	35[a]	6[a]	5[a]	4[a]	5[a]	25[a]	28[a]	31[a]	31[a]
(%)					19	14	12	13	81	86	88	87
Sum (kg ha^{-1})	113[b]	163[a]	131[b]	124[b]	50[b]	79[a]	50[b]	54[b]	63[a]	85[a]	81[a]	71[a]
(%)					44	48	39	43	56	52	61	57

T1: Farmers' practice (control); T2: Grass barrier; T3: MT + cover crop; T4: MT + relay crop.

[1] In T3 and T4, weeds include biomass of legumes.

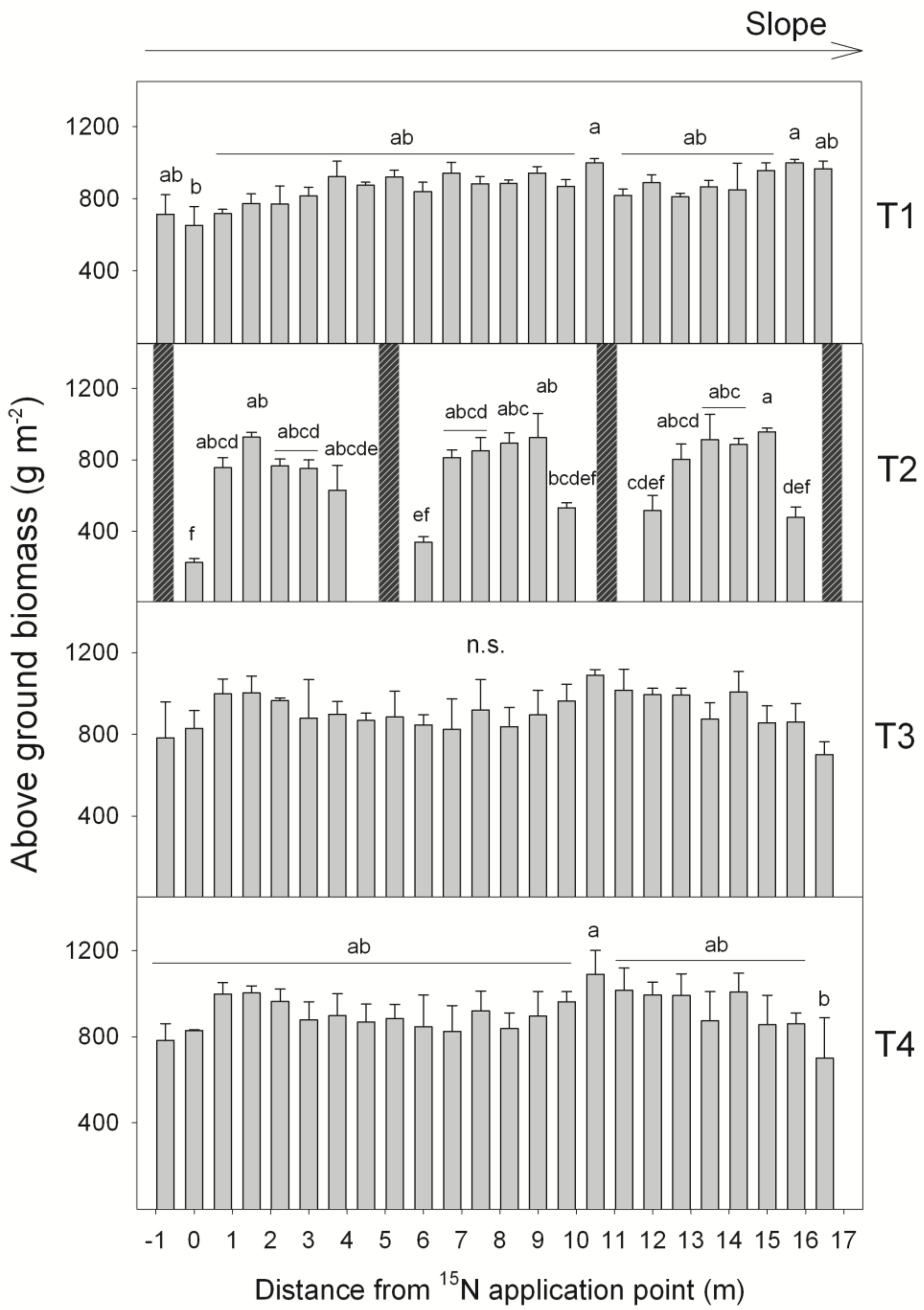

Fig. 3.3 Mean maize above ground biomass in g m^{-2}. Data were recorded in 2010 at Chieng Hac, Son La province, NW Vietnam. Values are means of three replicates. Bars followed by different letters within the same treatment indicate significant differences, n.s. = non-significant (Tukey test, $p<0.05$). T1: farmers' practice (control); T2: grass barrier; T3**:** minimum tillage + cover crop; T4: minimum tillage + relay crop. In T2 shaded areas represent grass barriers. Distance of 0 m indicates ^{15}N application row.

3.4.2 Relationship between maize growth and N fertilizer uptake

At 38 DAS, average LAI was around 0.6 (Fig. 3.4a). After juvenile growth, maize developed fast, reaching a maximum LAI of 1.8-2.2 between 63 and 79 DAS. T4 had a significantly higher maximum LAI than T1 and T2 but not when compared to T3. LAI tended to be lower in grass barrier plots than in both MT treatments and the control. At the final measurement all treatments had a LAI of around 2, without being significantly different. At 36 DAS, total leaf N concentration varied between 2 and 2.5% in the application row of labelled ^{15}N fertilizer and increased up to 3% at 43 DAS along with the fast leaf area development of maize (Fig. 3.4b). Differences among treatments were small and significantly lower in T2 at 74 DAS.

Maize uptake of labelled ^{15}N fertilizer (*Ndff*) was monitored in the row of application by punching the third youngest leaf of several plants (Fig 3.4c). *Ndff* was low before the second dressing of labelled ^{15}N, varying from 3 to 20%. After the second N dressing, *Ndff* sharply increased in all treatments, reaching 40-84% within a week. But the high *Ndff* value of T2 declined thereafter to the levels of T1 and T4. The *Ndff* of T3 remained low throughout the season, although differences between T3 and the other treatments were only statistically significant at 74 DAS.

The same leaf samples were used to assess changes of $\delta^{13}C$ signals during maize growth. At 36 DAS, $\delta^{13}C$ of the third youngest maize leaf ranged between -11.64 and -11.41 ‰ at the row of application of ^{15}N labelled urea (Fig. 3.4d). A week later (43 DAS) $\delta^{13}C$ increased in all treatments but the value was significantly lower in T2 (-11.38‰) than in the control (-11.12‰) and both MT treatments (T3: -10.88‰; T4: -10.96‰). Thereafter, $\delta^{13}C$ values decreased in all treatments, but increased again in T2 at 74 DAS.

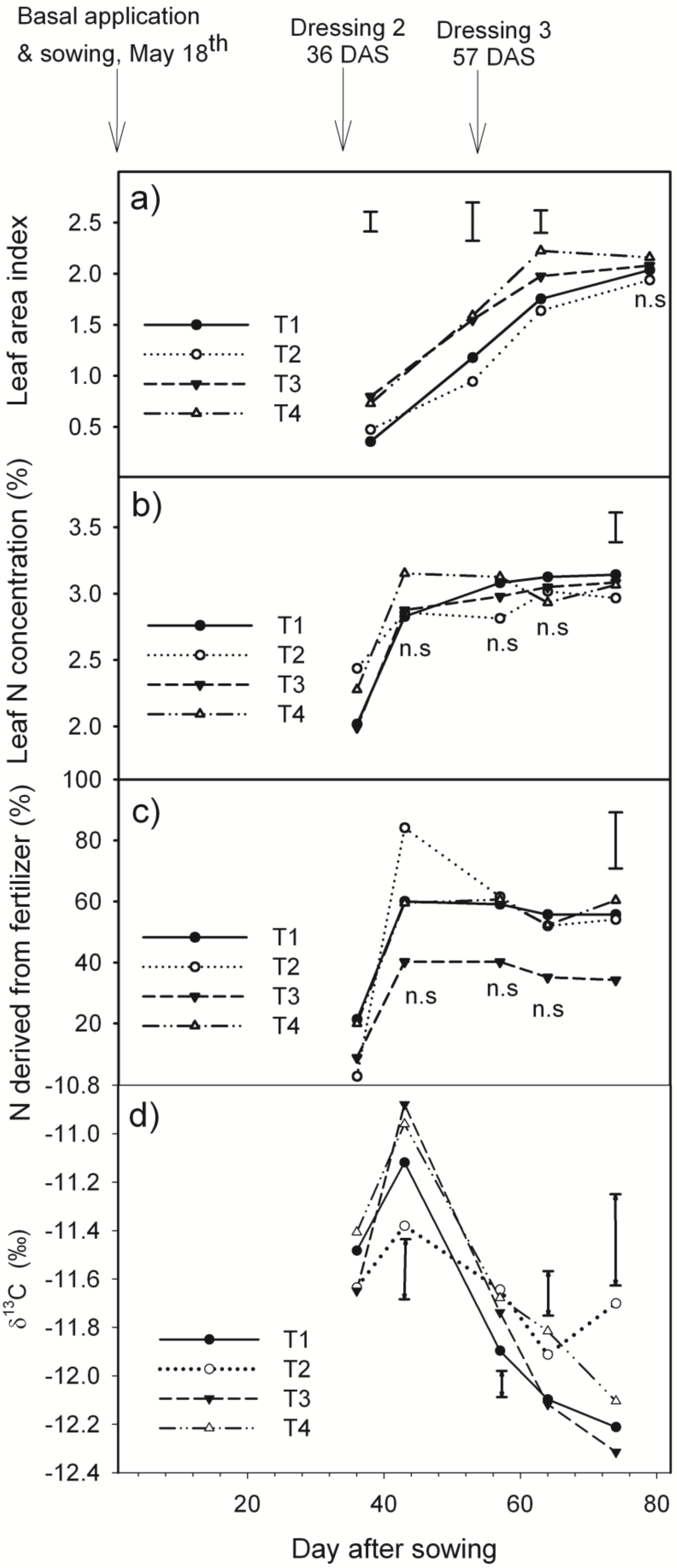

Fig. 3.4 (a) Leaf area index, (b) leaf N concentration, (c) nitrogen derived from fertilizer (%), and (d) $\delta^{13}C$ (‰) of the third youngest maize leaf collected from rows where ^{15}N labelled urea was applied. Data were recorded 5 times (36, 43, 57, 64, and 74 DAS) in 2010 at Chieng Hac, Son La province, NW Vietnam. Bars represent LSD at $p<0.05$, n.s.: not significant. At the first sampling time, plants of some plots were too small for sampling; hence no statistical analysis was possible. T1: farmers' practice (control); T2: grass barrier; T3**:** minimum tillage + cover crop; T4: minimum tillage + relay crop.

3.4.3 Plant recovery and soil-based translocation of labelled ^{15}N fertilizer

In the control (T1), total cumulative labelled ^{15}N fertilizer recovery by maize along the slope was 27.7% of the added ^{15}N (Table 3.5). In both MT treatments, corresponding values were in the range of 29-31%. The grass barrier treatment had a significantly lower ^{15}N recovery of 8.9% at the application row or cumulative 21.4% at system level when compared with non-grass barrier treatments. Most labelled fertilizer was recovered in the ^{15}N application row (21.6 to 25.6%) with recovery in T2 (5.6%) being significantly lower than in other treatments. Labelled fertilizer recoveries in maize rows above the application point and all other rows downhill amounted jointly to 2.7-3.8% of applied fertilizer N without being statistically different among treatments. In T2, 38.1% of the applied ^{15}N labelled fertilizer was found in Guinea grass, being the highest recovery by plants observed in all treatments partly due to its position next to maize row where labelled fertilizer was applied. However, in this treatment the recovery rates will change when scaling up to a hectare. The estimated N recovery rate on a hectare basis for Guinea grass was 17.6% (Table 3.5).

Weeds and legume residues collected after maize harvest recovered 2.8 to 3.8% of the applied ^{15}N of which most occurred close to the application position for non-grass barrier treatments (2.0 to 2.8%). In all cases, differences among treatments were not significant (Table 3.5). Total ^{15}N recoveries in above ground biomass of maize, grass and weeds were significantly greater in T2 (50.1% or 42.0% at system's level) than in the other treatments (31.5 to 34.1%) due to the large contribution of N fertilizer uptake by Guinea grass (Table 3.5).

Total ^{15}N recovery up to a soil depth of 80 cm varied from 22.1 to 34.3% but no statistically significant effects of soil conservation were found (Table 3.5). While minor amounts of 1.8-2.8% were found at a soil depth of 40-80 cm at the application point, most of applied ^{15}N remained in the main rooting zone of maize (0-40 cm), being much lower in T2 (6.6%) as compared to the other three treatments (13.9-16.9%) but without showing statistically significant differences. In contrast, downslope recovery of ^{15}N labelled fertilizer in the subsoil was dominant in T1 and T2, being significantly higher as compared to T3 while T4 was half way between T1/T2 and T3.

Figure 3.5 illustrates the vertical distribution of residual soil ^{15}N excess (‰) along the slope originating from the applied ^{15}N labelled fertilizer. Most of ^{15}N remained at the circumference of the row of application, strongly enriching the soil up to a depth of 40 cm; below that soil depth isotopic enrichment levels were low. Additionally, in all treatments almost similar enrichments were found in the zone directly above (-0.6 m) and below (0.9 m) the application row; however two distinct trends became visible. In treatments with minimum tillage and simultaneous or relay cover crops (T3 and T4), ^{15}N enrichments were higher above the application point at a soil depth 0-10 cm, while in treatments without such a management higher isotopic enrichments were found below the application point. Furthermore, at larger distances to the application position of ^{15}N

labelled urea, isotopic enrichments were higher in T1 and T2 compared to T3 and T4 where values were either negligible or tended to be zero.

Total recovery of ^{15}N tended to be largest in the grass barrier treatment with 76.3% when labelled fertilizer was applied at rows next to a grass strip or an estimated 68.3% at system level (considering fertilizer applied to all maize rows), without being statistically different to other the treatments varying from 53.9-65.9% (Table 3.5).

Table 3.5 Percent (%) ^{15}N recovery in above ground biomass of maize, legumes, grass, weeds, and soil as affected by soil conservation and position in the plot. Data were recorded in 2010 at Chieng Hac, NW Vietnam. Values are means of three replicates. Different letters indicate significant differences in the same row (LSD test, *p<0.05*).

	Farmers' practice	Grass barrier	MT + cover crop	MT + relay crop
Maize	**27.7 a**	**8.9 (21.4)$^{\alpha}$ b**	**29.0 a**	**30.9 a**
Grain	18.6 a	5.3 b	20.3 a	21.1 a
Stover	9.1 a	3.6 b	8.6 a	9.8 a
Recovery uphill	2.3 a	-- [1]	3.0 a	2.4 a
Recovery at application point	21.6 a	6.2[2] b	23.2 a	25.6 a
Recovery downhill at rows 3-24	a	2.7 [3] a	2.8 a	2a
Panicum maximum	--	**38.1 (17.6)$^{\alpha}$**	--	--
Uphill recovery; close to application point		23.6	--	--
Recovery in barriers downslope (sum of 3 barriers)	--	14.5	--	--
Weeds and legumes	**3.8 a**	**3.0 a**	**2.8 a**	**3a**
At application point	2.8 a	1.5 a	2.4 a	2.0 a
Downslope	1.0 a	1.6 a	0.4 a	1.2 a
Total plant recovery	**31.5 b**	**50.1 (42.0)$^{\alpha}$ a**	**31.8 b**	**34.1** b
Soil (0-80 cm)	**34.3 a**	**26.3 a**	**22.1 a**	**26.2** a
application row				
0-40 cm	16.9 a	6.6 a	16.3 a	13.9 a
40-80 cm	2.0 a	1.8 a	2.1 a	2.8 a
downslope[4]				
0-40 cm	2.2 b	5.5 a	1.8 b	2.6 ab
40-80 cm	13.2 a	12.4 a	2.0 b	6.9 ab
Runoff	**0.04 a**	**0.01 b**	**0.02 b**	**0.01 b**
Sediments[5]	**0.03**	**0.02**	**0.01**	**0.01**
Total recovery	**65.9 a**	**76.3 (68.3)$^{\alpha}$ a**	**53.9 a**	**60.3** a
Unaccounted losses	**34.1 a**	**23.7 (31.7)$^{\alpha}$ a**	**46.1 a**	**39.7** a

MT: Minimum tillage

[1] occupied by grass barrier (see Fig. 2)

[2] row 1 at grass barrier plots (see Fig. 2)

[3] row 2-18 at grass barrier plots (see Fig. 2)

[4] cumulative ^{15}N recoveries of rows at lower slope positions

[5] statistical analysis not available as number of sediment samples collected from each treatment was different

$^{\alpha}$ Values in brackets are up-scaled N recovery rates based on Eqs. (7) and (8) (see ''Chaper 3.3.8'')

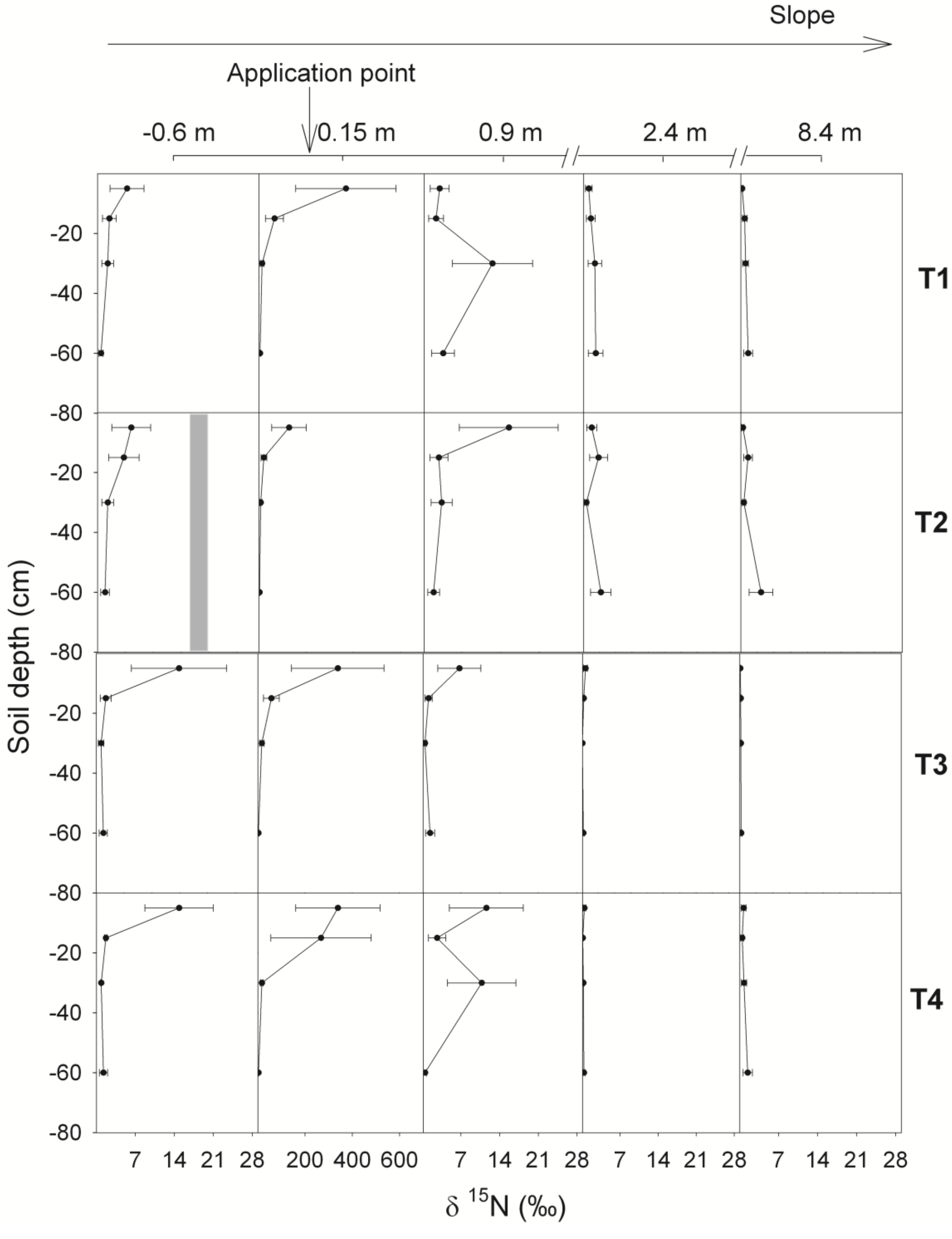

Fig. 3.5 Vertical distribution of residual ^{15}N excess (‰) in soil along the slope at four depths 0-10 cm, 10-20 cm, 20-40 cm, and 40-80 cm. Shading indicates grass barrier. Bars represent standard error of the mean. Data were recorded in 2010 at Chieng Hac, Son La province, NW Vietnam.T1: farmers' practice (control); T2: grass barrier; T3: minimum tillage + cover crop; T4: minimum tillage + relay crop.

3.4.4 N losses in maize cropping and estimated nitrogen balances as affected by soil conservation

The fertilizer N losses estimated by ^{15}N recovery in runoff and sediments monitored at a distance of 17 m downslope from the application point of labelled urea were less than 0.1%, whereby runoff recovery was significantly greater in the control than in all other treatments (Table 3.5). In contrast, total plot level N losses by runoff and eroded sediments were 2-25 kg N ha^{-1} and 2-123 kg N ha^{-1}, respectively (Table 3.6). Soil conservation practices significantly reduced erosion and surface N losses treatments compared to the control. Surface losses were least in both MT treatments, intermediate in T2 and highest in the control under farmers' practice (T1). Large amounts of the applied ^{15}N could not be accounted for: 34.1% in T1, 23.7% in T2 (31.7% at system level), 46.1% in T3, and 39.7% in T4; differences among treatments were not significant (Table 3.5).

Total plot level N input/output estimates indicated negative N balances of -142, -69, and -10 kg ha^{-1} for T1, T2, and T3 respectively but suggested positive N balances of +4 kg ha^{-1} for T4 (Table 3.6). If N recovery in soil was included in the calculation, negative N balance for T1 and T2 was less severity (-88 and -27 kg N ha^{-1}) while positive N balance was obtained for T3 and T4 (+25 and +45 kg N ha^{-1}). Further improvement of the N balance of T3 and T4 (+32 and +58 kg N ha^{-1}) could be achieved if biological fixation was taken into account. Under current farmers' practice, the largest N losses were associated with erosion (runoff + soil loss = 148 kg N ha^{-1}), accounting for almost half of the estimated output of 315 kg N ha^{-1}. Unaccounted losses, presumable due to losses by volatilization, de-nitrification, or leaching below 80 cm soil depth were 54 kg ha^{-1}, being similar to N export by maize grain (59 kg ha^{-1}). After extracting some maize stems for home consumption as fuel, farmers usually burn the remaining maize residues together with slashed weeds to ease tillage operations. As such, nitrogen inputs through ash were rather low (Dung et al. 2008). Hence, the burning activities induced N losses up to 54 kg ha^{-1} (cumulative N losses of burning stover and weeds, table 3.6), accounting for around 20% of the total N export. In T2, residue burning and removal of grass dry matter *P. maximum* caused losses of 52 and 78 kg N ha^{-1}, respectively with combined N losses accounting for about 40% of the total N export. For MT treatments, major N export was associated with harvest products and unaccounted losses. N losses by erosion and runoff in MT treatments were small (5-11 kg N ha^{-1}), while maize stover and legumes including weeds were mulched and, hence, considered as zero-changes in the N budget.

Table 3.6 Estimated nitrogen balance (kg N $ha^{-1}yr^{-1}$) for each treatment in 2010 at Chieng Hac, NW Vietnam. Values are means of three replicates. Values followed by different letters indicate significant differences in the same row (LSD test, $p<0.05$).

		Farmers' practice	Grass barrier	MT + cover crop	MT + relay crop
Input	Fertilizer	158	158	158	158
	Wet deposition[1]	15	15	15	15
Total input		173	173	173	173
Output	Maize grain[2]	59^a	37^b	72^a	64^a
(Plant	*Pan. maximum* [2]		78		
export)	Maize stover (burning)[2]	23	15		
	Weeds (burning)[2]	31	33		
	Legume (fodder)[3]			33	31
Total output in harvest		113	163	105	95
	Runoff[4]	25^a	9^b	3^b	2^b
	Soil loss[4]	123^a	21^b	2^b	9^b
	Unaccounted losses[5]	54^a	50^a	73^a	63^a
Total output		315	242	183	169
Partial N balance		-142	-69	-10	+4
N recovery in soil[6]		54	42	35	41
Balance with N recovery in soil		-88	-27	25	45
Balance with estimated biological fixation[7]				32	58

<u>Calculation of N balance:</u>

Partial N balance T1 or T2 = (Fertiliser + Wet deposition) – (Maize grain + maize stover + T2/*Panicum maximum* + Weeds + Runoff + Soil loss + Unaccounted losses)

Partial N balance T3 or T4 = (Fertiliser + Wet deposition) – (Maize grain + Runoff + Soil loss + Unaccounted losses)

Balance with N recovery in soil = Partial N balance + N recovery in soil

Balance with estimated biological fixation = Balance with N recovery in soil + Estimated biological fixation

[1] N in wet deposition (kg) = rainfall amount (m^3) * N concentration in rainfall (g/m^3)/1000 (Schmitter et al. 2012)

[2] Data from Table 3.4

[3] *Arachis pintoi* provided 1.16 Mg ha^{-1} with 2.8% N in a cut-and-carry system. Data of beans were obtained from farmer managed plots (1.20 Mg ha^{-1} with 2.6% N).

[4] $Total\ N\ in runoff = \sum_{i=1}^{n}(Runoff_i * N\%_i)$ where *n* is number of monitored runoff events and $N\%_i$ is the nitrogen concentration in runoff of the event *i*.

$Total\ N\ in soil\ loss = \sum_{i=1}^{m}(Soil\ loss_j * N\%_j)$ where *m* is number of monitored soil loss events and $N\%_j$ is the total nitrogen concentration of soil loss analysed by Kjeldahl method (data not shown) at the event *j*.

[5] $Unaccounted\ losses\ (kg\ N\ ha^{-1}) = Unaccounted\ losses\ (\%) * \text{amount of fertilizer N applied } (158\ \text{kg ha}^{-1})$ where percentages of unaccounted losses are adapted from table 5, in which value at system level is used for grass barrier treatment.

[6] $N\ recovery\ in\ soil\ (kg\ N\ ha^{-1}) = N\ recovery\ in\ soil\ (\%) * \text{amount of fertilizer N applied } (158\ \text{kg ha}^{-1})$

[7] Assuming 22% of N content in removal of *A. pintoi* (7 kg ha^{-1}) (Valles De La Mora and Cadisch 2010) or 42% of Adzuki bean (13 kg ha^{-1}) (Tsai et al. 1993) is biological fixation.

3.5 Discussion

3.5.1 Impact of minimum tillage combined with legumes on nitrogen fertilizer use efficiency (NFUE)

Our hypothesis that establishing soil conservation measures will improve nitrogen fertilizer use efficiency did not hold generally. In MT treatments with legumes as simultaneous or relay cover crop, NFUE of maize (29-31%) as well as that of the whole plant system (32-34%) were similar to farmers' practice with mono-cropping and intensive soil preparation (28 and 31%, respectively). These values of NFUE of maize (except in case of the grass barrier treatment) were in the range of other studies conducted in the region. Dourado-Neto et al. (2010) reported a 20-44% N recovery in maize for Malaysia, Sri Lanka, and Southern Vietnam. Similarly, Rowe et al. (2005) showed that 22-42% of urea-N were recovered by maize grown in a hedgerow intercropping system in a humid tropical environment of Indonesia. Pilbeam et al. (2002) reported slightly lower nitrogen use efficiencies (12-21%) in maize grown in Nepal, because of poor growth rates of maize. In the present study incorporation of fertilizer into the topsoil next to the maize plant may have enhanced NFUE, as much lower NFUE rates could have been expected based on the relatively high observed surface erosion and associated N losses. This procedure is practiced by farmers who have less cultivable land but sufficient labour force available; however most farmers in the area place their fertilizer uncovered on the soil surface leading either to higher volatilization (Blaise et al. 1996) or to down slope translocation of N by runoff.

A lower maize ^{15}N uptake trend in plots with a simultaneous cover crop (T3) (Fig. 3.4) suggests that maize during its juvenile growth, with a still poorly developed root system, was a poor competitor for N. Later on, decomposing legume and weed roots and litter fall presumably recycled part of assimilated ^{15}N originating from fertilizer, increasing its proportions in maize towards harvest (Cadisch et al. 1998). This is supported by the fact that recovery in maize or weeds at harvest (T3) was similar to the control (Table 3.5). When legumes are well-established as observed in the experiment in the third year, the proportion of N from legume roots remaining in the soil can be substantial, e.g. up to 45% of legume N (Yasmin et al. 2010). However, observed topsoil N in plots with simultaneous cover crop in the second year after Pinto peanut establishment (0.14%) was not higher than in the other treatments (0.14-0.15%). Hence, the proportion of soil derived N of T3 was not higher than those in the other treatments (Table 3.4), reflecting that potential positive legume effects have not been materialised within the experimental time; although short-term differences in fast turnover pools (e.g. microbial biomass) are likely to have occurred.

3.5.2 Enhanced systems level NFUE in soil conservation with grass barriers

Our hypothesis that establishing soil conservation measures will improve NFUE in plants did hold only for the treatment with *P. maximum* grass barriers, being 10 or 19% higher than under farmers' practice at systems level (taking into account application of fertilizer

N over whole plot and corresponding N uptake in barriers and maize rows) or when applied next to the barrier, respectively (Table 3.5). This increased system NFUE was achieved due to a high N recovery by grass barriers, which were very effective in acquiring fertilizer N. Further support for an improved N conservation and cycling in T2 is given by the enhanced N acquisition from soil which was by 22 kg ha^{-1} higher than that of the control (Table 3.4). If the harvested grass material would be left in the field as mulch rather than exported, the system would have achieved neutral balance N (Table 3.6). While the grass barrier system appeared to recycle more fertilizer-N than the other treatments, lowest N recovery by maize suggested severe competition for N inducing a 34% yield reduction compared to the control. Hence, the overall maize yield decline can be attributed to N competition on top of the reduced maize cropping area of 23% in T2. In contrast to maize, Guinea grass yield was highest in 2010 when considering the entire observation period (2009-2011) (Tuan et al. 2014), despite 2010 being a drier year. The maize-grass barrier system has a total net primary production that was equal or greater than the other treatments. Therefore it can be considered as an interesting ecological perspective for climate change adaptation.

During vegetative growth (45 DAS), high Ndff in maize rows close to grass barriers was the result of a o water stress induced reduced growth (Fig. 3.4) and hence ^{15}N concentration effect (Cadisch et al. 1989). Depleted maize leaf ^{13}C signatures in T2 confirmed that water stress most likely occurred during juvenile growth of maize (Fig. 3.4d), while N stress was not present as indicated by similar leaf N concentration as in non-grass barrier treatments (Fig. 3.4b). At later stages, Ndff in T2 decreased to the level of the other treatments coinciding with a lower growth, as shown by the lower LAI, indicating a further relative reduction of ^{15}N uptake by maize. Conversely, maize in rows close to barriers had to rely more on N of the native soil N pool, resulting in a higher proportion of N uptake derived from soil as shown by our results (Table 3.4). By 74 DAS, increased ^{13}C values but low leaf N concentration in T2 (Fig. 3.4) suggest that N stress occurred even under relatively high water availability conditions (Dercon et al. 2006a). At harvest, Guinea grass recovered three times as much labelled N as maize when ^{15}N was applied to a maize row close to the barrier suggesting that Guinea grass was heavily scavenging N from adjacent growing maize rows facilitated by its efficient and deep root system (Adjolohoun et al. 2013) and high growth rates (Tuan et al. 2014). This calls for a modified fertilizer application method when using such a soil conservation measure, e.g. by applying more N close to the barrier to compensate for competition effects or applying fertilizer to grass barriers as well.

3.5.3 N-fertilizer recycling and relation to nitrogen stored in soil pool

Our observed percentage of ^{15}N recovery in soil (22-34%) was similar to the value observed in paddy rice (32%) in Northwest Thailand (Kaewpradit et al. 2009) but much lower than in other studies with maize, e.g. Pilbeam et al. (2002) in which 58% of labelled ^{15}N persisted in the soil at maize harvest. Dourado-Neto et al. (2010) reported an average of 37% ^{15}N remaining in the soil after the third cropping season in 12 tropical sites around the world. Our low ^{15}N recoveries in soil were probably due to the fact that we took soil samples in between maize plants, being 20-25 cm away from the ^{15}N labelled fertilizer application point in the top maize row. In strongly weathered soils, as found at our study site, soil organic carbon (SOM) represents the dominant reservoir of nitrogen. We observed 46-73% of N uptake by maize was derived from native soil N (Table 3.4) being within the range of 42% obtained in Southern Vietnam and 77-82% reported for maize in Malaysia and Sri Lanka (Dourado-Neto et al. 2010). Thus, there is considerable potential to improve utilization of residual fertilizer N bounded to SOM and reduce N losses through a better N management. However, our current results did not support this hypothesis as no significant improvements in SOM or ^{15}N recoveries in MT treatments were observed. Designing improved N management approaches require knowledge of site-specific interactions and various levels of internal regulation to help farmers navigate between the lack of access and the excess fertilization problem in plant nutrition described by van Noordwijk and Cadisch (2002). One of such strategies would be synchronizing N mineralization or N fertilizer supply and crop N demand, temporal and spatially. For instance, pruning cover crops on-time may avoid reduced maize yields due to competition (Tuan et al. 2014). Additionally, as tillage accelerates decomposition of SOM (Häring et al. 2013), MT may conserve SOM and therefore retains more N in soil in the long run.

3.5.4 Impact of soil conservation on lateral downslope movement of N-fertilizer

In non-grass barrier treatments, amounts of ^{15}N fertilizer either recovered by maize, weeds and legumes down slope or taken up by the next maize row above the application point were rather small despite cropping on a steep slope (Table 3.5). In T2, recovery rates of the grass barrier upslope and downslope were relatively large as compared to maize ^{15}N recovery in the application row. This may be due to grass roots strongly interfering with maize roots in rows close to grass barriers. There were very low ^{15}N signals in runoff and soil loss, indicating a minor surface N translocation along the slope, likely as a result of the above discussed improved fertilizer application technique. Less runoff in the grass barrier treatment (56% reduction compared to the control; Tuan et al. 2014) did not only lead to lower ^{15}N losses downslope but concurrently induced an enhanced vertical translocation, raising the ratio of ^{15}N amount per unit of runoff at 40-80 cm soil depth downslope (0.29 kg in T2 compared to 0.14 kg accumulated N in T1 per mm runoff; data not shown). Residual ^{15}N at 40-80 cm was lower in both MT treatments when compared to the control. This suggests that both, simultaneous and relay cropping of legumes, reduced the risk of N leaching, probably owing to a better root interception (Cadisch et al. 2004) or improved soil structure (Pansak et al. 2010) associated with such systems.

At systems level, overall erosion caused the largest N losses in current farmers' practice (Table 3.6). The observed small N losses derived from labelled fertilizer in erosion events does not fully reflect general plot N fertilizer losses, as the ^{15}N-labelled urea was applied in a distance of 17 m uphill and most of the translocated ^{15}N was intercepted by crops in rows following the application point before reaching the collecting trough. Substantial amounts of ^{15}N were found in deeper soil layers (40-80 cm), while much less was found in plants along the slope, indicating that fertiliser-N was transported mainly by lateral subsurface movement rather than surface flow. It is also possible that most of these flows went deeper than the rooting zone, being more pronounced under intensive tillage such as in T1 and T2 (Table 3.5, Fig. 3.5). And if this N percolates deeper into the soil during the next rainy season, it is indeed more subject to leaching than likely to remain in the soil once it reaches beyond the main rooting zone of crops. Therefore, it is reasonable to assume that ^{15}N found at a soil depth of 40-80 cm is an indicator of N losses by leaching as most roots in maize, legume or grass based cropping systems are distributed at depths less than 40 cm (Rowe et al. 2005; Cook and Ratcliff 1984). While cumulative ^{15}N recoveries at a soil depth of 40-80 cm along the slope were similar in both, the control and the grass barrier treatment (Table 3.5), a decline in surface losses of the later indicates that probably a shift from surface to leaching losses occurred in grass barrier plots or more ^{15}N was deposited at lower soil depth by grass root turnover.

The average of unaccounted N losses of the four treatments in this study (35% as measured in ^{15}N microplots or 37% as estimated over whole plot) was slightly higher than the value under maize in Nepal (28%) (Pilbeam et al. 2002) but similar to the 40% reported by Dourado-Neto et al. (2010) in twelve tropical regions. The unaccounted N is presumably mainly lost via de-nitrification, and leaching below a soil depth of 80 cm.

3.5.5 Nitrogen balances and implications for sustainable nitrogen management

Estimated nitrogen balances were positive for both minimum tillage practices (T3 and T4) and negative for the control (T1) and the grass barrier treatment (T2), whereby the negative balance of T2 was less severe than that of T1 owing to decreased N losses by erosion. Current farming practice (T1) induced a negative N balance of -142 kg N ha^{-1} in which residue burning and erosion were major pathways for N losses. Thus, strategies for sustainable farming should include criteria aiming at reducing N losses, at least, of these two main pathways. The negative nitrogen balance estimate of farmer's practice in this study is probably somewhat overestimated since erosion at plot level (87 Mg ha^{-1}) was higher compared to catchment or watershed derived values (e.g. 61 Mg ha^{-1} by sediment fence method, Tuan et al. 2014).

Large exports of grass biomass by the cut-and-carry system induced a negative N balance (Table 3.6), suggesting that its N balance can be improved if part of grass harvest is left on the field. Alternatively, the N budget of the grass barrier system can be balanced by adopting no-burning crop residues and weeds.

When taking into account the N derived from fertilizer that remained in the soil, and N_2 fixed by legumes in MT treatments, N balances were positive, indicating a high N sustainability of these systems. A better nutrient interception by intense root activities in mixed systems, and presence of nutrients in micro pores can result in less nutrient leaching even under increased drainage conditions (Cadisch et al. 2004). Drinkwater et al. (1998) also pointed out that N leaching in a soybean-maize system was reduced by almost 50% when compared with conventional monocropping. Although maintaining a positive nitrogen balance, cover crop systems can lead to nitrogen competition with maize. With regard to selection of a legume for a balance between competition and safety-net efficiency in mixed-species systems, slow-growing, deep-rooting, and well-adapted N_2-fixing legumes are more preferable than fast-growing ones (Cadisch et al. 2004) as also shown in our case with the relay crop *P. calcaratus*. Therefore, further research is needed to assess short- and long-term effects of soil conservation measures involving legumes in accommodating main crops and raising soil N pools under humid and sub humid tropical conditions.

3.6 Conclusions

Positive N balances of minimum tillage treatments with a legume were associated with reduced N losses by erosion and abandonment of burning residues, indicating a viable option for hillside cropping on steep slopes. Although reducing runoff and soil loss on steep slopes, conservation measures did not improve fertilizer maize nitrogen use efficiency (FNUE) at least in the first season. Over subsequent seasons however, total N use efficiency is probably increasing due to improved N recycling and reduced soil losses. Conversely, in case of grass barriers, fertilizer nitrogen use efficiency by maize strongly decreased due to competition for N between Guinea grass and maize. Additionally, in grass barriers fertilizer N reached deeper soil layers as the reduced runoff speed led to a longer retention period of fertilizer N in the area between two barriers and potentially increased infiltration. Modified fertilizer application schemes addressing both competition for N and N leaching should improve performance of the system, e.g. by targeted increased fertilizer application to maize rows next to grass barriers.

Regulating and conserving SOM is important for a sustainable N supply, as about half N in maize was derived from the native soil mineral N pool. The tested legume and minimum till based soil conservation measures seemed to reduce ^{15}N translocation to deeper soil layers (40-80cm), being considered as indicator of reduced N leaching.

Soil conservation measures significantly decreased longer distance ^{15}N losses derived from fertilizer by sediments and runoff (<0.1%), because the majority of ^{15}N added was vertically translocated and intercepted by plants along the slope closer to the fertilizer application point before reaching collecting devices at the bottom of plots. Despite an improved application method, the maize crop recovered less than 31% of fertilizer N. Erosion and residue burning were the main pathways of N losses in the current farming system where total annual N loss in runoff and sediment exceeded the amount of fertilizer input. When erosion is almost eliminated, as under minimum tillage with legume cover crops or relay cropping, N losses by de-nitrification, volatilization, or leaching have to be addressed calling for further research attention. Thereby, a revised land use strategy towards reduced erosion, higher fertilizer use efficiency, and sustained income need to be tested and implemented in fragile mountainous environments as often found in Southeast Asia mainland.

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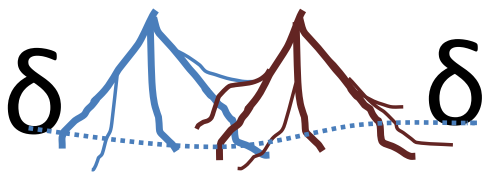
Chapter

4

Identifying resource competition in maize based soil conservation systems using ^{13}C and ^{15}N isotopic discrimination



4 IDENTIFYING RESOURCE COMPETITION IN MAIZE BASED SOIL CONSERVATION SYSTEMS USING ^{13}C AND ^{15}N ISOTOPIC DISCRIMINATION[3]

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4.1 Abstract

Soil conservation measures such as establishing grass barriers or cover crops effectively control erosion but also provoke competition which reduces yields of companion crops. We used ^{13}C and ^{15}N natural abundance profiles to identify causes of competition of soil conservation measures on a field with 59% slope in Northwest Vietnam three years after establishment. Treatments were maize under farmer's practice (T1, control), maize with Guinea grass barriers (T2), maize under minimum tillage (MT) with Pinto peanuts as cover crop (T3), and maize under MT and relay cropped with Adzuki beans (T4). A pre-test using data from zero-N-plots revealed that abundance of water and limited nitrogen availability induced low grain N concentrations, enriched leaf $\delta^{13}C$, and reduced maize grain yield. Similar low N leaf concentrations and elevated $\delta^{13}C$ values were observed in maize growing close to frequently pruned grass barriers under positive water balance conditions, indicating that yield decline in these rows can be attributed mainly to N competition. Enriched $\delta^{15}N$ values of maize from rows next to barriers indicated reliance on soil N rather than on ^{15}N depleted fertilizer N. Vigorous cover crop growth under MT resulted in maize yield decline due to N competition while relay-cropped legumes did not trigger inter-species competition having a similar maize yield, leaf N concentration, $\delta^{13}C$, and $\delta^{15}N$ as the control.

Keywords: competition, cover crops, grass barriers, relay cropping, stable isotopes

[3] This chapter is based on: Tuan VD, Hilger T, Cadisch G. (2015). Accepted for publication in Archives of Agronomy and Soil Science

4.2 Introduction

Particularly during the last two decades, erosion has become a serious environmental threat in Southeast Asia due to extended maize mono-cropping on steep slopes (Hilger et al. 2013). Although soil conservation measures such as grass barriers, minimum tillage with simultaneous cover crops or relay cropping are very effective in reducing erosion (Pansak et al. 2010; Pansak et al. 2008; Phiên et al. 2002), their negative impact on crop yields makes farmers less willing to adopt such techniques (Hilger et al. 2013). Reduced yields due to competition for light, nutrients, and water between crops and associated plants have been widely reported for mixed systems (Clay et al. 2009; Dercon et al. 2006b; Pansak et al. 2007; Smeltekop et al. 2002).

The term competition refers to a process of acquisition of a shared resource or to consequences this has for the growth and productivity of competing plants. For a farmer, competition matters when competing plants differ in output per unit resource acquired (van Noordwijk & Cadisch 2002). To quantify mechanisms responsible for competition-based yield loss, ^{13}C isotope discrimination can be used for better understanding water or nutrient induced stress (Clay et al. 2005; Dercon et al. 2006a; Gitz Iii et al. 2005). Due to complex N and water interactions on plant physiology there are still knowledge gaps on understanding relationships between abiotic stress and isotopic signatures of ^{13}C. Hence a combined analysis of the stable isotopes ^{13}C and ^{15}N may help to identify the underlying causes of competition in mixed systems which, in turn, may help to revise crop management mitigating negative impacts on crop yields.

Generally, plants contain less ^{13}C than the atmospheric CO_2. They are, therefore, “depleted” of ^{13}C relative to the atmosphere. This depletion is caused by enzymatic and physical processes that discriminate against ^{13}C in favour of ^{12}C. The magnitude of discrimination (Δ) varies among plants using different photosynthetic pathways. C_4 plants have lower Δ than C_3 plants as a result of the processes and enzymes involved in C_4 photosynthesis. This is explained by the small extent to which inorganic carbon diffuses back from the vascular bundle to the mesophyll where malate or aspartate is decarboxylated, producing (intercellular space) CO_2 and pyruvate or alanine. The organic carbon that diffuses back to the mesophyll cells will be re-fixed by PEP carboxylase. Most of the $^{13}CO_2$ that accumulates in the bundle sheath cells is ultimately assimilated (Farquhar 1983; Lambers et al. 1998); hence the isotope fractionation of CO_2 in C_4 plant is smaller than that of C_3 plants, clustering around -11‰ to -14‰ (Cerling et al. 1997).

Carbon isotope discrimination (Δ) differs from $\delta^{13}C$ in that it describes only that change in isotopic composition induced by the plant, eliminating variation as a result of a starting value of the atmospheric CO_2 used for photosynthesis (Farquhar 1983). Variation in ^{13}C discrimination in response to environmental and genetic drivers is small but significant. However, interpreting the variation in Δ of C_4 plants is challenging because it cannot be attributed to a single major factor (Cernusak et al. 2013). A model to describe Δ was first proposed by Farquhar (1983) and has recently been updated to include ternary correction (Farquhar & Cernusak 2012). This correction accounts for the influence of transpiration on the diffusion of CO_2 between the atmosphere and the intercellular air space. The term ‘ternary’ refers to three interacting gases: CO_2, water vapour and air.

The simplified model for ^{13}C discrimination can be written as follows:

$$\Delta = a\frac{(c_a - c_i)}{c_a} + [b_4 + \phi(b_3 - s)]\frac{c_i}{c_a} \quad (1)$$

where c_a and c_i are the CO_2 mole fractions in the ambient air and in the intercellular air spaces, respectively, b_4 and b_3 the carbon discrimination by the enzymes PEP carboxylase (-5.7‰ at 25°C) and Rubisco (29‰), respectively, ϕ the leakiness of the bundle sheath cells, and s the carbon fractionation during leakiness (1.8‰).

Equation 1 shows that in the simplest case scenario the variation in ^{13}C discrimination depends on both instantaneous ratio of intercellular to ambient CO_2 mole fractions (c_i/c_a) and leakiness ϕ. The term leakiness (ϕ) represents the proportion of carbon fixed by PEP carboxylase leaking out of the bundle-sheath. There is either a positive or a negative correlation between Δ and c_i/c_a, depending on whether ϕ is larger or smaller than 0.37. The extent of leakiness is determined by the bundle sheath conductance to CO_2, which depends on physical properties, such as the presence of a suberized lamella (Hatch et al. 1995), and on the CO_2 gradient between the bundle-sheath and mesophyll cells, which in turn depends on the balance between PEP carboxylase and Rubisco activities (Peisker & Henderson 1992).

The response of ^{13}C discrimination of C_4 plants to water stress is opposite to that of C_3 plants. Under most environmental conditions, ϕ is <0.37, and Δ is expected to increase with decreasing water availability as a result of decreasing c_i/c_a (Cernusak et al. 2013). Dercon et al. (2006a) pointed out that $\delta^{13}C$ values in maize could be related to soil moisture and N availability. They concluded that ^{13}C decreased with increasing water stress, but increased with decreasing N availability. Under nitrogen stress conditions, Rubisco activity decreased more than PEP activity causing a significant reduction in the Rubisco/PEP activity ratio. Such a decreased partitioning of N to Rubisco activity increased leakiness and reduced photosynthesis which led to depleted ^{13}C values of sugarcane under greenhouse conditions (Ranjith et al. 1995). In contrast, results of Pansak et al. (2007) showed higher ^{13}C enrichment of maize leaves towards hedges or barriers. ^{13}C signals of maize leaves in combination with shoot N and available soil nitrate across the slope pointed to a major role of N availability in the reduced yield response of crops towards the barriers. Hussain et al. (2015) also showed that lack of N increased maize grain $\delta^{13}C$ in rows close to *Leucaena leucocephala* hedgerows when no N fertilizer was applied. This effect was less pronounced when urea was applied.

To our knowledge, understanding of the effects of environmental variables on ^{15}N natural abundance is far from being complete (Peri et al. 2011). Variation of natural ^{15}N abundance in soils is supposed to occur due to the contribution from different nitrogen sources. Soil N is usually more enriched in ^{15}N as microbes in the soil discriminate against ^{15}N during decomposition, mineralization, nitrification, and denitrification that leave the soil organic N enriched in ^{15}N (Nadelhoffer et al. 1996; Wang et al. 2011). Therefore, plants relying more on soil organic N should probably be enriched in ^{15}N in their biomass as compared to plants obtaining N mainly from inorganic fertilizer or biological N fixation from air with their mostly depleted ^{15}N values (Valles De La Mora & Cadisch 2010; Wang et al. 2011). Hence, the difference of ^{15}N values from various sources can be used to estimate their relative contribution to the crop N uptake (Dalal et al. 2013). By using both ^{13}C and ^{15}N natural abundance techniques, Smeltekop et al. (2002) revealed that maize yield losses were due to the competition with an undersown legume (*Medicago scutellata)*, primarily owing to N stress rather than water stress.

The objectives of this study were to (i) identify the cause of competition between maize and associated crops by using combined ^{13}C and ^{15}N techniques together with standard methods to determine N availability and plant N uptake and (ii) assess impact of soil conservation methods on resource competition of the studied systems. We hypothesized that grass barriers, simultaneous or relay grown cover crops influence competition between maize and associated crops spatially in different ways. Therefore, the stable isotopes ^{13}C and ^{15}N can be used to identify the causes of competition. Vigorous growth of grass barriers is likely to have negative impacts on nearby maize rows, while cover crops or relay cropping may affect maize plants over the whole plot depending on their growth rate and temporal development.

4.3 Materials and Methods

4.3.1 Experimental site

This study was carried out during 2011 in the Chieng Khoi (CK) commune (520 m a.s.l., 21.02° N and 104.32° E), Northwest Vietnam, two years after trial establishment. In addition, data collected during 2010 at a soil conservation experiment in the Chieng Hac (CH) commune (260 m a.s.l., 21.02° N and 104.37° E), around 10 km away from the Chieng Khoi site, were used for a pre-test. The climate is characterized by tropical monsoon rains falling between May to October followed by a relatively dry cool season from November to March. The monthly mean temperatures are 21 °C, ranging from a minimum of 16 °C in February to a maximum of 27 °C in August (Schmitter et al. 2010; Tuan et al. 2014). Annual rainfall was 1305 mm (2010) at CH and 1299 mm (2011) at CK. The soils at CH were classified as Alisols to Luvisols, depending on their clay content and at CK as Luvisols to Calcisols, depending on their carbonate content. The top soil (0-15 cm) at CK had a $pH_{(H2O)}$ of 5.2-7.1 and a silty clay soil texture. Organic carbon was low to moderate (0.76-1.26%), total nitrogen low (0.08-0.13%), and C:N ratio of the top soil layers up to 30 cm at CK 8.1-10.0, and 9.4-9.7 at CH. Available potassium was high to very high (56-147 mg K kg^{-1}) while available P (Bray I) was low (mostly <5 mg P kg^{-1}). Exchangeable cations at both sites were dominated by Ca^{2+} (100-225 $mmol_c$ kg^{-1}), being lower at CH (Breunig 2011; Reinhardt 2009). Further information can be obtained from Tuan et al. (2014).

4.3.2 Experimental setup

Three soil conservation measures represented by maize with Guinea grass (*Panicum maximum*) barriers (T2), maize under minimum tillage (MT) with Pinto peanut (*Arachis pintoi*) as a cover crop (T3), and maize under MT with relay cropping of Adzuki beans (*Phaseolus calcaratus*) (T4) were compared against the current farmer's maize cropping practice based on slashing, burning and intensive ploughing (control, T1). The experiments consisted of 12 bounded plots, arranged as a randomized complete block design with three replicates. Slope gradients were 53-59%. At CH, the same setup was used but additionally three plots under current farmer's practice without N fertilization were established. These zero-N-plots were used to assess the impact of N deficiency on crop yield and associated changes of ^{13}C values in 2010 before starting the sampling campaign at CK in 2011. For the pre-test, T1, T2, and the zero-N treatments (T0) were used only.

All treatments received the same amount of fertilizer: 158 kg N, 17.5 kg P, and 58.6 kg K per ha as urea (46% N), potassium chloride (60% K), and a compound NPK fertilizer (5.0% N, 4.4% P and 1.6% K). N was split-applied: 3.2% as basal dressing, 49.3% at the 4-5-leaf-stage as second dressing, and 47.5% at the anthesis stage as third dressing. The zero-N-plots received the same amount of P and K as all other treatments in the forms of superphosphate and potassium chloride.

Plots of T0, T1 and T2 were hand-hoed twice before maize sowing, whereas in both MT treatments (T3 and T4) small furrows for planting were prepared just before maize sowing and covered with soil thereafter to minimise soil disturbance. Maize (local hybrid LVN-10) was planted at a spacing of 24 cm in the row and 75 cm between rows on May 17-19th, 2010 at CH and on May 7th, 2011 at CK. Four 1-m-wide *Panicum maximum* barriers were transplanted at intervals of 6 m on June 6th and 9th, 2009 at CK and CH, respectively. Pinto peanuts were transplanted between maize rows spaced 20 cm apart along contour lines (approximately 66 thousands cutting-stem holes per ha) once in June 2009 as permanent soil cover. Adzuki beans were sown between maize rows (approximately 30 thousands double-seed holes per ha) one month after maize sowing. Weeding was done in all treatments by hand-hoeing. The non-grass barrier plots treatment had 100% cultivable area for maize with 24 rows (Fig. 4.1a), whereas maize occupied 77% of plot area with 18 rows in the grass barrier treatment (Fig. 4.1b). The remaining area of T2 was reserved for four rows of grass. In 2011, grass barriers were pruned four times to a height of 30 cm to avoid shading of maize. *Arachis pintoi* was cut three times during early season (0, 31 and 58 days after sowing maize) when its growth was considered proliferate. Maize was harvested on September 14-15th, 2011 at CK and on September 5-11th, 2010 at CH.

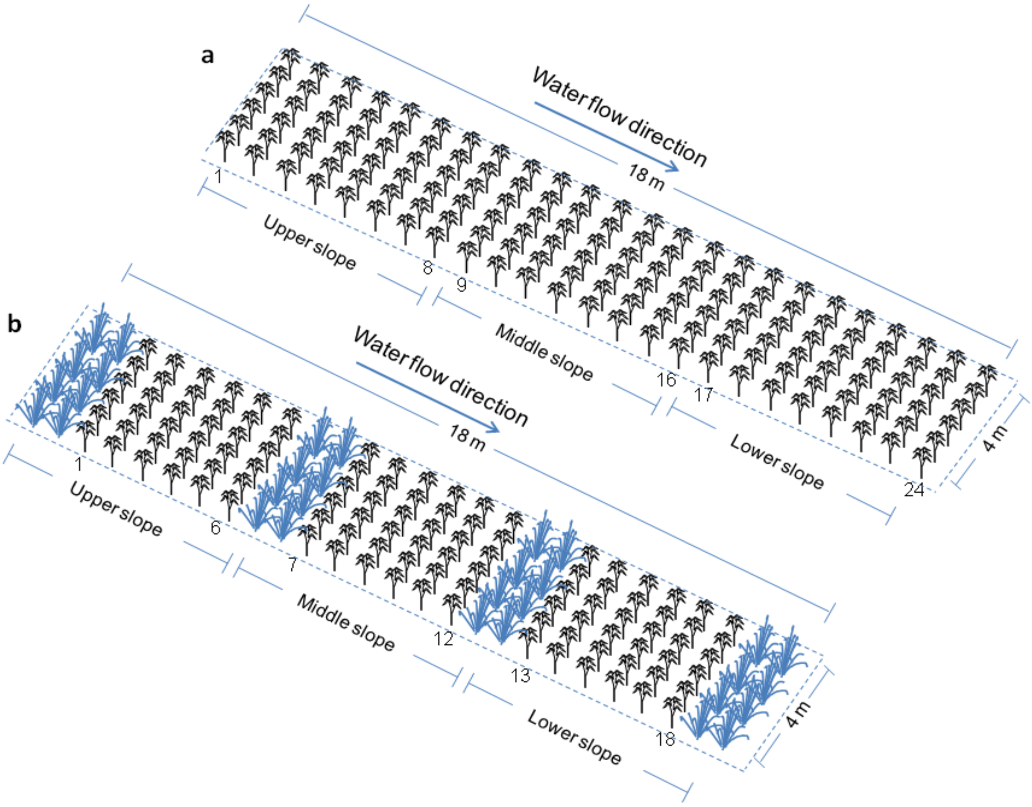

Fig. 4.1 Layout of field plots (a) without grass barriers (T1, T3 & T4); (b) with grass barriers (T2) at Chieng Khoi, NW Vietnam. T1: Farmers' practice (control); T2: Grass barrier; T3: Minimum tillage + cover crop; T4: Minimum tillage + relay crop

4.3.3 Partial soil water balance

Evapotranspiration was calculated following the FAO Penman – Monteith equation for daily time steps and then summed up for monthly values (Fig. 4.2). The evapotranspiration of monocropped maize (*ETc*, mm day^{-1}) was calculated according the following equation:

$$ET_c = K_c * ET_o \qquad (2)$$

where ET_o (mm day^{-1}) is the reference evapotranspiration and K_c the crop coefficient. The following estimated *Kc* values adapted to the local maize hybrid variety with a vegetation period of 130 days were used: 0.8 for initial phase with duration of 30 days, 1.0 for the development phase with duration of 40 days, 1.2 for the middle phase with duration of 30 days (Allen et al. 1998). The K_c values of the period before the first rains and thereafter until maize sowing were 0.2 and 0.6, respectively. A value of 0.8 was used for the period after harvest till the on-set of the dry season. After that 0.6 was estimated for weeds remaining on the field (details for other treatments are presented in the annex).

The partial water balance (mm month^{-1}) was computed by subtracting evapotranspiration and runoff from rainfall as follows:

$$Water\ balance = Rainfall - ET_c - runoff \quad (3)$$

Runoff data were obtained from Tuan et al. (2014).

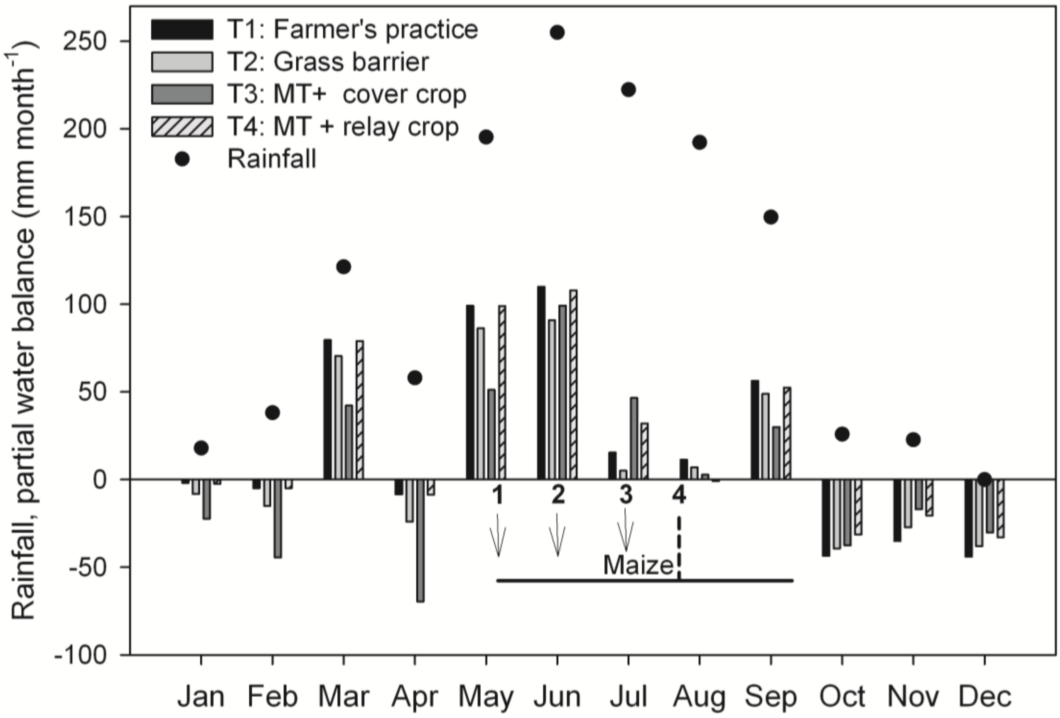

Figure 4.2 Monthly rainfall (filled circles) and partial water balance (PWB) as affected by soil conservation. Data were recorded in 2011 at Chieng Khoi, NW Vietnam. Values are means of three replicates. Arrows indicate 1: sowing and basal dressing (3.2% N); 2: 2nd dressing (49% N); 3: 3rd dressing (47.5% N); 4: maize leaf sampling. MT: minimum tillage.

4.3.4 Soil and plant sampling

At CK, soil (0-15 cm) was sampled at three points in between two rows, simultaneous with sampling of the third youngest leaf of three plants at anthesis stage of maize, 77 days after sowing (DAS). Each soil sample was split in two subsamples. One subsample was air-dried before being oven-dried at 60°C until constant weight was reached and then used to calculate the soil water content as follow:

$$SWC\ [\%\ dw] = 100\ (W - D)/D \quad (4)$$

where *SWC* is the soil water content, *W* the weight of wet subsample, and *D* the weight of the dry subsample.

The other subsample was stored at 4 °C until nitrate extraction by shaking 20 g soil with 0.1M KCl (soil:KCl ratio 1:2.5) for one hour before filtering the extract. The extracted NO_3^--N was subsequently determined by the colorimetric Cataldo method (Cataldo et al. 1975). At the end of the cropping season, top soil (0-15 cm) was sampled along the slope at three positions (top, middle and bottom) of each plot for determination of total soil ^{15}N values.

At CK, leaf area index (LAI) of maize was measured by using a LAI-2000 Plant Canopy Analyzer (LI-COR Biosciences, USA) at anthesis stage. To capture heterogeneity of grass barrier plots, five positions within the three alleys representing distance from barriers were measured (three in the middle of the alley, one close to upper barrier, and one close to lower barrier), while in each non-barrier plot, only three positions (top, middle and bottom of each plot) were necessary. At anthesis stage, in each plot the stem diameter of twenty maize plants was assessed at the first node above ground, including those plants sampled for leaf analysis at this stage.

Maize was harvested per row at 130 DAS. Grain yields from nine maize rows were used, i.e. two close to barriers and one in the middle of each of the three alleys in grass barrier plots or corresponding positions in non-grass barrier plots (Fig. 4.1). Fresh grain subsamples were weighed, then air-dried before oven drying at 60°C until constant weight was reached, and weighed again to determine fresh/dry weight ratios. These ratios were used to convert field-measured fresh weights into dry weights. Maize yields were reported as row-based or plot-based (in T2 including the areas devoted to grass barriers) values.

A pre-test was carried out at CH to identify the effect of omitting N-fertilizer and grass barriers under abundant water supply on maize growth and ^{13}C signature. Therefore, three leaves developed during a wet period were collected from each of three positions in mid-alley of each plot: central row and one row close to upper or lower grass barrier. Samples were processed in the same way as those taken at CK. Maize grain yield assessment followed the same procedure as described for CK.

4.3.5 $\delta^{13}C$ and $\delta^{15}N$ analysis

Leaf samples were first air-dried, then oven dried at 60 °C for 72 hours, and subsequently ball milled. Samples were analysed for ^{15}N and ^{13}C by using an Euro Elemental Analyzer coupled to a Finigan Delta IRMS (Thermo Scientific, Germany).

The stable isotope of carbon in a sample was reported as deviation from isotopic ratio of a standard:

$$^{13}C\ (‰) = [(R_{sample} / R_{standard}) - 1] * 10^3 \qquad (5)$$

where R denotes the ratio of stable carbon ($^{13}C/^{12}C$).

The $\delta^{13}C$ values were calculated by comparing the ratio of a sample (R_{sample}) relatively to the ratio R standard ($R_{standard}$) of Vienna Pee Dee Belemnite (V-PDB) standard (with $\delta^{13}C=0$).

The isotopic signature ($\delta^{15}N$) of applied urea was –0.29‰, while the NPK compound fertilizer contained 2.87‰ $\delta^{15}N$. From the total N applied, 87% was in the form of urea which resulted in an overall weighted ^{15}N signature of 0.11‰ for the applied N fertilizer.

4.3.6 Statistical analysis

Grain yield, biomass and $\delta^{13}C$ values of leaves were tested using a MIXED model of SAS ver. 9.0 (SAS Institute 2002), considering row as repeated measurement. When significant effects were indicated, means were compared using LSMEAN test. A one-way analysis of variance model GLM was used to assess LAI, $\delta^{15}N$, nitrate and soil moisture. In order to assess spatial variability among rows within treatment, GLM model was used and means were compared using LSD at $p<0.05$.

A logistic regression model of SigmaPlot 11.0 (Systat Software Inc. 2008) was used when significant correlation between two parameters were found.

4.4 Results

4.4.1 Maize performance in relation to soil conservation measures

A pre-test with a data set collected at CH in 2010 showed that maize grain yield decreased in rows close to grass barriers, while rows in the centre between two grass barriers had similar yield levels as rows of the control under current farmer's practice (Fig. 4.3a). Maize grain yields of rows close to the upper grass barrier were significantly lower than those of rows close to the lower barrier. Similar low maize yields, as in rows close to grass barriers, were found in zero-N maize monocrop plots (T0). Total-N of grains varied among treatments but was significantly lower in T0 only (Fig. 4.3b). Maize leaf $\delta^{13}C$ collected from rows in the centre between two grass barriers and in the control treatment had similar depleted carbon isotopic values. However, isotopic signals of maize leaves taken at rows close to barriers had less depleted $\delta^{13}C$ values (Fig. 4.3c); differences were significant when maize leaves were collected in rows close to the lower barrier. In zero-N-plots, leaf ^{13}C values were also significantly less depleted than in central rows of T2 and rows of the control. These results indicate that lack of nitrogen (T0) induced a lower grain yield, lower total N grain concentration, and less depleted $\delta^{13}C$ values.

At CK, maize grain yield of the maize monocrop control (T1) was 5.4±0.2 Mg ha^{-1} in 2011 (Table 4.1). Grass barrier (T2) and cover crop (T3) treatments had significantly lower yields than the control, whereas the relay crop treatment, T4, had the same yield as the control. In case of T2, yield data were area corrected as grass barriers occupied part of the plot. Both, the grass barrier treatment and the simultaneous cover crop treatment with *A. pintoi* significantly decreased maize leaf area index (LAI) and stem diameter values at anthesis stage (77 days after sowing) as compared to T1 and T4 (Table 4.1).

To further understand the direct impact of soil conservation on maize performance, we investigated maize yields per row across the slope. On average, row-based maize yields were, with around 540 g m^{-2}, similar in T1 and T4, being significantly larger than those of T2 (Table 4.1). Maize grain yields varied along the slope in all treatments, the variability being strongest in T2 (Fig. 4.4). In T2, means of grain yield were 221±46 g m^{-2} and 369±70 g m^{-2} for rows next to the upper or lower grass barrier, respectively, being significantly lower than those of central rows (average: 676±30 g m^{-2}; Table 4.2). This indicates that the vigorous growth of *P. maximum* suppressed maize growth in rows next to the grass barrier.

Table 4.1 Leaf area index (LAI) and stem diameter measured at anthesis stage (77 days after sowing), and maize grain yield measured at harvest as affected by soil conservation. Data were recorded in 2011 at Chieng Khoi, NW Vietnam.

Treatments	LAI	Stem diameter (cm)	Area corrected yields ($Mg\ ha^{-1}$)	Row based yields ($g\ m^{-2}$)
T1: Farmers' practice	2.3±0.12 a[α] (9)[β]	2.0±0.02 a (60)	5.4±0.2 a (27)	540±15 a (27)
T2: Grass barriers	1.6±0.08 b (15)[#]	1.9±0.03 b (60)	3.4±0.4 c (27)	422±44 b (27)
T3: MT + cover crop	1.8±0.07 b (9)	1.8±0.03 c (60)	4.6±0.2 b (27)	457±23 ab (27)
T4: MT + relay crop	2.5±0.16 a (9)	2.0±0.02 a (60)	5.4±0.2 a (27)	539±19 a (27)

[α] Treatment means and ± standard errors, [β] no. of samples is shown in parenthesis. Different letters in the same column indicate significant differences at $p<0.05$.

Kenward Roger method was used to calculate the degrees-of-freedom where number of samples was unbalanced.

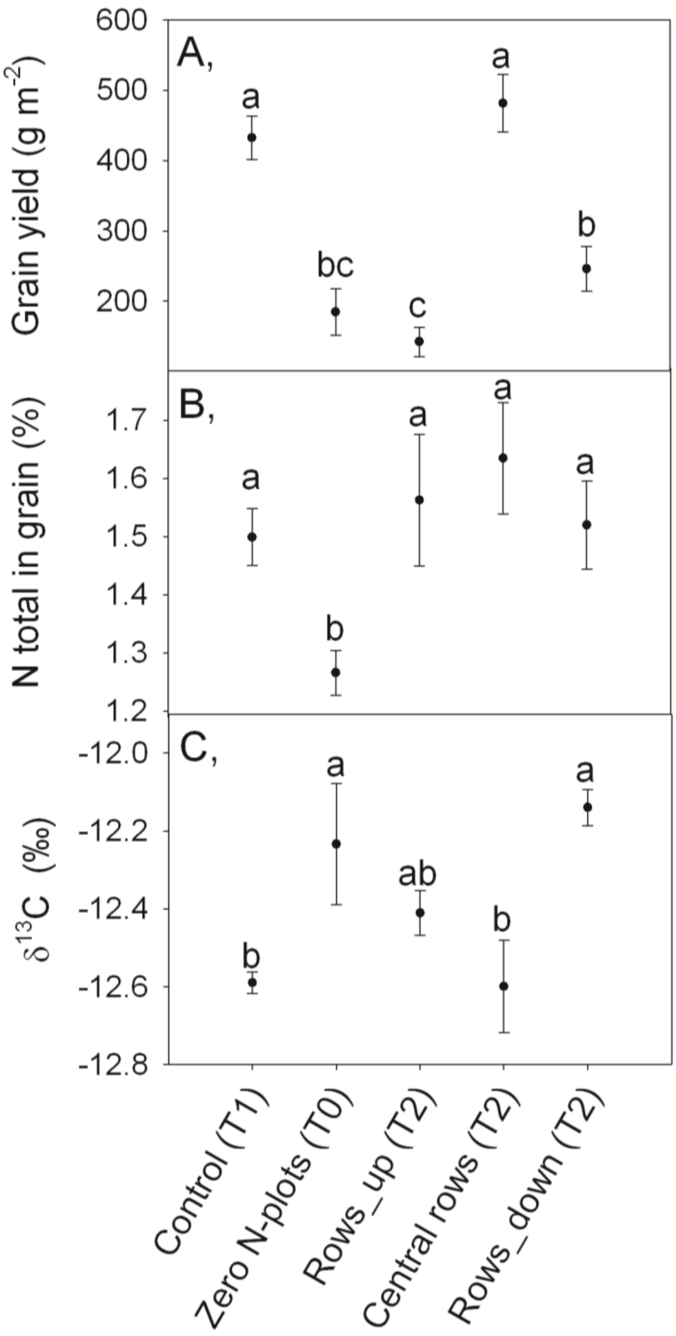

Figure 4.3 Maize grain yield (A) and N concentration of grains (B), $\delta^{13}C$ values of the third youngest leaf developed during a wet period and sampled at harvest (C) collected from maize plants in the middle of an alley/plot for the farmers' practice (maize monocrop control, T1), zero-N maize monocrop (T0), and grass barrier treatment (T2) in 2011 at Chieng Hac, NW Vietnam. Rows_up (T2): maize rows close to upper grass barriers, Rows_down (T2): maize rows close to lower grass barriers. Error bars denote standard errors. Means followed by the same letter are not significantly different ($p<0.05$).

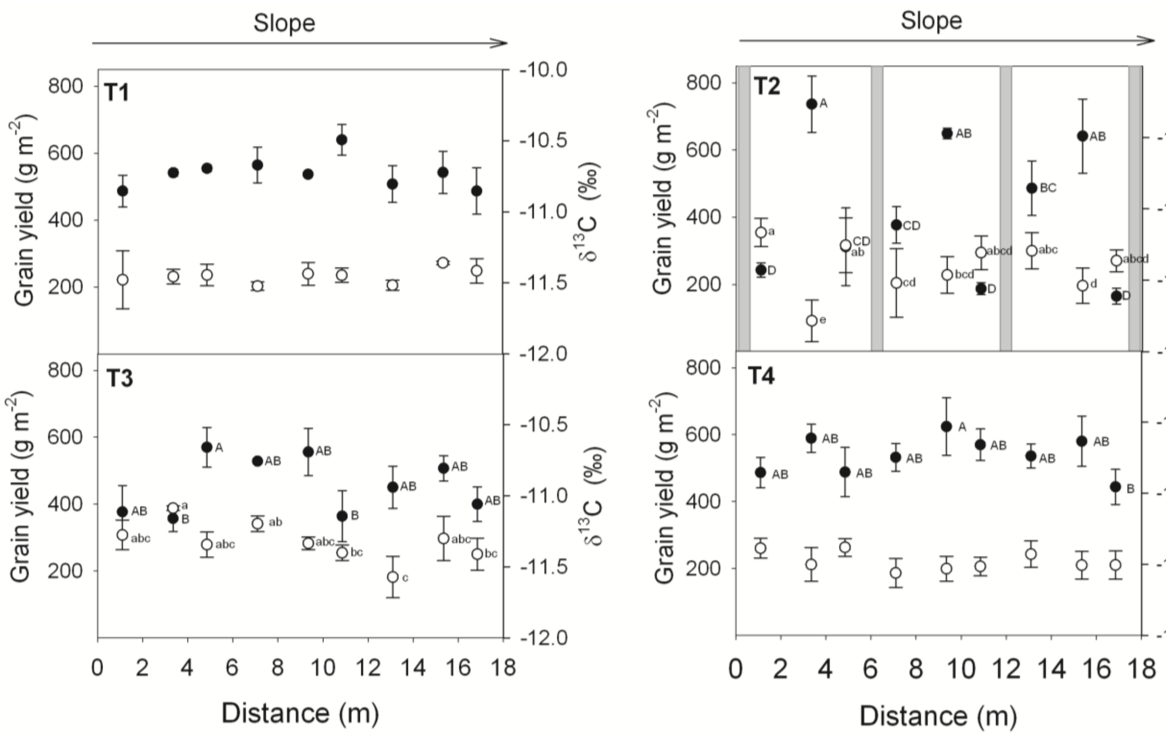

Figure 4.4 Effect of soil conservation measures on maize grain yield (•) and $\delta^{13}C$ values (o) of the third youngest leaf at anthesis (77 day after sowing). Data were recorded at Chieng Khoi, NW Vietnam. T1: Farmers' practice (maize monocrop, control); T2: Grass barrier; T3: Minimum tillage + cover crop; T4: Minimum tillage + relay crop. Error bars denote standard errors. Shadings in the chart correspond to grass barrier positions in plots. Means followed by the same letter are not significantly different ($p<0.05$) within each treatment (capital letters for maize yield, small letters for $\delta^{13}C$).

4.4.2 N concentration, ^{15}N and ^{13}C in the third youngest maize leaf

Mean N concentration of the third youngest leaf followed the order T4≥T1≥T3>T2, indicating that both grass barriers and simultaneous cover crops induced a reduction of N in maize leaves around anthesis stage (Table 4.2). There were no significant differences in leaf N concentrations among rows from non-grass barrier treatments (T1, T3, and T4), whereas higher leaf N concentrations were observed at central rows (2.90%) of the alleys in the grass barrier treatment (T2; Fig. 4.5) than in rows close to barriers (2.62-2.65%) (Table 4.2). $\delta^{15}N$ values of the third youngest leaf originating from maize rows close to barriers were also higher than those collected from a middle row of alleys. This suggests that maize close to barriers obtained more N from the soil which was relatively enriched in $\delta^{15}N$ (7.3‰) than N from fertilizer (weighted ^{15}N of 0.11‰). Major water competition was discounted because of a positive water balance over the whole cropping season (Fig. 4.2) and the observation that soil water content was similar across treatments at anthesis (Table 4.2).

Mean $\delta^{13}C$ values of maize leaves collected in T3 (MT with cover crop) were higher (less depleted) than in T1 (control) and T4 (MT with a relay crop), while those of the grass barrier treatment were intermediate and did not significantly differ from other treatments (Table 4.2). A clear distinction could be made within T2 where less depleted $\delta^{13}C$ values were observed in rows close to grass barriers compared to central rows of an alley (Table 4.2). There were no significant differences of ^{13}C signals among rows in T1 and T4 treatments. Spatial variability of $\delta^{13}C$ values in T3 was large but no clear trend was found (Fig. 4.4).

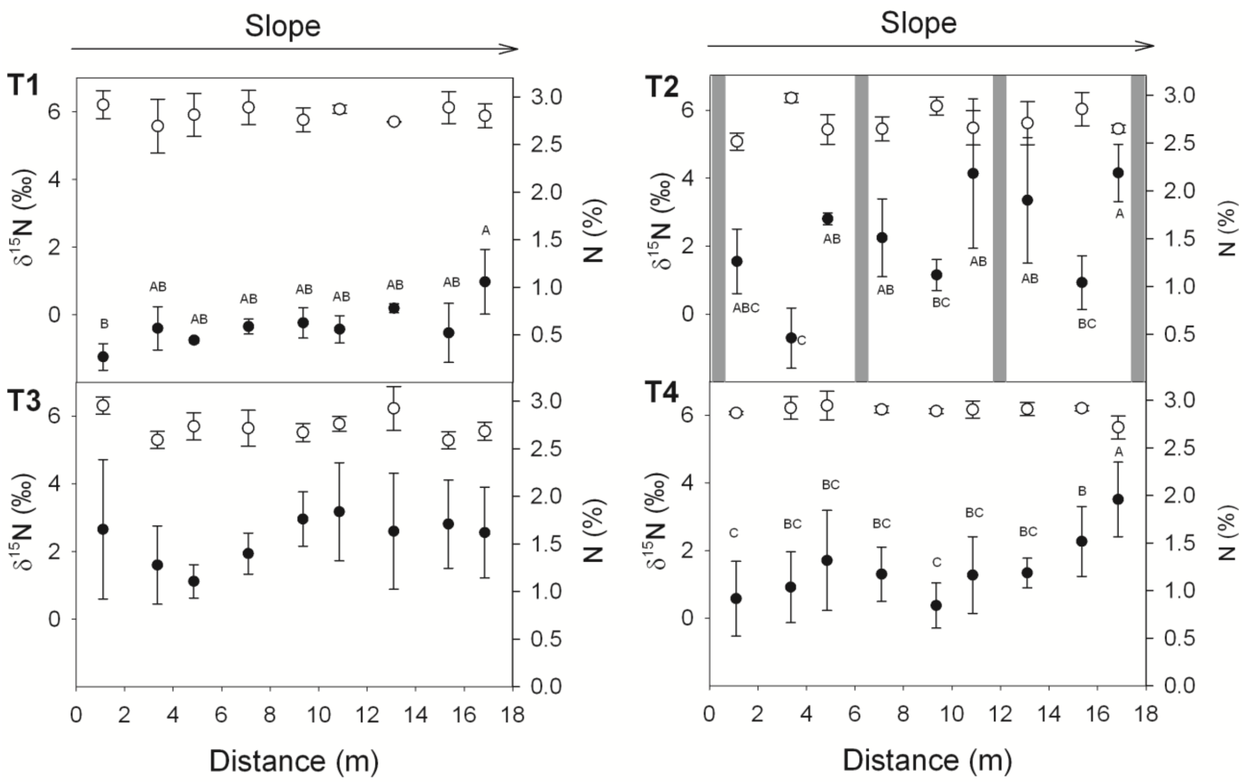

Figure 4.5 Effect of soil conservation measures on total N concentration (o) and $\delta^{15}N$ values (●) of the third youngest maize leaf at anthesis at Chieng Khoi, NW Vietnam. T1: Farmers' practice (control); T2: Grass barrier; T3: Minimum tillage + cover crop; T4: Minimum tillage + relay crop. Error bars denote standard errors. Shadings in the chart corresponding to grass barrier positions in plot. Means followed by the same letter are not significantly different ($p<0.05$) within each treatment (small letters for total N, capital letters for $\delta^{15}N$).

Table 4.2 Maize grain yield at harvest, N total, $\delta^{13}C$ values, $\delta^{15}N$ values in the third youngest leaf, NO_3^--N and water content in top soil collected at anthesis stage (77 days after sowing), and $\delta^{15}N$ in top soil sampled at harvesting time as affected by soil conservation. Data were recorded in 2011 at Chieng Khoi, NW Vietnam.

Treatment	Grain yield	N in leaf	$\delta^{13}C$ in leaf	$\delta^{15}N$ in leaf	Soil NO_3-N	Soil water content	Soil $\delta^{15}N$ at harvest
	$g\ m^{-2}$	%	‰	‰	$mg\ kg\ soil^{-1}$	%	‰
T1: Farmers' practice (Control)	540±15 ^{A}	2.74 ^{AB} (27)	-11.45 ^{B} (27)	1.2 ^{B} (27)	6.8 ^{A} (27)	24.6 ^{A} (27)	6.8 ^{A} (3)
T2: Grass barrier- mean	422±44 ^{B}	2.54 ^{C} (27)	-11.41 ^{AB} (27)	1.0 ^{B} (27)	6.2 ^{A} (27)	24.0 ^{A} (27)	7.3 ^{A} (3)
- Rows close to upper barrier	369±70 ^{b} (9)	2.62 ^{b} (9)	-11.33 ^{a} (9)	2.4 ^{a} (9)	7.6 ^{a} (9)	24.3 ^{a} (9)	n.a
- Central rows	676±30 ^{a} (9)	2.90 ^{a} (9)	-11.60 ^{b} (9)	0.5 ^{b} (9)	5.9 ^{a} (9)	23.3 ^{a} (9)	n.a
- Rows close to lower barriers	221±46 ^{c} (9)	2.65 ^{b} (9)	-11.31 ^{a} (9)	2.7 ^{a} (9)	5.2 ^{a} (9)	24.4 ^{a} (9)	n.a
T3: MT + cover crop	457±23 ^{AB}	2.69 ^{BC} (27)	-11.33 ^{A} (27)	2.8 ^{A} (27)	6.0 ^{A} (27)	24.5 ^{A} (27)	7.6 ^{A} (3)
T4: MT + relay crop	539±19 ^{A}	2.87 ^{A} (27)	-11.48 ^{B} (27)	0.7 ^{B} (27)	6.8 ^{A} (27)	23.7 ^{A} (27)	6.9 ^{A} (3)

Number of samples is shown in parenthesis. Different letters in the same column indicate significant differences at $p<0.05$ (capital letters for treatment comparison, small letters for position comparison within T2). n.a: not available

4.4.3 Relationship between $\delta^{15}N$ values, N-leaf, and soil NO_3^--N

Significant negative linear correlations between N-leaf and ^{15}N isotopic signatures were found in grass barrier (T2) and cover crop (T3) treatments with slopes of -2.13 and -4.44, respectively (Fig. 4.6). These relationships indicated that N-deficiency increased with increasing uptake of soil-derived N, which was relatively enriched in ^{15}N. In T1 and T4, no such correlation was found. NO_3^--N of top soils at anthesis stage were similar across all treatments, indicating no impact on maize growth by this factor (Table 4.2) at that time. However, negative exponential correlations were observed between available NO_3^--N in soil and leaf $\delta^{15}N$ values of non-grass barrier treatments (T1, T3, and T4).

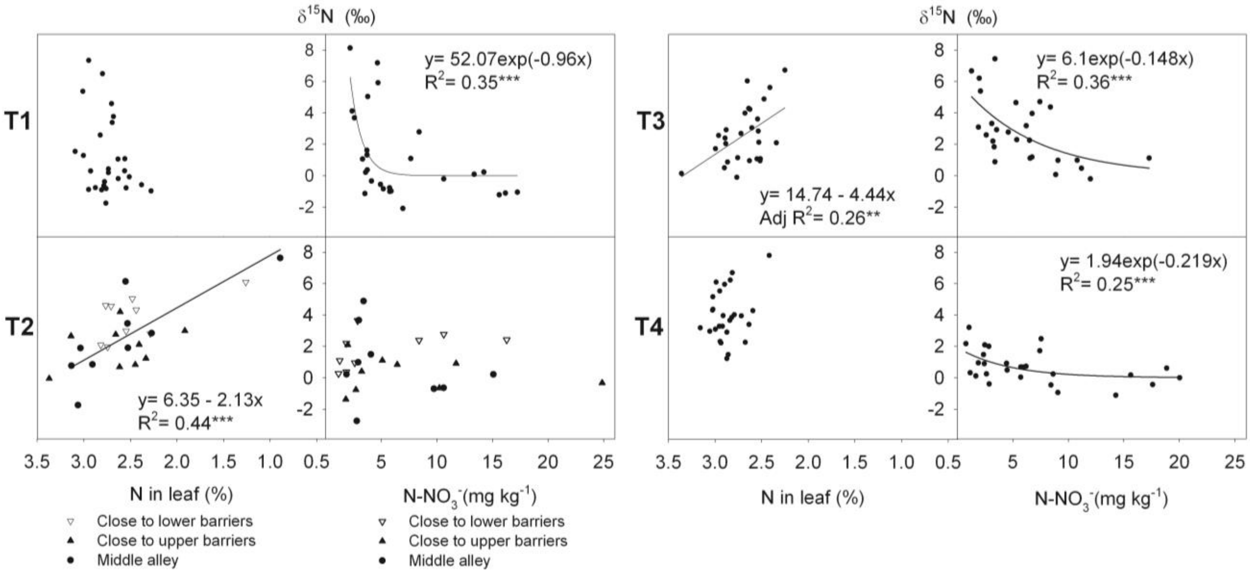

Figure 4.6 Relationships between $\delta^{15}N$ values and N concentration in the third youngest leaf collected at anthesis stage (77 DAS) and available NO_3-N in top soil 0-15 cm sampled at the anthesis stage for the farmer's practice (control, T1), grass barriers (T2), minimum tillage + cover crop (T3), minimum tillage + relay crop (T4) at Chieng Khoi site, NW Vietnam.

4.5 Discussion

This study agreed with results from Dercon et al. (2006a) and Pansak et al. (2007) that maize growth decreased towards grass barriers (Fig. 4.4). Stronger declining maize yields at the rows close to lower barriers as compared with those close to upper barriers (Table 4.2) could be attributed to the architecture of *P. maximum* roots which anchor towards upper direction on steep slopes (Chiatante et al. 2002). As a result, the grass probably competed for N more with maize rows above than below the barrier. This was reflected by nitrate concentrations in the topsoil which tended to be more depleted at the upper part of the barrier. Soil fertility changes due to translocation and deposition of sediments on upper and lower parts within an alley, respectively, could potentially induce increased crop yield following slope direction (Dercon et al. 2006b). However, such a crop response pattern was not observed along the slope in this study (Fig. 4.4). Cumulative soil erosion of the grass barrier treatment reached 200 t ha^{-1} three years after its establishment (Tuan et al. 2014). This corresponds to a topsoil removal of 1.3 cm (mean bulk density of 1.5) which most probably did not create significant changes in soil fertility up to a soil depth of 30 cm (Reinhardt 2009). Nitrogen budgets of tillage systems were generally negative due to N-losses in farmer's practice or large export of *Panicum maximum* cuttings in the grass barrier treatment (Tuan et al. 2015). This is also supported by findings of Tuan et al. (2015) who showed under similar conditions that Guinea grass barriers strongly competed with maize growing in rows adjacent to them, scavenging 74% of the fertiliser-N applied to maize. Minimum tillage combined with mulching and legume intercropping (T3 and T4) was more effective in controlling erosion as soil loss was reduced by at least 52% compared to farmer's practice (Tuan et al. 2014). N cycles of such soil conservation measures are often balanced (Tuan et al. 2015) but their applicability on a larger scale depends on how their requirements and benefit match social-economic conditions, i.e. promoting cattle rearing in the region may encourage farmer to plant more cover crops despite their negative impact on maize growth and performance.

4.5.1 Nitrogen deficiency induced plant $\delta^{13}C$ enrichment

At Chieng Hac, enriched $\delta^{13}C$, low grain nitrogen concentration, and reduced grain yield data indicated that N-deficiency induced less depleted $\delta^{13}C$ values observed in leaves developed during a wet period in zero N-fertilizer plots under maize monocropping and in rows close to grass barriers. Nitrogen stress generally leads to smaller plants which took up less water, thereby indirectly reducing water stress which consequently reduces carbon isotopic discrimination, represented by an increase (less negative value) of $\delta^{13}C$ in maize (Dercon et al. 2006a; Farquhar et al. 1989). On the other hand, increased nitrogen supply increases total root length (Wang et al. 2005) which improves access to water, thereby indirectly enhancing water availability to a certain degree (Kondo et al. 2000). At CK, rows grown next to barriers (T2) showed a reduced N concentration and elevated $\delta^{13}C$ values, exhibiting the same pattern as observed in zero N-fertilizer plots under maize monocropping and rows close to barriers at Chieng Hac. Such a trend reaffirmed that lack of N caused an increase in $\delta^{13}C$ values (Figs. 3b and c). The decline in grain yield associated with lower N concentration of maize leaves in T3 or in rows close to barriers (T2) indicated that N deficiency occurred at CK, being responsible for the decline of maize yield in these two soil conservation measures. If nitrogen stress did not occur under such conditions, maize leaves should be more depleted in $\delta^{13}C$ and having a higher N concentration. This also can be explained by a recently updated model by Cernusak et al. (2013) pointing out that $\delta^{13}C$ values are primarily controlled by two factors, i.e. ratio of intercellular to ambient CO_2 concentration (c_i/c_a), and bundle-sheath leakiness (ϕ). When increased N stress occurs, lower N leaf concentration results in higher instantaneous c_i/c_a (Cernusak et al. 2007). Recently obtained and more reliable estimates of the bundle-sheath leakiness from instantaneous measurements of gas exchange showed that this portion was relatively small (<0.3) and constant under a wide range of conditions (temperature, water availability or genotype). For such ϕ values, the increased c_i/c_a as a consequence of N stress reduced ^{13}C discrimination (enriched ^{13}C) (Cernusak et al. 2013). This update, therefore, supports our results that enriched ^{13}C values in zero-N fertilizer plots or rows close to barriers were induced by N deficiency. However, it may contradict previous assumptions, *i.e.* high impact of environmental factors on ϕ variability, and the simplified model that reduced N supply would lead to depleted ^{13}C in C_4 plants (Ranjith et al. 1995).

Table 4.3 Summary of relationship between ^{13}C in C_4 plant and water and nitrogen availability in soils. Arrows represent relative increase or decrease.

	$\delta^{13}C$ values	**$\Delta^{13}C$ discrimination**	**Reference**
Nitrogen			
High N supply	↓	↑	(Dercon et al. 2006a)
N stress increases	↑	↓	(Clay et al. 2005; Dercon et al. 2006a)
Water			
Water availability limited	↓	↑	(Clay et al. 2001; Dercon et al. 2006a)
Water and nitrogen			
Increase of water stress & high N supply	↓	↑	(Dercon et al. 2006a)
High water availability combined with N stress	↑	↓	(Dercon et al. 2006a)
High water availability combined with high N supply	↑	↓	(Pansak et al. 2007)
Combination of water and N stress	↓	↑	(Dercon et al. 2006a)

4.5.2 Stable isotope ^{15}N facilitating understanding of nitrogen competition

In the present study, a larger N uptake from fertilizer by *P. maximum* (78 kg N ha^{-1}) than by maize (52 kg N ha^{-1}) was observed (unpublished data). Such a strong competition is driven by the fact that *P. maximum* roots explore the soil intensively and are very efficient in nutrient uptake (Cook & Ratcliff 1985). Irrespective of ecotypes, Adjolohoun et al. (2014) reported that *P. maximum* plants under a cut-and-carry system plundered soil nutrients due to their competitive rooting systems. Likewise, *Leucaena leucocephala* hedges and *Brachiaria ruziziensis* barriers also acquired much of applied fertilizer N as observed by Pansak et al. (2007) which points to the need of site-specific fertilizer application, such as increased fertilizer dressings to maize rows close to the barriers. In our study, N-fertilizer rate was probably not high enough to overcome the competition for nitrogen.

In T3, N competition can be attributed to a considerable N uptake of 50 kg N ha^{-1} by the simultaneously growing cover crop, *A. pintoi*, and associated weeds (1.8 Mg dry matter ha^{-1}) (Tuan et al. 2014) being equivalent to a 53% N uptake by maize. Unlike *P. maximum*, the cover crop established by seedlings developed slowly in the year of trial establishment. In the third year, an already well-established *A. pintoi* grew vigorously after the onset of the rainy season. Thus, a good soil cover and protection was provided but simultaneously increased the potential of *A. pintoi* to compete for fertilizer N. Therefore, maize was forced to use more N derived from mineralisation of soil organic matter that was enriched in ^{15}N compared to fertilizer N (Clay 1997). This resulted in a higher proportion of soil ^{15}N in maize N uptake, leading to relatively elevated ^{15}N in plant tissues in T3 compared to the other treatments (Table 4.2).

Similar growth patterns of T1 and T4 (e.g. LAI, %N and isotopic signatures) indicated that the level of interspecies competition for N was negligible in T4. Furthermore, intra-species N competition (if it happened at all in both, T1 and T4) was weaker than the inter-species N competition in T3 or in rows close to grass barriers in T2. A slightly improved yield observed in T4 may be attributed to a complementary belowground resource use (Cadisch et al. 2002) and the fact that sowing beans 30 days after maize did not lead to competition for light and nutrients with the main crop. The direct benefit of nitrogen fixation from *P. calcaratus* was probably not significant in the short term; although it appeared to be a better N_2 fixer than *A. pintoi* based on its lower $\delta^{15}N$ values. However, subsequent crops may receive a higher residual benefit from N_2 fixation (Giller & Cadisch 1995). In agreement with this, Giller et al. (1991) found that less than 5% of N were transferred from beans to maize in a pot experiment during the cropping cycle. Over time, nitrogen contributions from legumes may increase soil-N which will help improving crop yields. However, N originating from fixation has to undergo decomposition and later mineralization, followed by nitrification inducing isotopic fractionation (Högberg 1997) which may result in ^{15}N values similar to those of ^{15}N depleted urea or closer to those of soils if N_2 fixation by legumes is poor. Thus, top soil ^{15}N data collected three years after trial establishment showed no significant difference between legume and non-legume treatments (Table 4.2). In the long-term, N accumulation derived from symbiotic N_2 fixation may decrease soil ^{15}N by e.g. 2‰ as observed in woody tree legume stands (Boutton & Liao 2010).

A significant decline in $\delta^{15}N$ values in maize with increasing NO_3^--N availability in soil (Fig. 4.6), and enriched $\delta^{15}N$ values in maize leaves collected from rows close to the barriers (Table 4.2) suggested that the increased availability of soil N was associated with fertilization as indicated by lower ^{15}N values. Other way around, plants of central rows of the grass barrier treatment obtaining a higher proportion of fertilizer N depleted in $\delta^{15}N$ resulted in lower ^{15}N values in their tissues. Increasing $\delta^{15}N$ values associated with decreasing N concentrations of maize in T2 and T3 (Fig. 4.6) suggest that their companion plants, *P. maximum* or *A. pintoi*, strongly competed for N provided by fertilizer in both systems. Furthermore, ^{15}N signals of fertilizers, soils, and plants can be used to estimate the proportions of soil and fertilizer N contributing to N uptake by plants (Clay 1997; Dalal et al. 2013; Kim et al. 2008) if no other source is involved. When $\delta^{15}N$ values are distinct for N sources, e.g. low in fertilizer and high in soil, then ^{15}N values of plants reflect the proportion of N derived from these sources. However, we have to act with caution when using plant $\delta^{15}N$ to trace N source, as plant $\delta^{15}N$ values also reflect fractionation of N isotopes during transformation, absorption, assimilation, allocation and loss of N from plants (Robinson 2001). Furthermore, the labile fraction that plants can assimilate from soil N pool is generally more enriched in $\delta^{15}N$ compared to the N pool of bulk soil (Evans 2007) due to fractionation occurring during nitrogen transformation processes such as nitrification (Mariotti et al. 1981) and/or denitrification (Delwiche & Steyn 1970). Cumulative effects of such fractionations generally result in plant $\delta^{15}N$ values being lower than those of total N soil, e.g. without fertilizer application, a difference of 0.3‰ between maize and soil was observed in South Korea (Choi et al. 2002).

4.6 Conclusion

Reductions in maize growth and leaf-N concentration in combination with less depleted $\delta^{13}C$ values and a lower $\delta^{15}N$ signature allowed identifying N competition as the driving factor for yield decline in T3 (MT with cover cropping of *A. pintoi*) and in T2 (with *P. maximum* grass barriers) particularly in rows close to grass barriers. In T4, relay cropped *P. calcaratus* did not compete for N with maize and was therefore the best option among all treatments. $\delta^{15}N$ values in plant tissue can potentially be used as a first indicator for testing N competition in new farming systems where inorganic fertilizer functions as depleted ^{15}N labelling material compared to the usually enriched soil derived N. The combined use of $\delta^{15}N$ and $\delta^{13}C$ values in relation to their driving discrimination factors in the soil-plant system can strongly improve the identification of the causes (N or water) of competition and their underlying mechanism. Future research should quantitatively investigate nitrogen competition levels in relation to $\delta^{15}N$ values and how they can be used to predict crop yield under various soil conditions and water regimes. By evaluating temporal and spatial synchrony between resource availability and demands of the system, a better spatial and temporal adjustment of fertilizer and crop management can be achieved.

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Annex to the chapter 4. Estimated evapotranspiration coefficient (Kc) for four treatments at Chieng Khoi, NW Vietnam.

Phase	T1		T2		T3		T4	
	day	Kc	day	Kc[#]	day	Kc	day	Kc
Slash, burn and ploughing-sowing		0.2 until first rain, after that 0.6		0.38 until first rain, after that 0.74		0.5 until first rain, after that 1.1 (*A. pintoi*)		0.2 until first rain, after that 0.6
Initial	30	0.8	30	0.8	30	##	30	@
Development	40	1.0	40	1.0	40	##	40	@
Mid-season	30	1.2	30	1.2	30	##	30	@
Till harvest	30	1.0	30	1.0	30	##	30	@
After harvest till dry period		0.8		0.8		1.1[$]		0.8[$$]
Dry period (mid-Oct onward)		0.6		0.6		0.6		0.6

ET_0 calculator developed by FAO was used to calculate ET_0 for all treatments.

T1: control, T2: grass barriers, T3: minimum tillage with *A. pintoi*, and T4: minimum tillage with *P. calcaratus*.

T2: *P. maximum*, perennial grass occupied 23% area.

[#] Calculation of Kc for T2 at the period before sowing proportionally to area occupied by grass barrier (23%), and bare soil (77%): $Kc = \frac{1*0.23+0.77*0.2}{1} = 0.38$, where grass has Kc=1.0, bare soil has Kc=0.2. After that $Kc = \frac{1*0.23+0.77*0.6}{1} = 0.74$ where grass has Kc=1.2, bare soil has Kc=0.6.

T3: *A. pintoi* Kcb = 1.1, adapted from groundnut, table 17 (FAO 56) (Allen, et al. 1998).

[##]: Calculation based on intercropping (Fig. 45, FAO 56), and equation 72 (page 199, FAO 56).

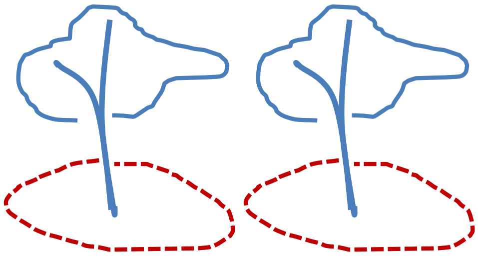
[$] Remaining of *A. pintoi* stands in the field reduced growth rate by onset of dry season starting around harvest, Kc=Kcb=1.1.

[$$] Kc=0.8 stands of *P. calcaratus* was estimated to be the same as Fababean, table 17 (FAO 56) (Allen, et al. 1998)

[@]: Calculation is similar to T3.

Chapter 5

General discussions



5 GENERAL DISCUSSIONS

5.1 Soil conservation: old debate in the context of steep slopes in Northwest Vietnam but still a hot topic

Maize monocropping on sloping land in Northwest Vietnam has led to severe soil erosion and is generally considered as an unsustainable system (Chapters 2, 3). Data of this study demonstrated that most of soil erosion occurred the first weeks after sowing, when high rainfall intensities coincided with a low ground cover of fields. When applied, conservation measures effectively reduced soil loss and runoff as compared to the farmers' practice from second year after trial establishment (2010). If applied at the beginning of the season, other studies reported that conservation measures controlled erosion in the year of establishment immediately, e.g. grass strips or *Leucaena* hedgerows in Pansak et al. (2008) and *Tephrosia* hedgerows as in Hoang Fagerström et al. (2002). Such effectiveness in controlling erosion was not observed in the field trials of this study, as conservation measures were set up after the critical period (Chapter 2).

The average relative reductions observed in two experiments across two years (2010 and 2011) were 58, 97, and 77% for soil loss; 27, 73, and 47% for runoff at grass barriers, MT with cover crop, and MT with relay crop, respectively compared to the respective controls (Table 2.5 and Fig. 2.2 of Chapter 2). This reduction of soil loss in the grass barrier treatment compared to that in the controls was less than results reported by Pansak et al. (2008) for Vetiver grass *(Chrysopogon zizanioides)* strip or Ruzi (*Brachiaria ruziziensis)* grass barrier in Northwest Thailand (75-87%), probably due to steeper slopes at present study site. The soil loss reduction in the MT treatments, however, was comparable to a value of 78% recorded by Araya et al. (2011) in Northern Ethiopia, or values of 66-86% on subtropical Ultisols in Yunnan Province, China reported by Barton et al. (2004).

The ratio of annual soil loss to annual runoff decreased when soil conservation was applied, indicating an increase in efficiency of the conservation measure against surface flow of the same amount with time (Fig. 2.3, Chapter 2). Reduced erosion rates associated with conservation measures were largely attributed to improved ground cover rates at the onset of the cropping season as compared to farmers' practice. As ground cover measured at erosive period increased, annual soil loss declined, represented by a power regression (Fig. 2.6, Chapter 2). Extreme soil loss of 108 Mg ha^{-1} day^{-1} at the onset of the rainy season was observed on 20^{th} of June 2011 in Chieng Khoi, when high intensity rain fell on soil with a cover rate of 60% in the farmers' practice plots (Chapter 2). A storm event with higher energy occurred 22 days later when there was a soil cover of 87% causing a soil loss of just 9.7 Mg ha^{-1} day^{-1} only, indicating the importance of ground cover in protecting soil under tropical conditions. Working in the same area, Anh et al. (2014) also confirmed that ground vegetation cover together with understory biomass and bulk density are the most important characteristics influencing soil erosion. These three prevailing factors are governed more by the specific characteristics of different types of forests or agricultural crops rather than the broad classification of land use (e.g., forest vs. agriculture).

At critical periods, grass barriers (T2) provided a minimum of 23% cover which improved protection of soil. The barriers cut off slope length which contributed to erosion reduction. At the same period, in minimum tillage treatments, further increases in ground cover rates were obtained by a combination of both living vegetation (weeds) and crop residues (litters). While segetal vegetation contributed the same proportion to ground cover in both minimum tillage and tilled treatments (34%), litter had a greater proportion in minimum tillage (24%) than in tilled treatments (7%) (Tuan et al. 2012).

Reduced erosion at T2 can potentially also be attributed to a decline in runoff speed, as the barriers break surface flows and reduce the formation of rills and gullies (Morgan 2005). For minimum tillage and a legume, their effectiveness in erosion control would be attributable to improvement of aggregate stability of soil surface (Morgan 2005), increase in infiltration rates and water storage through combined physical and biological effects (Roth et al. 1988; Erenstein 2002; Thierfelder and Wall 2012).

Nitrogen and organic carbon losses reflect this pattern of erosion (Chapter 2, Fig. 2.2). High variations in N and organic C losses were observed at both experimental sites across the monitored years (2010 and 2011). Under farmers' practice, N-losses by erosion measured at bounded plots varied from about 60 kg $ha^{-1}yr^{-1}$ at Chieng Hac in 2011 to over 270 kg $ha^{-1}yr^{-1}$ in 2010 at Chieng Khoi (Fig. 5.1). For this treatment, yearly OC losses varied from around 450-1200 kg ha^{-1} in Chieng Hac, reaching 940-1700 kg ha^{-1} in Chieng Khoi (Fig. 5.1). Conservation measures significantly reduced N and OC losses in 2010 and 2011 for the Chieng Khoi site, while such significant differences were only observed for Chieng Hac in 2010 when there were much higher erosion rates in the controls.

Nitrogen loss rates of Chieng Hac are very similar to values of 46-98 kg $ha^{-1}yr^{-1}$ as measured by Hoang Fagerström et al. (2002) under upland rice, being within the range of 29-75 kg ha^{-1} yr^{-1} observed by Dung et al. (2008), but higher than a value of 21 kg $ha^{-1}yr^{-1}$ observed by Loc et al. (1998). On less steep slopes in Northwest Thailand, erosion induced lower N losses (i.e. below 15 kg $ha^{-1}yr^{-1}$) compared to the observations of this study. Using erosion bridges, Van De et al. (2008) estimated a N losses of 179 kg $ha^{-1}yr^{-1}$ under cassava, being close to N loss rates measured in extreme conditions of Chieng Hac in 2010 and Chieng Khoi in two monitored years (Fig. 5.1).

Though monocropping based on slashing, burning and ploughing induced high N and OC losses, a decline in soil fertility was not observed within the framework of our three years study (Chapter 3), probably due to the high thickness of the soil up to several meters as seen in nearby excavated slopes. However, in the long-term soil fertility of the study area can decline as consequence of severe erosion and intensive agriculture (Clemens et al. 2010). Such a degradation is attributed to the losses of organic carbon induced by erosion and accelerated decomposition rates due to repeated tillage and weeding activities (Häring 2013). Fires may cause N and OC losses due to burning on residue or on SOM in the soil surface. However, in the region, fires are not considered a main source of degradation as they are generally short (Dung et al. 2008); therefore residue burning causes losses of some nutrients and recyclable organic matter in slashed materials rather than having an effect of high temperature, causing loss of SOM in the soil surface.

Results of the study also demonstrated that soil conservation significantly reduced N and OC losses in the second and third year after their establishment. More specifically, grass barriers reduced N and OC losses at Chieng Hac to just around 1/5 of the controls in 2010 and ½ in 2011. At Chieng Khoi, the grass barriers reduced N and OC losses to around ½ of the controls in both years (Fig. 5.1). Minimum tillage with legume treatments (T3, T4) decreased N and OC losses to a greater extend, being just below 1/5 and ½ of the controls at Chieng Hac and Chieng Khoi, respectively. Mean annual N losses from runoff observed at the farmers' practice were 23 kg N ha^{-1} in two sites, being higher than those from conservation plots (4-15 kg N ha^{-1}, Fig. 5.1). Such reductions were attributed to the effectiveness of conservation measures in controlling erosion (Chapter 2). Under rice cultivation on slopes of 40-45%, Hoang Fagerström et al. (2002) observed N losses of 3 kg ha^{-1} by runoff and 72 kg ha^{-1} by soil loss in the same study region of Vietnam, being similar to the observations at the Chieng Hac site in 2011. Compared to the annual N loss of about 9 kg by soil loss and 4-5 kg N ha^{-1} by runoff from control plots observed by Pansak et al. (2008) under MT with mulching in Northeast Thailand, these values were higher in the study sites because of steeper field (slopes 53-69% compared to 21-28%), being intensively tillage and without mulch cover. At catchment scale, the data on erosion recorded in unbounded plots also demonstrated that steepness and slope length are crucial factors in controlling erosion under high rainfall intensity conditions (Chapter 2).

The average ratio of C:N in sediment and runoff at both sites varied from 4.7-7.9 (Fig. 5.2), being much lower than the ratio in the topsoil of 16.4-17.3 (Table 2.1, Chapter 2), indicating eroded materials were richer in nitrogen than the parent material. Enrichment ratios with factors of 1.3-4.3 (OC) and 2.6-6.3 (N) in eroded sediments were also observed by Cogle et al. (2002) under semiarid tropical conditions. Low C:N in runoff also indicates that a substantial amount of inorganic N originated from either fertilizer or mineralized SOM was probably released into runoff. Although sediments and runoff are richer than the original materials, their redistribution along cascades is uneven, causing C and N variation for soils in lowland (Schmitter 2011). Often, coarse and low nutrient content particles deposit at first, finer and nutrient rich sediments go further downward; thereby increase of SOC and total N was found with descending position along cascades. It is likely that higher nutrient content in runoff transporting for longer distance induced such variation in soil fertility of paddy cascades. Information on nutrient contents of the runoff and their distribution, hence, is essential for fertilizer management in paddy and lowlands.

5.2 Feasibility of adopting soil conservation

Results of the previous section showed the need for immediate and widespread soil conservation application in the research area. To increase the probability of the adoption of such measures by local farmers, a coherent long-term soil conservation strategy need to be designed and implemented with the participation of all local stakeholders (Schad et al. 2012). This needs to initiate discussions with farmers and local extension service on selecting measures for the trials. Apart from controlling erosion, two selected methods - grass barriers and cover crops - reflected farmer's interest in improved fodder production, while the relay crop treatment expressed their expectation of extra income from additional production of Adzuki beans. However, some disadvantages of conservation measures remain that may discourage adoption. Concerns of farmers included decreased maize yields, increased labour requirements if herbicides are not used, and the unstable socio-economic conditions of land users due to external factors such as possible land reallocation (Douglas 2006; Saint-Macary et al. 2010).

The observed reduction in crop yields by the grass barrier treatments of this study were similar to those found in Northwest Thailand (26%) (Pansak et al. 2008). This yield reduction was attributed to reduction of maize cropping area, and nitrogen competition (Chapter 4). Within alley, significant increases in crop yield response were not observed along slope because translocation and deposition of eroded sediment within time frame of the study was not enough to create significant changes in soil fertility for the lower part (Chapter 4). Though the grass barrier measure is regarded as plundering soil N reserves (Chapter 3), farmers are unlikely to take that into account, unless the benefit of additional fodder from grass cuttings outweighs biomass produced by weeds. A major constraint of the method is the initial investment for planting material and additional labour (30% increase). Such increase in labour demand coincides with other important farming activities, e.g. fertilizing or weeding for paddy/maize fields, acting as disincentive to adopt the grass barrier option (Chapter 2).

Minimum tillage with a simultaneously established cover crop (*A. pintoi*) reduced maize yields (up to 35%) due to competition if control of legume growth by cuttings was not done in time. Such an integration of cut-and-carry practice into livestock systems can provide substantial amounts of protein-rich fodder (*A. pintoi)* that may compensate for the reduction in maize production (Chapter 2).

Minimum tillage with a relay crop *P. calcaratus* kept maize yield, at least, at local farmers practice's level within the three years of the experiment. However, vigorous growth of the Adzuki bean (*P. calcaratus*) may hide maize cobs and blocks pathways needed by farmer to collect maize cobs. Thus it is often seen as less appropriate, and this issue restricts number of adopters (Erenstein 2002). Lack of labour for collecting beans, which ripen during time of maize harvesting, also hinders acceptance of this approach. Thereby, the MT with a relay crop seems to be most promising either for small farms that are capable to harvest both maize and bean at the same time or affordable to hire additional labour force.

Finally, mulching decreases evaporation and increases water availability of the soil, improves its structure, and stabilizes its aggregates (Mulumba and Lal 2008). Mulching appears feasible since biomass production in the area is greater than demands for feed and fuel (Valbuena et al. 2012). Practically, farmers may collect still-green stems and leaves on the field close to their homestead for cattle, leaving majority of residues on the field for mulching. However, mulching also requires complicated weeding, and may attract rats and snakes as claimed by farmers in the area. Alternatively, crop residues may be piled up along the contour line for the subsequent crop (Fig 5.3) as initiated by some farmers in the area. For cattle farmers natural fodder basis might be too small and hence they would need improved fodder systems, e.g. fodder banks, protein banks.

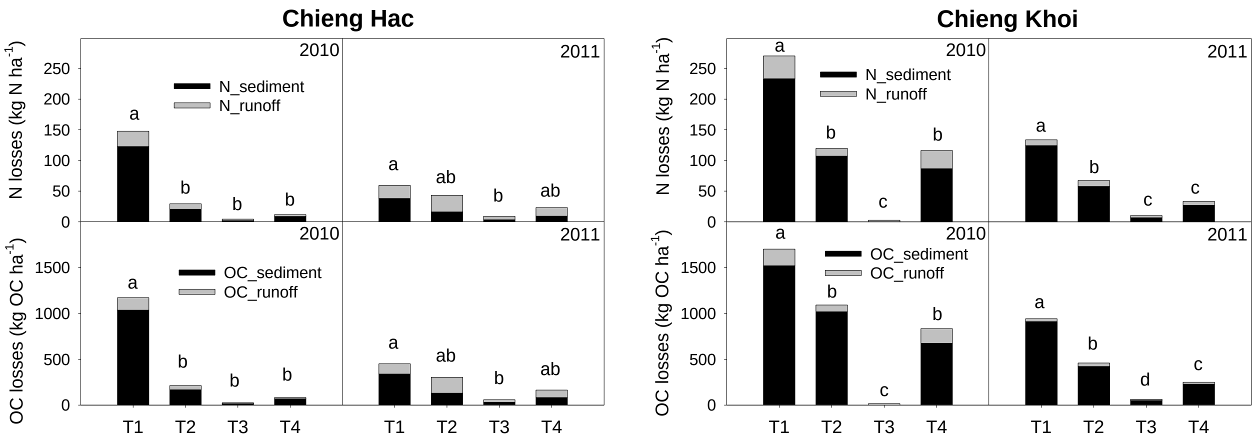


Figure 5.1 Annual total nitrogen losses and organic carbon (OC) losses by soil loss (sediment) and runoff for the second and third year after establishment (2010, 2011) at Chieng Hac and Chieng Khoi, NW Vietnam. T1: Farmers' practice (control); T2: Grass barrier; T3: Minimum tillage + cover crop; T4: Minimum tillage + relay crop. Different letters indicate significant differences (*$p<0.05$,* LSD test*)* within site for each year.

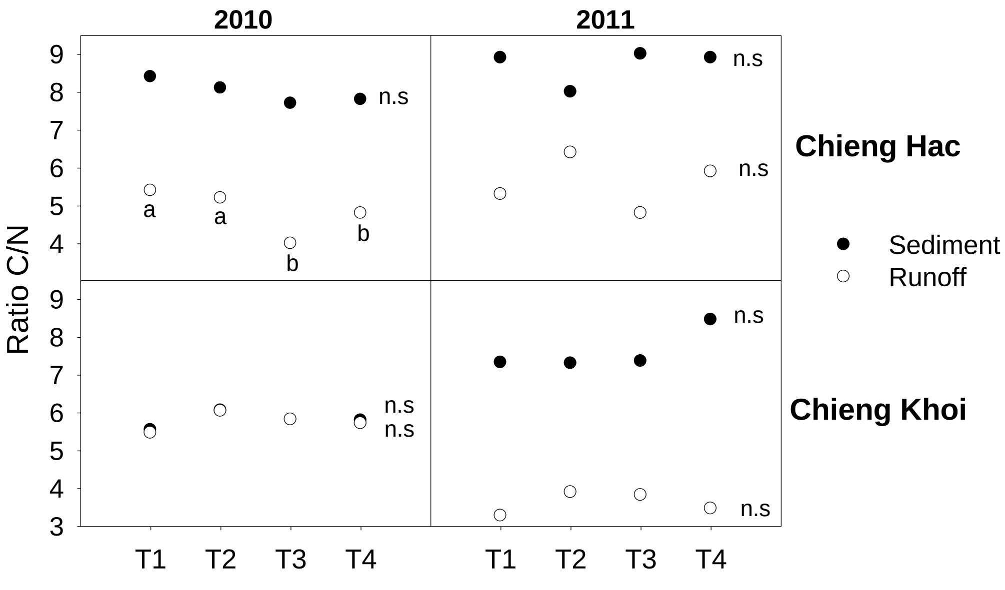


Figure 5.2 Ratio of C to N in sediments (•) and runoff (o). Data were collected at Chieng Hac and Chieng Khoi, NW Vietnam during the second and third year after establishment (2010, 2011). T1: Farmers' practice (control); T2: Grass barrier; T3: Minimum tillage + cover crop; T4: Minimum tillage + relay crop. Different letters indicate significant differences within site for each year (*$p<0.05$,* Tukey test*)*; n.s = non-significant.

Figure 5.3 Piling up maize residues as barriers for subsequent crops on hillsides in Yen Chau, NW Vietnam

5.3 Is there a way to sustain nitrogen for maize-based cropping on steep slopes?

On average, soils at the study sites contain roughly 7500 kg N per ha (0.1% N up to 50 cm, bulk density of 1.5) (Chapter 3). If current trend of erosion under slash and burn practices remains unchanged, an annual estimated N-loss of 142 kg N ha^{-1} is expected (Chapter 3), resulting to halve the soil N reserves (up to 50 cm depth) within 26 years. Thus, continuously using fertilizers, even with new, more efficient hybrid varieties, under such conditions is unable to mask soil fertility depletion in the uplands in the long run. Likewise, if current annual soil loss of 87 t ha^{-1} as in the case of Chieng Hac (equal to a truncation of 0.58 cm soil depth) occurs persistently, the plough layer of 15 cm would totally be removed in 26 years. A similar trend was observed for soil organic carbon (SOC) in the area where SOC losses were an order of magnitude larger than SOC input (Häring 2013). Soils depleted in N and SOM usually require a recovery time much longer than the degradation period. For instance, without any other intervention, it was estimated to take about 20 years to recover from the impact of a 4-year cropping cycle under slash and burn agriculture (Dung et al. 2008).

The nitrogen balance is based on data in 2010 at bounded plots from Chieng Hac, which usually neglects the effect of the deposition along slope. When the average erosion rate under farmers' practice at unbounded plots of 44 t ha^{-1} (Chapter 2) is used, estimated nitrogen losses by runoff and sediments are 13 kg and 62 kg N ha^{-1}, respectively being much lower than current measurements of 25 kg and 123 kg N ha^{-1}, respectively (Table 3.6 in Chapter 3). As such N balance is less negative ((-68 kg N ha^{-1}), representing half of the estimated N balance when erosion was measured at bounded plots. Even with this reduced negative N balance, the current farming practice is far from being sustainable in terms of soil fertility. Though fertilizer N input is expected to enhance N sustainability by reducing erosion through improved soil cover (Dung et al. 2008) and compensate for N export by plant uptake, the observed large erosion due to low ground cover rate at onset of the rainy season suggests that improved soil cover may be far more important than fertilization. The results of the study also imply that without appropriated soil conservation, increase of N-fertilizers would not warrant a sustainable soil N amount in the long term, but rather create higher risk of N losses (Chapter 4).

The nitrogen balance improved when one of the three tested soil conservation measures was used, being largely accredited by reduction in erosion (Chapters 2, 3). Grass barriers strongly reduced severity of the negative N balance compared to the control (Chapter 3). This improvement of N balance was attributed to a strong reduction in erosion in combination with a decline in maize uptake, but offset by high uptake of the grass barrier (Table 3.6 in Chapter 3). Therefore, in this system, soil-N can be balanced only if at least a part of cut grass from the barrier is applied as mulch. In the same region, the use of *Tephrosia candida* as mulch proved to be a system that supplied enough N and P to meet crop requirement (Hoang Fagerström et al. 2002). For the study area, by mulching maize residues 20% of it would become new soil-C within one year (Häring, personal communication).

At minimum tillage with simultaneously cover crop or relay crop, reduction in N-loss through reduced erosion in combination with omission of burning plant residues resulted in positive N balances of 23-36 kg ha^{-1} (Table 3.6, Chapter 3). Assuming 22% (Valles De La Mora and Cadisch 2010) or 42% (Tsai et al. 1993) of N content in *A. pintoi* (-7 kg ha^{-1}) or Adzuki bean (- 13 kg ha^{-1}) derived from fixation, their positive N balances were further improved, indicating a high N sustainability of these systems.

In the present study, fertilizer well-incorporated into the soil probably minimized ammonium volatilization (Blaise et al. 1996) but N fertilizer use efficiencies of maize were below 31% in all treatments, being slightly lower than the mean value of 33% found across 12 tropical areas around the world (Dourado-Neto et al. 2010; Smil 1999). Although reducing runoff and soil loss on steep slopes, conservation measures did not improve maize nitrogen use efficiency (Chapter 3). Alternatively, a mixed system where integration of a cover crop combined with mulching into alleys between grass barriers, may improve the overall N balance. Likewise, relay crop and mulching integrated into a grass barrier system could possibly enhance the N balance. The measures maybe adoptable if appropriate support is provided, e.g. incentive for creating extra area which foster soil conservation need to be accommodated in the landscape.

5.4 Determining causes of N competition and defining feasible management strategies for alleviating the N competition problem in soil conservation systems

One of the strongest arguments against soil conservation is the competition for water and nutrients. Indeed, in this study, elevated $\delta^{13}C$ values and reduced N leaf concentration in maize plants grown next to grass barriers or at cover crop plots at Chieng Khoi under good water supply conditions indicated that their yield declines were mainly due to N competition (Chapter 4). The observed higher competition level at Chieng Khoi as compared to Chieng Hac in 2011 could be attributed to more favourable conditions for *A. pintoi* growing at the former than those at the latter sites (Chapter 2).

In this study, natural abundance level of ^{15}N was used to complement the $\delta^{13}C$ technique. Under field conditions, the ^{15}N abundance of plants depends on (i) the source of plant N (e.g. soil, precipitation, gaseous N compounds, N_2-fixation), (ii) the depth in soil from which N is taken up, (iii) the form of N used (e.g. NH_4^+, NO_3^-, organic N sources), and (iv) the influence of mycorrhizal symbioses and fractionations during and after N uptake by plants (Nadelhoffer et al. 1996). In the studied systems, it is reasonable to assume that contribution of N-fixation in the study time was negligible and fractionation processes during N uptake were similar; hence, ^{15}N plants most likely reflect ^{15}N sources (soil or fertilizer).

Soil-N source is usually enriched ^{15}N, while commercial fertilizer is commonly close to air ^{15}N ($\delta^{15}N$ varies between −1 to +1‰) (Evans 2007), making N-fertilizer become 'depleted' and cheap labelling material. When an associated plant (*P. maximum* or *A. pintoi*) strongly competes for readily available N-fertilizer with main crop, N uptake of the main crop is more enriched in ^{15}N due to an increased N proportion derived from the soil, leading to elevated ^{15}N values in the main crop relative to a monocropping system. It is therefore suggested that ^{15}N plants can also be used as a first indicator of N-competition. Soil nitrate at Chieng Khoi (6-8 mg NO_3^--N kg^{-1}) was relatively low as compared with data found in Northwest Thailand (60 mg NO_3^--N kg^{-1}) by Pansak et al. (2007), indicating that N supply was limited. This low N supply in our site indicated that physiological discrimination process was unlikely to have occurred as N uptake by the crop was fully assimilated.

Under field condition, separating causes and processes of competition is not always straightforward as complex interactions of environment and internal physiology both influence isotopic discrimination simultaneously. ^{15}N data in soil-plant system as presented in this study were demonstrated to further strengthen $\delta^{13}C$ discrimination techniques in identifying N competition.

When a plant growing under soil conservation measures is more efficient in fertilizer N uptake than the main crop (e.g. *P. maximum* or *A. pintoi*), a modified fertilization scheme has to be developed, i.e. more N shall be applied for rows close to the barrier to compensate for that effect or fertilizer must be applied to the grass barriers as well. Alternatively, root pruning of the grass barrier by deep ploughing and/or increasing the distance between barrier and main crops may be advantageous to alleviate nutrient stress (Guo et al. 2008); however, this is hardly possible on steep slopes as found in the research area. For the cover crop method, better control of *A. pintoi* as practiced in 2011 at Chieng Khoi mitigated negative effect of *A. pintoi* (Chapter 2).To reduce the competition for N during the initial stages of growth as observed in 2010 at Chieng Khoi, the basal fertilizer dressing needs to be increased so that sufficient N would be available for *A. pintoi*. This improved fertilization scheme, however, requires extensive knowledge on dynamics of N acquisition by plants.

5.5 The way ahead

Current monocropping based on slash and burn on steep slopes in Northwest Vietnam poses high risks of severe erosion, and threats to sustainability for future crop production. Most erosion in this system occurred early in the season, when high rainfall intensities coincided with a low soil cover rate. Conservation methods shall, therefore, emphasize measures that increase ground cover rate during erosive period, in order to protect the soil surface from erosive rains at the start of the rainy season. Increased cover rate could be obtained by applying mulch, cover crops, or grass strips. The combination of increasing ground cover and minimum tillage strongly enhanced protection at the onset of the season (Chapter 2). To better cope with extreme rainfall events according to predicted climate change in the future (IPCC 2007), perennial cover crops or agroforestry system that provide year-round cover need to be investigated.

Current monocropping gradually mines soil-N resources due to N-losses by residue burning and erosion, making the land vulnerable to degradation in the long run. Though the use of grass *P. maximum* as barriers controls erosion well and provides a large quantity of fodder, it negatively influenced maize performance. With yields similar to the level of farmers' practice, and sustaining soil nitrogen, conservation measures would be adoptable if resource competition (e.g. nitrogen) is minimized and its co-product is profitable. Additionally, conservation measures should take N losses into account by integrating modified fertilizer application schemes to address N competition as well as N leaching. Field management e.g. pruning roots or cutting of above ground parts of associated crops, could alleviate nutrient stress of the main crop.

Under on-farm experimental conditions, an increase in $\delta^{13}C$ values of the C4 crop was associated with nitrogen deficiency.^{13}C isotopic values in combination with data on N-uptake, crop performance, and particularly ^{15}N could be used to elucidate causes of resource competition. Use of ^{15}N data in a fertilized system should provide more information on how N uptake is governed. Furthermore, expanding our knowledge of the influence of agricultural activities (e.g. fertilizer application) on soils, water, and vegetation cover to natural abundance ^{15}N values would explain better the nitrogen cycle in a specific ecosystem.

The tested conservation measures foster high potentials in controlling erosion and providing benefits, but lack of broader social-economic aspects, calling for further acquisition of such knowledge, especially their applicability on a larger scale in order to enhance possibility of acceptance. As farmers are experts on their land, proper incentives probably encourage them to find the best option and management practice. Researchers should therefore find out what, how, and where incentives need to be placed for sustainable cultivation. In parallel, legislation on erosion control needs to be issued in more details and practiced. For instance, farmers could see hydrological links between hill slopes and valley flat land at micro watershed scale, in which their fish ponds can be negatively impacted by eroded sedimentation at close-by fields and forested areas. If these links are taken into account when carrying out land allocation policy, there should be incentive for farmers performing conservation. Currently, the rate of forestland allocation to communities and individuals in Vietnam just consists of 28% of planned areas, of which 'quality' allocation is still low due to many factors e.g. transparency in sharing profit from forestland (Long 2013). Therefore, improving forestland allocation and 'agricultural' land tilting policies may positively influence adoption.

6 SUMMARY

Recent maize cultivation expansion into steep forested uplands in Vietnam led to severe erosion, soil degradation, and strong environmental impacts. Despite effectively controlling erosion, conservation measures often reduce crop yields due to resource competition. To foster uptake of soil conservation, a study including two experiments with bounded plots at two communes - Chieng Hac (21.02° N, 104.37° E, inclination: 53%) and Chieng Khoi (21.02° N, 104.32° E, inclination: 59%) - was carried out over a period of three years (2009-2911). The treatments included maize monocropping under intensive tillage and fertilization (T1, control), maize with *Panicum maximum* as grass barrier (T2), maize under minimum tillage (MT) with Pinto peanut (*Arachis pintoi)* as cover crop (T3), and maize under MT and relay cropped with Adzuki beans (*Phaseolus calcaratus)* (T4). Soil loss in 2010 and 2011 were also measured using sediment fences on unbounded maize fields under current farmers' practice.

The first part of the study assessed the magnitude of erosion and the mitigation potentiality of soil conservation measures. Under farmers' practice, annual soil losses of bounded plots reached up to 174 t ha^{-1}, being much higher than those from unbounded fields (up to 111 t ha^{-1}). The majority of the soil loss occurred early in the season, when high rainfall intensities coincided with a low percent ground cover (<30%). To keep erosion rates below a tolerable soil loss (3 t $ha^{-1}yr^{-1}$) on steep slopes (53-59%) under an average annual rainfall of 1270 mm, a theoretical minimum ground cover of 95% is required at the onset of the crop season which was hardly achievable under monoculture system. Under conservation measures erosion was reduced by 39-84% in grass barriers or by 93-100% in MT with cover crops. A yield decline of 26% was observed in grass barrier treatments or up to 35% of cover crop plots if Pinto peanuts were not cut on time. Both options provided animal feed, up to 5.5 t $ha^{-1}yr^{-1}$ dry matter of grass or 1.8 t ha^{-1} yr^{-1} dry matter of Pinto peanuts. Despite these potential benefits, constraints such as labour for grass barriers and cover crop establishment and cutting it afterwards, or difficulties in accessing and collecting maize cobs due to proliferate growth of Adzuki beans may hinder adoption by local farmers. To increase the incentive for adoption, the conservation system also has to use N fertilizer more efficiently. Therefore, the second part of the study examined the fate of applied ^{15}N-labelled urea at the Chieng Hac site in 2010. At harvest, 21.6% of the labelled ^{15}N was recovered by maize in T1, 8.9% in T2, 29% in T3, and 30.9% in T4. In T2, maize and *P. maximum* competed heavily for N with a total of 23.6% of the applied ^{15}N found in the barriers next to application point. About 46-73% of the maize N uptake was derived from the soil, showing the important role of inherent soil N in these fertilized systems. MT reduced ^{15}N translocation to deeper soil layers (40-80 cm), indicating a safety net function. Downslope translocation (>17 m) of applied ^{15}N was <0.1 kg ha^{-1} as the majority of ^{15}N added was vertically translocated and intercepted by plants along the slope. Despite implementation of an improved fertilization

method, approximately 24-46% of N-fertilizer was unaccounted for, presumably lost via volatilization, denitrification, and leaching below 80 cm. Measured data for plot level showed that current farming practice (T1) induced a negative N balance of -142 kg N ha^{-1} in which residue burning and erosion were major pathways for N losses. A less severe negative N balance in T2 was attributed to reduced N losses by erosion while positive N balances of MT treatments were accredited to strongly reduced N losses via erosion and abandonment of burning plant residues in these treatments.

The third part of the study investigated causes of competition in conservation systems three years after their establishment (2011). A pre-test at Chieng Hac in 2010 showed that abundance of water and the lack of N fertilization induced low grain N concentrations, enriched $\delta^{13}C$ values in leaves, and reduced maize grain yield. This pattern was also observed in maize rows grown next to grass barriers or in cover crop plots at Chieng Khoi under good water availability conditions, indicating that these yield declines were mainly forced by lack of N. Additionally, a positive water balance throughout the maize cropping season further confirmed that water stress was absent. Moreover, enriched $\delta^{15}N$ values of maize rows close to the barriers suggested that these plants had to rely on soil N rather than on ^{15}N derived from fertilizer N. Similarly, results of MT with simultaneous growth of *A. pintoi* pointed to N competition, resulting in a maize yield decline due to vigorous cover crop growth in T3. In contrast, MT with a relay crop (T4) had a similar maize yield, leaf N concentration, $\delta^{13}C$, and $\delta^{15}N$ as the control, suggesting N and water competition did not occur.

In conclusion, soil erosion and nitrogen balances of current farming practice showed the urgent need to safeguard land resources, counteracting soil degradation but maintaining crop yields. The tested conservation techniques provide a range of characteristics to be considered as a sustainable system. The grass barrier as well as conservation systems controlled erosion, while minimum tillage with a cover crop further improved the nitrogen balance, and finally minimum tillage with a relay crop adds another advantage in maintaining crop production. Likelihood of adoption, however, may vary with how well appropriate incentives and land use policy fit to the area.

7 ZUSAMMENFASSUNG

In der jüngsten Vergangenheit hat die Expansion des Maisanbaus in bewaldeten Hanglagen im Hochland Vietnams zu starker Erosion, Bodendegradation und schweren Auswirkungen auf die Umwelt geführt. Trotz effektiver Erosionskontrolle an steilen Hängen, reduzieren die Schutzmaßnahmen, aufgrund von Ressourcenkonkurrenz, häufig die Ernteerträge. Um dies zu fördern, wurde eine Studie mit zwei Experimente, mit geschlossenen Parzellen in zwei Gemeinden - Chieng Hac (21.02° N, 104.37° E, Neigung 53 %) und Chieng Khoi (21.02° N, 104.32° E, Neigung 59 %) - über drei Jahre (2009-2911) durchgeführt. Die Behandlungen beinhalten intensive Bodenbearbeitung und Düngung (T1, Kontrolle), Mais mit *Panicum maximum* als Grasbarriere (T2), Mais unter Minimalbodenbearbeitung (MT) mit *Arachis pintoi* als Gründüngung (T3) und Mais unter MT und Überlappungsanbau mit *Phaseolus calcaratus* (T4). Zusätzliche Vor-Ort-Messungen des Bodenverlusts wurden mit Sedimentzäunen auf nicht eingegrenzten Maisfeldern in 2010 und 2011 durchgeführt.

Der erste Teil der Studie untersucht das Ausmaß der Erosion und das Reduzierungspotential durch Bodenschutzmaßnahmen. Unter aktueller bäuerlicher Praxis erreichten die jährlichen Bodenverluste der geschlossenen Parzellen mit bis zu 174 t ha^{-1} viel höhere Werte als die Parzellen mit Sedimentfallen (bis zu 111 t ha^{-1}). Der Großteil des Bodenverlusts trat früh in der Saison auf, wenn hohe Niederschlagsintensitäten zusammen mit einem geringen Prozentsatz an Bodenbedeckung (<30 %) auftreten. Um die Erosionsraten an steilen Hängen (53-59 %), bei einer durchschnittlichen jährlich Niederschlagsmenge von 1270 mm, unter einem tolerierbaren Bodenverlust (3 t $ha^{-1}yr^{-1}$) zu halten, ist eine theoretische Mindestbodenbedeckung von 95 % zu Beginn der Anbauzeit erforderlich, was bei Monokulturen schwer erreichbar ist. Unter der Anwendung von Schutzmaßnahmen wurde die Erosion um 39 bis 84 % mit Grasbarrieren und um 93 bis 100 % bei MT mit Gründüngung reduziert. Ein Ertragsrückgang von 26 % wurde bei Behandlungen mit Grasbarrieren und bis zu 35 % bei Gründüngungsparzellen beobachtet, wenn die Pinto-Erdnüsse nicht rechtzeitig zurückgeschnitten wurden. Mit bis zu 5,5 t ha^{-1} $Jahr^{-1}$ Grastrockenmasse oder 1,8 t ha^{-1} $Jahr^{-1}$ Trockenmasse von Pinto-Erdnüssen, lieferten beide Optionen Futtermittel. Trotz dieser möglichen Vorteile können Hemmnisse, wie der Arbeitsaufwand für die Etablierung von Grasbarrieren oder Gründüngung und der anschließende Schnitt, oder Schwierigkeiten beim Erreichen und Sammeln von Maiskolben, aufgrund starken Wachstums der Adzukibohnen, die Akzeptanz der ansässigen Landwirte erschweren. Um den Anreiz für eine Akzeptanz zu erhöhen, muss ein Bodenschutzsystem auch Stickstoffdünger effizienter nutzen.

Im zweiten Teil der Studie wurde daher im Jahr 2010 der Verbleib des verwendeten ^{15}N-markiertem Harnstoff in Chieng Hac untersucht. Bei der Ernte wurden von Mais 21,6 % des markierten ^{15}N in T1, 8,9 % in T2, 29 % in T3 und 30,9 % in T4 aufgenommen. In T2 haben Mais und *P. maximum* stark um N konkurriert, wobei insgesamt 23,6 % des applizierten ^{15}N in den Barrieren neben dem Applikationsortes gefunden wurden. Etwa 46 bis 73 % des von Mais aufgenommenen Stickstoffs stammte aus dem Boden, was die wichtige Rolle des inhärenten Bodenstickstoffs in solchen gedüngten Systemen zeigt. MT reduzierte die ^{15}N Translokation in tiefere Bodenschichten (40-80 cm), was auf eine Funktion als Sicherheitsnetz hinweist. Die hangabwärts gerichtete Translokation (>17 m) des ausgebrachten ^{15}N war <0,1 kg ha^{-1}, weil die Mehrheit des ausgebrachten ^{15}N vertikal verlagert und von den Pflanzen entlang des Hanges abgefangen wurde. Trotz Umsetzung eines verbesserten Düngeverfahrens, blieben ungefähr 24 bis 46 % des N-Düngers vermisst, was vermutlich auf Volatilisation, Denitrifikation und Auswaschung unter 80 cm zurückzuführen ist. Die Messdaten auf Versuchsfeldebene haben gezeigt, dass die aktuelle landwirtschaftliche Praxis (T1) eine negative N-Bilanz von -142 kg N ha^{-1} verursacht, bei der die Verbrennung von Ernterückständen und Erosion die wichtigsten Wege für die N-Verluste darstellen. Eine weniger schwerwiegende negative N-Bilanz in T2 wurde auf verringerte erosionsbedingte N-Verluste zurückgeführt, während positive N-Bilanzen der MT-Behandlungen mit stark reduzierten erosionsbedingten Stickstoffverlusten und dem Verzicht auf Verbrennung von Ernterückständen erklärt werden kann.

Im dritten Teil der Studie wurden drei Jahre nach Feldetablierung der Versuche (2011) die Ursachen für die Konkurrenz in den Erosionsschutzsystemen untersucht. Ein Vorabtest in Chieng Hac im Jahr 2010 zeigte, dass bei gutem Wasserdargebot und gleichzeitigem Mangel an mineralischer N-Düngung, niedrige N-Konzentrationen in den Maiskörnern, angereicherte $\delta^{13}C$ Werte in den Blättern und eine Reduktion des Maiskornertrags beobachtet werden konnten. In Chieng Khoi wurde dieses Muster auch in Maisreihen beobachtet, die neben Grasbarrieren oder auf Parzellen mit gleichzeitiger Gründüngung wuchsen, obwohl gute Wasserverfügbarkeitsbedingungen herrschten. Dies weist daraufhin, dass die Ertragsrückgänge vor allem durch einen Mangel an N verursacht wurden. Zusätzlich hat die positive Wasserbilanz, die während der gesamten Maisanbausaison herrschte, bestätigt, dass Wasserstress nicht vorkam.

Außerdem deuten die angereicherten $\delta^{15}N$ Werte in den Maisreihen, welche dicht an den Grasbarrieren stehen, daraufhin, dass diese Pflanzen stark auf die Aufnahme von Bodenstickstoff angewiesen waren anstatt auf den mit ^{15}N markierten Stickstoffdünger. In ähnlicher Weise deuten die Ergebnisse der MT bei gleichzeitigem Wachstum von *A. pintoi* auf eine N-Konkurrenz hin, was zu in einem vermindertem Maisertrag aufgrund kräftigen Deckpflanzenwachstums in T3 geführt hat. Demgegenüber hatte MT mit gestaffelten Anbau eines Bodenbedeckers (T4) einen ähnlichen Maisertrag, N-Konzentration in den Blättern, $\delta^{13}C$- und $\delta^{15}N$–Werte wie die Kontrolle, was darauf hindeutet, dass keine Konkurrenz um N und Wasser auftrat.

Abschließend wird darauf hingewiesen, dass Bodenerosion und Stickstoffbilanzen der gegenwärtigen landwirtschaftlichen Praxis die dringende Notwendigkeit aufzeigen, die

Bodenressourcen zu sichern, ihrer Degradation entgegenzuwirken ohne die Ernteerträge zu mindern. Die getesteten Bodenschutztechniken besitzen eine Reihe von Eigenschaften, um als nachhaltige Systeme betrachtet werden. Die Grasbarrieren kontrollierten die Erosion effektiv, während Systeme mit Minimalbodenbearbeitung und Gründüngung bei der Verbesserung der Stickstoffbilanz einen Sprung nach vorne machten. Minimalbodenbearbeitung mit Überlappungsanbau stellt dabei einen weiteren Vorteil bei der Aufrechterhaltung der Pflanzenproduktion dar. Die Wahrscheinlichkeit, dass diese Maßnahmen angenommen werden, hängt jedoch vermutlich davon ab, wie gut eine Förder- und Landnutzungspolitik auf die besonderen Erfordernisse einer Region angepasst ist.

8 REFERENCES

Adjolohoun S, Zoffoun AG, Adandédjan C, Toléba SS, Dagbénonbakin G, Sinsin B (2013) Influence of Panicum maximum ecotypes on plant root growth and soil chemical characteristics after 3-year study in Soudanian region of West Africa. Arch. Agron. Soil Sci. 60 (1):75-86.

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration-Guidelines for computing crop water requirements-FAO irrigation and drainage paper 56. FAO, Rome, Italia, http://www.fao.org/docrep/X0490E/x0490e00.htm

Anh PTQ, Gomi T, MacDonald LH, Mizugaki S, Van Khoa P, Furuichi T (2014) Linkages among land use, macronutrient levels, and soil erosion in Northern Vietnam: A plot-scale study. Geoderma 232–234:352-362.

Araya T, Cornelis WM, Nyssen J, Govaerts B, Bauer H, Gebreegziabher T, Oicha T, Raes D, Sayre KD, Haile M, Deckers J (2011) Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use Manag. 27 (3):404-414.

ARS-USDA (2011) SamplePoint Measurement Software 1.53. Washington DC, US.

Balagopalan C, Padmaja G, Nanda SK, Moorthy SN (1988) Cassava in Food, Feed and Industry. CRC, Roca Raton, pp. 205.

Barton AP, Fullen MA, Mitchell DJ, Hocking TJ, Liu L, Wu Bo Z, Zheng Y, Xia ZY (2004) Effects of soil conservation measures on erosion rates and crop productivity on subtropical Ultisols in Yunnan Province, China. Agric. Ecosyst. Environ. 104 (2):343-357.

Benavides-Solorio J, MacDonald LH (2001) Post-fire runoff and erosion from simulated rainfall on small plots, Colorado Front Range. Hydrol. Process. 15 (15):2931-2952. doi:10.1002/hyp.383

Bergsma E, Charman P, Gibbons F, Hurni H, Moldenhauer W, Panichapong S (1996) Terminology for soil erosion and conservation. ISSS: ITC: ISRIC, pp. 322.

Bergström LF, Kirchmann H (1999) Leaching of total nitrogen from nitrogen-15-labelled poultry manure and inorganic nitrogen fertilizer. J. Environ. Qual. 28 (4):1283-1290.

Bich NV (2007) Agriculture and rural development of Vietnam after twenty of Doi Moi- the pass and present. National Political Publishing House, Hanoi, Vietnam, pp. 583 (Vietnamese).

Binh DKNT, Phuong LTV, Douglas I, Van De N, McMorrow J, Lindley S, Van TT, Thanh LH, Tho N (2008) Local knowledge and economic realities affecting soil erosion in the Rach rat catchment, Vietnam. Geographical Res. 46 (1):17-26.

Blaise D, Tyagi PC, Khola OPS (1996) Ammonia volatilization from urea as affected by the addition of iron pyrites and method of application. Nutr. Cycl. Agroecosyst. 46 (2):97-101.

Blevins DW, Wilkison DH, Kelly BP, Silva SR (1996) Movement of nitrate fertilizer to glacial till and runoff from a claypan soil. J. Environ. Qual. 25 (3):584-593.

Boll L (2008) Spatial variability of maize and cassava productivity in Uplands of Northwest Vietnam. MSc. Thesis, Institute of Plant production and Agroecology in the Tropics and Subtropics, Hohenheim University, Stuttgart, Germany.

Booth DT, Cox SE, Meikle TW, Fitzgerald C (2006) The accuracy of ground-cover measurements. Rangeland Ecol. Manage. 59(2):179-188.

Boutton TW, Liao JD (2010) Changes in soil nitrogen storage and $\delta^{15}N$ with woody plant encroachment in a subtropical savanna parkland landscape. J. Geophys. Res.: Biogeosci. 115 (3):1-10.

Bowman WD, Hubick KT, von Caemmerer S, Farquhar GD (1989) Short-term changes in leaf carbon isotope discrimination in salt-and water-stressed C4 grasses. Plant Physiol. 90 (1):162-166.

Breunig J (2011) Micro variability of soil properties on erosion research site in Chieng Hac commune, Yen Chau District, Northern Vietnam. BSc. thesis, Institute of Soil Science and Land Evaluation, Hohenheim University, Stuttgart, Germany.

Bruun T, de Neergaard A, Lawrence D, Ziegler A (2009) Environmental consequences of the demise in swidden cultivation in Southeast Asia: carbon storage and soil quality. Hum. Ecol. 37 (3):375-388.

Cadisch G, Gathumbi SM, Ndufa JK, Giller KE (2002) Resource acquisition of mixed species fallows-competition or complementarity? In: Cadisch G, Gathumbi SM, Ndufa JK, Giller KE (Eds.) Integrated plant nutrient management in Sub-Saharan Africa: From concept to practice, pp. 143.

Cadisch G, Oliveira OCd, Cantarutti R, Carvalho E, Urquiaga S, Bergstrom L, Kirchmann H (1998) The role of legume quality in soil carbon dynamics in savannah ecosystems. In: Bergstrom L, Kirchmann H (Eds.) Carbon and nutrient dynamics in natural and agricultural tropical ecosystems. CAB International, pp. 47-70.

Cadisch G, Sylvester-Bradley R, Nosberger J (1989) ^{15}N-Based estimation of nitrogen fixation by eight tropical forage-legumes at two levels of P: K supply. Field Crops Res. 22 (3):181-194.

Cadisch G, Willigen Pd, Suprayogo D, Mobbs DC, Noordwijk Mv, Rowe EC, Ong CK (2004) Catching and competing for mobile nutrients in soils. In: Noordwijk Mv, Cadisch G, Rowe EC (Eds.) Below-ground interactions in tropical agroecosystems: concepts and models with multiple plant components. CAB International, Wallingford, pp. 171-191.

Casper BB, Jackson RB (1997) Plant competition underground. Annu. Rev. Ecol. Syst. (28):545-570.

Cassman KG, Dobermann A, Walters DT (2002) Agroecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO 31 (2):132-140.

Cataldo DA, Maroon M, Schrader LE, Youngs VL (1975) Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid 1. Commun. Soil Sci. Plant Anal. 6 (1):71-80.

Catchpoole VR (1975) Pathways for losses of fertilizer nitrogen from a Rhodes grass pasture in south-eastern Queensland. Crop and Pasture Sci. 26 (2):259-268.

Cerling TE, Harris JM, MacFadden BJ, Leakey MG, Quade J, Eisenmann V, Ehleringer JR (1997) Global vegetation change through the Miocene/Pliocene boundary. Nature 389 (6647):153-158.

Cernusak LA, Ubierna N, Winter K, Holtum JA, Marshall JD, Farquhar GD (2013) Environmental and physiological determinants of carbon isotope discrimination in terrestrial plants. New Phytol. 200 (4):950-965.

Cernusak LA, Winter K, Aranda J, Turner BL, Marshall JD (2007) Transpiration efficiency of a tropical pioneer tree (*Ficus insipida*) in relation to soil fertility. J. Exp. Bot. 58 (13):3549-3566.

Chaplot VAM, Rumpel C, Valentin C (2005) Water erosion impact on soil and carbon redistributions within uplands of Mekong River. Glob. Biogeochem. Cycles 19 (4): Art. No. GB4004, pp. 1-12.

Chiatante D, Scippa SG, Di Iorio A, Sarnataro M (2002) The influence of steep slopes on root system development. J. Plant Growth Regul. 21 (4):247-260.

Choi WJ, Lee SM, Ro HM, Kim KC, Yoo SH (2002) Natural ^{15}N abundances of maize and soil amended with urea and composted pig manure. Plant Soil 245 (2):223-232.

Clay DE (1997) Comparison of the difference and delta ^{15}Nitrogen approaches for evaluating liquid urea ammonium nitrate utilization by maize. Commun. Soil Sci. Plant Anal. 28 (13-14):1151-1161.

Clay DE, Clay SA, Liu Z, Reese C (2001) Spatial variability of ^{13}C isotopic discrimination in corn. Commun. Soil Sci. Plant Anal. 32 (11-12):1813-1827.

Clay DE, Clay SA, Lyon DJ, Blumenthal JM (2005) ^{13}C discrimination in corn grain can be used to separate and quantify yield losses due to water and nitrogen stresses. Weed Sci. 53 (1):23-29.

Clay SA, Clay DE, Horvath DP, Pullis J, Carlson CG, Hansen S, Reicks G (2009) Corn response to competition: growth alteration vs. yield limiting factors. Agron. J. 101 (6):1522-1529.

Clemens G, Fiedler S, Cong ND, Van Dung N, Schuler U, Stahr K (2010) Soil fertility affected by land use history, relief position, and parent material under a tropical climate in NW-Vietnam. Catena 81 (2):87-96.

Cogle A, Rao K, Yule D, Smith G, George P, Srinivasan S, Jangawad L (2002) Soil management for Alfisols in the semiarid tropics: erosion, enrichment ratios and runoff. Soil Use Manag. 18 (1):10-17.

Cogo NP, Moldenhauer WC, Foster GR (1983) Effect of crop residue, tillage-induced roughness, and runoff velocity on size distribution of eroded soil aggregates. Soil Sci. Soc. Am. J. 47 (5):1005-1008.

Cong PT, Minh PQ, Tam HV, Duy NB (2001) Use of stable isotope ^{15}N in nitrogen balance and residue recovery in maize-soybean growing in high plateau Southern Vietnam. Annual proceeding of Institute of agricultural Science for Southern Vietnam (Vietnamese).

Cook BG, Pengelly, B.C., Brown, S.D., Donnelly, J.L., Eagles, D.A., Franco, M.A., Hanson, J., Mullen, B.F., Partridge, I.J., Peters, M. and Schultze-Kraft, R. (2005) Tropical Forages: an interactive selection tool. CSIRO, DPI&F(Qld), CIAT and ILRI. http://www.tropicalforages.info/key/Forages/Media/Html/Arachis_pintoi.htm. Accessed Aug 2010.

Cook SJ, Ratcliff D (1984) A study of the effects of root and shoot competition on the growth of green panic (*Panicum maximum var. trichoglume*) seedlings in an existing grassland using root exclusion tubes. J. Appl. Ecol. 21:971-982

Cook SJ, Ratcliff D (1985) Effect of fertilizer, root and shoot competition on the growth of Siratro (*Macroptilium atropurpureum*) and green panic (*Panicum maximum var. trichoglume*) seedlings in a native speargrass (*Heteropogon contortus*) sward. Crop and Pasture Sci. 36 (2):233-245.

Dabley S, Justice V (2012) RIST rainfall intensity summarization tool, version 3.6. USDA-ARS, Washington DC.

Dalal RC, Strong WM, Cooper JE, King AJ (2013) Relationship between water use and nitrogen use efficiency discerned by ^{13}C discrimination and ^{15}N isotope ratio in bread wheat grown under no-till. Soil Tillage Res. 128:110-118.

De Costa W, Surenthran P (2005) Resource competition in contour hedgerow intercropping systems involving different shrub species with mature and young tea on sloping highlands in Sri Lanka. J. Agric. Sci. 143 (5):395-405.

Delwiche CC, Steyn PL (1970) Nitrogen isotope fractionation in soils and microbial reactions. Environ. Sci. Technol. 4 (11):929-935.

Dercon G, Clymans E, Diels J, Merckx R, Deckers J (2006a) Differential ^{13}C isotopic discrimination in maize at varying water stress and at low to high nitrogen availability. Plant Soil 282 (1-2):313-326.

Dercon G, Deckers J, Poesen J, Govers G, Sanchez H, Ramirez M, Vanegas R, Tacuri E, Loaiza G (2006b) Spatial variability in crop response under contour hedgerow systems in the Andes region of Ecuador. Soil Tillage Res. 86 (1):15-26.

Douglas I (2006) The local drivers of land degradation in South-East Asia. Geographical Res. 44 (2):123-134.

Dourado-Neto D, Powlson D, Bakar RA, Bacchi OOS, Basanta MdV, Keerthisinghe G, Ismaili M, Rahman SM, Reichardt K, Safwat MSA (2010) Multiseason recoveries of organic and inorganic nitrogen-15 in tropical cropping systems. Soil Sci. Soc. Am. J. 74 (1):139-152.

Drinkwater LE, Wagoner P, Sarrantonio M (1998) Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396 (6708):262-265.

Dung NV, Vien TD, Lam NT, Tuong TM, Cadisch G (2008) Analysis of the sustainability within the composite swidden agroecosystem in northern Vietnam. 1. Partial nutrient balances and recovery times of upland fields. Agric. Ecosyst. Environ. 128 (1-2):37-51.

Duran ZVH, Rodriguez PCR (2008) Soil-erosion and runoff prevention by plant covers: A review. Agron. Sustain. Dev. 28 (1):65-86.

El-Swaify SA (1997) Factors affecting soil erosion hazards and conservation needs for tropical steeplands. Soil Technol. 11 (1):3-16.

Engel FL, Bertol I, Ritter SR, Paz Gonzalez A, Paz-Ferreiro J, Vidal Vazquez E (2009) Soil erosion under simulated rainfall in relation to phenological stages of soybeans and tillage methods in Lages, SC, Brazil. Soil and Till. Res. 103 (2):216-221.

Erenstein OCA (1999) The economics of soil conservation in developing countries: the case of crop residue mulching. PhD thesis, Mansholt Institute. Wageningen University, Wageningen, Netherlands.

Erenstein OCA (2002) Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. Soil Tillage Res. 67 (2):115-133.

Evans RD (2007) Soil nitrogen isotope composition. In: Lajtha, K., Michener, R. (Eds.) Stable isotopes in ecology and environmental science. Blackwell publishing, Singapore, pp. 83-98.

Evans RD, Bloom AJ, Sukrapanna SS, Ehleringer JR (1996) Nitrogen isotope composition of tomato (*Lycopersicon esculentum* Mill. cv. T-5) grown under ammonium or nitrate nutrition. Plant Cell Environ. 19 (11):1317-1323.

Farquhar GD (1983) On the nature of carbon isotope discrimination in C4 species. Funct. Plant Biol. 10 (2):205-226.

Farquhar GD, Cernusak LA (2012) Ternary effects on the gas exchange of isotopologues of carbon dioxide. Plant Cell Environ. 35 (7):1221-1231.

Farquhar GD, Ehleringer JR, Hubick KT (1989) Carbon isotope discrimination and photosynthesis. Annu. Rev. Plant Biol. 40 (1):503-537.

Fox J, Vogler J (2005) Land-use and land-cover change in montane mainland Southeast Asia. Environ. Manag. 36 (3):394-403.

Friday JB, Fownes JH (2002) Competition for light between hedgerows and maize in an alley cropping system in Hawaii, US. Agrofor. Syst. 55 (2):125-137.

Fry B (2006) Stable isotope ecology. Springer, New York, US, pp. 308.

Gardner JB, Drinkwater LE (2009) The fate of nitrogen in grain cropping systems: a meta-analysis of ^{15}N field experiments. Ecol. Appl. 19 (8):2167-2184.

Garrity DP, Mercado Jr A, Solera C (1995) Species interference and soil changes in contour hedgerows planted on inclines in acidic soils in southeast Asia. Kang BT, Osiname A O, Larbi A (Eds.), Alley farming research and development, International Institute of Tropical Agriculture, Ibadan, Nigeria (1995), pp. 351–365.

Garten CT (1993) Variation in foliar ^{15}N abundance and the availability of soil nitrogen on Walker Branch watershed. Ecology 74 (7):2098-2113.

Geissler C, Kuhn P, Bohnke M, Bruelheide H, Shi X, Scholten T (2012) Splash erosion potential under tree canopies in subtropical SE China. Catena 91:85-93.

Giller KE, Bergstrom L, Kirchmann H (1998) Tropical legumes: providers and plunderers of nitrogen. In: Bergstrom L, Kirchmann H (Eds.) Carbon and nutrient dynamics in natural and agricultural tropical ecosystems. CAB International Wallingford, UK, pp. 33-45.

Giller KE, Cadisch G (1995) Future benefits from biological nitrogen fixation: an ecological approach to agriculture. Plant Soil 174:255–277.

Giller KE, Ormesher J, Awah FM (1991) Nitrogen transfer from *Phaseolus* bean to intercropped maize measured using ^{15}N-enrichment and ^{15}N-isotope dilution methods. Soil Biol. Biochem. 23 (4):339-346.

Giller KE, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res. 114 (1):23-34.

Gitz Iii DC, Liu-Gitz L, Britz SJ, Sullivan JH (2005) Ultraviolet-B effects on stomatal density, water-use efficiency, and stable carbon isotope discrimination in four glasshouse-grown soybean (*Glyicine max*) cultivars. Environ. Exp. Bot. 53 (3):343-355.

GSO Vietnam (2010) Result of the Vietnam household livings standards survey 2010. Hanoi, Vietnam.

http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=12426 Accessed Sep 2014.

GSO Vietnam (2014) Diện tích ngô phân theo địa phương (Maize growing areas by province). http://www.gso.gov.vn/default.aspx?tabid=390&idmid=3&ItemID=14089 Accessed Sep 2014.

Guo ZL, Zhong C, Cai CF, Ding SW, Wang ZM (2008) Nitrogen competition in contour hedgerow systems in subtropical China. Nutr. Cycl. Agroecosyst. 81 (1):71-83.

Ha HAP, Huon S, Tureaux THd, Orange D, Jouquet P, Valentin C, Rouw AD, Duc TT (2012) Impact of fodder cover on runoff and soil erosion at plot scale in a cultivated catchment of North Vietnam. Geoderma 177-178:8-17.

Ha PQ, Tuan VĐ (2006) Study on the improvement of the fertilizer nitrogen efficiency to rice in 4 crops based intensive cropping system on Haplic Acrisols through ^{15}N technique. Vietnam Soil Sci. 26:70-72 (Vietnamese).

Häring V (2013) Effects of land use change on soil organic carbon dynamics in Northwest Vietnam. PhD thesis, Institute of Soil Science and Land Evaluation (310), Hohenheim University, Stuttgart.

Häring V, Fischer H, Cadisch G, Stahr K (2013) Implication of erosion on the assessment of decomposition and humification of soil organic carbon after land use change in tropical agricultural systems. Soil Biol. Biochem. 65:158-167.

Hatch MD, Agostino A, Jenkins CL (1995) Measurement of the leakage of CO_2 from bundle-sheath cells of leaves during C4 photosynthesis. Plant Physiol. 108 (1):173-181.

Heistermann M, Müller C, Ronneberger K (2006) Land in sight?: Achievements, deficits and potentials of continental to global scale land-use modeling. Agric. Ecosyst. Environ. 114 (2–4):141-158.

Hilger T, Keil A, Lippe M, Panomtaranichagul M, Saint-Macary C, Zeller M, Pansak W, Dinh TV, Cadisch G (2013) Soil conservation on sloping land: technical options and adoption constraints. In: Fröhlich, HL, Schreinemachers, P, Stahr, Clemens, G (Eds.). Sustainable land use and rural development in Southeast Asia: Innovations and policies for mountainous areas. Springer, pp. 229-279.

Hoang Fagerström MH, Nilsson SI, van Noordwijk M, Phien T, Olsson M, Hansson A, Svensson C (2002) Does *Tephrosia candida* as fallow species, hedgerow or mulch improve nutrient cycling and prevent nutrient losses by erosion on slopes in northern Viet Nam? Agric. Ecosyst. Environ. 90 (3):291-304.

Högberg P (1997) Tansley Review No. 95: ^{15}N natural abundance in soil-plant systems. New Phytol. 137 (2):179-203.

Hood-Nowotny R, Van Kessel C, Vanlauwe B (2008) Use of tracer technology for the management of organic sources. In: Guidelines on Nitrogen Management in Agricultural Systems, TCS 29. IAEA, Vienna, Austria, pp. 237.

Hudson NW (1993) Field measurement of soil erosion and runoff. FAO Soils Bullentin 68, Rome, Italia. http://www.fao.org/docrep/t0848e/t0848e00.HTM.

IAEA (2001) Use of istope and radiation method in soil and water management and crop nutrition, TCS 14. Training course series. Vienna, Austria, pp. 247.

IPCC (2007) Climate Change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.)]. Cambridge University Press, Cambridge, UK and New York, US, pp. 996.

Jamieson NL, Le TC, Rambo AT (1998) The development crisis in Vietnam's mountains. East West center special reports No.6, Honolulu, Hawaii, US, pp. 32.

Kaewpradit W, Toomsan B, Cadisch G, Vityakon P, Limpinuntana V, Saenjan P, Jogloy S, Patanothai A (2009) Mixing groundnut residues and rice straw to improve rice yield and N use efficiency. Field Crops Res. 110 (2):130-138.

Keil A, Saint-Macary C, Zeller M (2009) Maize boom in the uplands of Northern Vietnam: economic importance and environmental implications. Paper presented at the TropenTag 2009, Hamburg, Germany, October 6 – 8.

Kelley HW (1983) Keeping the land alive: soil erosion-its causes and cures. Soils bulletin 50, FAO, Rome, Italia. http://www.fao.org/docrep/t0389e/t0389e00.htm.

Kim K-I, Clay DE, Carlson CG, Clay SA, Trooien T (2008) Do synergistic relationships between nitrogen and water influence the ability of corn to use nitrogen derived from fertilizer and soil? Agron. J. 100 (3):551-556.

Kondo M, Murty MVR, Aragones DV (2000) Characteristics of root growth and water uptake from soil in upland rice and maize under water stress. Soil Sci. Plant Nutr. 46 (3):721-732.

Laflen JM, Colvin TS (1981) Effect of crop residue on soil loss from continuous row cropping. Trans. ASAE (Am. Soc. Agric. Eng.) 24 (3): 0605-0609.

Lal R (2007) Anthropogenic influences on world soils and implications to global food security. Adv. Agron. 93:69-93.

Lambers H, Chapin FS, Pons TL (1998) Plant physiological ecology, second edition. Springer, NY, US, pp. 605.

Larsen IJ, MacDonald LH, Brown E, Rough D, Welsh MJ, Pietraszek JH, Libohova Z, de Dios Benavides-Solorio J, Schaffrath K (2009) Causes of post-fire runoff and erosion: water repellency, cover, or soil sealing? Soil Sci. Soc. Am. J. 73 (4):1393-1407.

Le Bissonnais Y, Arrouays D (1997) Aggregate stability and assessment of soil crustability and erodibility: II. Application to humic loamy soils with various organic carbon contents. Eur. J. Soil Sci. 48 (1):39-48.

Le Doanh Q, Tuan HD (2004) Improving indigenous technologies for sustainable land use in northern mountainous areas of Vietnam. J. Mt. Sci. 1 (3):270-275.

Leopold A (1953) Conservation from Round River. Oxford University Press, US, pp. 145-157.

Loc DC, Thai P, Siem NT, Toan TD (1998) Effect of farming techniques on steep lands in Hoa Binh province. In: Phien T, Siem NT (Eds.) Sustainable farming on sloping lands in Vietnam. Nha xuat ban Nong nghiep, Hanoi, Vietnam, pp. 112-126 (Vietnamese).

Long TM (2013) Review on forest and land allocation in Vietnam. In: Proceeding of conference Land use and management in minority comunity in Viet Nam, Hanoi, Vietnam, 1 November 2012. SPERI, CODE, CIRUM, Hanoi, Vietnam, pp. 12 (Vietnamese).

Lu Y-C, Watkins KB, Teasdale JR, Abdul-Baki AA (2000) Cover crops in sustainable food production. Food Rev. Int. 16 (2):121-157.

Ly L Ruminant production in Vietnam and development of forage in smallholder farm (1995). In: Enhancing sustainable livestock-crop production in smallholder farming systems, Proceedings of the fourth meeting of forage regional working group on grazing and feed resources of Southeast Asia, Nha Trang, Vietnam, 20-24 March, pp. 57-62.

MacDonald L, Welsh M, Brown E, Libohova Z (2006) Middle East watershed monitoring and evaluation project: Accuracy and costs associated with erosion monitoring using sediment traps. Unpublished report, pp. 26.

Mai VT, Keulen H, Hessel R, Ritsema C, Roetter R, Phien T (2013) Influence of paddy rice terraces on soil erosion of a small watershed in a hilly area of Northern Vietnam. Paddy and Water Environ. 11 (1-4):285-298.

Mamedov AI, Levy GJ, Shainberg I, Letey J (2001) Wetting rate, sodicity, and soil texture effects on infiltration rate and runoff. Soil Res. 39 (6):1293-1305.

Margaritescu M, Moldovanu A, Boeriu P, Rolea AME (2011) Ultrasonic measuring system for deposition of sediments in reservoirs. In: Proceedings of MECAHITECH, Bucharest, Romania, 22 - 23 September, pp. 253-257.

Mariotti A, Germon JC, Hubert P, Kaiser P, Letolle R, Tardieux A, Tardieux P (1981) Experimental determination of nitrogen kinetic isotope fractionation: Some principles; illustration for the denitrification and nitrification processes. Plant Soil 62 (3):413-430.

Marshall JD, Brooks JR, Lajtha K (2007) Sources of variation in the stable isotopic composition of plants. In: Michener R, Lajtha K (Eds.) Stable isotopes in ecology and environmental science. Blackwell publishing, Singapore, pp. 22-60.

McGregor KC, Bingner RL, Bowie AJ, Foster GR (1995) Erosivity index values for northern Mississippi. Transactions of the ASAE 38 (4):1039-1047.

Mills AJ, Fey MV (2004) Effects of vegetation cover on the tendency of soil to crust in South Africa. Soil Use Manag. 20 (3):308-317.

Minot N, Epprecht M, Anh TTT, Trung LQ (2006) Income diversification and poverty in the Northern uplands of Vietnam. Research report, vol 145. International Food Policy Research Institute (IFPRI), Washington, D.C, pp. 145.

MONRE (2011) Environment report of Vietnam 2010. Hanoi, Vietnam, pp. 199 (Vietnamese).

Moore DC, Singer MJ (1990) Crust formation effects on soil erosion processes. Soil Sci. Soc. Am. J. 54 (4):1117-1123.

Morgan RPC (1978) Field studies of rainsplash erosion. Earth Surf. Process. Landf. 3 (3):295-299.

Morgan RPC (2005) Soil erosion and conservation, 3rd edn. Blackwell Science Ltd, Oxford, England, pp. 298.

Mulumba LN, Lal R (2008) Mulching effects on selected soil physical properties. Soil Tillage Res. 98 (1):106-111.

Nadelhoffer K, Shaver G, Fry B, Giblin A, Johnson L, McKane R (1996) ^{15}N natural abundances and N use by tundra plants. Oecologia 107 (3):386-394.

Neef A, Kirchmann K, Schwarzmeier R, Sangkapitux C (2000) Devolution of resource management, tenure security, and resource conservation - evidence from upland regions of Thailand and Vietnam. In: International symposium II on montane mainland Southeast Asia (MMSEA) "Governance in the natural and cultural landscape", Chiang Mai, Thailand, July 1-5.

Nikolic N, Schultze-Kraft R, Nikolic M, Bocker R, Holz I (2008) Land degradation on barren hills: a case study in northeast Vietnam. Environ. Manag. 42 (1):19-36.

NRCS (2007) Conservation practice standard 330-Contour farming. Idaho, US, pp. 3.

Pansak W, Dercon G, Hilger T, Kongkaew T, Cadisch G (2007) ^{13}C isotopic discrimination: a starting point for new insights in competition for nitrogen and water under contour hedgerow systems in tropical mountainous regions. Plant Soil 298 (1):175-189.

Pansak W, Hilger T, Lusiana B, Kongkaew T, Marohn C, Cadisch G (2010) Assessing soil conservation strategies for upland cropping in Northeast Thailand with the WaNuLCAS model. Agrofor. Syst. 79:123-144.

Pansak W, Hilger TH, Dercon G, Kongkaew T, Cadisch G (2008) Changes in the relationship between soil erosion and N loss pathways after establishing soil conservation systems in uplands of Northeast Thailand. Agric. Ecosyst. Environ. 128 (3):167-176.

Pardo LH, Hemond HF, Montoya JP, Fahey TJ, Siccama TG (2002) Response of the natural abundance of ^{15}N in forest soils and foliage to high nitrate loss following clear-cutting. Can. J. For. Res. 32 (7):1126-1136.

Pasuquin JM, Saenong S, Tan PS, Witt C, Fisher MJ (2012) Evaluating N management strategies for hybrid maize in Southeast Asia. Field Crops Res. 134:153-157.

Peisker M, Henderson S (1992) Carbon: terrestrial C4 plants. Plant Cell Environ. 15 (9):987-1004.

Peri PL, Ladd B, Pepper DA, Bonser SP, Laffan SW, Amelung W (2011) Carbon ($d^{13}C$) and nitrogen ($d^{15}N$) stable isotope composition in plant and soil in Southern Patagonia's native forests. Glob. Chang. Biol. 18 (1):311-321.

Phien T, Loan LD (2005) From research results to establishment of cultivation model on slopping lands of small households. In: Bo NV, Phien T, Dinh BD, Son TT, Cung DV, Hanh NM (Eds.) Proceeding on National Institute for soil and fertilizer 30 years anniversary Hanoi, Vietnam, pp. 470-484 (Vietnamese).

Phiên T, Siêm NT (2002) Sustainable land use for slopping regions in Vietnam Hanoi agriculture publishing house, Hanoi, Vietnam, pp. 339 (Vietnamese).

Phien T, Vinh NC (2002) Soil organic matter management for sustainable cassava production in Vietnam. In: Howeler RH (Ed.) Cassava research and development in Asia: Exploring new opportunities for an acient crop. Proc. 7th regional cassava workshop, Bangkok, Oct 28- Nov 1. CIAT, pp. 234.

Phong TA (1995) Bare land in our country. Vietnam Soil Sci. 5:67-69 (Vietnamese).

Pilbeam C, Gregory P, Tripathi B, Munankarmy R (2002) Fate of nitrogen-15-labelled fertilizer applied to maize-millet cropping systems in the mid-hills of Nepal. Biol. Fertil. Soils 35 (1):27-34.

Pingali PL, Shah M (2001) Policy re-directions for sustainable resource use: The rice-wheat cropping system of the Indo-Gangetic Plains. J. Crop Production 3 (2):103-118.

Podwojewski P, Orange D, Jouquet P, Valentin C, Thiet N, Janeau JL, Toan DT (2008) Land-use impacts on surface runoff and soil detachment within agricultural sloping lands in Northern Vietnam. Catena 74:109-118.

Poreba GJ (2006) Caesium-137 as a soil erosion tracer: a review. Geochronometria 25:37-46.

Porto P, Walling DE (2012) Using plot experiments to test the validity of mass balance models employed to estimate soil redistribution rates from ^{137}Cs and $^{210}Pb_{ex}$ measurements. Appl. Radiat. Isot. 70 (10):2451-2459.

Powlson DS, Hart PBS, Poulton PR, Johnston AE, Jenkinson DS (1992) Influence of soil type, crop management and weather on the recovery of 15N-labelled fertilizer applied to winter wheat in spring. J. Agric. Sci 118 (1):83-100.

Ramos-Scharron CE, MacDonald LH (2007) Measurement and prediction of natural and anthropogenic sediment sources, St. John, US Virgin Islands. Catena 71 (2):250-266.

Ranjith S, Meinzer F, Perry M, Thom M (1995) Partitioning of carboxylase activity in nitrogen-stressed sugarcane and its relationship to bundle sheath leakiness to CO_2, photosynthesis and carbon isotope discrimination. Funct. Plant Biol. 22 (6):903-911.

Rao ACS, Smith JL, Parr JF, Papendick RI (1992) Considerations in estimating nitrogen recovery efficiency by the difference and isotopic dilution methods. Fertilizer Res. 33 (3):209-217.

Reardon T, Vosti SA (1992) Issues in the analysis of the effects of policy on conservation and productivity at the household level in developing countries. Q. J. Int. Agr. 31:380-380.

Reinhardt N (2009) Evaluation of a Study Site for sustainable Yield Increase in Northern Vietnam. BSc. thesis, Institute of Soil Science and Land Evaluation, Universität Hohenheim, Stuttgart, Germany.

Robichaud PR, Brown RE (2002) Silt fences: an economic technique for measuring hillslope soil erosion. General Technical Report RMRS-GTR-95. Rocky Mountain Research Station, Ft. Collins, CO, US, pp. 24.

Robinson D (2001) $\delta^{15}N$ as an integrator of the nitrogen cycle. Trends Ecol. Evol. 16 (3):153-162.

Romkens MJM, Prasad SN, Whisler FD, Anderson MG, Burt TP (1990) Surface sealing and infiltration. In: Anderson MG, Burt TP (Eds.) Process studies in hillslope hydrology. John Wiley & Sons, Chichester, UK, pp. 127-172.

Roth CH, Meyer B, Frede HG, Derpsch R (1988) Effect of mulch rates and tillage systems on infiltrability and other soil physical properties of an Oxisol in Parana, Brazil. Soil Tillage Res. 11 (1):81-91.

Rowe EC, Van Noordwijk M, Suprayogo D, Cadisch G (2005) Nitrogen use efficiency of monoculture and hedgerow intercropping in the humid tropics. Plant Soil 268 (1):61-74.

Saint-Macary C, Keil A, Zeller M, Heidhues F, Pham Thi My D (2010) Land titling policy and soil conservation in the northern uplands of Vietnam. Land Use Policy 27 (2):617-627.

SAS Institute (2002) SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc, Cary, NC.

Schad I, Schmitter P, Saint-Macary C, Neef A, Lamers M, Nguyen L, Hilger T, Hoffmann V (2012) Why do people not learn from flood disasters? Evidence from Vietnam's northwestern mountains. Natural Hazards 62 (2):221-241.

Schmitter P (2011) Carbon and nitrogen redistribution across the landscape and its influence on paddy rice production in Northwest Vietnam. PhD thesis, Institute of Plant Production and Agroecology in the Tropics and Subtropics, Hohenheim University, Stuttgart, Germany.

Schmitter P, Dercon G, Hilger T, Thi Le Ha T, Huu Thanh N, Lam N, Duc Vien T, Cadisch G (2010) Sediment induced soil spatial variation in paddy fields of Northwest Vietnam. Geoderma 155 (3-4):298-307.

Schmitter P, Fröhlich HL, Dercon G, Hilger T, Huu Thanh N, Lam NT, Vien TD, Cadisch G (2012) Redistribution of carbon and nitrogen through irrigation in intensively cultivated tropical mountainous watersheds. Biogeochemistry 109 (1):133-150.

Shaxson TF (1993) Conservation-effectiveness of farmers' actions: a criterion of good land husbandry. In: Baum E, Wolff P, Zöbisch MA (Eds.), Topics in applied resource management, vol. 3, Witzenhausen, German Institute for Tropical and Subtropical Agriculture (DITLS), Germany, pp. 103–128.

Shireman JV, Colle DE, Rottmann RW (1978) Growth of grass carp fed natural and prepared diets under intensive culture. J. Fish Biol. 12:457-463.

Siem NT, Phien T (1992) Deterioration risk of the uplands in Vietnam and research priorities for their management. Vietnam Soil Sci. 2:32-34 (Vietnamese).

Slaets JIF, Schmitter P, Hilger T, Lamers M, Piepho H-P, Vien TD, Cadisch G (2014) A turbidity-based method to continuously monitor sediment, carbon and nitrogen flows in mountainous watersheds. J. Hydrol. 513, 45-57.

Smeltekop H, Clay DE, Clay SA (2002) The impact of intercropping annual 'Sava' snail medic on corn production. Agron. J. 94 (4):917-924.

Smil V (1999) Nitrogen in crop production: An account of global flows. Glob. Biogeochem. Cycles 13 (2):647-662.

Sogbedji JM, van Es HM, Yang CL, Geohring LD, Magdoff FR (2000) Nitrate leaching and nitrogen budget as affected by maize nitrogen rate and soil type. J. Environ. Qual. 29 (6):1813-1820.

Stahr K, Clemens G, Schuler U, Erbe P, Haering V, Cong N, Bock M, Tuan V, Hagel H, Le Vinh B, Rangubpit W, Surinkum A, Willer J, Ingwersen J, Zarei M, Herrmann L (2013) Beyond the horizons: challenges and prospects for soil science and soil care in Southeast Asia. In: Fröhlich, HL, Schreinemachers, P, Stahr, Clemens, G (Eds.). Sustainable land use and rural development in Southeast Asia: Innovations and policies for mountainous areas. Springer, pp. 31-107.

Stevens RJ, Laughlin RJ, Kilpatrick DJ (1989) Soil properties related to the dynamics of ammonia volatilization from urea applied to the surface of acidic soils. Fertilizer Res. 20 (1):1-9.

Stevens WB, Hoeft RG, Mulvaney RL (2005) Fate of nitrogen-15 in a long-term nitrogen rate study: I. Interactions with soil nitrogen. Agron. J. 97 (4):1046-1053.

Stroosnijder L (2005) Measurement of erosion: is it possible? Catena 64 (2):162-173

Systat Software Inc. (2008) Sigmaplot Version 11. San Jose, California, US.

Thang C, Sanh M, Wiktorsson H (2004) Effects of supplementation of mixed cassava (*Manihot esculenta*) and legume (*Phaseolus calcaratus*) fodder on the rumen degradability and performance of growing cattle. Asian-Aust. J. Anim. Sci. 21 (1):66-74.

Thao LB (1997) Vietnam, the country and its geographical regions. The Gioi Publishers, Hanoi, pp. 617.

Thapa BB, Cassel DK, Garrity DP (1999) Ridge tillage and contour natural grass barrier strips reduce tillage erosion. Soil Tillage Res. 51 (3):341-356.

The Fertilizer Institute (2014) What are the 4Rs. http://www.nutrientstewardship.com/what-are-4rs. Accessed 1 Oct 2014.

Thierfelder C, Wall PC (2009) Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res. 105 (2):217-227.

Thierfelder C, Wall PC (2012) Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. Soil Use Manag. 28 (2):209-220.

Toan TD, Podwojewski P, Orange D, Phuong ND, Phai DD, Bayer A, Thiet NV, Rinh PV, Renaud J, Koikas J (2005) Effect of land use and land management on water budget and soil erosion in a small catchment in northern part of Vietnam. In: Proceedings of SSWM 2004, International conference on innovative practices for sustainable sloping lands and watershed management, 5-9 September 2004, Chiang Mai, Thailand, pp. 109-122.

Tomich TP, Thomas DE, van Noordwijk M (2004) Environmental services and land use change in Southeast Asia: from recognition to regulation or reward? Agric. Ecosyst. Environ. 104 (1):229-244.

Tomlin AD, Shipitalo MJ, Edwards WM, Protz R (1995) Earthworms and their influence on soil structure and infiltration. In: Hendrix PF (Ed.) Earthworm ecology and biogeography in North America. CRC Press, Boca Raton FL, pp. 159-184.

Tsai SM, Da Silva PM, Cabezas WL, Bonetti R (1993) Variability in nitrogen fixation of common bean (*Phaseolus vulgaris* L.) intercropped with maize. Plant Soil 152 (1):93-101.

Tuan V, Hilger T, Vien T, Cadisch G (2015) Nitrogen recovery and downslope translocation in maize hillside cropping as affected by soil conservation. Nutr. Cycl. Agroecosyst. 101 (1):17-36.

Tuan VD, Hilger T, MacDonald L, Clemens G, Shiraishi E, Vien TD, Stahr K, Cadisch G (2014) Mitigation potential of soil conservation in maize cropping on steep slopes. Field Crops Res. 156:91-102.

Tuan VD, Shiraishi E, Hilger T, Vien TD, Cadisch G (2012) Maize cropping on steep slopes - the potential of soil cover in mitigating erosion: Experiences from NW Vietnam. In: Conference on Sustainable land use and rural development in mountain areas, Hohenheim University, Stuttgart, Germany, 16-18 April 2012.

Turkelboom F, Poesen J, Trebuil G (2008) The multiple land degradation effects caused by land-use intensification in tropical steeplands: A catchment study from northern Thailand. Catena 75 (1):102-116.

Ubierna N, Sun WEI, Kramer DM, Cousins AB (2013) The efficiency of C4 photosynthesis under low light conditions in *Zea mays, Miscanthus x giganteus* and *Flaveria bidentis*. Plant Cell Environ. 36 (2):365-381.

Unkovich M, Herridge D, Peoples M, Cadisch G, Boddey B, Giller K, Alves B, Chalk P (2008) Measuring plant-associated nitrogen fixation in agricultural systems. ACIAR Monograph Series No. 136. Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia, pp. 258.

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gerard B, Rufino MC, Teufel N, van Rooyen A (2012) Conservation agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crops Res. 132:175-184.

Valentin C, Agus F, Alamban R, Boosaner A, Bricquet JP, Chaplot V, Guzman Td, Rouw Ad, Janeau JL, Orange D, Phachomphonh K, Phai DD, Podwojewski P, Ribolzi O, Silvera N, Subagyono K, Thie´baux JP, Toan TD, Vadari T (2008) Runoff and sediment losses from 27 upland catchments in Southeast Asia: Impact of rapid land use changes and conservation practices. Agric. Ecosyst. Environ. 128 (4):225-238.

Valles De La Mora B, Cadisch G (2010) Assessment of N_2 fixation by three forage peanut ecotypes using ^{15}N natural abundance technique. Rev. Mex. Cienc. Pecu. 1 (2):99-114.

Van Bo N, Mutert E (2003) Balanced Fertilization for Better Crops in Vietnam. Potash & Phosphate Institute, Southeast Asia Programs, Singapore, pp. 141.

Van De N, Douglas IAN, McMorrow J, Lindley S, Thuy Binh DKN, Van TT, Thanh LH, Tho N (2008) Erosion and nutrient loss on sloping land under intense cultivation in Southern Vietnam. Geographical Res. 46 (1):4-16.

van Noordwijk M, Cadisch G (2002) Access and excess problems in plant nutrition. Plant Soil 247 (1):25-39.

Van Oost K, Govers G, De Alba S, Quine TA (2006) Tillage erosion: a review of controlling factors and implications for soil quality. Prog. Phys. Geogr. 30 (4):443-466.

Vandermeer JH (1992) The ecology of intercropping. Cambridge University Press, pp. 237.

Vanlauwe B, Sanginga N, Merckx R (1998) Recovery of *Leucaena* and *Dactyladenia* residue nitrogen-15 in alley cropping systems. Soil Sci. Soc. Am. J. 62 (2):454-460.

Vien TD, Leisz SJ, Lam NT, Rambo AT (2006) Using traditional swidden agriculture to enhance rural livelihoods in Vietnam's uplands. Mt. Res. Dev. 26 (3):192-196.

Vogel H (1988) Deterioration of a mountainous agro-ecosystem in the third world due to emigration of rural labour. Mt. Res. Dev. 8 (4):321-329.

Wallbrink PJ, Murray AS (1993) Use of fallout radionuclides as indicators of erosion processes. Hydrol. Process. 7 (3):297-304.

Wang Y, Mi G, Chen F, Zhang J, Zhang F (2005) Response of root morphology to nitrate supply and its contribution to nitrogen accumulation in maize. J. Plant Nutr. 27 (12):2189-2202.

Wang Z, Liu F, Kang S, Jensen CR (2011) Alternate partial root-zone drying irrigation improves nitrogen nutrition in maize (*Zea mays* L.) leaves. Environ. Exp. Bot. 75 (2012):36-40.

Wezel A, Luibrand A, Thanh LQ (2002a) Temporal changes of resource use, soil fertility and economic situation in upland Northwest Vietnam. Land Degrad. Dev. 13 (1):33-44.

Wezel A, Steinmuller N, Friederichsen JR (2002b) Slope position effects on soil fertility and crop productivity and implications for soil conservation in upland northwest Vietnam. Agric. Ecosyst. Environ. 91 (1-3):113-126.

Wilson JR, Ludlow MM, Fisher MJ, Schulze E (1980) Adaptation to water stress of the leaf water relations of four tropical forage species. Funct. Plant Biol. 7 (2):207-220.

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: A guide to conservation planning. Agricultural Handbook No. 537. Agriculture Research Service, Washington, DC, US, pp. 58.

World Bank (2004) Economic growth, poverty, and household welfare in Vietnam. The World Bank Group, Hanoi, Vietnam, pp. 628.

Xu Z, Myers R, Saffigna P, Chapman A (1993) Nitrogen fertilizer in leucaena alley cropping. II. Residual value of nitrogen fertilizer and leucaena residues. Fertilizer Res. 34 (1):1-8.

Yasmin K, Cadisch G, Baggs EM (2010) The significance of below-ground fractions when considering N and C partitioning within chickpea (*Cicer arietinum L.*). Plant Soil 327 (1-2):247-259.

Yen Chau Dept. Agricuture (2010) Agricultural report of the district in 2009 and planning for 2010, issued on 10th November 2010 (Vietnamese).

Yen Chau Dept. Agricuture (2011) Agricultural report of the district in 2010 and planning for 2011, issued on 16th November 2011 (Vietnamese).

Young A (1989) Agroforestry for soil conservation. CAB International, Wallingford, UK, pp. 276.

Zhao B, Li X, Liu H, Wang B, Zhu P, Huang S, Bao D, Li Y, So H-B (2011) Results from long-term fertilizer experiments in China: The risk of groundwater pollution by nitrate. NJAS Wageningen J. of Life Sci. 58 (3):177-183.

Ziegler A, Bruun T, Guardiola-Claramonte M, Giambelluca T, Lawrence D, Thanh Lam N (2009) Environmental consequences of the demise in swidden cultivation in montane mainland Southeast Asia: Hydrology and geomorphology. Hum. Ecol. 37 (3):361-373.