Reshaping upland farming policies to support nature and livelihoods

Lessons from soil erosion in Southeast Asia with emphasis on Lao PDR

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Institut de recherche pour le développement

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MSEC

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Main cover image: Panoramic view showing typical land use in a montane environment near Luang Prabang, northern Lao PDR. A crop of upland rice and newly planted teak trees are growing in the foreground. Rapidly expanding plantations of teak trees stand on both sides of the road. The fields above are used to grow annual crops of mainly upland rice, maize and Job's tears, as part of shifting (swidden) cultivation systems. Towards the mountain ridges, the dense, predominantly evergreen vegetation is either long-term fallow or old secondary forest.

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Project

This research study was initiated as part of the project, Management of Soil Erosion Consortium (MSEC).

Collaborators

This study is a collaboration of the following organizations:

Institut de Recherche pour le Développement, Marseille, France

International Water Management Institute, Colombo, Sri Lanka

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Donors

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- Institut de Recherche pour le Développement (IRD), France

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About the Management of Soil Erosion Consortium (MSEC)

In 1998, the International Board for Soil Research and Management (IBSRAM) and the Asian Development Bank (ADB) formed the Management of Soil Erosion Consortium (MSEC) to assess the causes and extent of soil erosion in Southeast Asia. In a first phase, lasting 4 years, MSEC sought to:

- quantify erosion in small catchments cultivated according to local practices that were representative of those areas, excluding modern industrial farming; and
- test alternative farming practices that would combat land degradation and improve household livelihoods for communities inhabiting sloping lands and mountainous regions.

A second phase of MSEC, supported by the International Water Management Institute (IWMI) and Institut de Recherche pour le Développement (IRD), operated in Indonesia, Lao PDR, the Philippines, Thailand and Vietnam with national partners (Box 1) from 2003 onwards. The ultimate goal of this phase was to achieve sustainable development of watersheds by addressing the twin objectives of conserving resources and underpinning food security. This report summarizes scientific knowledge generated by MSEC over the past 10 years, focusing on biophysical aspects of soil erosion and the influence of related land-use policies. Although the most detailed studies took place in Lao PDR, findings from those studies are relevant to upland areas across the MSEC project sites. Today, MSEC is in its third phase.

Alain Pierret / IRD

Box 1

National partners

The following institutions were national partners of MSEC during research carried out in the second phase of the project:

- Indonesia: Indonesian Center for Agricultural Land Resources Research and Development (ICALRRD)
- Lao PDR: National Agriculture and Forestry Research Institute (NAFRI)
- The Philippines: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD)
- Thailand: National Park, Wildlife and Plant Conservation Department (NPWPCD)
- Vietnam: National Institute for Soils and Fertilizers (NISF)

Main messages and recommendations

What is 'shifting cultivation' and how has it changed in recent years?

- Shifting cultivation involves cutting down vegetation, burning it in situ and then planting crops on the cleared land. Once crops are harvested, the land is left 'fallow' for natural vegetation to regrow. This agricultural system has traditionally been widely practiced in many parts of the tropics. In some countries, historically, land was left fallow for as long as 20 to 30 years. On the Management of Soil Erosion Consortium (MSEC) study site in Northern Lao PDR, fallow periods dropped from around 8 to 9 years during the 1970s to around 2 to 3 years in recent times.

- The widespread beliefs that removing vegetation during shifting cultivation contributes significantly to deforestation, and burning it adds greenhouse gases to the atmosphere, have led the Government of Lao PDR to adopt policies to minimize this agricultural practice in order to address deforestation.

Alain Pierret / IRD

What has the work of MSEC revealed about soil erosion in Southeast Asia's uplands?

- Four main soil erosion processes are at work in Southeast Asia's uplands: inter-rill; tillage; gully (linear); and land mass movements. How riparian (riverside) zones are managed, and changes to vegetation and tree cover, can also affect rates of soil erosion and downstream sediment loads.

- Inter-rill, tillage and gully erosion are predominantly influenced by land use rather than environmental characteristics at both plot and catchment scales. For example, the common burning of teak litter and the sparse understory vegetation in mature plantations increases inter-rill and gully erosion.

- Converting land, from traditional shifting cultivation production systems to short rotations or permanent cropping of species such as maize, cassava or teak, can result in substantial increases in erosion and nutrient depletion on farmers' plots far beyond any tolerable rate of soil loss. This increases land degradation and reduces yields to the disadvantage of farmers.

Lessons learned from studies on land use and soil conservation

- The findings confirm that soils under shifting cultivation become less degraded than those under other agricultural practices, especially the continuous cultivation of cash crops such as maize or cassava.

- Traditional shifting cultivation methods, with the fallow period at least eight times longer than the cropping period, tend to keep average sediment losses under one tonne per hectare per year (t/ha/yr), which is well within natural rates of soil regeneration. This system also supports the accumulation of stable organic carbon in the soil. Reducing the fallow period not only increases rates of soil erosion but also reduces yields. Farmers then need to open further fields, multiplying erosion, or intensify farming with the use of fertilizer.

- Many farmers cannot afford these alternatives. As a result, they invest in other cash crops, often exacerbating the land problem, or move out of crop production completely. The younger generation, especially, appears to be discouraged.

- One of the main questions for government officials, development agencies and researchers interested in the well-being of farmers is how to support local efforts to adapt to change, or, as a minimum, to avoid constraining them.

Recommended ways forward

- Current policies on land-use planning, in general, and on upland agriculture and forest protection, in particular, need reviewing in light of the research carried out by MSEC. A better balance is needed between preserving natural vegetation and sustaining upland farming against soil degradation, and protecting downstream areas from increasing sediment loads.

- From the water perspective, careful planning is also needed. Reforesting catchments to prevent rivers and reservoirs from silting may have the negative impact of reducing water yields and availability for downstream users.

- To limit sediment transport, riparian zones should be systematically kept outside the area for annual cropping and ideally protected by grass cover to maintain their limited, but essential, sediment-filtering function.

- Taking a broader regional view, policies relying on restrictions should be accompanied by supporting opportunities so that affected populations can adapt more easily. Given increasing population densities and hence greater land-use pressures, it might be appropriate to introduce incentives that support a shift to non-farm activities.

Alain Pierret / IRD

Introduction

Population growth is not only affecting land-use planning in China and South Asia but is also of concern in other Asian regions. A large part of the debate on the Laotian uplands crystallizes around the issues of population growth and shifting cultivation. Although overall population density appears very low (at just 24 inhabitants per square kilometer), the density per 'potential arable land' can be 20 times higher, leading to significant land pressure and environmental degradation. In this context, shifting cultivation represents a major source of contention.

Remi Negre / IRD

Shifting cultivation is where farmers temporarily clear land to plant crops and then allow vegetation to regenerate naturally after harvesting. The process involves cutting down existing vegetation, burning it when dry, sowing and harvesting crops, then leaving the land uncropped for a period long enough to enable a secondary forest to regenerate. Wherever the system is used, there is a general trend towards shorter fallow periods, although the actual fallow lengths vary from place to place.

In Southeast Asia, some 50 million upland farmers practice shifting cultivation. Their cyclical removal of vegetation (slash-and-burn) has shaped the widespread belief that such farming methods contribute to deforestation. Some researchers have also suggested that the practice of burning land to release nutrients plays a significant role in amplifying the anthropogenic greenhouse effect. Since the Earth Summit held in Rio de Janeiro in 1992, the Food and Agriculture Organization of the United Nations (FAO) has advocated replacing shifting cultivation with continuous sedentary cultivation, as this is judged to be less harmful to the environment.

Based on interviews with elderly farmers of Northern Lao PDR, for example, Roder et al. (1994) reported average fallow periods declining from 38 to 5 years between the 1950s and 1992. The MSEC project in northern Lao PDR reported fallow periods of 8 to 9 years in the 1970s declining to just 2 to 3 years in 2003. Shorter fallow periods give rise to reduced yields due to enhanced soil nutrient depletion, greater soil compaction, and increased pressure from insects and weeds.

Nutrients contained in natural vegetation growing before crops are sown are released during the process of slashing and burning. Although shifting cultivation is characterized by lower productivity when compared to fertilized soils, the practice is favored by farmers in regions with poor populations, where land pressure is low to moderate and farming inputs are expensive.

One outcome of changes towards more intensive farming systems has been an increase in soil erosion on the given plot. Erosion occurs when natural forces, such as rainfall, flowing water, gravity or human actions, wear away soil or geological material from one place in the landscape and deposit it elsewhere. Soil erosion occurs naturally. However, agricultural land use can significantly accelerate soil erosion, particularly in uplands, causing land degradation.

In an overview of the soil erosion situation in Thailand, Samrit et al. (1997) reported that some 68,200 square kilometers (km^2) of the country were subject to shifting cultivation, and that rubber, orchard, field crop and agroforestry production experienced soil erosion rates of 0.1–100 t/ha/yr. They also reported that a further 62,600 km^2 of steep hill country under shifting cultivation and field crop production experienced extremely severe soil erosion rates in excess of 100 t/ha/yr.

In Lao PDR, where studies in this report are focused, land tenure policies aimed at increasing government control over upland resources have reduced areas in which upland farmers can grow crops to such an extent that they have shortened fallow periods to a highly unsustainable 2 or 3 years. Where a hectare of land would once have been cultivated one year in nine, this intensification now means that same hectare might be used one year in four. Cutting the fallow period in this way, and requiring plots to be used more regularly, has reduced the potential of land to recover and regenerate, exposed it to more erosion, and, consequently, diminished its fertility. The large majority of farmers working on the sites included in the MSEC project complained that they experienced decreasing crops yields and increasing erosion.

To counteract this, farmers have been faced with the choice of using costly fertilizer, expanding their lowland paddies, or intensifying their farming operations further to the permanent cultivation of cash crops. This has exacerbated the problem and increased land degradation. Meanwhile, land taken out of low-intensity shifting cultivation has been converted to forest plantations. While trees are perceived as being beneficial to soil conservation, there are significant differences between species. Introducing plantations of certain species can have impacts on soil erosion and the catchment water balance. Overall, the changes have made a wider area of land vulnerable to degradation, even where statistics show increasing percentages of tree plantations commonly perceived as pillars of soil conservation.

Alain Pierret / IRD

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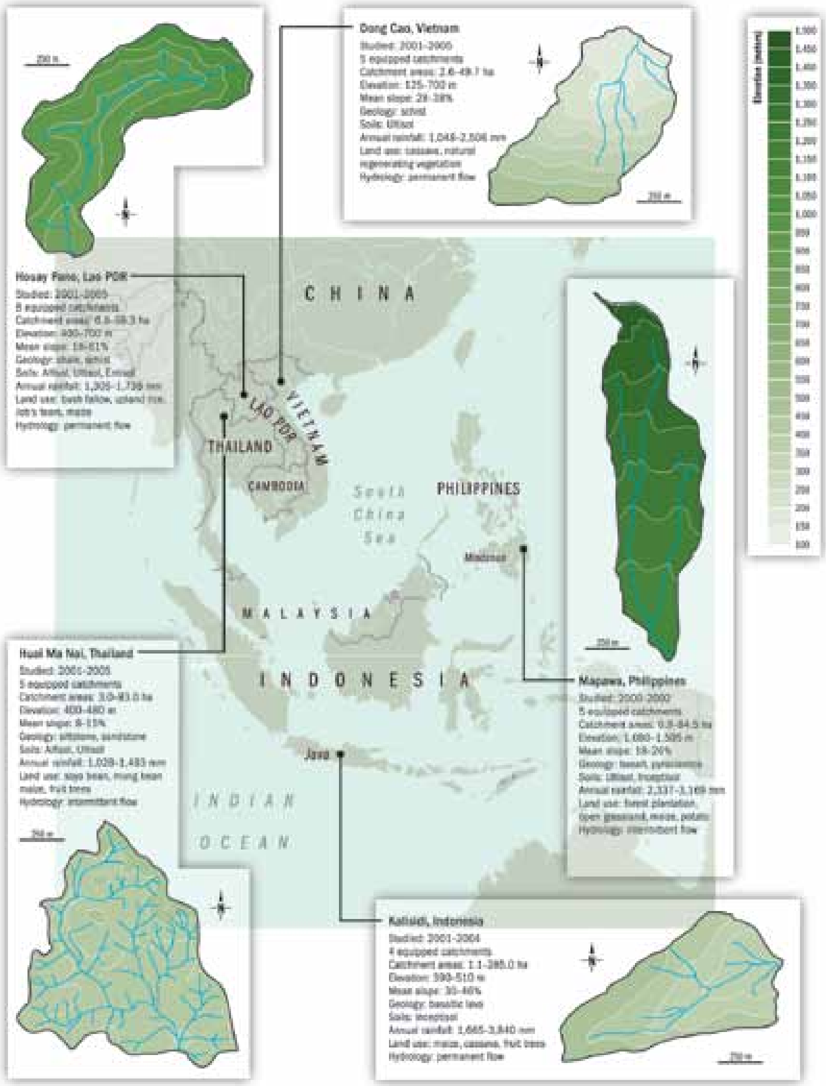
The monitoring sites used for the study

The MSEC team selected monitoring sites jointly with local stakeholders, including national partner institutions. Selected catchments were representative of the overall characteristics of watersheds in the region and were readily accessible for monitoring. The 27 catchments and sub-catchments chosen ranged from 0.6 to 285 hectares (ha) in total surface area and exhibited mean slope steepness of 8% to 61% (Figure 1). Sites were monitored from the year 2000. More details about the catchments can be found in Maglinao and Leslie (2001), Maglinao et al. (2003) and Wani et al. (2003).

Figure 1

Location map of the MSEC catchments in Indonesia, Lao PDR, the Philippines, Thailand and Vietnam (center), with digital elevation models (DEMs) of each of these catchments showing sub-catchments and channel networks, plus characteristics of each site.

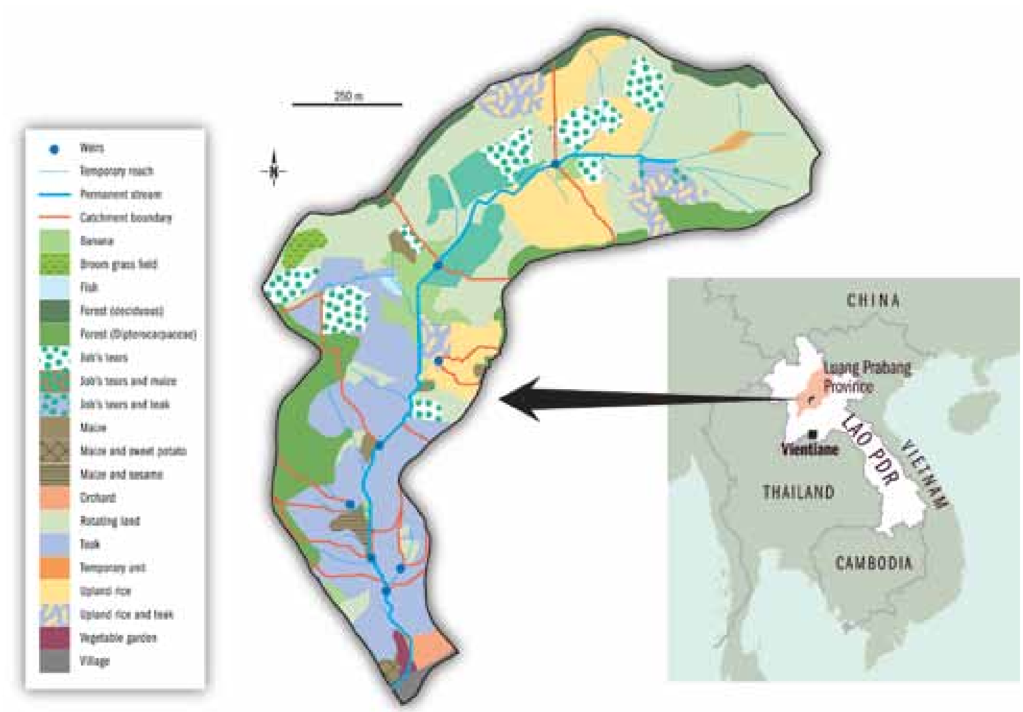


Characteristics of the Houay Pano catchment

The Houay Pano catchment in Lao PDR was the focus of the detailed soil erosion studies reported here. It lies near the Ban Lak Sip village, 10 kilometers (km) south of the city of Luang Prabang, which is considered a World Heritage site by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Figure 2). The catchment, which covers 0.62 km², encompasses nine sub-catchments with differing land uses. Elevation ranges from 400 meters (m) to more than 800 m above mean sea level. The terrain is steep with a mean slope gradient of 30%; gradients range from 0% to more than 100%. The area has a wet-dry monsoon tropical climate, with an average annual rainfall of around 1,300 millimeters (mm) per year. Seventy-seven percent of rainfall occurs during the rainy season from mid-May to mid-October, while the period between November and March is cool and mostly dry.

Figure 2

Maps showing the location of, and land uses (2010) within, the Houay Pano catchment, Lao PDR.



The drainage system of the Houay Pano catchment comprises a 1,200-m perennial stream of irregular topography, which receives water from several ephemeral waterways. The stream originates in the upper, mountainous part of the catchment and later becomes a tributary to the Houay Xon, which itself is a sub-tributary of the Num Dong River before its confluence with the Mekong River in Luang Prabang. Slopes adjacent to the river are mainly convex or convex-concave, steep and narrow. Most of the riparian land is covered with native grasses and shrubs dominated by *Microstegium ciliatum,* bamboo or banana plantations.

The catchment's geological substrate comprises metamorphic and sedimentary rocks. Using the taxonomy of the United States Department of Agriculture (USDA), soil distribution from hilltop to valley bottom typically comprises shallow Inceptisols along the crests; deep, clayey Ultisols and Alfisols (which cover 30% and 50% of the catchment area, respectively) along the slopes; and poorly drained clayey Dystrochrepts at the foot slopes and along the stream banks. As a general trend, soil thickness decreases from a few meters to a few tens of centimeters in the uphill direction. Likewise, the thickness of organic topsoil horizons decreases dramatically from the base to the top of slopes. Ultisols cover 73% of Lao PDR and a third of the wider MSEC study region, implying that findings at the Houay Pano site can be of direct relevance to similar upland areas.

Alain Pierret / IRD

Most tropical lowland rainforests of dipterocarp trees were cleared in the late 1960s and slopes have since been used to grow crops. In 1994, the Land and Forest allocation scheme designated land across the Houay Pano catchment for uses aimed at 'protection and production'. At this time, village boundaries were identified and demarcated from land that was allocated to be conserved or regenerated as forest. Today, 65% of the catchment is under a system of shifting cultivation and crop rotation typical of Southeast Asia. In most years, an area smaller than 15% of the overall catchment is actually cropped, while the rest of the farmland is under fallow or fast-growing tree plantations. Vegetation includes residual mixed deciduous and dry dipterocarp forests, regenerated secondary forest mixed with grass (bush fallow), teak (*Tectona grandis L.*) and banana plantations, orchards, and annual upland crops such as rice, maize *(Zea mays L.)*, groundnut and the grain-bearing tropical plant, Job's tears *(Coix lacryma-jobi)*. Upland rice and Job's tears account for 80% of the crops, on average. The area under teak rapidly expanded from less than 7% in 2007 to around 25% in 2010.

Shifting cultivation policy across Lao PDR

The Government of Lao PDR has defined and redefined the country's land-use planning policies, first as a means to stop deforestation, and later to turn land into capital. Supported by foreign funding, the Land Use Planning and Land Allocation (LUPLA) program has become the government's main policy tool for minimizing shifting cultivation. New regulations, together with land-tenure policies aimed at increasing the government's control over upland resources, dramatically reduced the area in which upland crops could be grown.

This prompted farmers to cut their fallow periods to an unsustainable 2 or 3 years. Declining upland rice yields subsequently forced them to focus more strongly on growing maize, as well as the less-demanding cassava *(Manihot esculenta)* and Job's tears, planting more paddy in the valley bottoms, or investing in tree plantations. The shorter periods for soil regeneration, plus changing cropping patterns and cultivation methods, have resulted in further loss of soil fertility. This has affected the livelihoods of upland farmers to the extent that some have moved completely out of crop farming (Box 2).

Box 2

LUPLA: More harm than good?

The Land Use Planning and Land Allocation (LUPLA) program is one of the main tools used by the Government of Lao PDR for managing rural development and natural resources. In its early form, the program constituted an agreement between local and national authorities defining land available for agrarian use. The remaining land was classified, by default, as forest. After 1993, local authorities were instructed to limit each household to three plots. This restriction, to which a rule limiting the fallow period to not more than 3 years was later added, was designed to further limit the perceived negative impact of shifting cultivation on the pristine forest cover.

While the official scope of LUPLA is national, its objectives and actual implementation appear very much influenced by the official discourse on land degradation. For example, among the eight objectives of the program, five are largely aimed at resolving the above-mentioned 'upland issue': to eradicate shifting cultivation; to intensify and diversify upland agriculture; to preserve forests and watersheds; to preserve biodiversity; and to improve the living conditions of the upland populations by adoption of a sedentary lifestyle. Official statistics show that, by 2005, LUPLA had been implemented in some 7,130 lowland and upland villages, representing approximately 440,000 households. How this equates with reality on the ground, however, is less certain, given the hardship it caused for the farming communities.

After more than two decades of implementation and despite being officially aimed at improving the living conditions of upland-dwelling communities, many studies have shown that Lao PDR's program of land reform (LUPLA) has had rather negative impacts on upland livelihoods. For example, the strong effort to protect forest areas has drastically reduced the agricultural land available per capita, caused a general degradation of working conditions and farm productivity, and hence decreased food security and increased poverty. In the recently published National Growth and Poverty Eradication Strategy (NGPES), the Government of Lao PDR called for a reassessment of the LUPLA program.

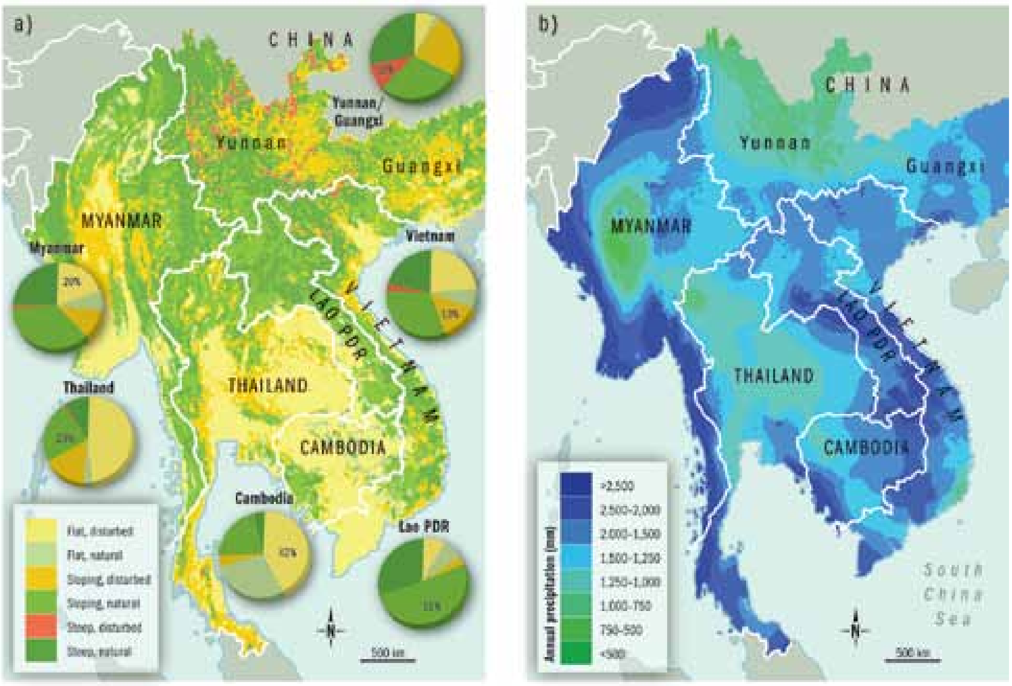
Main source: Lestrelin 2010

Types of erosion affecting Southeast Asia's uplands

To better understand soil degradation in the uplands of Southeast Asia, MSEC scientists identified four main types of erosion affecting the survey sites across the region. These are: inter-rill; tillage; gully (linear); and land mass movements. The examples of erosion, presented here, are mainly based on the work carried out in Lao PDR. However, all forms of erosion occur across the subregion in differing frequencies related to variations in topography, land use and rainfall (Figure 3). The observed forms of erosion may well be more common in the other project countries, as farming practices can strongly affect patterns of soil erosion, and Lao PDR has the lowest percentage of agricultural land use among these countries.

Figure 3

(a) Distribution of topography and land use, with pie charts showing percentages of 'natural' land cover (includes intact and degraded forests) versus cropped land.
(b) Rainfall across the subregion.



Inter-rill erosion

Surface runoff is where rain travels over the ground rather than infiltrating the soil. It can happen when soil is waterlogged or when the surface is impervious. When rain falls on exposed ground, droplets dislodge soil particles. Splashing carries them into the air and deposits them in shallow overland flows. Droplets stir up these flows, which helps carry sediment downhill to meet slightly larger flows or rills. This is known as inter-rill erosion. Slope, vegetation cover and surface roughness all influence the volume of soil particles that become detached and the distance sediment is transported by water flows.

Soil crusting often occurs as a result of rain falling on exposed soil. Water droplets striking soil aggregates, and water flowing across the soil, break aggregates into individual particles that settle into, and block, surface pores. This causes the surface to seal over, which dries to form a crust. Crusts tend to be relatively thin, dense and somewhat continuous. They greatly reduce infiltration and increase runoff (Box 3). The increased runoff leaves less water for plants. Soil crusting can also prevent seedlings from emerging. If a crust develops soon after planting, the failure rate can be such that the entire crop has to be replanted.

Alain Pierret / IRD

Findings from Houay Pano catchment

Results obtained from 147 1-square meter (m^2) micro-plots in Lao PDR yielded an average runoff coefficient of 30%. This is the percentage of rainfall that runs off over the ground during a rainstorm. A coefficient of 0% means that all the rainfall penetrates into the soil. A coefficient of 30%, as observed in soils in upland rice cultivation, means there is a good chance that soil particles will become detached and be eroded, which the scientists found to be the case. A wide range of runoff coefficients were measured from the micro-plots, influenced by the range of land uses (Patin et al. Forthcoming). The figures ranged from approximately 10% for soils under fallow to nearly 50% for soils under teak tree plantations. Upland rice crops yielded, on average, 1.4 t/ha/year for 1 year of cultivation and 4 years of fallow (Box 4). These figures are relatively high but inferior to the soil losses observed under maize and cassava (see section, *The influence of land use* on page 14).

Box 3

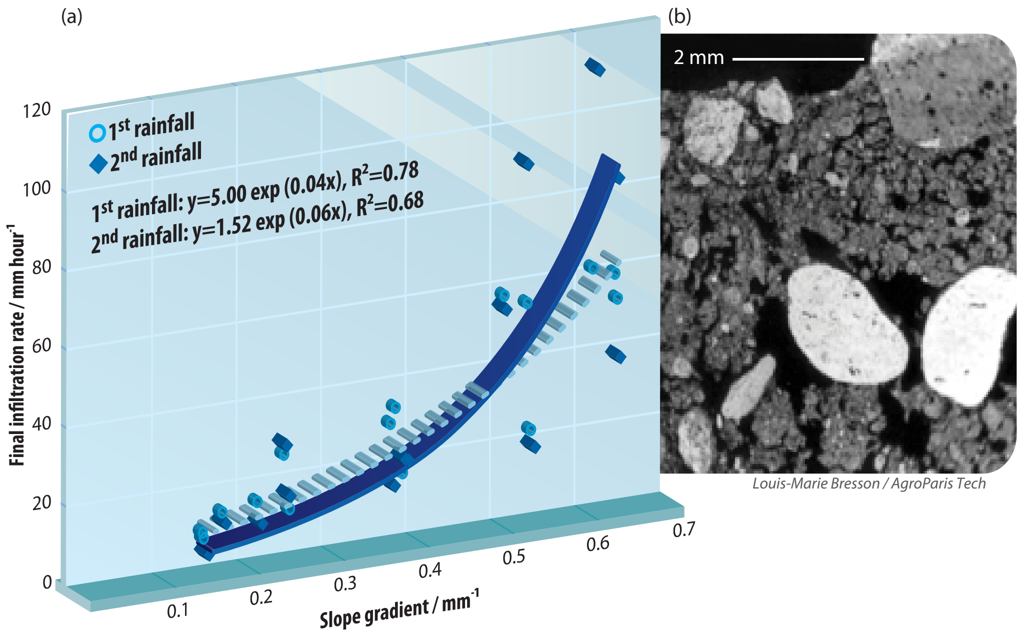
Slope gradient, soil crusting and water infiltration

There is no simple relationship between water infiltration into the soil and slope gradient, at the local scale. Some studies have found these two variables to be completely independent of each other, while others have noted a decrease in infiltration with slope increase. Sometimes, this is the case up to a critical slope threshold, after which infiltration becomes independent of gradient once more. Some scientists have even found that, in certain circumstances, infiltration increases with slope gradient.

The MSEC researchers working at study sites in Lao PDR and Thailand found that infiltration increased and soil detachment decreased as slope gradient increased (Figure 4). Field observations supported this finding; structural 'packing' crusts associated with soil particles being dislodged and redistributed by raindrops were more abundant on gentler slopes than steep ones. Such soil crusting offers a likely explanation for lower infiltration and greater soil detachment observed on gentler slopes. This is applicable to the most common soils in the region, such as Luvisols, as well as Ultisols and Alfisols with highly stable micro-aggregates.

Figure 4

(a) Infiltration rate as a function of slope gradient, for two simulated rainfall events.
(b) Thin section of a packing crust. Note: the lighter coloured particles in the packing crust are made of gravel, the presence of which reduces the ability of rain to infiltrate the soil. Source: Janeau et al. 2003.



Louis-Marie Bresson / AgroParis Tech

Inter-rill erosion increased with rising clay content of the surface layer of soil. Clay soils are not usually prone to erosion but those at the study site were mainly formed of micro-aggregates similar to sand grains. These kinds of 'pseudo-sand' aggregates are easily detachable and transportable, given sufficient runoff. Soil crusting and aggregate breakdown from rainfall impact were relatively low, confirming that the detachment and transport of stable aggregates by shallow runoff resulted from prevailing inter-rill erosion processes (although crusts protect the soil directly beneath them from erosion, they generate runoff which enhances the risks of inter-rill erosion downhill). Inter-rill erosion rates were of the same order of magnitude as rates of gully erosion (see page 18).

Light-to-moderate crusting processes at this site formed the packing crusts. Crusting was probably not severe because the soils had a high organic carbon content associated with the high clay content, along with a relatively low number of cultivation cycles compared to more intensively cultivated soils. Also, crusting processes tend to be limited on steep slopes. This explains why infiltration was high in the upper steep slopes of the catchment. Water infiltrated upslope tended to emerge downslope near the stream.

Box 4

A question of scale

It is not possible to simply extrapolate the runoff and sediment yield figures from micro-plots to calculate sediment eroded over larger scales, because these processes are scale-dependent. Erosion rates measured from micro-plots are generally much higher than at the catchment scale, because there is little opportunity for sediment to be deposited over the small surface area of the quadrats. Generally, at the micro-plot scale, soil detachment decreases with increasing slope due to reduced surface crusting and higher infiltration on steep slopes, although this is dependent, to a certain extent, on soil type and soil cover.

For example, when soil is covered with trees, leaves form a continuous litter that protects soil from direct raindrop impact on gentle slopes. This litter is patchy on very steep slopes because some leaves are removed by runoff and accumulate behind obstacles, such as tree stumps. Therefore, there are two conflicting trends in forested conditions: (a) where there is increased crusting with decreasing slope, and (b) where crusting hazards increase as slope steepness increases. This explains variations in results on crusting published in the literature. Detailed studies on the ground are vital to explain the situation at specific sites.

At larger scales, runoff and erosion measurements integrate the effects of landscape mosaics, riparian vegetation and the hydraulic connectivity arising from rills and gullies along hill slopes. Erosion processes also include tillage and gully (linear) erosion, and mass movements. In very steep environments, landslides are not uncommon even under tree cover because of the weight of the vegetation added to the wet soils. Once a landslide has occurred, it usually concentrates runoff in the newly formed depression, and favors inter-rill and gully erosion.

The influence of land use

MSEC work across Southeast Asia showed that the type of crop cover strongly influences the amount of surface runoff and inter-rill erosion rates. In Vietnam, for example, measurements from catchments on a 40% slope yielded a surface runoff coefficient of less than 16%, and an average soil detachment rate of 7 t/ha/year under cassava and 0.3 t/ha/year under ruzi grass *(Brachiaria ruziziensis)*. Here, the observed surface runoff was directly related to the presence of surface crusts. Soils were most prone to crusting when unprotected from raindrop impact at the onset of the rainy season, as in the case of cassava. Surface runoff and soil detachment were reduced twofold and tenfold, respectively, when land was covered by ruzi grass.

The MSEC scientists monitored climate, hydrology, erosion, land use and crop yields in the 27 catchments selected in the project's five countries. Over 10 years, they assessed the influence of a range of land uses on surface runoff and inter-rill erosion. This work, summarized by Valentin et al. (2008), found no relationship between increase of upland rice, runoff and sediment yield, but showed that traditional shifting cultivation (over the years under cropping and fallow) results in, on average, very low sediment yields of 0.9 t/ha/year compared to other land uses. The best overall predictors of increasing sediment yield were, interestingly, related to the areal percentages of maize, Job's tears and cassava. The work reconfirmed that cropping systems with short rotations pose a much greater threat to soils than cropping systems under shifting cultivation with long rotations.

Conclusion

From local scales to catchments of a few hectares, inter-rill erosion can cause significant sediment losses, in the process damaging the agronomic potential of sloping land. However, because material is generally deposited along hill slopes, it is unlikely that the entire amounts of sediments are carried, via this process, outside the catchment from which they originate. Nonetheless, inter-rill erosion contributes to sediment loads in gullies (see page 18). In this way, a portion of the sediments mobilized by inter-rill erosion reaches main waterways and is exported over long distances.

Tillage erosion

Tillage is the preparation of soil for cultivating crops. It ranges from digging, turning and raking soil by hand to mechanical ploughing or harrowing. Tillage erosion shifts soil from the top of fields to the bottom, exposing subsoil at the crest. Eventually, eroded subsoil from higher levels in the field covers topsoil at lower levels. This can have significant effects on yields and productivity, as subsoils often provide unfavorable conditions for crop growth. If crop growth is poor, soil is exposed to surface runoff, promoting further erosion. Also, weed invasions often occur.

Traditionally, upland rice is cultivated without farmers preparing land before sowing, besides slashing and burning fallow vegetation. In this traditional system, there is no soil disturbance during weeding, as weeds are allowed to grow to a size sufficient for them to be removed by hand. Fallow periods are usually around 8 or 9 years but might be as long as 20 or 30 years, enabling regrowth of trees. Over time, increasing pressure on land resources has prompted farmers to adopt shorter fallow periods, which promote weed growth. As a result, superficial tillage has become necessary during the cropping cycle.

If left undisturbed, weeds that appear just after sowing can severely reduce yields. Farmers have responded by using a small curved hoe to eliminate weeds before they grow large enough for pulling out by hand. As fallow periods have decreased, they have often had to introduce a second round of superficial tillage. Many have eventually resorted to using deep tillage with a medium-sized hoe to prepare the land for sowing, plus three weeding rounds, using the small curved hoe, to remove weeds through the cropping cycle. This is the situation with most current short-fallow shifting cultivation systems, which correspond to the most degraded situations.

Alain Pierret / IRD

Findings from Houay Pano catchment

An exponential relationship directly relates tillage erosion to slope gradient. In the Houay Pano catchment, where the average slope gradient is 70%, tillage erosion yields 8 t/ha/year. Crop species and local weed pressure have a strong influence, as local farmers only till those areas covered by weeds and during periods when weeds can potentially harm crops. Ground cover is also important, as plant stems, such as those left after burning in traditional shifting cultivation, create obstacles that can trap aggregates detached by tillage.

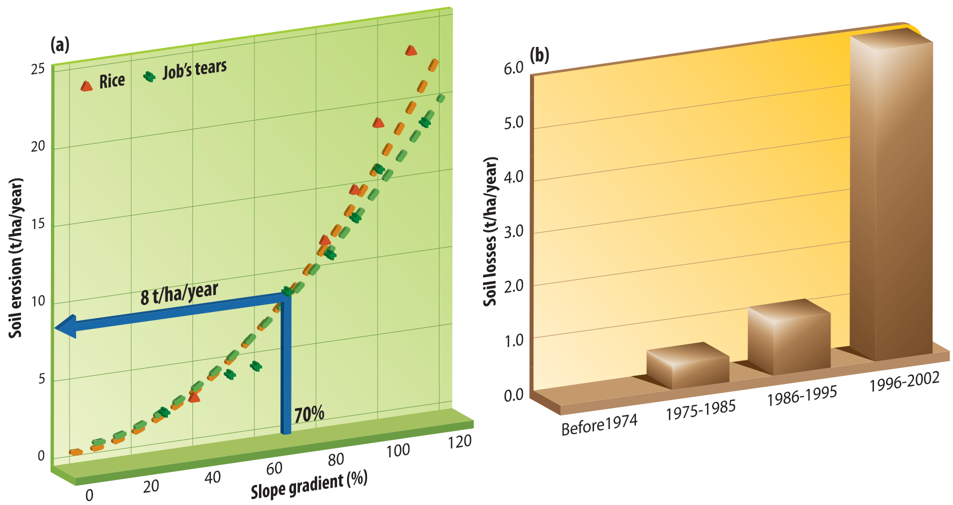
Alain Pierret / IRD

Shifting cultivation in Lao PDR has, over the past three decades, evolved towards more sedentary cropping systems. This is in line with the government's land-use planning policies and the widespread application of the LUPLA program across the mountainous areas of the country (as explained in Box 2 on page 10). The shorter fallow periods have exposed fields to increasing weed pressure, which has, in turn, required farmers to use more frequent and deeper tillage operations to remove increasingly aggressive weeds. Regression models based on current cultivation practices show that soil losses have increased since 1964, following an increase in the number and intensity of tillage operations (Figure 5).

Figure 5

(a) Tillage erosion due to weeding of upland rice, as influenced by slope gradient.

(b) Evolution of soil losses during the last 40 years, on a field with a 60% slope. Source: Dupin et al. 2009.



Conclusion

Tillage erosion is highly predictable, since it is related to cultivation practices and weed pressure. It yields sediments in amounts proportionate to slope steepness. The relationship between slope steepness and sediment yields exists because tillage loosens and separates aggregates that then behave like small gravels. These are more easily displaced and travel further distances on steep slopes under the force of gravity.

Gully (linear) erosion

At the onset of the rainy season, impermeable crusts tend to form on bare, freshly tilled soil. This causes rain to run off over the ground rather than infiltrate the soil. This runoff concentrates into tiny streams and, if the flow increases sufficiently, cuts the surface to form a rill (as described in the section, *Inter-rill erosion,* on page 11). This deepens as the water-borne sediment abrades the bottom of the rill. As the process continues, the edges cave in and the dislodged material is carried away down the deepening gully. In tropical areas, linear erosion is a major contributor to soil degradation and the sediment load carried by rivers. Evidence from China shows that, at the square-kilometer scale, gullies can account for up to 85% of the sediment discharged into a downstream reservoir.

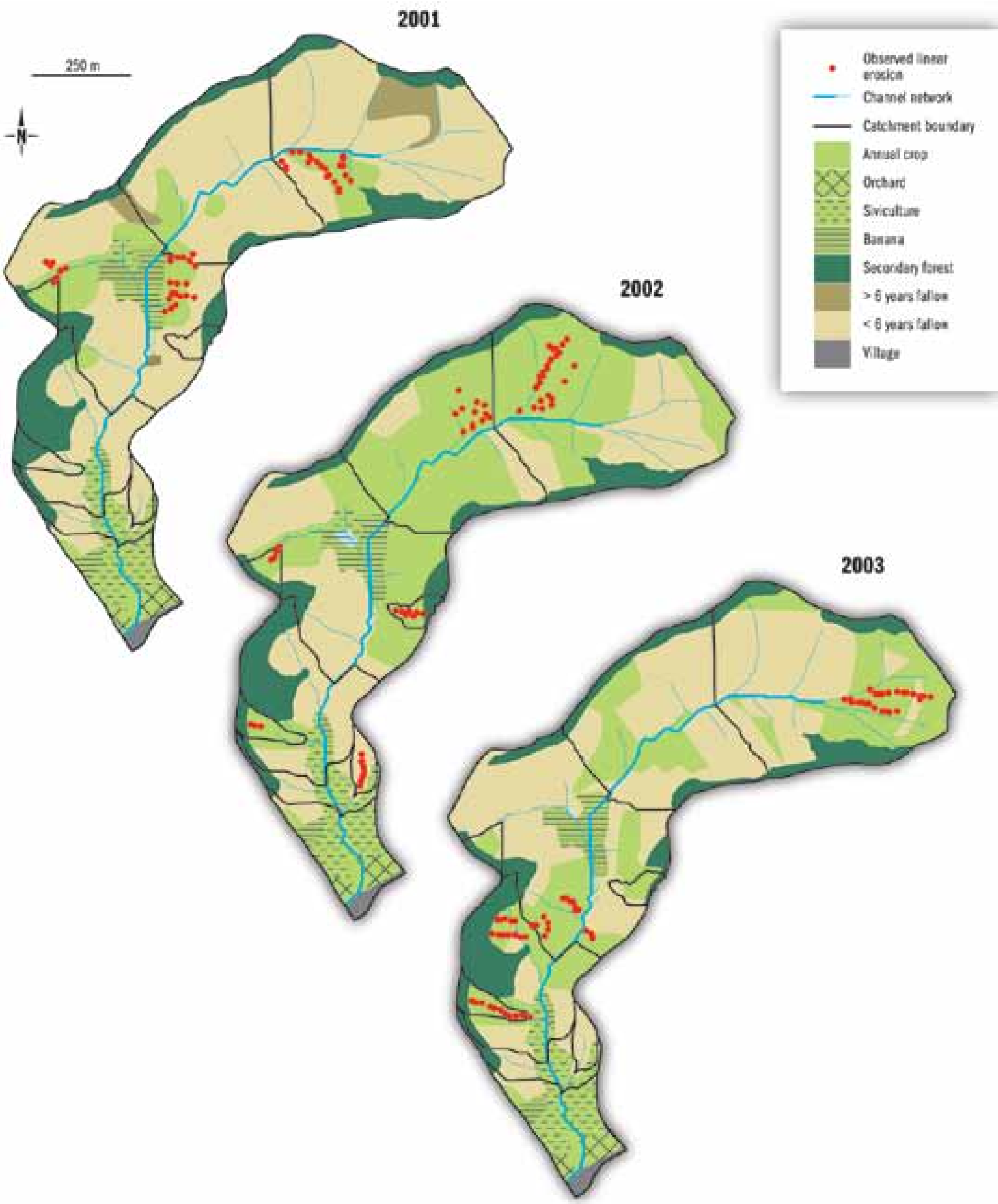
Alain Pierret / IRD

Findings from Houay Pano catchment

Scientists identified 52 active gullies between 2001 and 2003 in the Houay Pano Basin. These yielded a total of 242 tonnes of sediment, corresponding to an annual erosion rate of 1.3 t/ha/year for the catchment. Expressing this figure relative to cropped areas increases the volume of erosion from these linear features to 9.5 t/ha/year, which is the same order as the values reported under tropical conditions in Kenya and well over the rate at which soil naturally regenerates. There was a strong relationship between linear erosion and annual cropping (Figure 6).

Figure 6

Locations where linear erosion occurred in 2001, 2002 and 2003 within the Houay Pano catchment, as indicated by the red dots. Note the relation between the linear features and annual cropping. Source: Chaplot et al. 2005.



The work in Lao PDR revealed that linear erosion was highly variable spatially (0 to 18 t/ha/year within a catchment smaller than 1 km²) and temporally (0.1 to 2.4 t/ha/year from one rainy season to another). This variability was related to environmental conditions, topography, land use and climate. Once established, linear erosion features are very difficult to control; they continue to shift water and sediments for several years, even when conservation practices are implemented.

Because gullies create hydraulic connections between hill slopes and valley bottoms, riparian areas (see page 24) become less effective at trapping runoff and sediments caused by inter-rill erosion once gullies are in place. For this reason, it is crucial for farmers to adopt management options that minimize the formation of gullies. These include, keeping the soil surface covered as permanently as possible and tilling only if absolutely necessary. Any tilling should be done as superficially as possible, along contour lines.

Conclusion

Gully erosion yields moderate to high amounts of sediment and remains an active process even when rainfall intensity is low. Once initiated, gullies and other linear erosion features hydraulically link hill slopes to valley bottoms and rivers. This opens up pathways via which sediments can be carried over long distances and minimizes the sediment-trapping effect of land beside rivers.

Land mass movements

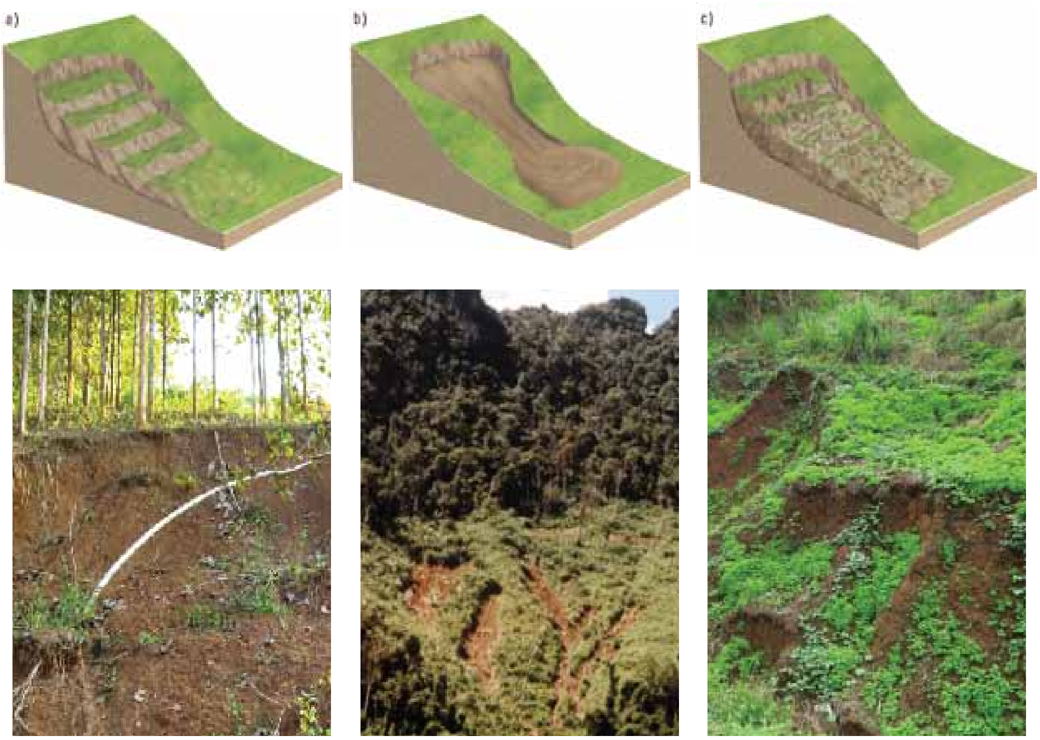
Landslides, or land mass movements, occur when masses of rock, earth or debris move down a slope. They can be small or large and can happen slowly or quickly. Mud and earth flows are rivers of debris saturated with water. A system called the EPOCH classification identifies different types of landslides (Figure 7).

Findings from Houay Pano catchment

MSEC scientists identified 57 landslides, during a single rainy season (2006) along a stretch of the river approximately 10 km long in the Houay Xon catchment. Varying in form and size, according to EPOCH they were predominantly translational (49%) and rotational (46%) slides, and a marginal fraction (5%) were earth flows. They primarily occurred at the bottom of hill slopes.

Figure 7

Diagrams and photos of the three main types of land mass movement, as explained in the EPOCH classification, observed in northern Lao PDR. (a) Rotational landmass on a road cut adjacent to a teak tree plantation in Luang Prabang District. Note that, despite having well-developed root systems, several trees collapsed with the landslide. (b) Earth flows in fallow regrowth just below old secondary forest growing on karst landforms (Nam Ou District). (c) Debris slide on the banks of the Houay Pano stream, illustrating the detrimental effect of removing riparian vegetation. Diagram source: Cruden and Varnes 1996.



Alain Pierret / IRD

There was no simple relationship between topography and the occurrence of mass movements; landslides occurred on both gentle and steep slopes. Geological, geomorphological, soil and vegetation characteristics all contributed to determining when and where mass movements took place (Box 5). Fruit trees and teak plantations dominated vegetation in the study area. Although an analysis of soil reinforcement by teak roots suggested that these are likely to improve soil cohesion, many landslides were observed near or within teak plantations. Human activities, prompted by rapid economic development, were found to enhance vulnerability to soil mass movements.

Box 5

Antecedent rainfall, rainfall intensity and landslides

Landslides typically begin after a period of prolonged rainfall followed by an intense downpour that triggers movement. The 2006 rainy season in Luang Prabang followed this pattern. Villages reported that several landslides, some of them identified within the Houay Pano catchment, took place within 72 hours of heavy rain that fell on September 19. Annual rainfall for the year was 1,234 mm, which was 169 mm less than the 30-year average of 1,403 mm. However, there were several intense rainfall events during the rainy season. Four such events yielded more than 50 mm of rainfall (on March 29, July 2, July 25 and September 19) and several downpours had intensities between 50 mm and 100 mm per hour (mm/h) or more.

The most intense rainfall occurred at the start of the rainy season on March 29. Its intensity was 155 mm/h for a total cumulated rainfall of 58 mm. Rainfall events were of a lower magnitude in April and June, but two intense events occurred on July 2 (52–90 mm/h) and July 25 (75–77 mm/h). From August through to early September, it rained regularly but with lower intensity and depth, apart from one heavy shower, which had an intensity of 70 mm/h.

On September 19, there were two downpours, lasting 2 hours and 06 minutes and 1 hour and 36 minutes. These had a maximum intensity of 95 mm/h and cumulated rainfall of 107 mm. They resulted in the flooding of villages near the stream and destroyed bridges and houses. The rainy season ended with an event of 80 mm/h intensity and 35 mm depth. The rain on September 19 was characterized by rainfall intensities, antecedent rainfall indices and cumulative rainfall during the preceding 3 and 15 days that were over thresholds defined by Chleborad et al (2006).

The researchers identified three main ways in which human activities could promote landslides. First, land shortages often forced new settlers to build in the immediate vicinity of waterways in areas that were potentially unstable. Similarly, teak plantations were often developed rapidly on steep slopes and without clear management guidelines. Second, dams, retaining walls and other structures built for protection against floods were poorly designed and collapsed easily in response to rapid rises in water levels. Third, the poor design of urban infrastructure, such as roads, increased the risk of mass movements.

Because landslides are very localized and difficult to predict, the scientists could not easily assess how much soil loss they would account for. However, the impacts of mass movement erosion on land productivity can be significant. For example, production losses of up to 80% at field scale and 20% at farm scale have been measured on pastoral grazing land. Similarly, wood volumes in plantations have declined by 35–50% at some affected sites. When compared to surface erosion processes, landslides tend to influence site productivity more severely but over smaller areas.

Conclusion

Land mass movements are related to geology, soils, geomorphology, land use and weather, including antecedent rainfall conditions and intensity. Sediment yields resulting from land mass movements are consequently very difficult to estimate and forecast precisely.

Marie Lebreton / IRD

Role and management of the riparian zone

Riparian zones form the interface between land and river ecosystems. They represent a potential sink for sediments washed over land that might otherwise end up in the water and travel downstream. The intensification of cultivation on sloping land accelerates erosion processes, especially tillage erosion. Managing the riparian zone, therefore, offers an opportunity to counteract negative impacts on water quality and dams associated with higher sediment loads entering rivers and lakes.

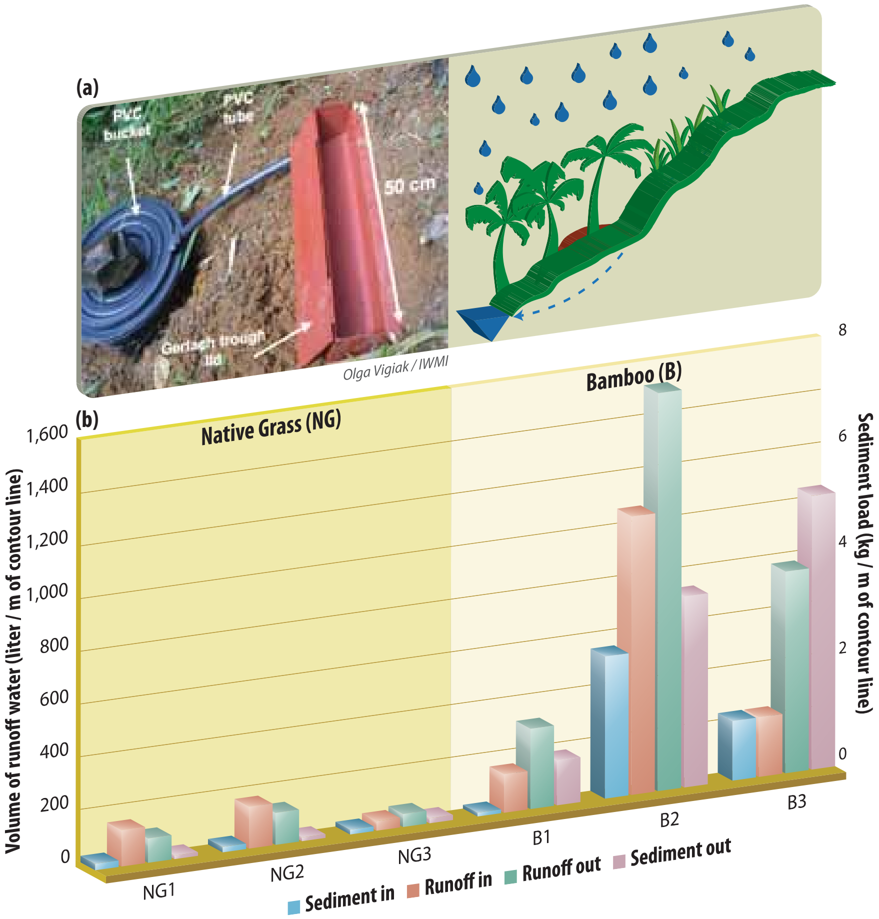
Riparian vegetation can act as a trap for sediments and water. Its effectiveness depends on incoming flow rates and the size of sediment particles, the type of vegetation, plus the hydrology and topography of the riparian zone. Research on the effects of vegetation in temperate climates shows that riparian areas can retain 70–99% of pollutant loads. In Lao PDR, however, where riparian soils are often steep and clayey, and where water seepage from soils is common, possibilities for infiltration are limited.

Findings from Houay Pano catchment

Scientists monitored incoming and outgoing flows across riparian sites to assess their sediment-trapping efficiency. This involved digging troughs connected to buckets and then measuring the amount of runoff collected in the buckets after rainfall (Figure 8). The grass *Microstegium ciliatum A. Camus* yielded the highest water-trapping efficiency, while the banana (*Musa* sp.) resulted in the highest sediment-trapping efficiency. Bamboos (mainly *Dendrocalamus* sp. and *Cephalostachyum virgatum*), meanwhile, had poor water- and sediment-trapping efficiencies, and allowed water and sediments to pass through the riparian zone. The median outflow runoff from rice sites was nine times higher than the inflow, and the median outflow sediment concentration was two to five times higher than the inflow sediment concentration.

Figure 8

(a) The device used to monitor the sediment-trapping effect of riparian vegetation, 0.50-m wide Gerlach troughs connected by PVC tubes to water buckets.
(b) Volume of runoff water and sediment load entering and exiting native grass and bamboo sites within the Houay Pano catchment during the 2005 and 2006 monsoon seasons. NG and B figures are replicate measurements. Source: Vigiak et al. 2007; Vigiak et al. 2008.



The results suggest that, although grass strips and low-tillage banana plantations may reduce the sediment concentration of runoff, they do not act as sediment traps. Cultivating annual crops in the riparian zone, meanwhile, delivers turbid runoff to the stream, severely affecting water quality. Given the mountainous conditions of the study site, it cannot be expected that soil erosion caused by farmers cultivating sloping lands can be contained through interventions limited to riparian zones. Control of erosion on sloping land, therefore, remains essential. Annual crops should not be cultivated close to streams to avoid bank erosion and water contamination.

Conclusion

In the context of the uplands of Southeast Asia, riparian zones appear to be very sensitive environments which, if managed improperly, can deliver high volumes of sediments into water bodies. Riparian zones should, therefore, be kept outside of the area for annual cropping and ideally protected by grass cover, to maintain their limited but essential sediment-filtering function.

Vegetation and water resources

Although extensively studied, the hydrological role of vegetation and the impact of deforestation in watersheds remain controversial. There is a widespread belief that deforestation leads to reduced groundwater availability during the dry season, but a number of sites show higher water yields after trees have been removed. This is because trees act as pumps, extracting water from the soil and transpiring it to the atmosphere. Thus, an immediate effect of tree removal is a rise in the water table and increased dry-season flows.

Alain Pierret / IRD

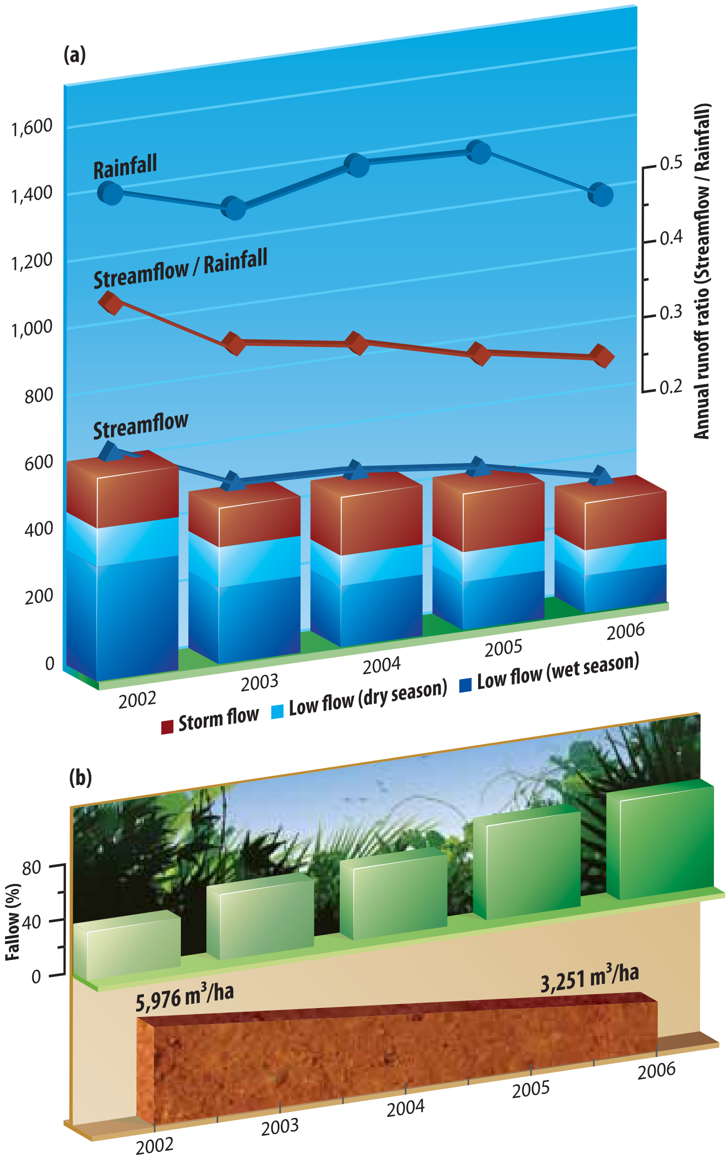
Findings from Houay Pano catchment

Low-flow generation from the uplands is considered one of the most important watershed issues in Southeast Asia. MSEC researchers analyzed low flow during wet and dry seasons for 6 years in the Houay Pano headwater catchment. They concluded that, regrowth of vegetation after fallow periods significantly affected the hydrological regime of the catchment. Their observations showed specifically that:

- the development of fallow vegetation increased the fraction of rainfall transpired or intercepted by the canopy;
- there was increased root water uptake after regrowth of perennial vegetation;
- the regrowth reduced groundwater recharge and subsurface reserves, and lowered the water table, limiting stream feeding by shallow groundwater;
- the depleted groundwater led to a drop in the annual stream water yield due to a decrease in the prevailing dry-season flow and in the flow occurring between storms during the wet season (Figure 9);
- subsurface groundwater was the main contributor to floods. Overland flow (surface runoff) contributed most significantly to flood waters during rainfall events in the first 2 years of fallow regrowth.

Figure 9

(a) Annual rainfall (mm), total annual streamflow to rainfall ratio (annual runoff ratio) and total annual streamflow (mm) in the Houay Pano catchment from 2002 to 2006.
(b) Graph shows percentage of fallow and corresponding volume of soil eroded during the same period. Source: Ribolzi et al. 2008.



The work demonstrated that water resources in the uplands of northern Lao PDR are sensitive to land use and, therefore, vulnerable to inappropriate management. Based on the findings of MSEC, the current policy of the Government of Lao PDR aimed at eradicating shifting cultivation will have a number of consequences on the water balance of the catchments.

The results show that care has to be taken when introducing deep-rooted perennial crops, which will most likely reduce groundwater recharge and dry-season flows. The drop in the water table will probably be more pronounced than during the fallow cycle of shifting cultivation when shrubs and trees re-emerge. Cultivating shallow-rooted species, on the other hand, will increase dry-season flows and result in a rise in the water table. There are large differences between different tree species. For example, the roots of teak can penetrate to 12 m (Box 6).

Box 6

Teak and erosion

Teak trees have long been known to support erosion (Laurie and Griffith 1942). The widespread management practice of removing and burning litter in teak plantations induces soil crusting, which reduces rainwater infiltration, supporting runoff and various forms of erosion. The MSEC studies showed that once foliage is fully developed, teak exacerbates soil erosion as its large leaves concentrate rain into heavy drops. This increases the erosive power of the rain.

If such hydrological changes are not assessed and planned for in advance, they could jeopardize production of other food and fiber crops. Introducing monocultures over large areas of biophysically and geomorphologically diverse landscapes, including sensitive riparian areas, will most likely result in vulnerable systems in which water flows, soil stability and crop yields will be highly unpredictable. Consequential indirect impacts could significantly influence the water budget of catchments (Box 7).

Alain Pierret / IRD

Conclusion

Land-use change has major implications for water resources. Vegetation pumps up water in the soil and transpires it to the atmosphere. Trees generally transpire more water than shrubs and crops, so the net immediate effect of deforestation is a rise in the water table and increased dry-season flows.

Box 7

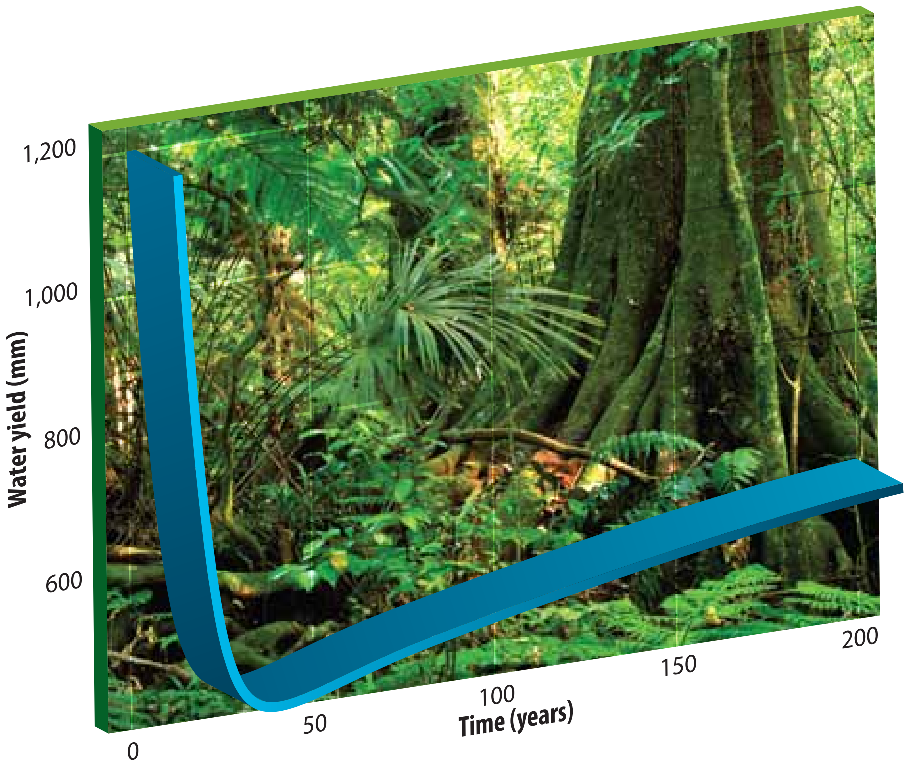
Streamflow and forest growth

The Kuczera curve describes the relationship between mean annual streamflow and the age of a forest (Figure 10). The curve is based on the observed hydrological responses of eight large Australian catchments (50–500 km^2) to extensive wildfires in January 1939, after which known proportions of each catchment were converted from old growth to regrowth. An initial increase in streamflow occurs during the first few months of trees becoming established, because of very low evapotranspiration (this is not shown on the curve). Within 10 to 30 years, a rapid decline takes place until a minimum is reached, which depends on the mix of species that makes up the vegetation.

The minimum corresponds to the maximum evapotranspiration reached as the canopy closes over. Once this minimum is reached, water yield rises for decades as trees grow older. The term 'Leaf Area Index (LAI)' is used to define the total upper leaf surface of vegetation divided by the surface area on which the plants grow. Generally, 0 (zero) equates to bare ground and 6 to a dense forest. Some scientists have suggested that changes in the LAI are responsible for the relationship between water yield and tree age. However, detailed investigations show that a leaf's ability to conduct water declines with age, so this might have a stronger influence on water yields than LAI.

Figure 10

Theoretical example of a Kuczera curve, showing a decrease in stream water yield in the order of 700 mm within the first few years of tree establishment, followed by slow and partial recovery over a period of more than 200 years. Source: Kuczera 1987.



Soil carbon stocks and fluxes

During fallow periods of shifting cultivation, the grasses and shrubby vegetation that gradually recolonize the environment capture carbon from the atmosphere and store it in organic compounds that make up the living tissues of plants. When plots are cleared and burned to grow crops, some of this carbon is released back to the atmosphere, while about 20 grams of carbon per kilogram (kg) of soil gets incorporated into the top 5 centimeters (cm) of the soil. Between 10% and 20% of this soil organic carbon gets locked up in a very stable form of charcoal, known as 'biochar' or black carbon.

Alain Pierret / IRD

Findings from Houay Pano catchment

The MSEC research showed that, contrary to widespread opinion and results from previous studies, shifting cultivation practiced on tropical hillsides can also contribute to soil carbon storage. Measurements were taken of the amount of organic matter in the top 40 cm of 581 soil auger drillings. Analysis showed that black carbon was preferentially deposited where relief showed abrupt changes in elevation. This suggests that black carbon gets washed downslope by runoff water and deposited on the flattest parts of slopes, where rainwater infiltrates the ground (Figure 11).

How farmers practice shifting cultivation influences the carbon storage capacity. When they burn the secondary forest that develops after several years of fallow, they generally do not pull out the tree stumps. The remaining coarse roots that stem from trunks tend to limit erosion locally and create micro-sites where carbon gathers. Research to test this theory on the slopes of northern Lao PDR confirmed this trend at a national scale.

Examination of 3,471 soil profiles taken across the country highlighted a correlation between land use and soil organic carbon stocks, with the largest being found under forest, smaller stores under shifting cultivation and the smallest under continuous cultivation. Regionally, stocks of soil organic carbon correlated to total annual rainfall and latitude. At hillslope level, they related to the distance to the stream network and slope angle.

Conclusion

When burning slashed vegetation prior to cultivating crops, some mineralization of organic matter occurs and this results in carbon dioxide (CO_2) emissions. However, a significant fraction of wooden plant tissues is transformed into black carbon. This is a very stable form of carbon that can be stored in the soil for long periods of time. This stable carbon is subsequently redistributed within catchments via erosion, with only a small fraction transported over long distances.

Olivier Ribolzi / IRD

Figure 11

Diagrammatic representation of the washing down of black carbon by runoff water along hillsides freshly 'slashed and burned' for cultivation, and subsequent trapping of black carbon on the flattest parts of the slopes. Source: Chaplot et al 2007, 2009.

Overall conclusion

A large part of the debate on the Laotian uplands crystallizes around the issues of population growth and shifting cultivation. Overall, with a density of just 24 inhabitants per square kilometer, and even if the population continues to increase by the current rate, demographic pressure does not appear to be an immediate major threat to the environment. Nevertheless, when only the 'potential' or 'suitable' arable land is considered, the net population density will reach critical values in many areas leading to significant pressure and environmental degradation. Based on this analysis, strict conservation measures for the remaining forests have been put in place. In this context, shifting cultivation represents a major source of contention.

MSEC activities to date have generated essential information to address key research issues related to managing soil erosion and water resources in the uplands of Southeast Asia. A key finding is that under normal rainfall conditions, traditional shifting cultivation with fallow periods of at least eight times longer than the cropping season, tend to keep sediment losses under one t/ha/yr, which is well within natural rates of soil regeneration. Reducing the length of the fallow period might initially result in similar sediment loads, as the number of exposed plots under cropping will remain the same. However, as soon as these plots become overused and can no longer produce what is needed, farmers are forced to open a second plot, requiring more labor and increasing erosion at catchment scale. Alternatively, they have to adapt by using fertilizer, cultivating other crops, shifting to livestock farming or even moving out of agriculture altogether. Although the shift to shorter fallow rotations is preventing deforestation, as planned, it is also intensifying erosion and having negative impacts for farmers.

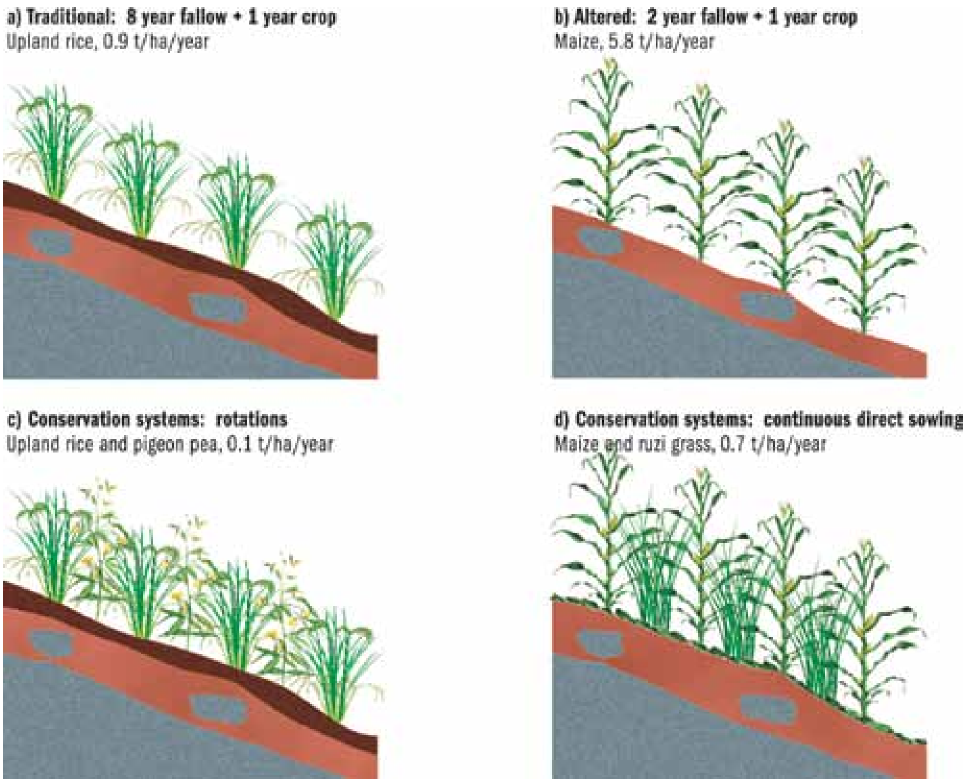
Despite the detailed studies undertaken in Lao PDR and across the region, a number of unaddressed issues remain. A major difficulty lies in the fact that there is no unifying biophysical framework to reconcile results obtained at different scales. This was clearly illustrated by the MSEC work on inter-rill erosion. Studies showed that, while this process is of foremost importance at the local scale, it is less prevalent at the catchment scale. There is no 'one-fits-all' technical recommendation that will address the whole range of issues related to soil erosion.

Another major difficulty in drawing firm conclusions about soil erosion and how to combat it is related to climate variability. Extreme rainfall events, such as typhoons, have a significant impact on soil erosion that can exceed the impacts of changes to cropping systems. A single event in Vietnam in July 2003 accounted for 42% of the total sediment that year. Such events, which cause significant erosion through processes including mass movements, should be seen as natural, and managed by balancing the positive and negative impacts associated with sediment creation. Sediment-rich floodwaters provide natural fertilization to crops grown in the Asian deltas, for example, and are, therefore, important to the global rice supply. A basin-wide approach is needed for any social cost-benefit analyses aimed at ascertaining the impacts of upstream actions on downstream communities and water users.

The increasing probability of extreme rainfall events, predicted to come with climate change, would drastically increase erosion rates. Preventative 'no regrets' approaches require authorities to focus on stabilizing slopes prone to landslides and managing riparian zones more effectively. Changes in traditional land uses, especially shifts to large-scale permanent cropping, tree plantations or biofuel production, will require increased soil conservation measures as these systems yield much higher rates of soil erosion than traditional cropping practices (see Figure 12). If incentives are not put in place to reward upland communities for adopting appropriate land-use management systems, it is likely that land degradation will increase in the next few decades, with the impacts being felt by urbanized and industrialized lowland communities.

Figure 12

Mean annual soil erosion rates when land is managed by (a) a full cycle of traditional cultivation; (b) altered shifting cultivation systems, and two conservation systems; (c) rotations with improved fallow; and (d) continuous direct sowing (Source: Valentin et al. 2008).



The results presented here have a number of broader policy implications. First, the studies indicate that, despite an explicit government policy aimed at improving both socioeconomic and environmental conditions, the resulting changes can backfire if they disadvantage key actors. Lestrelin and Giordano (2007) suggest that preliminary experimentation, incorporating medium- or long-term monitoring of pilot areas, should occur before policies are implemented on a large scale. At a minimum, substantial consultation to gather opinions from those upon whom policies are being imposed may help to reduce potential negative consequences. Second, the results suggest that applying a policy which uses constraints to drive change should be complemented by the provision of opportunities, so that the affected communities can adapt to the new circumstances. The available short-term options used so far have led, in part, to further degradation of the resource base, threatening livelihoods and weakening overall system stability.

Alain Pierret / IRD

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