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The multiple land degradation effects caused by land-use intensification in tropical steeplands: A catchment study from northern Thailand

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ABSTRACT

The strongly incised mountain landscape of northern Thailand has changed dramatically during the last few decades due to increased population pressure, agricultural commercialization, limitation to use old fallows and reforestation of upper catchments. The traditional shifting cultivation with fallow periods of 7 years and longer was gradually replaced by 1 to 4 year fallow periods. As a result, in high population areas the landscape became dominated by fields planted to rainfed upland crops, wetland rice terraces, fallow vegetation, and patches of secondary forest. This new land-use system seems to have triggered new land degradation processes that are easy to observe when travelling through this landscape.

The objective of this research was to assess the multiple effects of land-use intensification in a tropical steepland environment on land degradation processes. A case study was conducted at Pakha village (located in Thailand's northern most Chiang Rai province), which is dominated by steepland with average slope gradients ranging from 30 to 70%. Soil erosion processes were monitored in a selected catchment for 2 years, and informal interviews were conducted to elucidate farmers' perceptions regarding land degradation processes.

The rapid land-use changes at the *Dze Donglo* catchment (164 ha) resulted in severe and accelerated land degradation, including tillage erosion (386 ton/year), inter-rill and rill erosion (502 ton/year), gully erosion (423 ton/year), and landslides (7572 ton during 1994). Water erosion is most common in intensively farmed areas. The combination of runoff-generating areas, runoff-concentrating features and connectivity led to extensive gully erosion. Landslides were most common in steep fallows and in wetland terraces along incising streams. Many of these steepland degradation processes interacted with each other (i.e. rills with gully erosion, tillage erosion with water erosion, gullies with landslides). The observed land degradation processes matched very well with farmers' perceptions. This study enabled to identify potential land degradation hotspots and indicates the necessity to analyze steepland degradation processes in a holistic way.

1. Introduction

Tropical mountainous areas are inhabited by an estimated 500 million people, many of whom practice subsistence agriculture (Jackson and Scherr, 1995). In the mountains of mainland Southeast Asia, a gradual process of agricultural commercialization has taken place over the last 50 years, resulting in a decline of shifting cultivation and an increase of paddy rice and cash crops (Fox and Vogler, 2005). Over the last three decades, this transition also occurred in the hills of northern Thailand, where it has been driven by population increase, immigration, the protection of the state controlled remaining forest areas, limitation to use old fallows, reforestation of upper catchments, the expansion of rural communication infrastructure, and market integration (Trébuil et al., 2006). The traditional shifting cultivation system, characterized by at least 7 year long fallow periods, was gradually replaced by short-fallow periods (1 to 4 years) or even permanent agriculture, which currently occupies more than half of the farmed area. As a result, in highly populated areas the hill landscapes became dominated by rainfed fields, wetland terraces, secondary fallow vegetation, and patches of (disturbed) forest.

As headwater streams comprise 60–80% of the cumulative length of river networks (Benda et al., 2005), land-use changes in headwater areas can have important downstream impacts. Areas with hillslopes steeper than 20% are defined as steeplands (Lal, 1990), and when cultivated under tropical conditions, they are prone to land degradation. However, soil erosion processes on these steeplands have been poorly documented so far. In northern Thailand, soil loss from agricultural land is almost exclusively measured at runoff plots, and the reported soil loss rates from these plots vary tremendously (between 0.1 and 500 ton/ha/year, summary by Turkelboom, 1999). This large range is caused by differences in

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topography, soil conditions, rainfall, cropping systems and measurement methods. These results indicate that soil loss in agricultural land can be considerable and become a threat to long-term agricultural sustainability. On the other hand, these data also indicate that cultivation of steep slopes does not automatically result in high soil loss rates. Therefore, simple standard recommendations for land management are not advisable for these highlands. Researcher-controlled runoff plots help us to quantify the intensity of soil erosion at plot level and to identify the role of some controlling factors, but one can wonder whether the narrow focus on runoff plots is the best approach to obtain a realistic assessment of soil erosion in steep catchments and to design sustainable catchment approaches:

- Many of the measurements from standard runoff plots give a false illusion of accuracy by dissection of the actual farming circumstances into single-variable "slices", whereas most biophysical systems are dominated by interactions (Stocking, 1996).
- Plots introduce artificial boundary conditions. In actual conditions, soil erosion by water is usually interconnected along the hillslope. Erosion research at the micro and field level often overlooks other forms of erosion (e.g. gully erosion, tillage erosion, mass movement) or erosion generated by rural landscape features, such as trails, roads, and settlements.
- Land users' management practices have an important impact on soil erosion. As land use on tropical hillslopes is predominantly managed by smallholders, their heterogeneous and variable soil and cropping practices are very difficult to imitate under on-station conditions. As a result, 'farmer treatments' are often unrealistic (e.g. continuous upland rice cultivation for 7 years, weed-free cultivation).
- Very often, the focus on on-station runoff plots results in a disconnection between researchers and the actual farming conditions.

Consequently, the importance to study soil erosion beyond the borders of the classical runoff plot has been recognized over the last decade (Evans, 1993; Poesen et al., 1996a). van Noordwijk et al. (2004) advocate the need for a landscape approach which includes lateral flows, as these form an important part of the causal chain of environmental management issues. Catchment studies were also strongly endorsed by the Technical Advisory Committee of the Consultative Group on International Agricultural Research (TAC, 1996). For these reasons, catchment studies have been gaining popularity in recent years. However, what is the best approach to understand and manage catchment dynamics in tropical steeplands?

- Erosion models are regularly used as an alternative to overcome the lack of empirical data from steeplands. One group of studies are linking models for inter-rill and rill erosion (e.g. (R)USLE) with GIS-derived terrain mapping data (Funnpheng et al., 1991; Rao et al., 1994; Ravishankar et al., 1994; Vezina et al., 2006). Such a theoretical exercise provides an attractive shortcut. However, by using a model beyond its limits of validity, it is very likely that irrelevant or unrealistic conclusions are produced. There are some catchment-based soil erosion models, such as EGEM (Ephemeral Gully Erosion Model, Merkel et al., 1988), LISEM (Limburg Soil Erosion Model, De Roo et al., 1994), WEPP (Water Erosion Prediction Model; Flanagan and Nearing, 1995), EUROSEM (Morgan et al., 1998) and WATEM-SEDEM (Van Rompaey et al., 2001). These models do not always take into account the range of mechanisms responsible for gully erosion or the presence of site-specific features, such as contour trenches, tracks, and roads, that concentrate overland flow (Souchère et al., 2003; Moeyersons, 2003) leading to major errors in the spatial and temporal prediction of linear erosion. They also do not include mass movement processes along gully sides and the extension of gullies by head cutting (Poesen et al., 1998). Finally, all of them have been developed and calibrated for gently undulating landscapes (slopes <20%). Considering the controversial findings and recommendations of a model-based study in the highlands of Tigray (Northern Ethiopia), Nyssen et al. (2006) warn against the transposing of environmental models from one region to another without field checks. Extensive fieldwork remains necessary for site-specific calibration and validation. Neglecting to do so may result in improper understanding of the processes at hand, and consequently in ill-targeted and costly remediation schemes.
- Hydrological approaches at the catchment scale are an alternative to study water and sediment movement in steep catchments. In such studies, stream flow and sediment loads of catchments and basins are usually correlated with rainfall, topography, or land-use parameters (e.g. Management of Soil Erosion Consortium, MSEC for South-East Asia, Valentin et al., 2006). Such an approach provides insights about what is moving out of a catchment and can identify some possible causing factors. However, correlations do not reveal processes as the catchment is usually treated as a 'black box'.
- Detailed emperical studies at the catchment level have led to a better measurement and understanding of the effects of roads and paths as runoff and sediment sources (Morgan, 1980; Herweg, 1988; Tapp, 1990; Bruijnzeel, 1990; Harden, 1992, 1996; Grieve et al., 1995; Ziegler and Giambelluca, 1997). Rural settlement areas were also identified as major runoff producing areas (Moeyersons, 1989 in Rwanda, Rydgren, 1990 in Lesotho, and Purwanto, 1999 in Indonesia). However, most of these studies focus on these water erosion processes in isolation.

Based on the above observations, one realizes that tropical steeplands are in dire need of much more empirical and holistic catchment studies. Such type of research should aim at a better identification of steepland erosion processes and their determining factors and interactions. A few integrated catchment studies were conducted in the gentle sloping areas of northwestern Europe (e.g. Papy and Souchère, 1993; Vandaele and Poesen, 1995; Davidson and Harrison, 1995; Poesen et al., 1996b) and in Mediterranean, sloping olive orchards (Klewinghaus et al., 2006). Besides the usual landscape features, they emphasise the importance of field parcel patterns, roads, and tillage directions for the occurrence of erosion features. Similar catchment studies in tropical steeplands remain very rare (e.g. Rijsdijk and Bruijnzeel (1990) and Purwanto (1999) who studied terrace-dominated valleys in Java). The objective of this research in northern Thailand was to assess and better understand the multiple effects of land-use intensification and market integration on land degradation processes in a tropical steepland environment.

2. Study area and methodology

2.1. Study area

The study was conducted at Pakha village, located in Mae Chan District of Thailand's northern most Chiang Rai Province (20°8¢ N and 99°37¢ E, for map see at Turkelboom et al., 1997). From the geo-climatological point of view, it represents the steeper and wetter highlands of northern Thailand. Average annual rainfall is about 2100 mm. From socio-economic point of view, it represents an advanced stage of transition to short-fallow and semi-commercial agriculture. The latter criterion was chosen, as it is expected that this will be the future situation for many of the present subsistence and semi-remote villages in the highlands of Southeast Asia.

Pakha village was established in 1977 in an area with secondary forests and fallow land. For about 10 years, Pakha farmers practised shifting cultivation and the most dominant crops were upland rice, maize and bit of beans. Land pressure increased rapidly due to a ten-fold increase in population over 20 years, the enforcement of restrictions regarding the access to fallow land, and reforestation programmes. In 1995, the population density in Pakha was 65 inhabitants per km^2, which is relatively high for a steepland environment. The first transition in land use (1983–1988) was caused