ບົດບາດຂອງຊະນິດພັນພືດຕ່າງໆ ຕໍ່ປະສິດທິພາບ ໃນການອະນຸລັກດິນ ແລະ ນ້ຳ ຢູ່ພາກເໜືອຂອງ ສປປ ລາວ

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ບົດຄັດຫຍໍ້

ຈຸດປະສົງໃກາສຶກສາຄັ້ງີ້ ແມ່ເພື່ອປະເມີບົດບາດອັສຳຄັຂອງພືດພັທີ່ຢູ່ແຄມຫ້ວຍ ໃກາປ້ອງກັຮັກສາດິ ແລະ ້ຳ ຢູ່ທາງພາກເໜືອ ຂອງ ສ ປ ປ ລາວ ໂດຍຳໃຊ້ອຸປະກອ ໃກາເກັບກັກ້ຳທີ່ໄຫຼບ່າ ແລະ ອັດຕາກາຕົກຕະກອໃເຂດໂສູງ ແລະ ຄ້ອຍຊັ. ໃ ຊ່ວງລະດູຝົ ປີ 2005, ໄດ້ມີກາສຶກສາ 6 ຮູບແບບສະພາບພື້ທີ່ ກັບພືດພັ 3 ປະເພດ (ຫຍ້າທຳມະຊາດ, ໄມ້ໃຜ່, ຕົ້ກ້ວຍ) ໂດຍໃຊ້ວິທີກາຂອງ Gerlach . ໃກາສຶກສາຄັ້ງີ້ ໄດ້ມີກາວັດແທກປະລິມາຂອງ້ຳໄຫຼບ່າ ແລະ ກາຕົກຕະກອໃເວລາທີ່ມີ້ຳໄຫຼເຂົ້າ ແລະ ໄຫຼອອກທີ່ມີຕໍ່ອຸປະກອເກັບກັກ້ຳ, ໂດຍມີ 3 ຈຸດ ທີ່ມີທີ່ຕັ້ງຢູ່ໃແວລະດັບສູງຈາກແຄມຫ້ວຍ ແລະ ອີກ 3 ຈຸດ ມີທີ່ຕັ້ງຕິດກັບແຄມຫ້ວຍ. ໃພື້ທີ່ ທີ່ມີພືດພັປົກຄຸມ, ສິ່ງເສດເຫຼືອຂອງຫຍ້າ, ແລະ ພຸ່ມໄມ້ຂະໜາດສູງໃຫຍ່ ກໍ່ໄດ້ມີກາສັງເກດສຶກສາໃທຸກໆເດືອ. ປະລິມາກາໄຫຼບ່າ (TE_R) ແລະ ກາຕົກຕະກອ (TE_{TS}). ອີງຕາມຜົຂອງອຸປະກອເກັບກັກ້ຳ ເຫັວ່າ ໃພື້ທີ່ ທີ່ມີຫຍ້າທຳມະຊາດກາເກັບກັກຕະກອ ມີປະສິດທິຜົສູງກວ່າ (TE_R= 0.25; TE_{TS}= 0.13), ແຕ່ໃທາງກົງກັຂ້າມກັ ກໍ່ຄືໃພື້ທີ ທີ່ມີກາຜະລິດັ້ ຈະມີຄ່າວັດແທກຂັດກັກັບຄ່າຂໍ້ມູທີ່ຢູ່ຂ້າງເທິງ ຄື: (TE_R= -0.28; TE_{TS} = -0.94 ໃສະພາບໄມ້ໃຜ່ທີ່ປູກ; TE_R = -1.36; TE_{TS} = -2.02 ໃສະພາບສວກ້ວຍ). ປະລິມາຂອງ TE_R ແລະ TE_{TS} ກໍ່ມີກາກ່ຽວເື່ອງກັກັບຄວາມໜາແໜ້ ແລະ ລວງສູງຂອງພຸ່ມໄມ້ໃຫຍ່, ລວງສູງຂອງຫຍ້າທຳມະຊາດ ແຕ່ມັກໍ່ເປັລັກສະະທີ່ສຳຄັຄືກັອົ່ງໃສວກ້ວຍ ທີ່ປາສະຈາກກາກຳຈັດພືດພຸ່ມໄມ້ໃຫຍ່. ້ັ ຍັງເປັຜົກະທົບີ່ງທີ່ມີຕໍ່ອຸປະກອກັກເກັບ້ຳ ກໍ່ຄືຜົກະທົບຕໍ່ເື່ອງມາຈາກສັດສ່ວລະຫວ່າງພື້ທີ່ ທີ່ມີພືດພັແຄມຫ້ວຍ ແລະ ລະດັບຄວາມຄ້ອຍຊັສູງ. ເພື່ອຫຼຸດຜ່ອປະລິມາກາໄຫຼຂອງຕະກອທີ່ມາຈາກໂພູສູ່ຫ້ວຍ້ຳ, ມັມີຄວາມສຳຄັທີ່ຈະຕ້ອງຮັກສາພື້ທີ່ໃຫ້ມີພືດຄຸມດິໄວ້ເພື່ອກັເຊາະເຈື່ອ (Buffer area) ລະຫວ່າງພື້ທີ່ກາຜະລິດ ແລະ ສາຍຫ້ວຍ ທີ່ເໝາະສົມ.

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SOIL AND WATER CONSERVATION EFFICIENCIES OF RIPARIAN VEGETATION TYPES IN NORTHERN LAO PDR

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ABSTRACT

The aim of this research was to evaluate the role of riparian vegetation of a headwater stream of northern Lao in trapping hillslope runoff and sediments. In the rainy season 2005, six sites on three vegetation types (natural grass, bamboo and banana) were equipped with Gerlach troughs. Three troughs were placed at the upper rim of the riparian area and three at the lower rim to measure event inflow and outflow runoff volumes and sediment loads. Site vegetation cover, grass biomass, and undergrowth height were monitored monthly. Runoff (TE_R) and sediment load (TE_{TS}) trapping efficiencies were highest in natural grass sites (TE_R = 0.25; TE_{TS} = 0.13), whereas they were negative in cultivated sites (TE_R = -0.28; TE_{TS} = -0.94 under bamboo; TE_R = -1.36, TE_{TS} = -2.02 under banana). TE_R and TE_{TS} were correlated to undergrowth density and height, which was highest in natural grass, but was also important where banana was cultivated without destroying undergrowth vegetation. Trapping efficiencies were also correlated to the ratio between riparian area and upslope contributing area. To reduce the amounts of hillslope sediment delivery to streams and preserve the water quality of water bodies, it is important to maintain a buffer area between cultivated fields and streams. The minimum width of the riparian zone should be adapted to the size of the upslope cultivated areas.

Keywords: *soil conservation, trapping efficiency, riparin vegetation, Nothern Laos, Gerlach trough*

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I. Introduction

In Northern Lao PDR growing human pressure on agricultural land has accelerated degradation processes along hillslopes and increased the sediment yields delivered to streams (Moa et al., 2002; Lestrelin et al., 2005). Chaplot et al. (2003a) reported runoff and interrill erosion rates under slash and burn system measured in 1-m^2 microplots up to 140 t/ha y.

Proper management of riparian vegetation can prevent nonpoint source pollutants from reaching water bodies (Dillaha et al., 1986; Karssies and Prosser, 1999), and may thus offer a way to reduce the off-site impacts of land degradation occurring along the steep slopes of Northern Lao PDR. Riparian areas are ecotones placed at the interface of terrestrial and aquatic ecosystems, whose hydrology is characterized by the interface of hillslope and stream (or river) processes (Karssies and Prosser, 1999). In riparian areas, important ecological functions, i.e. stream bank stabilisation, nutrient and pollutants filtration, and in-stream habitat control, as well as economic activities take place. Thus, the management of these areas bears important consequences for stream water quality and for rural population livelihood.

The main mechanisms of filtering pollutants in riparian areas are by (1) enhancing infiltration, which reduce runoff volumes, thus favours particle sedimentation; (2) reducing runoff velocity, which creates a backwater area, i.e. an area of slow moving water, in the upper part of the vegetation where settling of sediments can thus be favoured; (3) protecting the stream banks and the riparian soils from direct erosion; (4) filtrating solid particles; and (5) adsorbing pollutants on soil and vegetation surfaces (Dillaha et al., 1986; Karssies and Prosser, 1999). Infiltration is by far the most important mechanism with which riparian vegetation filter the incoming hillslope surface flows of sediment and soluble pollutants, but when subsurface flows are important, seepage and excess saturation flows can forfeit it (McKergow et al, 2004).

The effectiveness of vegetation in trapping sediments depends on many factors, such as (i) incoming flow rates and sediment particle size, with coarser particles more easily trapped in the riparian area; (ii) vegetation cover and type, which affect infiltration rate and roughness of soil surface; (iii) hydrologic and topographic settings of the riparian area, especially width, slope, and ratio of riparian width divided by the upslope contributing area (buffer-upper ratio) (Dillaha et al, 1986; Karssies and Prosser, 1999; Abu-Zreig et al., 2004).

Much research on the effects of vegetation in riparian areas have concentrated in the temperate zones of the world, where riparian areas have been reported to retain 70-99 % of incoming loads (e.g. Abu-Zreig et al. 2004). There is still a lack of information about tropical riparian areas (Karssies and Prosser, 1999; McKergow et al., 2004). McKergow et al. (2004) were among the few to study riparian areas trapping efficiency in open field conditions of the wet tropics and reported trapping efficiencies of incoming sediment of 37 - 46 %, but also negative values when exfiltration in the riparian area was observed.

Little is known about the vegetation types and the hydrology of riparian zones of Northern Lao PDR, and their effectiveness in filtering hillslope runoff and sediment flows. The aim of this research was to evaluate the role of riparian vegetation of a headwater stream in trapping hillslope incoming runoff and sediments generated by sheet and interrill erosion. Two specific objectives were identified: (1) assessing the hillslope runoff and sediment flows reaching the riparian areas, and (2) assessing the trapping efficiency of these flows by three common riparian vegetation types of a small headwater catchment of the upland hills of Northern Lao PDR.

II. Materials and Methods

The headwater catchment of Houay Pano (64 ha) is located at Ban Lak Sip, Luang Prabang province. It receives an average of 1259 mm of rain per year, most of it during the monsoon season that lasts from half May to half October. Altitude ranges from 400 to more than 800 m. The catchment is representative of the no-input slash and burn system of South East Asia, and underwent a reduction of the fallow period from 10-15 years to the actual 5-2 years (Moa et al. 2002; Chaplot et al., 2003a; de Rouw et al., 2005; Lestrelin and al., 2005). The catchment stream is a tributary of the Xon stream, which flows in the Nam Dong River before its confluence to the Mekong. The main reach consists of a 1200 m long, 3-m wide second-order perennial stream of irregular topography with average slope gradient of 0.19 m/m (Ribolzi et al., 2005). Riparian areas are mainly of convex or convex-concave shape, steep (60 % on average, but ranging from 10 to 130 %), and narrow (average width 9 m, ranging from 4 to 23 m). Stream banks are high (0.95 m in average) and steep (200% slope in average).

More than 43 % of the riparian areas along Houay Pano stream is covered by a grass and shrub vegetation dominated by *Microstegium ciliatum* (Njanung);

bamboos, especially *Dendrocalamus sp.* (Mai hok) and *Cephalostachium virgatum* (Mai hia), cover 19% of riparian areas; cultivation of banana stands extends over 15% of the riparian areas. The remaining riparian areas are covered by forest vegetation (15%), cassava (6%) and Napier grass (3%). The three vegetation types selected for this study were natural grass dominated by *M. ciliatum*, bamboo, and banana. The latter was preferred to forest cover because it represented the effect of cultivation near streams.

Above-ground vegetation characteristics that could be related to trapping efficiency were monitored once per month from July to October. Canopy cover and ground cover were estimated visually on a 3 x 3 m area; density of grass stems was counted on a 1 x 1 m area; undergrowth height was measured as the average of three undergrowth plants per site; grass biomass of a 1 x 1 m plot was cut, oven-dried and weighted.

Six sites with two slope settings, gentle (slope <= 20%) and steep (> 20%) were selected (Table 1). The sites were equipped with six 0.50-m wide Gerlach troughs (Gerlach, 1967; Fig. 1). Three troughs were placed at the upper rim of the riparian area and three at the lower rim. In the rainy season 2005, after each rainfall event volumes of runoff and sediment concentration of water trapped in the Gerlach troughs were measured.

Runoff and total sediment load flows were measured for each rim of three troughs and expressed per meter of contour line (in l/m and kg/m). Trapping efficiency TE was calculated as (McKergow et al., 2004; Abu-Zreig et al. 2004):

$$TE = (X_{in} - X_{out}) / X_{in} \qquad (1)$$

where X_{in} is the inflow as measured in the three upper rim troughs, and X_{out} is the outflow as measured in the three lower rim troughs. TE was calculated for runoff volumes (TE_R) and for sediment loads (TE_{TS}).

III. Results

Vegetation characteristics. Table 2 shows the characteristics of the three vegetation types for the period July-October 2005. Differences among vegetation types were all significant at probability level $\alpha = 0.05$. No significant change in any of the monitored properties was detected throughout the season. Natural grass sites showed the highest values of ground cover, number of grass stems, grass biomass and undergrowth height. Compared to bamboo sites, banana stands had higher undergrowth vegetation cover in terms of density of grassstems, biomass and height, but similar ground cover, because of the higher litter cover in bamboo sites.

Seasonal runoff and sediment flows. During the monitoring period (20 July - 15 October 2005), 23 rainfall events totalling 657 mm of rain generated runoff in the riparian sites. Rainfall amounts ranged from 1.5 to 72 mm, reaching 30-minute maximum intensities ranging from 3 to 68 mm/h. In some cases, Gerlach troughs were found full, and overflow probably occurred. In the whole monitoring period, cases of overflown Gerlach troughs were found for site 2A (3 cases, lower Gerlach rim), 2B (2 cases, lower Gerlach through rim), 3B (2 cases, in the upper Gerlach rim), and especially for the site 3A, where 16 times troughs of the lower rim were found full. Presence of overflown troughs caused underestimation of water and sediment flows. This is particularly true for site 3A.

Fig. 2 shows total runoff volumes inflows and outflows per site. Total inflow ranged from 87 to 700 l/m, whereas outflow ranged from 58 to 996 l/m. Site 1A received and released the smallest amount of runoff, whereas site 2B showed the highest inflow and outflow runoff volumes. There was a net reduction of runoff flows in the two natural grass sites and in site 3B, where infiltration of incoming flow occurred.

Fig. 3 shows the total flows of sediment loads per site. Inflows ranged from 0.04 to 2.66 kg/m; outflows from 0.05 to 3.58 kg/m. Only in two sites (1B and 3B) there was a net reduction of sediment loads. The increase of sediment load across riparian zones was due to both increases of surface runoff and sediment concentrations.

Flow event distributions. The distributions of event inflows and outflows were log-normal. Geometric mean of runoff was 2.8 l/m in the inflow and 4.2 l/m in the outflow. Geometric mean of sediment load was 0.003 kg/m in the inflow and 0.005 kg/m in the outflow. Student's t-tests showed that inflows and outflows were significantly different at $\alpha = 0.01$.

Table 3 shows the Spearman's correlation coefficients of inflow runoff and sediment load with (i) rainfall event characteristics, i.e. amount, 30-minute maximum intensity, duration, average intensity, and antecedent moisture index as defined in Casenave and Valentin (1992), and (ii) site upslope specific area, i.e. the ratio of the watershed contributing surface divided by the length of the downslope discharge face (Bren, 2000), which in this case was calculated at the upper rim of the riparian area. Not surprisingly, inflow runoff increased with rainfall events that had larger amounts, higher intensities and that fell on wetter catchment conditions. Runoff and sediment load were highly correlated: high runoff always meant large incoming sediment amounts.

Inflow sediment loads increased with larger upslope specific areas. However, it is not clear if the difference of inflow sediment load was related to the upslope specific area or to upslope land use, or combination of both: the sites with the highest upslope specific area are those where upslope land use is banana stand (Table 1). Upslope banana stands showed significantly higher inflow sediment load than fallow or teak fields. The difference between 2 or 3 years fallow and teak was instead negligible.

Event trapping efficiencies. Trapping efficiencies per event varied greatly. Fig. 4a and 4b show the box plots of event trapping efficiencies per site for runoff (TE_R) and total sediment load (TE_{TS}). In more than 50% of cases trapping efficiencies were negative, meaning that outflows were larger than inflows, i.e. the riparian area contributed runoff and/or sediment to the stream instead of retaining them. Maximum trapping efficiencies were 0.84 for TE_R and 0.91 for TE_{TS}. However median TE values were positive for runoff only in site 1A, and for sediment load in sites 1A and 1B.

Differences among trapping efficiencies per vegetation type were tested by the non-parametric Kruskall-Wallis tests (at α = 0.01; n = 138). TE_R and TE_{TS} resulted to be significantly different between natural grass (median TE_R = 0.25, TE_{TS} = 0.13), bamboo (median TE_R = -0.28, TE_{TS} = -0.94) and banana stands (median TE_R = -1.36; TE_{TS} = -2.09).

The relationship of trapping efficiencies with (1) inflow amounts, (2) rainfall characteristics, (3) site topography, and (4) riparian vegetation characteristics were explored by Spearman’s correlation coefficients (Table 4). Trapping efficiencies were independent from the inflow amounts and rainfall event characteristics. However, the rainfall events of season 2005 were never highly erosive. An important topographic factor affecting trapping efficiencies was the buffer-upper ratio, i.e. the ratio of the riparian area divided by the upslope contributing area. The higher the buffer-upper ratio, i.e. the larger the riparian zone in comparison to the cultivated land above it, the higher the trapping efficiencies. This confirms Dosskey et al. (2002) findings of the importance of appropriate upper-buffer ratios for design and management of riparian areas. Slope was positively correlated to TE_{TS}. This is contrary to literature reporting that higher slope settings reduce trapping efficiencies (e.g. Abu-Zreig et al., 2004), but it is probably due to thehigh outflow runoff measured in sites 2A and 3A. Moreover, it is difficult to separate the effects of riparian slope from the buffer-upper ratio, because these were negatively correlated (Spearman c.c. = -0.257).

TE_R and TE_{TS} were well correlated to all vegetation characteristics, and particularly to ground cover.

IV. General discussion

Hillslope flows. Gerlach troughs are unbounded devices. Compared to runoff plots, they offer the advantage that they do not exclude the contribution of runoff and sediment coming from the upper part of a hillslope, thus they allows studying surface runoff and erosion processes at the hillslope scale. However, their main disadvantage is that the extension of the upslope specific area is very uncertain. The upslope specific areas of Table 1 were estimated as the maximum hillslope length draining to the reach contour line of the sites, drawn on the basis of a detailed topographic survey (Chaplot et al., 2005). However, microtopography influences dramatically the direction of overland flow movement; presence of concentrated flow such as rills or gullies can divert overland flow pathways from the topographic slope direction. During the setting-up of the experiment, utmost care was taken to put the troughs in spots that allowed intercepting interrill and sheet flow. Linear erosion processes were therefore excluded from the assessments of this study, even if such processes are important in northern Laos (Chaplot et al., 2003b; 2005). Moreover, not all the hillslope contributes to surface runoff in all events: because of variable occurrence of infiltration along the slopes, the area that actually contributes surface runoff to the stream changes dynamically depending on the antecedent soil moisture conditions, rainfall amounts and intensities, and location of sources and sinks of runoff along the slope (Bergkamp, 1998). In Houay Pano catchment, research already confirmed that subsurface water movements are important and that infiltration along the slope is high (Ribolzi et al., 2005). Therefore, the upslope specific area per event may be far less than the estimated values of Table 1. Given such uncertainties in the estimation of upslope areas, this study focused on the fluxes of water and sediment per linear meter of contour line, under the assumption that the three Gerlach troughs basically intercepted the equivalent of 1.5 m of contour lines at the upper and lower rims of the riparian area. Still, underestimation of the flows occurred whenever there were cases of overflown troughs, which affected especially the lower rim of the riparian sites and particularly site 3A.

Notwithstanding these uncertainties, to understand hillslope processes it may be worth to express the through measurements in terms of runoff coefficients and soil loss rates. Assuming the upslope specific areas of Table 1, conservative estimates of seasonal inflows amounted to 1.2 - 8 mm of runoff (corresponding to runoff coefficients of 0.02-6 %) and 0.01 – 0.30 t/ha of sediment load, whereas and outflows amounted to 0.7- 10.4 mm of runoff and 0.01-0.37 t/ha of sediment load per season. These figures indicate low surface runoff and sediment loads reaching the stream, but the observation period (starting from 20th of July) covered only the second part of the monsoon season when soils are covered with vegetation.

In sites 2A, 2B and 3A, runoff dramatically increased across the riparian areas (Fig. 2). Average event inflow runoff coefficients were 0.31 % in site 2A, 1.55 % in site 2B, and 0.25 % in site 3A. However, outflow runoff coefficients were 0.61 % in site 2A, 2.00 % in site 2B and 1.09 % in site 3A. The substantial increase of runoff coefficients across these riparian sites may be explained by the occurrence of return flow and saturation excess runoff. Sites 2A, 2B and 3A corresponded to areas where groundwater feeding to the stream was suspected (Ribolzi et al., 2005). Our study confirms that return flow and saturation excess overland flow contributes to stream discharge and are important in Houay Pano riparian areas. Presence of seepage or return flow in the riparian areas reduces infiltration, hampers the filtering capacity of riparian zone, and exposes the area to enhanced erosion risks (McKergow et al. 2004).

Trapping efficiencies. Even if maximum event trapping efficiencies were high (> 0.80), the overall performance of riparian areas in retaining runoff and sediments were rather low. TE_R calculated for the whole season 2005 ranged from –3.25 in site 3A (banana on gentle slope) to 0.34 in site 1A (natural grass on gentle slope); whereas TE_{TS} for the whole season ranged from –10.73 in site 2A (Bamboo on gentle slope) to 0.54 in site 3B (banana on steep slope). Our findings compare quite well with the results of 4 years observations in the Australian wet tropics of McKergow et al. (2004), who found extremely variable event trapping efficiencies, with total TE_R ranging from -0.20 to 0.24 and TE_{TS} ranging from -0.51 to 0.46 depending on vegetation and topographic setting of the riparian site.

In particular, we expected higher performance of the natural grass, which maintains a high grass cover (Table 2). Natural grass was efficient in retaining runoff, and of consequence in trapping sediment loads, but not in reducing sediment concentration in the outflows. This confirms that the main mechanism by which riparian vegetation filters pollutants is by infiltration. In turn, infiltration was higher when canopy cover, ground cover, density of grass stems, grass biomass, and undergrowth height were high. The positive correlation between TE_R and vegetation characteristics (Table 4) confirms that vegetation density at ground level and undergrowth height increase runoff trapping efficiency (Dillaha et al., 1986; Karssies and Prosser, 1999; Abu-Zreig et al. 2004). Ground cover due to litter, as in the bamboo sites, was not effective in reducing runoff and sediment delivery to streams. On the contrary, bamboo sites were active sources of runoff and sediment to the stream. Krassies and Prosser (1999) had already reported that litter may not be effective and can be washed away during large rainfall events.

Quite surprisingly, site 3B, i.e. banana on steep slope, scored among the best total trapping efficiencies: $TE_R = 0.16$ and $TE_{TS} = 0.54$. Because of the high outflows recorded in site 3A, banana stands had low runoff and sediment load trapping efficiency. Beside differences in hydrologic settings, site 3A and 3B presented rather different undergrowth vegetation; site 3B had higher ground cover (55 %), density of grass stems (305 stems/m^2), grass biomass (113 g/m^2) and undergrowth height (0.47 m) than site 3A (with 32 % ground cover, 64 stems/m^2, 30 g/m^2 biomass, and 0.18 m undergrowth height). It seems thus that if banana stands are cultivated without removing the undergrowth vegetation, the riparian area may maintain runoff and sediment trapping efficiencies comparable to natural grass. More research should be conducted to verify these findings.

IV. Conclusions

The overall performance of riparian areas in retaining runoff and sediments were rather low. TE_R and TE_{TS} were positively correlated to canopy cover, ground cover, density of grass stems, grass biomass, and undergrowth height of riparian vegetation. Among the vegetation types, natural grass was the most effective vegetation to retain runoff and sediments. Cultivated riparian areas were active sources of sediment to the stream. However, when cultivation of banana did not eliminate undergrowth cover, trapping efficiencies were quite high and comparable to natural grass. This issue will require further investigation, because it suggests that riparian areas may maintain their filtering role even when put under proper cultivation. Under bamboo cover, instead, where under-storey vegetation is very poor, we recorded the largest outflow sediment loads.

TE_R and TE_{TS} were positively correlated to the ratio between riparian area and the upslope contributing area (buffer-upper ratio). This implies that in order to reduce the sediment delivery to water bodies, it is important to maintain a buffer area between the cultivated fields and the water bodies whose width depends on the extension of the cultivated areas above it.

Our study confirmed that in Houay Pano riparian sites the contributions of seepage and saturation excess flow to stream discharge are important. Saturation conditions near the stream may increase soil detachability to water runoff as well as trigger landslide movements and stream bank collapses. These sites may be important sources of runoff and sediment to the stream, and therefore erosion control in the riparian areas remains of the utmost importance for the maintenance of stream water quality.

Our study agrees with McKergow et al. (2004) observation that in wet tropics the potential retention of sediments in riparian areas may be limited by the presence of seepage and exfiltration of return flow. With these limited efficiencies, it may not be possible to preserve the water quality of streams by solely trapping the increasing sediment loads coming from agricultural land in the riparian zone. In other worlds, management of riparian areas will be an important management tool in complementation to and not in substitution of proper management of sloping lands.

V. Anexes

Table 1. Characteristics of the six riparian sites

site	vegetation	upslope specific area [1] (m^2/m)	slope (%)	width (m)	upslope land use	buffer-upper ratio[2]
1A	Natural grass *(Microstegium ciliatum)*	71.0	16	11.6	3 years – fallow	0.16
1B	Natural grass *(Microstegium ciliatum)*	61.6	58	10.4	teak	0.17
2A	Bamboo *(Cephalostachyum virgatum)*	59.8	20	8.8	2 years - fallow	0.15
2B	Bamboo *(Dendrocalamus sp.)*	87.6	70	7.9	banana	0.09
3A	Banana *(Musa sapientum)*	74.4	13	9.5	banana	0.13
3B	Banana *(Musa sapientum)*	66.0	52	7.5	banana	0.11

[1] The specific area is the ratio of the watershed contributing surface divided by the length of the downslope discharge face (e.g. Bren, 2000). In this case it is calculated at the upper rim of the riparian area.

[2] The upper/buffer ratio is the ratio of the watershed contributing surface divided by the riparian area surface (e.g. Dosskey et al., 2002).

Table 2. Average characteristics per vegetation type (n = 18; July-October 2005, Houay Pano)

Vegetation type	Canopy cover (%)	Ground cover (%)	Density of grass stems (n/m^2)	Grass Biomass (g/m^2)	Undergrowth height (m)
Natural grass	85	88	355	435	0.75
Bamboo	70	39	64	45	0.27
Banana	68	43	185	71	0.33

Table 3. Ranges and Spearman's correlation coefficients of inflow runoff and sediment load with rainfall characteristics and site upslope specific area (as defined in Table 1).

			min	max	Runoff	Sediment load
Runoff		l/m	0	167	1	
Sediment load		kg/m	0	1.1	0.925*	1
Rainfall	amount	mm	1.5	79.0	0.645*	0.508*
	30-min max intensity	mm/h	3	68	0.550*	0.553*
	Duration	h	0.2	22.3	0.388*	0.275*
	Average intensity	mm/h	1	46	-0.036	0.010
	Antecedent rainfall index	mm	0.15	71.92	0.675*	0.595*
Site upslope specific area		m^2/m	0.09	0.17	0.191	0.270*

* indicates significant correlation at $\alpha = 0.01$ (n = 138).

Table 4. Spearman's correlation coefficients of event runoff (TE_R) and sediment load (TE_{TS}) trapping efficiencies with inflow amounts, rainfall, site topographic settings, and riparian vegetation characteristics.

			TE_R	TE_{TS}
Trapping efficiency	TE_R		1	
	TE_{TS}		0,789*	1
Inflow amounts	Runoff	l/m	0,102	0,052
	Sediment load	kg/m	0,016	0,061
	Sediment concentration	g/l	-0,056	0,141
Rainfall	Rainfall amount	mm	-0,032	-0,037
	30 min max intensity	mm/h	0,019	0,039
	Duration	h	-0,156	-0,088
	Average intensity	mm/h	0,165	0,114
	Antecedent moisture index	mm	-0.016	-0.087
Site topography	Upslope specific area	m^2/m	-0,206	-0,146
	Width	m	0,217	0,156
	Buffer-upper ratio		0,286*	0,248*
	Slope	%	0,164	0,276*
Riparian vegetation	Canopy cover	%	0,571*	0,504*
	Ground cover	%	0,598*	0,512*
	Density of grass stems	n/m^2	0,473*	0,372*
	Grass biomass	g/m^2	0,490*	0,414*
	Undergrowth height	m	0.526*	0.515*

* indicates significant correlation at α = 0,01 (n = 138)

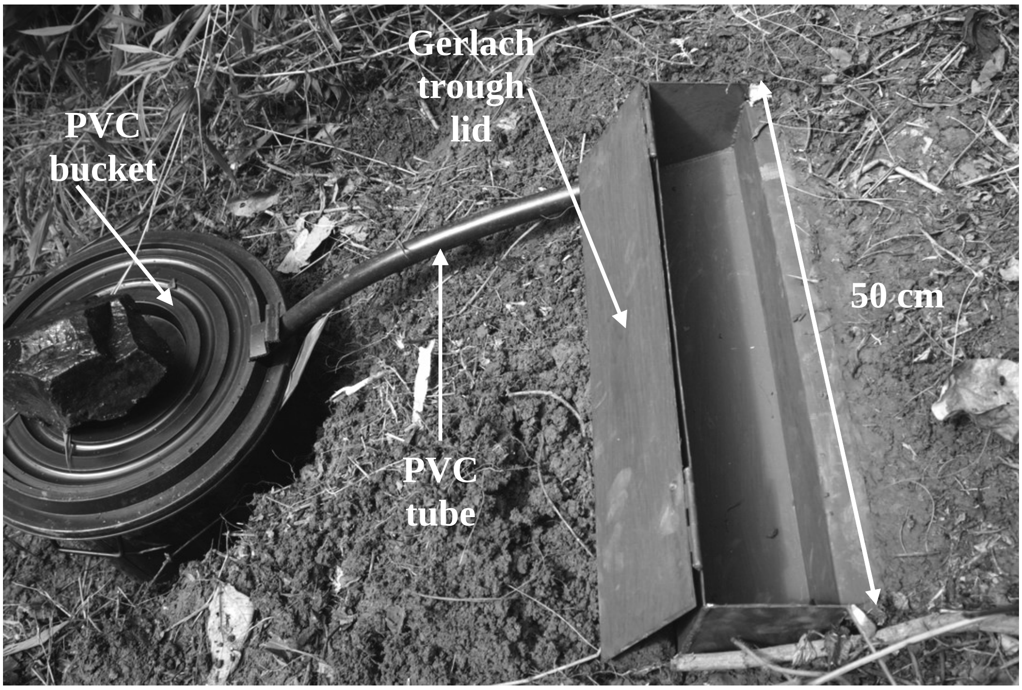

Figure 1. The Gerlach trough system used to collect event surface runoff.

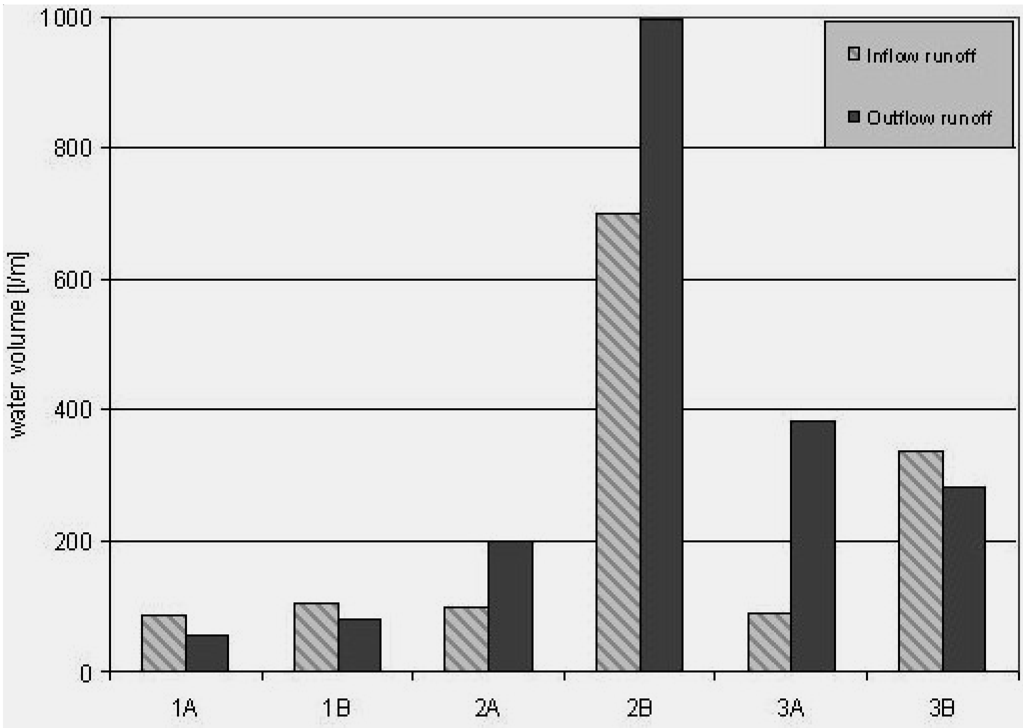

Figure 2. Total inflow and outflow runoff volumes (in l/m) per site, season 2005. 1A = natural grass on gentle slope, 1B = natural grass on steep slope; 2A = bamboo on gentle slope, 2B = bamboo on steep slope; 3A = banana on gentle slope; 3B = banana on steep slope.

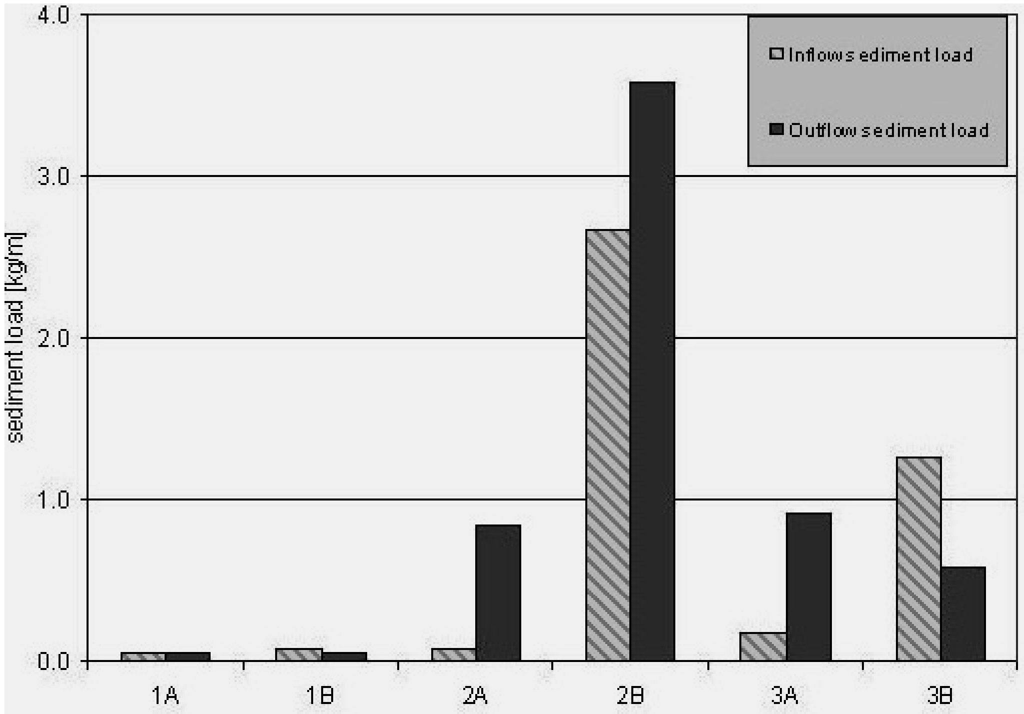

Figure 3. Total inflow and outflow sediment loads (in kg/m) per site, season 2005. 1A = natural grass on gentle slope, 1B = natural grass on steep slope; 2A = bamboo on gentle slope, 2B = bamboo on steep slope; 3A = banana on gentle slope; 3B = banana on steep slope.

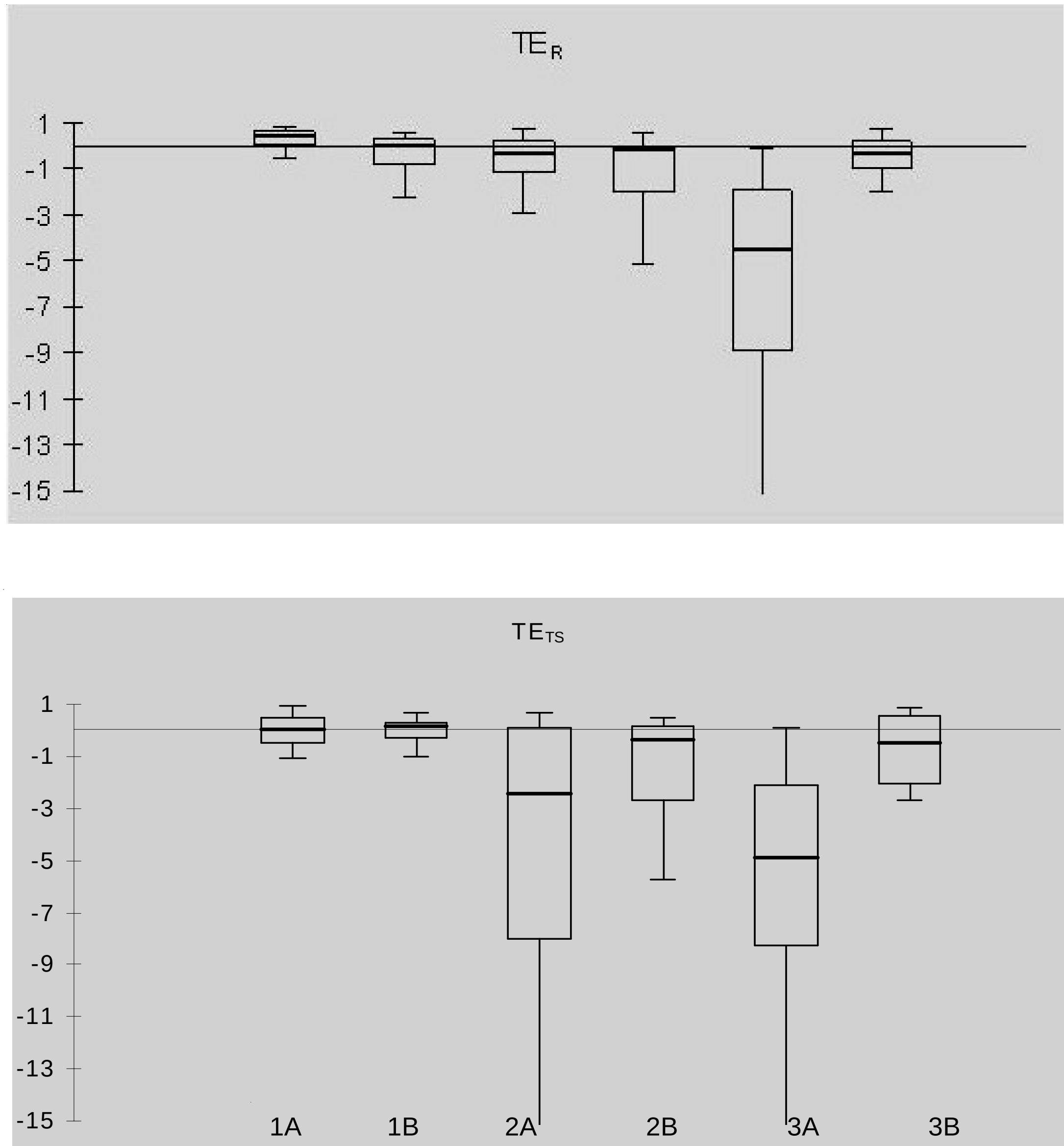

Figure 4. Box plots of (a) runoff event trapping efficiencies, and (b) sediment load event trapping efficiencies at the six riparian sites (truncated at -15). Whiskers indicate 10th and 90th percentile of the distribution; box limits indicate the 25th and 75th percentile; and black thick lines indicate event median values. 1A = natural grass on gentle slope, 1B = natural grass on steep slope; 2A = bamboo on gentle slope, 2B = bamboo on steep slope; 3A = banana on gentle slope; 3B = banana on steep slope.

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