Dispersal of Weed Seeds by Erosion and Flow Processes in Upland Fields

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Abstract

This study examined the impact of runoff water and soil erosion on the dispersal of weed seeds in small cultivated catchments. Water samples and soil samples were collected from eight hydrological stations in the Houay Pano headwater catchment, near Lak Sip village in northern Laos, during the first big event of the rainy season in 2005 (7th June, 2005). Samples were also taken from the topsoil near each station before the beginning of the rainy season. The number of viable seeds was determined for each sample using the simple seedling-emergence method. The rainstorm generated an outflow of approximately 4,000 kg of suspended material including some 970,000 viable weed seeds, transported by runoff water. Most of the seeds that left the catchment (an area of 64.6 ha) were troublesome composite weeds and grasses. The same rainfall event also generated a sediment load of 1,100 kg of soil that was trapped in the tank of the outlet (drained from 8.4 ha). This bedload carried 43,500 viable seeds. The study of the micro-catchments revealed that fields that were recently planted with rice, following local slash-and-burn practices, had a total seed flow of 61,000 viable seeds per hectare. Land covered by well-developed fallow vegetation, on the other hand, produced a seed flow of only approximately 500 viable seeds per hectare. It was also found that the riparian area and riverbank were the major sources of weed seeds in the stream during rainstorms. This study showed that a large amount of weed seeds are transported out of the catchment and are very likely to pollute the downstream cultivated lands. In the Houay Pano catchment, weed seed dispersal during rainstorms could be greatly reduced by management of the riparian area.

Keywords: weed dispersal, seed stocks, erosion, runoff, slash-and-burn, northern Laos.

1. Introduction

Slash-and-burn cropping practices in the uplands of Laos typically result in a landscape mosaic of crops and fallow plots on the hillslopes. In areas where fallow periods have been reduced to between one and four years, weeds infest not only crops but also the fallow land. Low thickets, grassy fallows and weedy fields generally produce huge quantities of seeds. In Laos, the flora is adapted to the annual monsoon cycle which means that most plants produce seeds in the dry season or at the very end of the rainy season. Thus, at the end of the dry season, the quantity of seeds reaches its annual peak. Most of these seeds are simply shed on the ground. Presumably a large number are then carried down the slope in surface flows produced by the first big rainstorm event of the rainy season.

The successful spread of weed seeds and subsequent infestation of new fields by irrigation water was well documented by Radosevich et al. (1997). This study investigated how weed seeds can spread by more natural processes such as in runoff water and detached soil. If runoff water and sediment flows during rainstorms contribute to the dispersal of weed seeds then cultivated land downstream could be polluted by seeds, adding to the negative off-site impacts produced by upland cropping. The study was carried out within the framework of the regional Management of Soil Erosion Consortium (MSEC) programme, and was able to make use of research inputs from vegetation, soil and agronomic studies carried out at the site since 2001. It was therefore also possible to examine the effects of different types of land use and changes in land-use systems on the dispersion of weed seeds.

2. Materials and methods

2.1 The study site

This study was conducted in Houay Pano, an upland valley with steep slopes approximately 10 km from Luang Prabang. Almost the entire 1,400-m long valley is cultivated by Kmhmu farmers from the nearby village of Lak Sip, using slash-and-burn techniques. The catchment in the study is a headwater catchment and existing MSEC infrastructure allowed sampling from well-determined and well-studied sub-catchments. The Houay Pano valley contains four sub-catchments (designated one to four, figure 1) which drain a permanently flowing stream. The area encompassing the four sub-catchments is covered in a mosaic of fallow land and fields on the slopes, patches of remnant forest on the crest, and a narrow riparian area including a riverbank. At Houay Pano there are also four gully micro-catchments (designated six to nine, figure 1) with a seasonal flow dependent on rainfall events. Since 2002, soil and water conservation techniques have been tested alongside the conventional slash-and-burn practices in these micro-catchments. At the time of sampling, on the 7th of June 2005, the date of the first erosive rainstorm of the rainy season, three different land-use systems were being practised in these micro-catchments: 1) in six and eight, an improved fallow system was being used so that land was covered by dense two-year-old fallow vegetation dominated by the legumes Pigeon pea (*Cajanus cajan* (L.) Millsp.) and Crotalaria (*Crotalaria micans* Link); 2) in seven, land was being cultivated under the conventional slash-and-burn system and the farmers had just completed the hill planting of rice so the soil surface was still bare; 3) in micro-catchment nine, following a system of annual cropping with mulch, the soil was covered by dead Ruzi grass mulch (*Brachiaria ruziziensis* Germain & C. Evrard) due to herbicide application just before planting. Some selected characteristics of the eight catchments are presented in table 1.

Table 1: Characteristics of the four sub-catchments (1-4) and four micro-catchments (6-9) at Houay Pano

	Hydrological stations							
	In the stream - permanent outflow				In a gully - temporal outflow			
	Station 1	Station 2	Station 3	Station 4	Station 6	Station 7	Station 8	Station 9
Total area drained (ha)	21.5	35.6	56.2	64.6	0.3	0.5	0.4	0.5
Total net to area (ha)[1]	21.5	14.1	20.6	8.4				
Area burned and planted (%)	8%	15%	17%	16%	0%	100%	0%	0%
Mean slope (%)	56%	57%	54%	54%	38%	54%	64%	40%
Land use	Mosaic of fields & fallow, teak, bananas and riparian zone				Improved fallow	bare field sowing	improved fallow	mulch sowing
Mean viable seed density/m²	274	368	223	308	271	207	591	906

[1] because sub-catchments are nested.

2.2 Sampling of water, sediment and seed stocks

Runoff water and detached soil were sampled using eight hydrological stations. Four stations, numbered one, two, three, and four (figure 1) were set-up in the stream which drains the four corresponding sub-catchments and had a permanent outflow. Four other hydrological stations, numbered six, seven, eight, and nine (figure 1), were placed in the gully at the outlet of micro-catchments six to nine. Station 5 does not generate useful data and was not used in this experiment. A hydrological station is a cemented tank acting as a sediment trap. It can also be equipped with an automatic water level recorder and an automatic water sampler, a device which collects water samples every five minutes. In this study all the stations were equipped with automatic water samplers except for stations six, eight and nine. This was because water infiltration in these three micro-catchments was very high and all the water and sediment produced by a rain event was trapped in the tank and could be sampled the next day. The functioning of the automatic samplers is described in the following example: on 7 June, the water level recorders in the hydrological stations recorded a peak water flow for the first time in the 2005 season (figure 2). The soil was already saturated due to a series of rain events which started on 26 May so that this major, high intensity rain event (44 mm, 105 mm/hour) led to massive overland flows. The sudden rise in water level in the tanks triggered the automatic water samplers. Through regular sampling, i.e. during the rising, peak, decreasing and slow-decrease phases, a good overview of the event was obtained. With this data, the various flows leaving the catchment could be calculated: total runoff and total suspended loads of soil and plant material. At the same time, the cemented tanks trapped most of the eroded soil sediments.

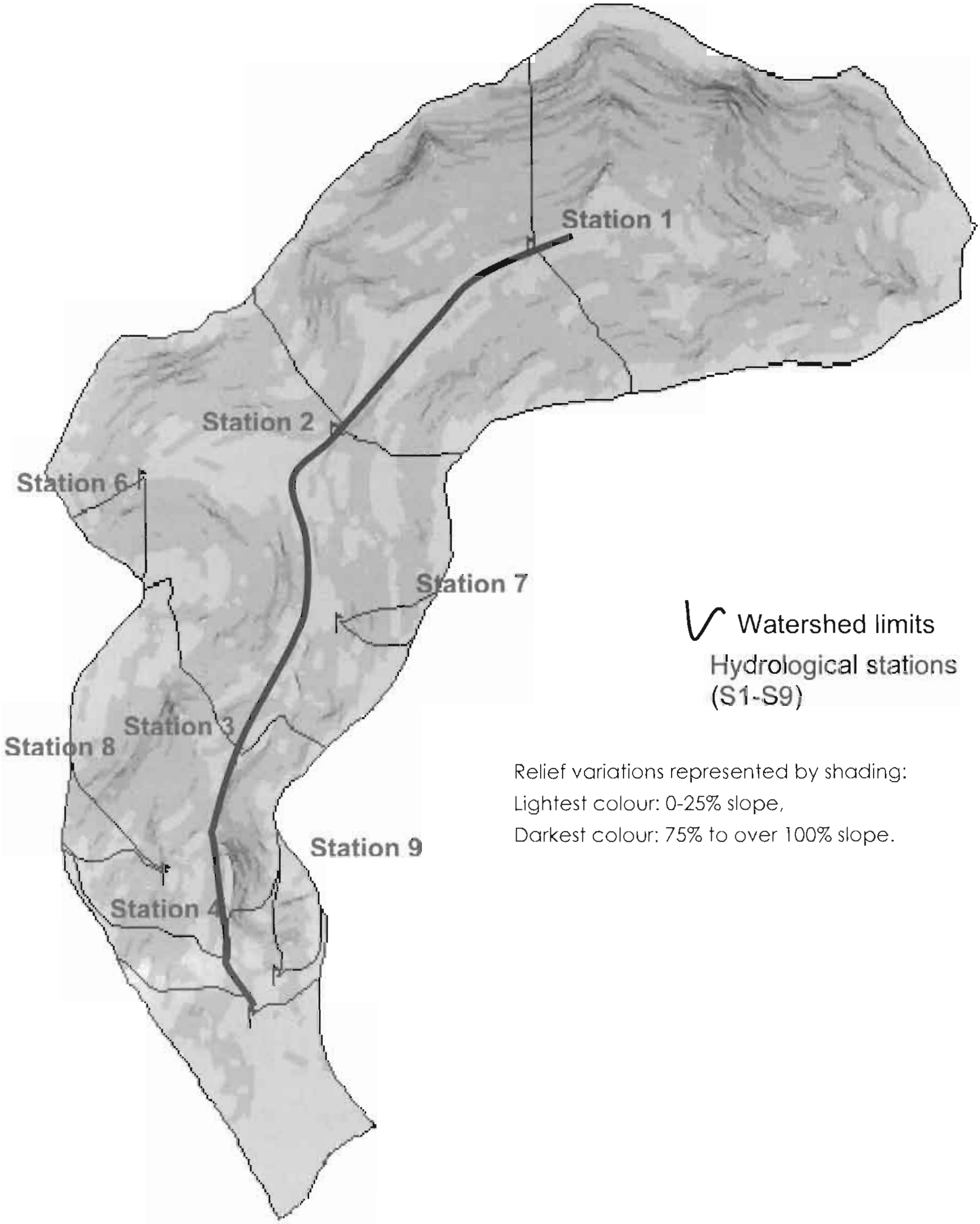

Figure 1: Map of Houay Pano watershed with sub catchments (1-4) and micro catchments (6-9)

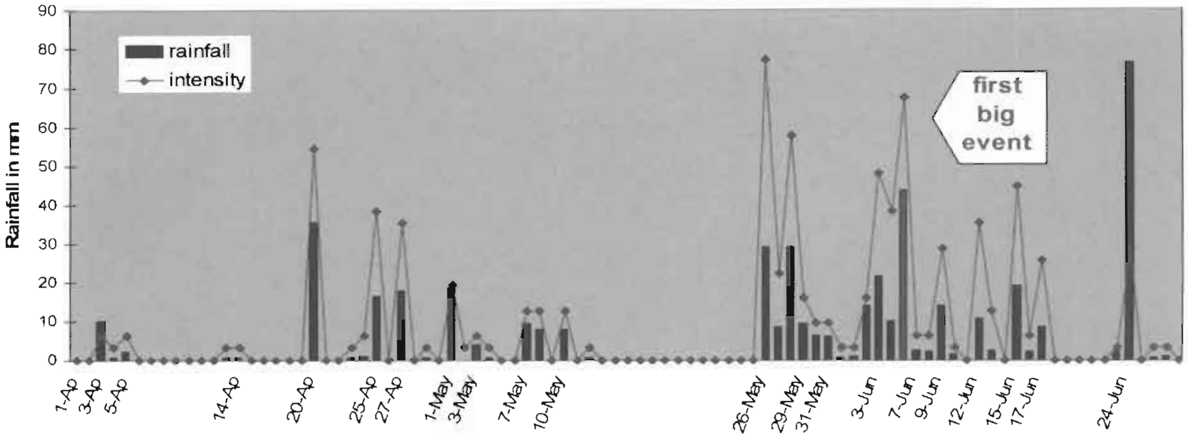

Figure 2: Rainfall pattern at the beginning of the 2005 rainy season: amount of rainfall and intensity

The sediments and suspended load generated by this event were subsequently scrutinised for viable seed by providing good conditions for germination. For stations with outflow (namely one to four and seven), the full set of bottled samples collected at the outlet was used and the presence of suspended seeds in the collected water samples was determined by simply pouring the water over sterile soil (8 kg). At stations where runoff remained in the tank (six, eight and nine, and the full station seven tank), the total amount of water in the tank was used in the experiment. This water was filtered for seeds by passing it slowly through a cotton bag containing 8 kg of sterile soil.

After the rainstorm, all water in the stations was evacuated and the bedload at the bottom of the tank was weighed. Seeds caught in these sediments were analysed by taking a sample that was equivalent to 8 kg of dry soil, from the bedload in the tanks. At stations six, eight and nine, there was not enough total sediment to match 8 kg of dry soil, so extra sterile soil was added to unify germination conditions.

To establish a link between transported seeds and their departure site, soil seed stocks were examined in each of the eight catchments. At the end of the dry season, between 28 April and 4 May 2005 before any rain had fallen, 2-cm deep samples of topsoil were collected, including litter, in each catchment as follows: sub-catchments one to four were sampled by systematic sampling of soil every 20 m along three walking lines: i) on the upper slope, 20 m under the crest, ii) mid-slope, iii) in the riparian zone, approximately 5 m from the stream. Micro-catchments six to nine were sampled systematically every 5 m along the contour line. The contour lines were 10 m apart from each other. Thus in each catchment approximately 100 samples were collected. Samples were cleaned by removing leaves, tree roots and stones, then mixed, and two 8-kg boxes of soil were prepared so as to have two seed stock repeats per catchment.

2.3 Determination of viable seeds in the samples

The soil samples were further processed to determine the number of viable seeds using a simple seedling-emergence method (Kropák, 1966), i.e. by placing them in separate shallow boxes (eight boxes for suspended material, eight for sediments, and 16 boxes for the seed stock), watering them continuously and then examining the various seedlings that gradually emerged. A nursery was built in Lak Sip village to house all the soil samples and keep them safe from external seed intrusions: it was totally covered with mosquito netting and the boxes were placed well above the ground. The boxes were wooden frames with a woven bamboo bottom that permitted free drainage. Thus each catchment was represented by four 8-kg boxes: one suspended load sample, one sediment sample and two seed stock samples. Observations were made every three or four days for five months. Emerging seedlings of common species were counted and carefully removed from the boxes as soon as they were large enough to be identified. Unknown plants and less common species were marked and counted while one or two plants were allowed to grow for identification. Dried voucher specimens were made of all the less common and unidentified plant species. These were brought to the herbarium at Chiang Mai University, Thailand, for identification by Dr J.F. Maxwell.

3. Results and discussion

3.1 Seed flow and erosion in the sub-catchments

The rainstorm on the 7 June 2005 produced a total water discharge in the stream of approximately 817,000 litres (l) over a period of six hours. At the valley outlet about 4,000 kg of suspended material left the catchment (64.6 ha) and an average sediment concentration of 2.63 g/l was measured (table 2).

Table 2: Characteristics of the first rainfall event producing runoff and erosion, 7 June, 2005

	Hydrological stations							
	In the stream - permanent outflow				In a gully - temporal outflow			
	Station 1	Station 2	Station 3	Station 4	Station 6	Station 7	Station 8	Station 9
Total discharge in rainstorm (litres)	182,400	514,500	707,300	818,600	221	158,400	1,683	2,308
Duration of flow (hours, minutes)	2h 20	5h 40	6H 00	5h 15	0h 20	1h 15	1h 25	0h 20
Cumulative suspended load leaving catchment (kg)	804	398	1,498	4,043	0.02	109	0.12	0.30
Mean sediment content of water sampled (g/litre)	1.50	0.81	0.88	2.63	0.09	3.68	0.07	0.13
Bedload sediment in tank (kg)	247	320	560	1,100	3.5	960	1.2	3.5

The amount of extra water in the stream due to the rainstorm was determined at each successive hydrological station on the stream. The amount of water increased from station one to three (table 2, from 182,400 l to 707,300 l) because the drained area was larger - 21.5 ha at sub-catchment one and 56.2 ha at sub-catchment three (table 1). However, the quantity of suspended material did not increase in the same way: far more sediment passed through station one (804 kg) than through station two (398 kg) and the concentration of sediment in the water did not increase either. Indeed, the water passing through stations two and three was remarkably clear, with an average of 0.81 g and 0.88 g sediment/l respectively. The water was considerably more turbid at station one and at the station four outlet (table 2). These irregularities are related to the fact that in sub-catchments two and three, the stream passes through swampy areas where the water is filtered by dense vegetation including Napier grass (*Pennisetum purpureum* Schumach.) and 'Boone' (a variety of *Colocasia esculenta* (L.) Schott).

Approximately 970,000 viable weed seeds were suspended in the water flowing out of the valley (table 3). As with the sediment, suspended seeds seemed to be filtered out in the swampy areas between stations one and two, with seed concentration dropping from 17 seeds/10 l at station one to 5 seeds/10 l at station two.

Table 3: Viable seed transport by runoff and erosion, 7 June, 2005

	Hydrological stations							
	In the stream - permanent outflow				In a gully - temporal outflow			
	Station 1	Station 2	Station 3	Station 4	Station 6	Station 7	Station 8	Station 9
Total seeds in suspended load	304,000	245,000[1]	786,000	972,000	1,423	2,973	25	23
Seeds per 10 litres of runoff water	17	5	11	12	64[2]	<1	<1	<1
Total seeds in bed-load sediment	24,200	8,600	15,700	43,500	7,200	30,100	184	2,700
Seeds per kg eroded soil	98	27	28	40	2,048[2]	31	153	766
Total seed flow per ha	15,200	7,500	14,800	20,200	26,800	61,500	538	5,400

[1] the stream flows through a swampy Napier grass-dominated area where filtration can occur.

[2] 98% of seeds are *Conyza sumatrensis* (Compositae) from five individual plants that happen to grow at the mouth of the station. Their presence has no relation with treatment (improved fallow). If corrected, values are: <1 seeds per 10 l runoff water; 117 seeds in kg eroded soil.

Following the same rainfall event, 2,227 kg of soil was trapped in the four tanks placed in the stream. A total of 92,000 viable seeds was estimated to be in these sediments. Although these large figures may give the impression that huge amounts of seed were carried away in the rainstorm, in fact these represented less than 0.5% of the total seed stock contained in the topsoil. Similar seed stock levels were determined in sub-catchments one to four with a mean viable seed density of 293/m^2 (coefficient of variance of 21%). Hence, a succession of erosive rainstorms would continue to disperse seeds into the flow and the seed stock will not be affected by these losses. In addition, a stock of weed seeds was also found in deeper soil layers. An average density of 1,746 viable seeds/m^2 was determined in plots sampled down to 10 cm (de Rouw et al, 2005). Thus, with progressive erosion, new weed seeds will be continuously available for transport.

3.2 Seed flow, erosion and land use

The relations between land use, erosion and seed flow were studied in the micro-catchments, and strikingly different results were obtained from the three land-use systems. Under improved fallow in sub-catchments six and eight, only a small amount of relatively clear runoff occurred, with an average sediment concentration of 0.09 g/l and 0.07 g/l respectively (table 2). Soil losses were also negligible, at only 12 kg and 3 kg per hectare in stations six and eight respectively. This suggests that under dense fallow vegetation most of the rain infiltrated and that the soil aggregates have excellent structure and good stability. Accordingly, runoff water and sediment carried away very few seeds (e.g. at station eight, only 25 seeds were found in 1,683 l of runoff and 184 seeds in 1.2 kg of sediment, although the seed stock was evaluated at 591 viable seeds/m^2; see tables 1, 2 and 3).

However, in micro-catchment seven, under upland rice cropping (bare soil, recently sown), the situation was very different. The total discharge due to the rainstorm was enormous, 158,400 l , and this water was highly turbid (3.68 g/l of sediment, table 2). However, runoff water carried away few seeds - only 3,000 approximately. Instead, more seeds were dispersed by soil erosion, with approximately 30,000 weed seeds in 960 kg of sediment. Results from this field thus suggest that ordinary slash-and-burn rice fields are particularly sensitive to erosion because the rain hits bare soil, and this is made worse by tillage which disturbs topsoil. A single rainstorm, at the onset of the rainy season, can thus generate erosion at a rate of 2 t/ha. Soil and water erosion cause a large amount of soil and water to be taken away from the cultivated area (Valentin, 2005).

When annual cropping was combined with mulching, as in micro-catchment nine, runoff water was relatively clear (0.13 g/l sediment), and almost no erosion occurred (7 kg/ha sediment), similar to under dense fallow. This indicates that most of the water infiltrated and that the mulch cover protected the soil successfully. It also demonstrates that a field can be cultivated without causing erosion, provided the soil is protected. Yet while the annual mulch inputs from Ruzi grass, cultivated as a cover crop during the dry season and left on the soil rather than being burned, increased soil stability, the same treatment led to a dramatic increase in weed seeds in the soil. The mean seed density of 906 seeds/m2 in surface layers was the highest recorded. The sediment eroded from micro-catchment nine also contained a much higher number of weed seeds compared to the other catchments (table 3). A similar build-up of weed seeds under mulch treatment was demonstrated in northern Laos by Roder et al. (1998).

In summary, the study of the micro-catchments showed that fields which were slashed, burned and recently planted with rice following local practice, had a total seed flow of approximately 61,000 viable seeds/ha. Land covered by well-developed fallow vegetation, on the other hand, had a seed flow of 1,000 viable seeds/ha. Most of these seeds leave the field in sediment; relatively few are just washed down the slope.

3.3 Weed species

More than 120 different plant species were found in the samples, of which 90 could be identified. Most of the seeds were troublesome and aggressive composite weeds and grasses. 74% of seedlings which germinated in the boxes belonged to the Compositae family. Compositae are very common throughout the watershed but do not dominate the vegetation everywhere. Though these plume-shaped seeds are obviously shaped for wind dispersal, erosion-related processes are also a very efficient way of dispersal. One Compositae species, *Ageratum conyzoides* L. accounted for 55% of all germinations, and the second most frequent species, *Spilanthes paniculata* Wall., for 13%; these two weed species dominated the seed stock in all eight catchments.

Micro-catchment six had a higher number of seeds, (1,423 for suspended load and 7,200 in bedload sediments, table 3), than the other catchments, especially relative to micro-catchment eight, which has the same land cover (25 and 184 seeds respectively). Seedlings of *Conyza sumatrensis* (Bth.)Walk, which also belongs to the Compositae family, represented over 90% of germinated seedlings in the samples. *Conyza* was present in the seed stock at a rate of 6% and was absent from the improved fallow vegetation except for a in small patch near the entrance to hydrological station six. Thus its close proximity to the tank, and the fact that even a few individuals of this species produce huge amounts of seeds, can explain the abnormally high quantities found in the suspended and bedload samples. These must have been swept into the tank by rain.

Apart from this exception, it was observed that very few seeds are actually dispersed by runoff in the micro-catchments. In contrast, seeds were abundant in the stream water, at concentrations more than tenfold higher than in runoff. Land in the micro-catchments was all cultivated or fallow fields, whereas in addition to these land types, the sub-catchments include a riparian area and a riverbank.

It is possible that seeds produced by this riparian vegetation in these areas are dropped next to the stream before being carried away into the flow during a rain shower, as was observed for weeds close to station six. This would explain the high density of weed seeds in stream water compared to in runoff water from fields and fallow land. Thus riverbanks and the riparian areas could have a strong, disproportional impact on weed seed dispersal by suspended flows. On examination of the species composition of seedlings which germinated from stream water samples, 11 species were found, falling into two groups. One group, containing five species, consisted of the extremely common weed species, mostly Compositae, which were present in almost all the catchment water samples. The second group of six species only grew from water samples collected in the stream. Four of these species could be identified and all are extremely common in the riparian area and on the riverbank. Although these species are common weeds and are disseminated among the crop and fallow vegetation, the only places where they really dominate the vegetation all year round is in areas close to the stream (*Microstegium ciliatum* A. Camus, *Commelina benghalensis* L., *Oxalis corniculata* L., *Cyperus cyperoides* L. Kuntze, Dovangvongsa, 2005). This result further supports the idea that the riparian area and the riverbank are major sources for most of the weed seeds in the stream during rainstorms.

4. Conclusion

Excessive weed growth resulting from very short fallow periods is at present one of the major constraints on upland production, particularly when farmers only have access to hand tools for removing weeds. Weedy types of vegetation typically produce huge quantities of seeds which are transported away from the parent plant by external agents such as wind, water or animals. This study demonstrates that weed seeds are successfully dispersed in runoff water and soil generated by erosion processes.

At the catchment scale (64.6 ha), a single large rainstorm event generated water discharge in the stream of approximately 818,000 l, carrying weed seeds at an average density of 12 viable seeds/10 l. Weed seeds in sediment occurred at a mean density of 48 seeds/kg of eroded soil. Together, during a single rainstorm, nearly a million viable seeds were exported from the watershed. Hence, it is likely that these weed seeds polluted the cultivated lands lying downstream.

At the field scale, the dispersal of weed seeds depended on the type of cover at the moment of the storm. A bare slash-and-burn field which had been recently cleared and planted with rice, yielded approximately 2 t of sediment/ha and with this about 61,500 seeds/ha left the field. Land covered by dense fallow vegetation did not contribute significantly to seed dispersal because only minor runoff and erosion occurred. Here seed flows of approximately 500 seeds/hectare were observed. Land covered by a dead Ruzi grass mulch did not generate much runoff or erosion either, though about 5,400 viable seeds/hectare were still exported from the field in only seven kilograms of sediments. This is because the practice of mulching instead of burning residues leads to a build-up of weed seeds in the field.

Runoff water flowing over fields or fallow land on the hillslopes was found to contain few weed seeds compared to the high seed densities found in stream water. In addition, seedlings which grew from seeds in the stream closely resembled the floristic composition close to the stream and on the river-bank. This suggests that seeds from the riparian area are mainly responsible for weed seed dispersal in the stream water. It may be concluded that weed seed dispersal during rainstorms could be greatly reduced by management of the riparian area alone, i.e. by replacing the dominant weedy and grassy vegetation with other plants.

References

Dovangvongsa, I. 2005. *Characterisation of vegetation and human activities in the riparian zone of a small headwater catchment, Houay Pano, northern Laos.* Final Report Bachelor's degree (in Lao), National University of Laos.

Kropák, Z. 1966. "Estimation of weed seeds in agricultural soil". *Pedobiologica.* 6:105-128.

Radosevich, S., Holt, J. and Ghersa, C. 1997. *Weed ecology, implications for management.* New York, USA: John Wiley & sons.

de Rouw, A., Phaynaxay, K., Soulilad, B. and Casagrande, M. 2005. "Estimation of weed seeds in cultivated soils, Luang Prabang province, Laos". *The Lao Journal of Agriculture and Forestry.* 11: 79-94.

Roder, W., Keoboulapha, B., Phengchanh, S., Prot, J. C. and Matias, D. 1998. "Effect of residue management and fallow length on weeds and rice yields". *Weed Research.* 38:167-174.

Valentin, C., Poesen, J. and Li, Y. 2005. "Gully erosion: impacts, factors and control". *Catena.* 63: 132-153.

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Luang Prabang, Lao PDR

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Correct citation for this work:

Gebbie, L., Glendinning, A., Lefroy-Braun, R. and Victor, M. (editors). 2007. *Proceedings of the International Conference on Sustainable Sloping Lands and Watershed Management: linking research to strengthen upland policies and practices.* Vientiane: NAFRI.

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