Tillage Erosion on Very Steep Slopes in Northern Laos

B. Dupin[1], K.B. Panthahvong[2], A. Chanthavongsa[3] and C. Valentin[4]

Abstract

In northern Laos, weed pressure is rapidly increasing as a consequence of the shortening of the fallow period. Due to the prevailing steep slopes, weeding operations can induce tillage erosion, which is the process of downhill soil movement caused by the force applied by agricultural tools and gravity. The objective of this study was to assess tillage erosion under on-farm conditions in northern Laos.

The experiment was conducted during the cultivation season of 2001 in the Houay Pano Catchment, located near Ban Lak Sip, in Luang Prabang District. The farmers cultivate upland rice and Job's tears after a 1-3 year fallow period with no external inputs. Tillage erosion due to land preparation was assessed on nine slope gradient classes (30-110 percent), with three replications. Tillage erosion due to weeding operations was monitored over the cultivation period on seven classes of slope in an upland rice field (30-85 percent) and in a Job's tear field (40-102 percent) located on the same Alfisol. In total, 76 measurements were performed, 27 for land preparation, 21 in the Job's tear field, and 28 in the upland rice field. For each measurement, 100 aggregates of 1-2 cm were dried, painted, and used as tracers. They were placed along a contour line marked by a string. Hoeing or weeding was then performed and the distance between each displaced aggregate and this benchmark line was measured, enabling the calculation of the soil flux caused by a tillage pass, and the annual tillage erosion rate per hectare. The results confirm the importance of tillage erosion on steep slopes (2, 4, and 18 t ha^{-1} $year^{-1}$ on slopes with gradients of 30, 60, and 100 percent, respectively). The other factors that affect tillage erosion are weed pressure as long as it increases depth and the number of tillage operations and contact cover because this traps aggregates and so reduces soil displacement.

In northern Laos, soil transported due to tillage are of the same order as those due to runoff as measured at the plot scale under traditional farmers' practices. Alternatives that limit weed infestation and thus tillage operation need to be developed and tested in terms of soil conservation.

Introduction

In northern Lao PDR, farmers practice slash-and-burn agriculture on steep hill slopes. Due to population growth, fallow periods are decreasing, which implies serious problems for the

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restoration of soil fertility and weed infestations. Increasing weed pressure is the major constraint in upland rice production. Not only are labour inputs massive but also frequent hoeing increases the risks of soil loss. Farmers cultivate upland rice and Job's tears after a 1-3 year fallow period and must allocate an increasing number of days to weeding operations (Table 1). Due to the prevailing steep slopes, these operations can induce tillage erosion. Tillage erosion is the process of downhill soil movement caused by the force applied by agricultural tools and gravity. This process (manual tillage erosion) was studied by Turkelboom *et al.*, in 1999 in northern Thailand to estimate soil losses due to deep (15 cm) hoeing operations. Soil flux by tillage erosion has been quantified as a function of slope angle and slope length. In Laos this manual practice consists of a very shallow scraping of the soil with two types of hoe to cut the weeds. However the repetition of this operation can lead to high levels of erosion. The objective of this study was to assess tillage erosion under on-farm conditions in northern Lao PDR.

Table 1. Cultivation practices for upland rice and Job's tears (cropping seasons 2001 and 2002)

	Upland rice		Job's tear field		
	Days ha^{-1}	Labour Input (%)	Days ha^{-1}	Labour input (%)	Tools
Field preparation (March)	41	14.5	27	14.0	Machete
Burning (April)	1	0.4	1	0.5	
Land preparation (May)	26	9.2	25	13.0	Hoe
Planting (June)	43	11.0	8	4.1	Bamboo stick
1st weeding (June)	36	51.9	53	55.4	Curveding hoe
2nd weeding (July)	38		22		Curveding hoe
3rd weeding (Aug)	38		32		Curveding hoe
4thrt weeding (Aug)	35				Curveding hoe
Harvest and transport (Sept)	25	8.8	25	12.9	Curveding hoe
Total	283	100	193	100	

Materials and Methods

The experiment was conducted during the cropping season of 2001 in the Houay Pano Catchment, located near Ban Lak Sip, in Luang Prabang District. The farmers weed their fields going up the slope.

Before starting the experiment, different tillage tools and techniques were noted while farmers were weeding. In addition, cultural history and the consequences of land use change were discussed with farmers. We mainly focused on the use of tillage.

The fields of Job's tears (*Coix lacryma Jobi*; "Mak Deuay" in Laotian,), are usually weeded twice whereas the rice fields require three or four weeding operations depending on the intensity and the type of invasion.

Tillage operation due to land preparation was assessed on nine slope gradient classes (30-110 percent), with three replications in a two-year fallow slashed, burnt, and traditionally hoed by farmers. Tillage erosion due to weeding operations was monitored over the cultivation period on seven classes of slope gradient in an upland rice field (30-85 percent) and in a Job's tear field (40-102%) located on the same Alfisol. In total 76 measurements were performed, 27 for land preparation, 21 in the Job's tear field, and 28 in the upland rice field.

For each measurement, we used the tracer method, which was the most reliable, as tested by Turkelboom *et al.* (1999). For each measurement, 100 aggregates of 1-2 cm were dried, painted, and used as tracers. They were placed along a contour line marked by a string. Hoeing or weeding was then performed and the distance between each displaced aggregate and this benchmark line was measured, enabling the calculation of the soil flux caused by the tillage pass, and the annual tillage erosion rate per hectare.

The soil mass that passes a unit contour length for one tillage pass, or soil flux Qt (Turkelboom *et al.,* 1999), was calculated using Eq. (1)

$$Qt = D_m Dr \qquad (1)$$

where Qt is the soil flux caused by tillage (in kg m^{-2} tillage $pass^{-1}$); D_m the mean downslope displacement distance of the tracers (m); D the mean tillage depth (m) and r the bulk density of the soil (kg m^{-2}), as measured with the cylinder method.

Mean soil losses per hectare for one tillage pass can be derived from the soil flux Eq. (1) and from the downslope field length using Eq. (2):

$$TE = Qt\,10/L \qquad (2)$$

where TE is the tillage erosion rate (t ha^{-1} tillage $pass^{-1}$), Qt the soil flux caused by tillage (kg m^{-2} tillage $pass^{-1}$); and L the downslope field length (m). To enable comparisons, a fixed value of L (50 m) was used.

Contrary to seedbed preparation, weeding is not space continuous. This manual practice consists of a very shallow scraping of the soil with a hoe to cut the weeds.

Tillage erosion due to weeding is given by Eq. (3):

$$TE_w = S_w\, TE \qquad (3)$$

Where TE_w is the tillage erosion rate (t ha^{-1} tillage $pass^{-1}$) due to a weeding operation; TE the tillage erosion rate derived from Eq. (2); and S_w the area effectively tilled during the weeding operation. In practice, we used C_w as a surrogate to S_w.

Knowing the number of hoeing (n_h) and weeding (n_w) operations, the annual tillage erosion (ATE) can be calculated using Eq. (4):

$$ATE = n_h\, TEp + n_w\, TE_w \qquad (4)$$

Where ATE is the annual tillage erosion (t ha^{-1} $year^{-1}$); TE_h and TE_w (t m^{-2} tillage $pass^{-1}$) are the tillage erosion due to hoeing and weeding operations, respectively; and n_h and n_w the number of hoeing and weeding operations, respectively.

Results

Soil Losses Due to Hoeing

Due to their growing capacity, *Graminaeae* and bamboos were systematically uprooted. Nevertheless hoeing remains most often very superficial with a mean depth of 2 cm. Figure 1 shows clearly the influence of the slope gradient.

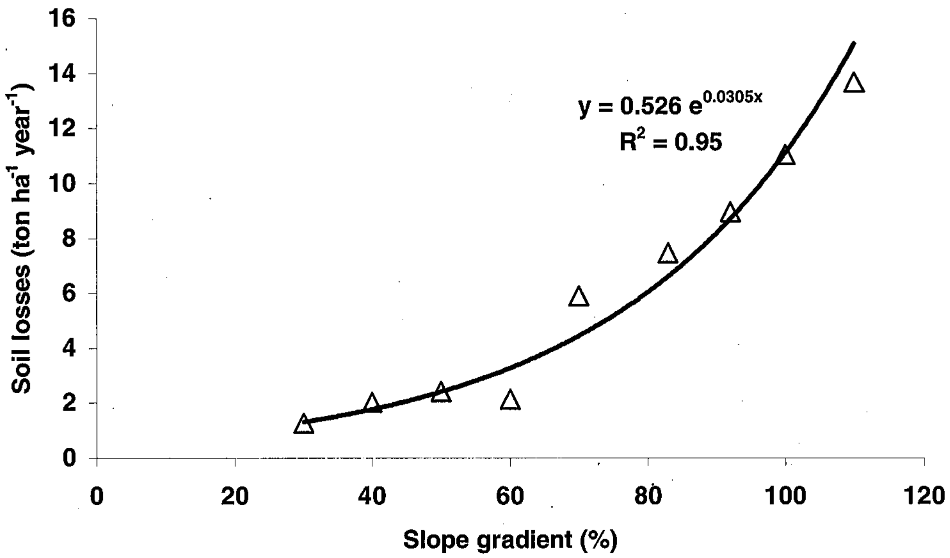

Figure 1. Tillage erosion due to hoeing as influenced by slope gradient

After burning on the short fallow, weeds infest the field and cover all the field area. Farmers are forced to hoe their fields to limit weed competition with the crop.

Tillage erosion due to this operation depends on aggregate stability, soil smoothness, and contact cover. The first operation affects stable aggregates that are reinforced by roots whereas a second hoeing displaces smaller aggregates on a smoother soil surface. As a result the second weeding generates higher tillage erosion because the soil surface is smoother and aggregates can thus roll further down. Usually, farmers practice only one hoeing but if they delay between this operation and the seeding they may need a second hoeing with higher associated tillage erosion rates.

Soil Losses Due to Weeding

The weeding operation consists of a very shallow scraping of the soil with a curved hoe. The repetition of this operation leads to important soil losses for both crops (Figures 2 and 3).

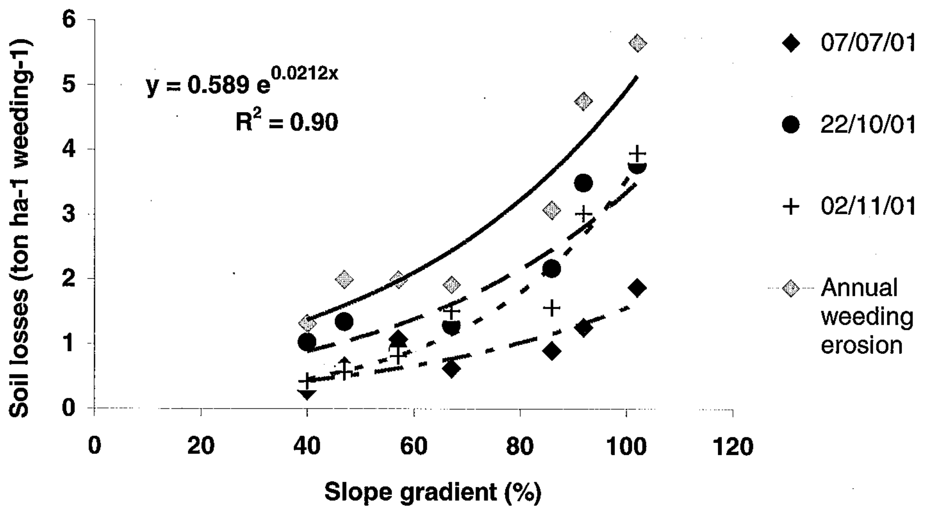

Figure 2. Tillage erosion due to weeding as influenced by slope gradient for Job's tears

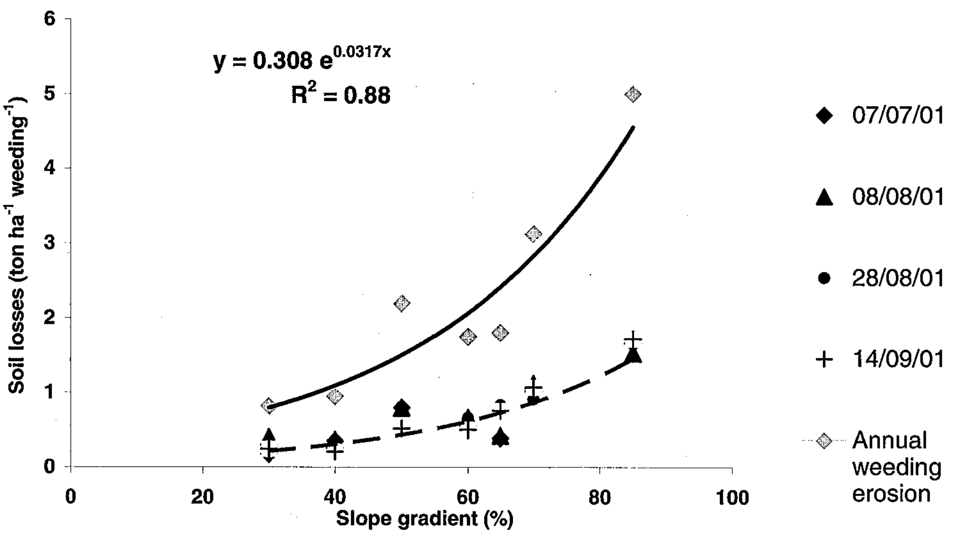

Figure 3. Tillage erosion due to weeding as influenced by slope gradient for upland rice

Weeding operations generate different rates of tillage erosion depending on several factors. These include the area effectively tilled and the contact cover that prevents the area from being displaced. This contact cover, directly in contact with the soil, is essentially composed of slashed weeds that are either left on the soil or gathered together. The basal cover of the crop is also a component of this cover since it is an obstacle to aggregate displacement. Contact cover plays a key role as it influences aggregate displacement distance and thus tillage erosion. Steeper slopes have more effect.

A multivariate regression based on the experiments shows a high significant relation (R^2 = 0.86) between the mean downslope displacement distance of the tracers (D_m), the slope gradient (S, %), and the contact cover (C_c, %), Eq. (5), Figure 4. Tillage erosion can thus be estimated replacing Qt as a function of the slope and the contact cover:

$$Qt = 44.42\ e^{(0.0265\ S\ -\ 0.0185\ Cc)}\ Dp) \qquad \text{Eq (5)}$$

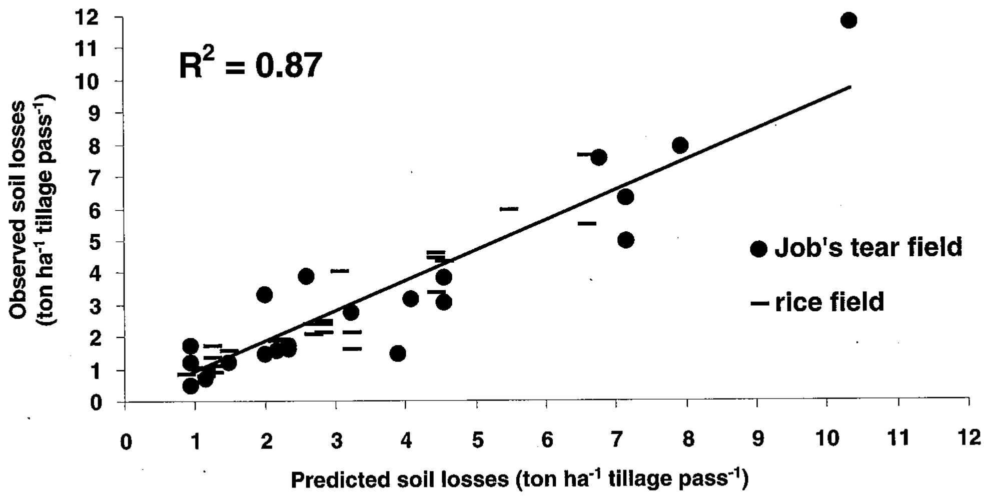

Figure 4. Relation between predicted values and observed values

Annual Tillage Erosion

Annual tillage erosion is high in both crops (Table 2). It is slightly higher for the steeper fields cultivated with upland rice than Job's tears because weeding erosion in an upland rice field is more severe than in a Job's tear field as this crop requires three weeding operations instead of two for Job's tear cultivation.

Table 2. Annual tillage erosion estimated from Eq (5) for Job's tears and upland rice

	Annual tillage erosion (t ha^{-1} yr^{-1})	
Slope gradient (%)	**Job's tears**	**Rice**
30	2.3	2.1
40	3.3	3.1
50	4.1	3.9
60	4.2	4.1
70	8.6	8.7
80	11.0	11.8
90	13.2	14.8
100	16.05	18.6
110	20.0	23.7

On a mean slope of 60 percent, soil losses due to tillage erosion are of the same order as those due to runoff as measured at the plot scale under traditional farmers' practices (5.7 t ha^{-1} $year^{-1}$; mean over five years, Phommasack *et al.*, 1998, 1999)

Discussion and Conclusion

Tillage erosion results from land preparation and from repeated weeding operations. Erosion in here is defined as the movement of soil from the higher elevation to and deposition at the lower portion of the slope. Our data confirm the importance of this erosion on very steep slopes and the exponential nature of the relationship between tillage and slope gradient.

The other factors that affect tillage erosion are weed pressure that increases depth and the number of tillage operations and contact cover that traps aggregates and thus reduces soil displacement.

In northern Laos, in a field with a mean slope of 60 percent, soil losses due to tillage erosion are of the same order of magnitude as those due to water erosion (4-5 t ha^{-1} $year^{-1}$). These soil losses affect the most fertile soil layer. Soil clods detached by tillage operations accumulate in the depressions or at the field limits.

Because of the increasing weed pressure, tillage erosion is likely to become very serious, especially on the steepest slopes, which will become more frequently cultivated. Alternative practices that limit weed infestation and thus tillage operations need to be developed. Where a short fallow period is still possible, improved fallow should be tested. This includes sowing pigeon pea (or *Crotalaria, Leucaena, Gliricidia*) in the previous crop (NAFRI, 2002). Pigeon pea grows faster and provides more nutrients to the soil than a fallow composed of natural species, and can limit weed proliferation. Two other practices can also limit tillage erosion. The first is the no till system that consists of mixing cropping cereals and the cover crop. The field is prepared without burning and without tillage operations. The cover crop reduces weed growth and the mulch provides nutrients. The second is contour planting. This limits soil movement as the soil moves downslope and accumulates in the lower portions of the alley. It induces the formation of terraces. The topsoil from the upper part of the alley moves downslope and accumulates in the lower part. Although terraces decrease tillage and water-induced erosion, they generate a dramatic change in soil physical, chemical, biological, and hydrological properties (Thapa *et al.*, 1999).

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Cover Photograph: Gullies formed on cultivated steep slopes, Houay Pano catchment, Lao PDR, photo. A. de Rouw.