Soil Erosion and Land Use in the Dong Cao Catchment in Northern Vietnam

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Abstract

The general goal of MSEC is to support farmers to conserve land and water resources, minimize natural resource degradation, and alleviate poverty through the enhanced adoption of sustainable land and water management systems on sloping lands. During the last three years, soil erosion management research has been conducted in the Dong Cao Catchment in northern Vietnam. The site has an area of 45 ha and is cultivated mostly to cassava. It was equipped to measure water budget, soil loss, and soil and water quality. There was a high annual variability of soil loss (from 1-15 t ha^{-1} $year^{-1}$) and this depends on both the amount and intensity of rainfall and the kind of land use. For example, soil loss in 2001 was six times more than the other years. The year 2001 had the highest total annual rainfall and a large proportion of the catchment was cropped with cassava. The suspended load measured during a rising flow showed that it can be even higher than the bedload and represents a large proportion of the total soil loss. Farmers in Dong Cao village are now more aware of the impact of land use on soil loss and soil fertility decline. Dialogue with farmers and different stakeholders from the local government, agricultural institutes, and research programs has been conducted to develop better understanding of how river basins respond to socio-economic changes.

Introduction

Soil erosion is commonly observed in sloping lands especially in the tropical zones of Southeast Asia. Farming and other economic activities in these areas have become environmentally unsustainable causing deleterious on- and off-site effects. While there have already been many studies conducted on soil erosion control and management, the results have not had any significant impact on sustaining upland development. It is now recognized that soil erosion cannot be studied in isolation from agricultural practices, but as part of a more complex problem including both biophysical and socio-economic considerations.

In 1999, the Management of Soil Erosion Consortium (MSEC) initiated a project aimed at developing and promoting sustainable and socially acceptable community-based land management options through a participatory and interdisciplinary approach in six countries in Asia, with support from the Asian Development Bank (ADB). The approach considered the catchment as the unit of study to develop soil conservation practices that are economically

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acceptable to farmers; to promote better land management decisions at the field and basin levels; and to encourage knowledge sharing across national and disciplinary boundaries. In essence, the catchment has served as a field laboratory for research and capacity building with local partners.

In Vietnam, the research was conducted on a 45 ha catchment on the sloping area of Tien Xuan commune, Luong Son District, Hoa Binh Province, 80 km from Hanoi, inside the Red River Basin (Figure 1). The Red River Basin is now confronted with the increasing challenges of water scarcity, population increase, and environmental degradation. The catchment was furnished with instrumentation for soil erosion and hydrological monitoring to evaluate the interactions between rainfall, runoff, groundwater, topography, soil quality, land cover, and climate to assess and predict the impact of land use and land management on soil losses, soil fertility, and solute transport in and through the watershed. This paper presents the results of three years of observation and monitoring of the biophysical and socio-economic changes in the Dong Cao Catchment in Vietnam. An attempt was made to relate its hydrological behavior with soil erosion, land use, and farm productivity.

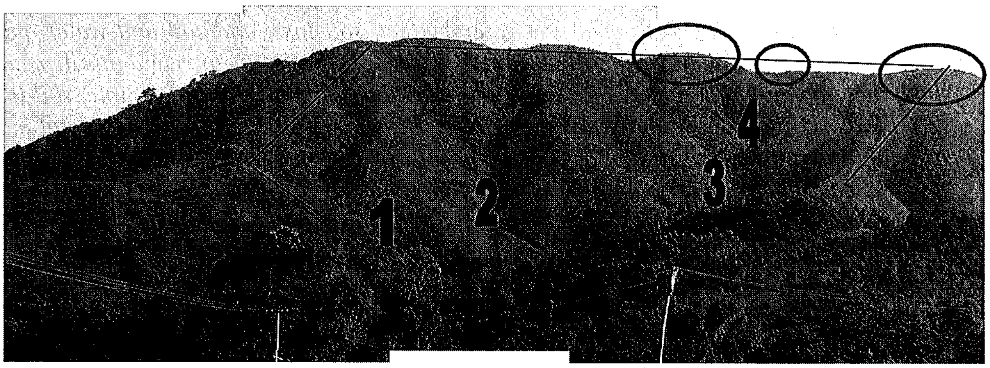

Figure 1. Overview of Dong Cao Catchment from the north (in June 2001). Watershed limit (red line) and mountain peaks (encircled in pink). The numbers indicate location of weirs

Approach and Methodology

The Study Site

The study site is about 45 ha and cultivated by farmers from Dong Cao village with mainly cassava in association with some trees (*Venitia montana, Acacia mangium*). The farmers (around 40 farm households and 200 inhabitants) share their work time between the lowlands to crop irrigated rice and the uplands to augment their income. The mean slope is 45 percent and the steepest slopes of around 120 percent are situated in the middle part of the basin, which is largely cultivated. The watershed was equipped to collect meteorological and hydrological data and evaluate soil losses on the sloping lands (Figure 2). The methodology for site characterization and instrumentation, data collection, monitoring and analysis for the evaluation of the on- and off-site effects of erosion was described in Toan *et al.* (2001).

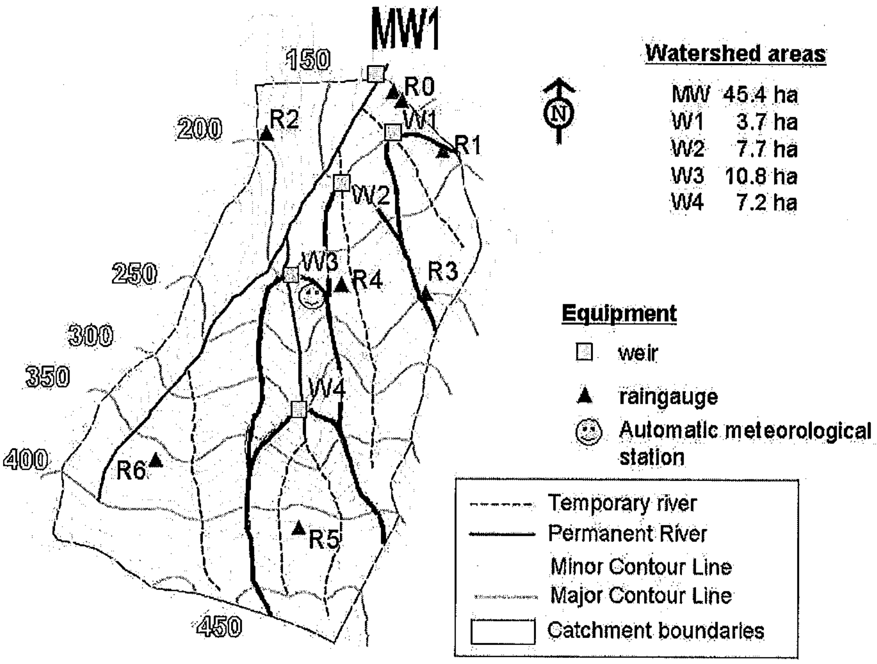

Figure 2. Distribution and location of equipment in the Dong Cao Catchment

Data Collection and Analysis

The catchment has four sub-catchments, identified as W1, W2, W3, and W4. Sub-catchments W1, W2, and W3 were equipped with sediment traps and weirs before they intersect with the main stream. One weir (MW) is on the main stream at the outlet of the catchment, and another (W4) is on the upper part inside the catchment above W3. Each sub-catchment has the same drainage intensity of around 8 m km^{-2}. The water level in each weir was recorded automatically (every five minutes) using Orphimedes-type automatic water level recorders. Water discharge calibration was also done. The total bedload sediments from each trap were weighed twice a month if it rained. Some soil, water, and sediment samples were analyzed at the NISF laboratory for chemical and physical properties. In 2002, three automatic sediment samplers (ASS) were set respectively on the main weir, W2 and W4. Since it was impossible to collect the water samples from each weir, the suspended sediment samples were collected only from the main weir and during four storm events. A survey via informal discussions with local farmers and key informants of the village was conducted to collect information from individual households on socio-economic conditions and agricultural practices.

Land Management Options

The hedgerow cropping system, a promising control practice, was introduced by the project as a land management option to reduce erosion and increase income. In this system, rows of shrubs, grasses, or perennial crops were planted at regular intervals across the slope of the field. Traditional crops are grown in the alleys between the hedgerows. The year 2002 was the last year for the diagnostic phase of catchment calibration. So now, new agro-ecological techniques have been proposed for evaluation in 2003. Moreover, a new weir has been installed to expand the results to a larger scale of around 120 ha.

Results and Discussion

Catchment Description

Soil distribution

The soils of the Dong Cao site have been mapped and represented as one single unit. The parent rock is volcanic-sedimentary schist, sometime presenting hard layers. The soil is deep (> 0.80 m) on hilltops and generally shallow (40-50 cm) on convex areas. Roots can however penetrate deeper through soft weathered rock beds between harder schist layers.

Very nice apparent runoff crusts with embedded stones occur on rectilinear slopes, especially on convex forms below matured cassava plants. This crust forms after weeding, which prevents the growth of new weeds. Soils located at surrounding summits where land is not totally cleared and with minimal erosion have a well-differentiated dark horizon. Other soils located on slopes or at the top of low hills (left bank, downstream of W3), show a very weak vertical differentiation of color, texture, and structure. The X-ray determination of four surface soil samples showed the strong predominance of kaolinite. This clay is accompanied with a very small amount of illite.

Climate

The climate of northern Vietnam (situated between 16 and 18 °N) is humid sub-tropical. The representative meteorological station of Dong Cao village is the Hoa Binh station, where the annual average is around 1,500 mm (average for 1961-2000). The main climatic characteristic is the strong yearly monsoon. In general, 80 percent of the rainfall occurs between May and October with a maximum in August. This season is also marked by a high rainfall hourly intensity of around 20-60 mm h^{-1}. During the winter, the air temperature is low, around 16-17°C between December and February; the monthly rainfall is less than 50 mm. Air humidity is high, often above 90 percent despite the low amount of rain.

The monthly rainfall has also a high interannual variability. For example, in August, the rainfall for the month could vary from 150-450 mm. Indeed one of the characteristics of the North Vietnam climate is its strong instability, which makes weather forecasting difficult. Thus, when the monsoon winds from the southwestern section are weakened by winds coming from Laos, periods of dryness can occur during the months which are usually the rainiest. The El Niño phenomenon also has an impact on the climate of this area: it leads to a period of dryness during the summer and a shift of the rainy season to September or October. In 1983, which was an El Niño year, it was dry in June, but October was especially humid (450 mm of rainfall against 150 mm in an average year). The rainfall deficit in June during the vegetable growing period has major consequences for the crop yields, since rainfall occurs when it is not needed.

This significant climatic variability creates some difficulties for farmers' food and income stability. Furthermore, at the beginning of the rainy season, all factors increasing the erosion process are present in the Dong Cao Catchment. These include high intensity rains, steep slopes, little ground vegetative cover, and inappropriate cultivation practices that generate erosion.

Catchment Hydrological Behavior

The monthly rainfall in the catchment showed similar behavior from 1999 to 2002 (Figure 3). The rainy season started at the beginning of April and ended in late September in 1999 and in October in other years. During the period, the Dong Cao Catchment was marked by one humid year, in 2001, with a total annual rainfall of 2,540 mm. Moreover, a total monthly rainfall of more than 600 mm was observed in July. It was an El Niño year in 2002 with July being especially dry and October being especially wet. However rainfall intensity behavior did not change: on the average, 60 percent of rainfall events have had an intensity of 5-25 mm h^{-1}, 15 percent with 25-50 mm h^{-1}, 10 percent with 50-75 mm h^{-1}, and 15 percent above 75 mm h^{-1}. The strong events occurred in June, July, and August in 2001 and in October 2002. The rainfall events varied from 81 in 1999 to 131 in 2001.

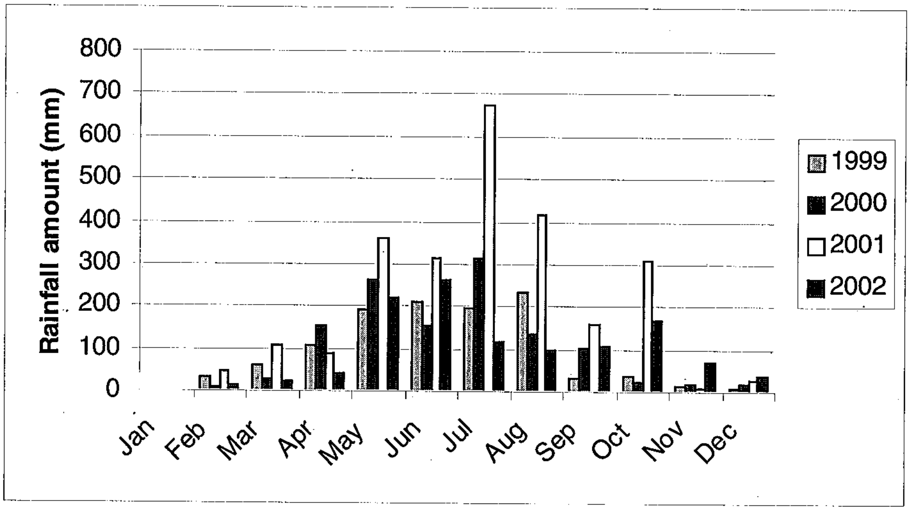

Figure 3. Monthly rainfall (in mm) in the Dong Cao Catchment from 1999 to 2002

The yearly runoff at the main outlet was around 15 L s^{-1}, with maximum flow in July and minimum flow in February. The largest monthly flow measured during 2000 to 2002 was in July 2001 with 60 L s^{-1} (Figure 4). The water volume which flowed in the stream during the whole year showed that the amount in 2001 was twice that in 2000. The runoff coefficient was about 50 percent in 2000 and 2001 and 65 percent in 2002. This means that a larger part of the rainfall in 2002 was lost by the watershed. This was certainly due to the major rainfall events in October 2002 (169 mm in five events). It was noted that the runoff coefficient was exceptionally high and the runoff of October recorded a second peak flow.

Only W3 and W4 recorded a continuous flow. In 2002, the annual runoff at the main weir (MW) was about 11.6 L s^{-1}. Runoff from W3 represents only 10 percent of this flow, while runoff from W2 and W4 accounted for 5 percent (Table 1). The runoff coefficient of these three sub-catchments ranged from 20-29 percent. The smallest sub-catchment, W1, recorded some flow only from May to July and in October. The runoff coefficient was very low indicating the high infiltration capacity of this sub-catchment, which incidentally was used for agroforestry.

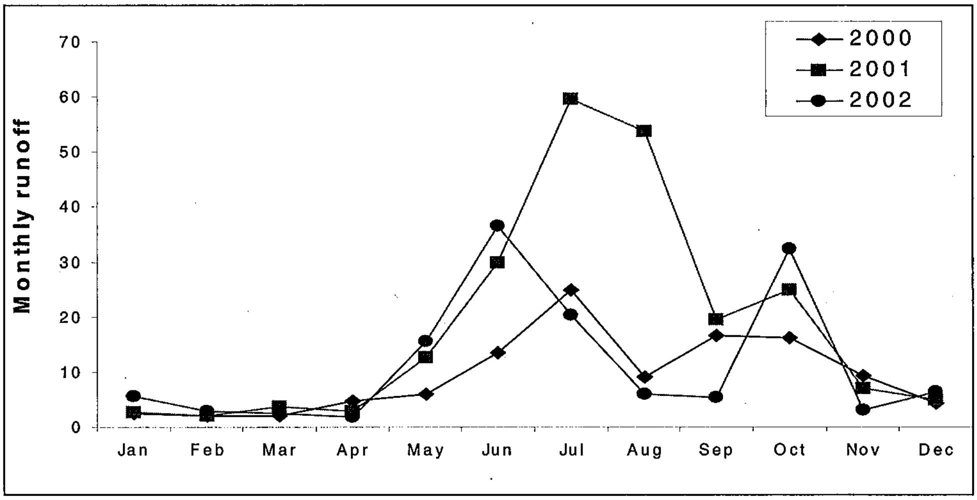

Figure 4. Monthly runoff (in L s^{-1}) in the Dong Cao Catchment from 2000 to 2002

Table 1. Monthly runoff of the main outlet and the outlets of each sub-catchment of the Dong Cao Catchment in 2002

Month	**Runoff (L s^{-1})**				
	MW	**W1**	**W2**	**W3**	**W4**
January	5.57	0.000	0.000	0.73	0.02
February	2.99	0.000	0.000	0.54	0.02
March	2.27	0.000	0.000	0.34	0.02
April	1.94	0.000	0.000	0.28	0.04
May	15.6	0.009	0.196	0.96	0.66
June	36.6	0.031	4.256	5.58	1.89
July	20.4	0.022	3.043	1.53	1.29
August	5.85	0.000	0.000	0.73	0.39
September	5.43	0.000	0.000	0.60	0.40
October	32.4	0.012	0.179	1.27	0.87
November	3.10	0.000	0.000	0.77	0.50
December	6.40	0.000	0.020	0.68	0.30
Yearly mean	11.6	0.006	0.641	1.17	0.53
Total water volume (m^3)	366,457	197	20,240	36,776	16,840
Surface area(ha)	45.5	3.7	7.7	10.8	7.2
Runoff (mm)	805	5	263	341	234
Rainfall (mm)	1,191	1,191	1,191	1,191	1,191
Runoff/rainfall ratio	0.68	0.0045	0.22	0.29	0.20

The monthly behavior of the runoff is the same for each weir (Figure 5). The rainfall had the same behavior in the entire catchment and consequently each weir showed a similar annual hydrograph in direct relation to the area of each sub-catchment, except for W1 where the flooding seemed quicker, presumably because of high infiltration.

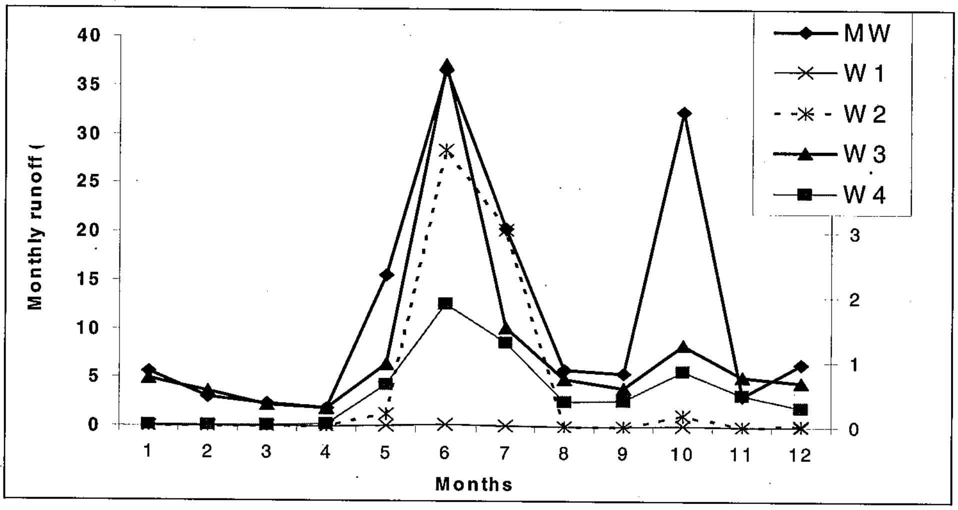

Figure 5. Monthly runoff (in L s^{-1}) during 2002 for each hydrological station of Dong Cao Catchment

The monthly runoff coefficient was very low from January to May and from August to December (around 20 percent for the main weir) and the largest part of the rainfall during this time was trapped by the soils and vegetation. Thus, the surface runoff becomes important only during June and July.

The hydrological behavior observed in the catchment showed that floods begin to occur with rainfall higher than 20 mm (and an average intensity of 50 mm h^{-1}). For example, there were only 14 rainfall events in 2002, which caused some flooding. It was also shown that the time lag between rainfall and runoff was very short, the rising runoff was maintained for about two hours on the average, and this rise took place during the night.

Soil Erosion and Nutrient Loss

Table 2 shows the total soil loss from the Dong Cao Catchment measured at the main weir. This represents the sum of the bedload and suspended load for 2001 and 2002 when measurement of the suspended load was done. No measurement of suspended load was conducted in 1999 and 2000.

Bedload

The yearly bedload measured at the main weir was estimated at 1.37 t ha^{-1} $year^{-1}$, ranging from 0.4 to 4 t ha^{-1} (Table 3, Figure 6). The observed monthly bedload for all years is shown in Figure 7. All the outlets of the sub-catchments showed the same behavior of the yearly bedload. The bedload also had a large monthly variability. The highest bedload was observed in May and July, with a range 0.2-0.3 t ha^{-1} per month. The same monthly behavior was observed in all sub-catchments.

Table 2. Total bedload measured at each weir and suspended load measured at main weir

Bedload (t ha^{-1})				
Weir (area, ha)	1999	2000	2001	2002
W1 (3.7)	0.93	1.23	6.69	1.30
W2 (7.7)	0.94	1.06	5.31	1.92
W3 (10.8)	0.43	0.37	1.59	0.78
W4 (7.2)	0.35	0.49	3.14	0.60
MW (45.5)	0.44	0.64	3.96	0.45
Suspended load (t ha^{-1})				
MW (45.5)	-	-	5.18	3.01
Total soil erosion (t ha^{-1})	0.44	0.64	9.14	3.46

Table 3. Yearly bedload measured from the outlets of the sub-catchments and main outlet of Dong Cao Catchment from 1999 to 2002

Year	**Bed load (t ha^{-1})**					
	MW	**W1**	**W2**	**W3**	**W4**	**Total**
1999	0.44	0.93	0.94	0.43	0.35	3.09
2000	0.64	1.23	1.06	0.37	0.49	3.79
2001	3.96	6.69	5.31	1.59	3.14	20.69
2002	0.46	1.30	1.93	0.79	0.60	5.08
Average	1.37	2.54	2.31	0.79	1.15	8.16

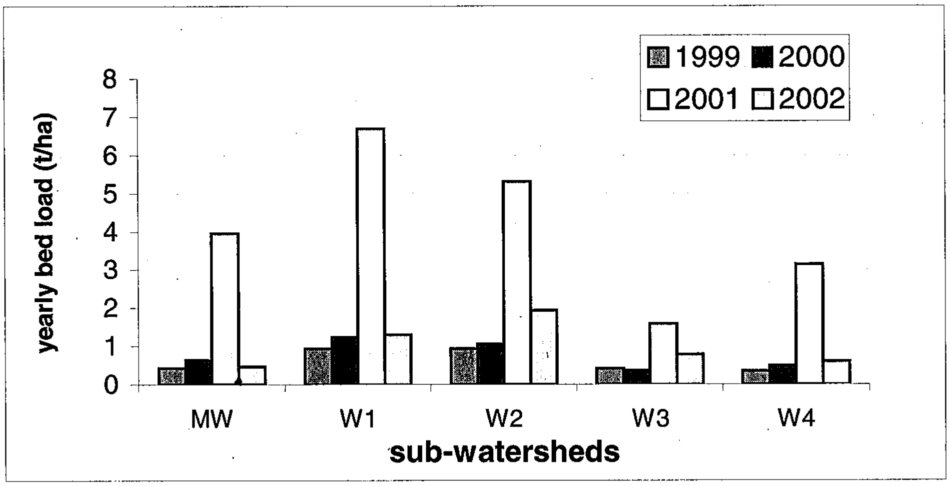

Figure 6. Yearly bed load (t ha^{-1}) from 1999 to 2002 for each weir of Dong Cao Catchment

It was observed that the bedload was relatively lower in 2002. The highest bedload was observed in W2 (2 t ha^{-1}) where cassava was planted. The other sub-catchments had bedloads of not more than 1 t ha^{-1}. This observation can be explained by the lower rainfall and the denser grass cover in 2002. Because 2002 was a relatively dry year, the area that was cultivated was smaller than the previous years and the areas earlier cultivated had been left with wild grasses. The effect of the hedgerows on soil erosion in W3 cannot however be accounted for.

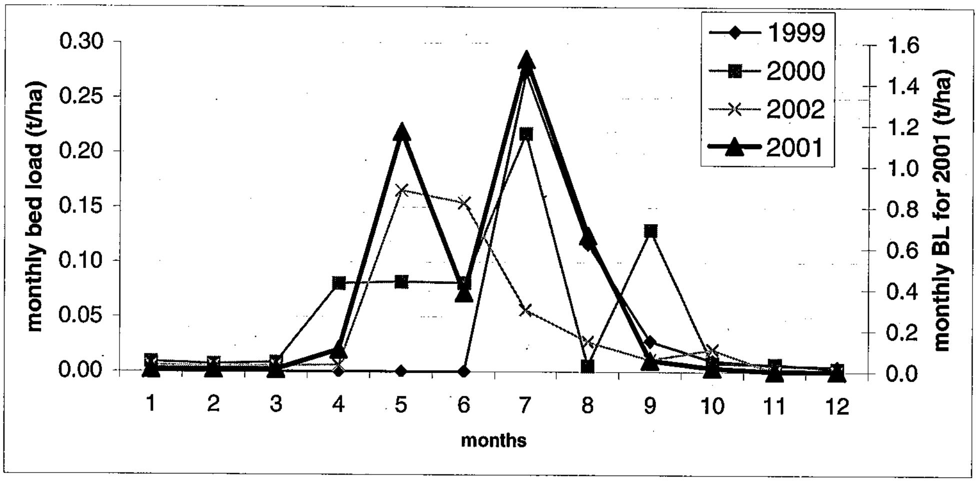

Figure 7. Monthly bedload (in t ha^{-1}) from 1999 to 2002 at main weir of Dong Cao Catchment

Suspended load

In 2002, the suspended sediments sampled from four rising events (7 July, 9 August, 30 August, 4 October) were measured on the main weir. The automatic samplers installed on W2 and W4 were not functioning. On the average, the mean suspended load during a rising period ranged from 0.9-2.9 g L^{-1} with a maximum load between 3 and 5 g L^{-1} (Table 4). This level of suspended load is high for stream water. It was noted that the suspended load remained high at around 0.5 g L^{-1} even after the discharge peak. Table 4 also shows that the highest suspended load was observed during the highest rainfall despite the fact that this occurred in October when the ground was well covered by vegetation.

Table 4. Suspended load measured at the main outlet of the Dong Cao Catchment during the rising phase of runoff at selected rainfall events in 2002

Characteristics	Event date in 2002			
	7 July	**9 August**	**30 August**	**4 October**
SL average (g L^{-1})	0.91	1.89	1.87	2.89
SL max (g L^{-1})	2.92	4.75	3.93	5.22
SL min (g L^{-1})	0.34	0.59	0.45	1.42
Event duration (min)	90 min	130 min	100 min	160 min
H / Q max (m) / (L s^{-1})	1.27 / 1, 120	1.04 / 120	1.02 / 76	1.1 / 305
H / Q min (m) / (L s^{-1})	0.87 / 8.6	0.83 / 3.5	0.82 / 2.6	0.82 / 2.6
Water volume (L)	1, 470 l	190 l	130 l	260 l
Rainfall amount (mm)	40 mm	20 mm	20 mm	64 mm

Figure 8 shows the behavior of the suspended load during the rising event of 9 August. This behavior was also observed in the other events, the maximum load occurring before the water peak and then decreasing in direct relationship with the water level decrease.

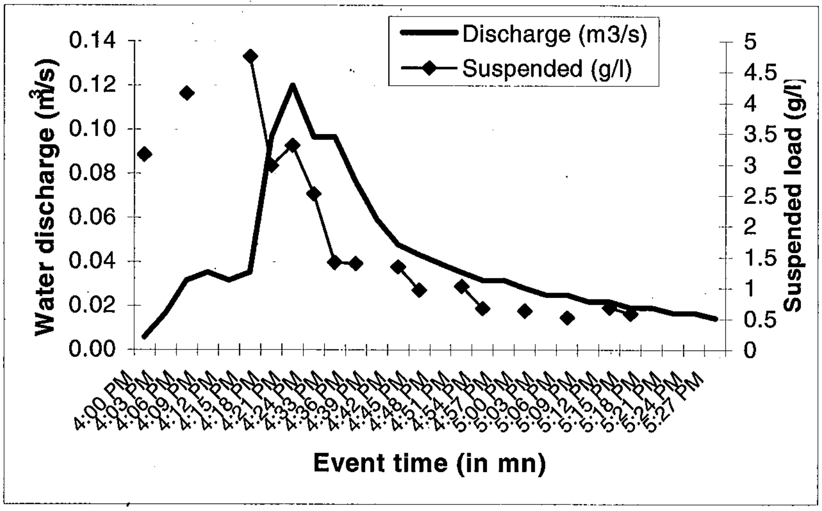

Figure 8. Suspended load (in g L^{-1}) during a rising event (August 9, 2002) in the main weir of Dong Cao Catchment

The suspended load measured in 2001 was estimated at 2.5 t ha^{-1} on the average compared to 3.4 t ha^{-1} in 2002. The value for 2001 was almost the same as the bedload while the suspended sediment was eight times the measured bedload in 2002. Thus, these few measurements of suspended load indicate the significance of this component in evaluating soil erosion in the Dong Cao Watershed.

Nutrient loss

Table 5 shows that the amount of suspended sediments carried by the runoff water measured at the main weir contained substantially higher amounts of nutrients than those contained in the bedload. In 2001, 380 kg ha^{-1} of OM, 21 kg ha^{-1} of N, 20 kg ha^{-1} of P_2O_5, and 8 kg ha^{-1} of K_2O were lost through water erosion. These amounts correspond to only 254, 7, 9, and 6 kg ha^{-1} of OM, N, P_2O_5, and K_20, respectively. The same trend was observed in 2002 but with a very much higher proportion of lost K_2O. This observation clearly indicates that soil erosion causes nutrient loss, which causes soil fertility decline on site and ultimately low crop yields and farmers' income.

The nutrients contained in the suspended sediments could be carried further down to rivers and reservoirs. In the study site, the Dong Cao River flows to the Cua Khau Reservoir. An analysis of the sediment samples from this reservoir showed some 1.6 percent OM, 0.15 percent N, 0.1 percent P_2O_5, and 1.3 percent K_2O (Table 6). These amounts are comparable with the nutrient contents in the uplands and the lost soil. In fact, it contains more OM and potassium than the upland soil. This shows that erosion seems to concentrate the fertility of the soil downstream.

Table 5. Total nutrient loss from the Dong Cao Catchment

	Nutrient in bedload (kg ha^{-1})											
	2000				2001				2002			
	OC	N	P_2O_5	K_2O	OM	N	P_2O_5	K_2O	OM	N	P_2O_5	K_2O
W1	58.1	1.6	3.4	2.2	342.5	16.5	16.8	7.8	26.3	3.5	1.3	5.7
W2	49.6	1.8	3.4	3.4	297.4	14.5	15.3	4.0	45.1	4.6	1.9	2.1
W3	18.3	0.9	1.3	1.2	86.8	4.7	4.9	1.7	15.5	1.6	0.9	1.7
W4	26.8	1.4	1.6	1.8	210.7	7.9	10.1	3.3	11.7	1.1	0.7	1.0
MW	20.1	1.0	1.7	2.5	253.8	7.3	9.1	6.4	8.4	0.9	0.5	0.9
Nutrient in suspended load (kg ha^{-1})												
MW	-	-	-	-	379.7	21.2	19.7	8.3	52.7	5.4	2.1	51.5

Table 6. Nutrient content of the suspended load (SL) and bedload (BL) sampled at the main weir, soil sample from W3, and the sediment sample from the Cua Khau Reservoir

Sample analyzed	Nutrient content (%)			
	OM	N	P_2O_5	K_2O
Suspended load (SL) from main weir	1.75	0.18	0.07	1.71
Bedload (BL) from main weir	1.95	0.22	0.10	0.2
Sediment from Cua Khau Reservoir	1.59	0.15	0.09	1.32
Soil sample from W3				
surface	1.12	0.17	0.24	0.09
middle	1.23	0.22	0.29	0.07

Land Management and Soil Erosion

Before 1970, the whole watershed was covered with primary forest. Deforestation led to the complete disappearance of the forest in the early 1980s. Since 1986, annual crops have been cultivated on the uplands with cassava as the most important crop. This indicates that the fertility of the soil is already low. It also shows that farmers do not give priority to farming the upland areas but simply use them to augment their income. They prefer to cultivated rice in the lowland areas.

In 1999, about 78 percent of the area of the catchment was cultivated to upland crops and about 5 percent was left forested. The forest species are *Venicia montana* (a small forest area of 0.9 ha near W1 at the bottom of the watershed) and 1.5 ha of eucalyptus on the left side of the main stream and covering a hill. Only cassava and a small area of taro were cultivated. These crops did not receive any fertilizers unlike the rice crops planted downstream.

In 2000 and 2001, the main annual crop was again cassava, representing more than 50 percent of the total watershed area (Figure 9). There was only about 0.35 ha of arrow root fields just below W2. The natural grass (10 ha, i.e. 22 percent of the total watershed area) was situated on the top of the watershed. In 1999, all the cassava was cultivated alone on the slope. In 2000, with the help of the government program and the MSEC program, some hedgerows of *Tephrosia candida* were planted on contour lines in W3. The farmers received financial support to plant *Acacia mangium* in association with cassava, on 9 ha in 2000 and 2 ha more in 2001. There was not much difference in the land use between 2000 and 2001. It is important to underline that there was no fallow during these two years.

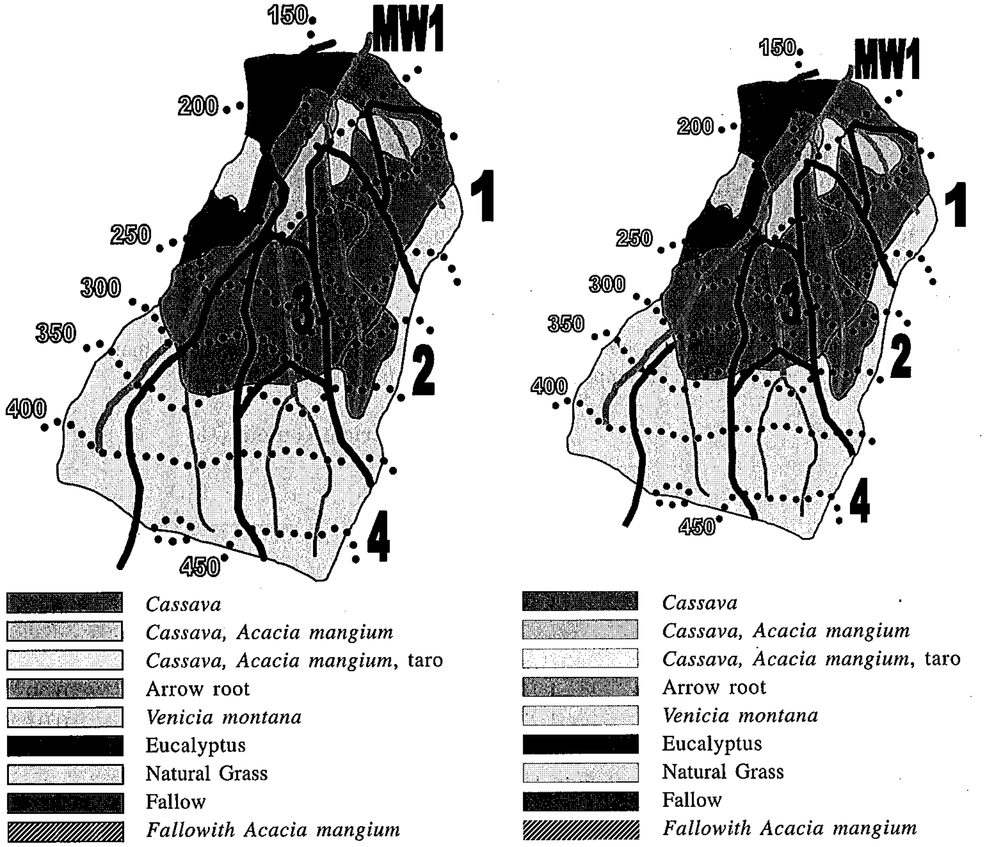

Figure 9. Land use in the Dong Cao Catchment for 2000 and 2001 (the legend in red shows what the use is). The dotted line is the contour line with indicated elevation in m

A large area was left fallow in 2002 and the area cultivated to annual crops was very much smaller (Figure 10). There was no cultivated area of cassava intercropped with *Acacia mangium* and cassava intercropped with taro during this year. There was only a small area (5 percent) cultivated to cassava monoculture in W2. The completely fallow area was about 14.8 ha (32 percent) and fallow with *Acacia mangium* of 11 ha (24 percent). The main reason for this large fallow area was the low and late rainfall in 2002. As mentioned earlier, this condition of the land use could have brought the lower erosion during the year. The highest bedload was observed in W2 (2 t ha^{-1}) where cassava was planted. The other sub-catchments had bedloads of not more than 1 t ha^{-1}.

Based on the observations of the hydrological behavior and soil erosion in the catchment and dialogue with the farmers, a number of land management options were introduced. These were: 1) contour planting of annual crops; 2) annual crop cultivation with hedgerows of *Tephrosia candida* and *Vetiveria zizanioides*; and 3) agroforestry, intercropping *Acacia mangium* with cassava. The effect of these options cannot yet be evaluated since little time has elapsed since their introduction. In addition, the high weather variability complicates the situation. The significant change in land use in 2002 made the evaluation of the effect of the hedgerows in W3 difficult.

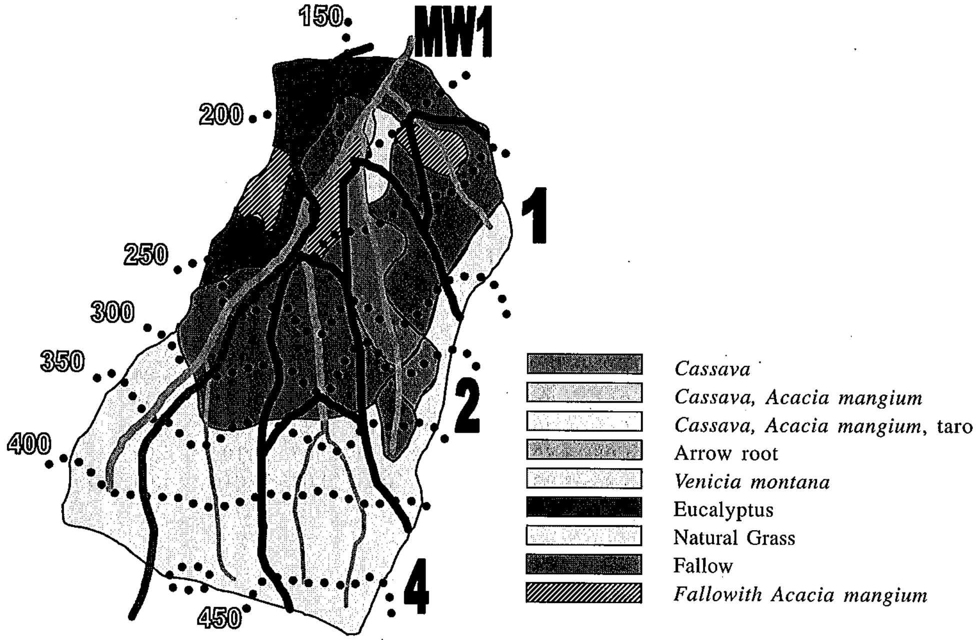

Figure 10. Land use in the Dong Cao Catchment for 2002 (the legend in red shows what the use is). The dotted line is the contour line with indicated elevation in m

Soil Erosion and Farm Productivity

Farming is the main source of livelihood of the people living in the watershed. Activities in the watershed are mostly undertaken in the middle slope of the watershed, where the slope is steep. The areas in the foothills already have low fertility because of long-term cultivation. Therefore, farmers move up to the middle part where the velocity of surface water runoff and erosion are lower. There is no more scope to move further up as this area should be maintained as forest land. Thus, in order to meet the increasing food demand, farmers need to take care of their own land and improve its soil fertility by using appropriate technologies for sustainable production.

Table 7 indicates that from 1999 to 2002 all indicators of soil fertility in the cultivated land as well as in the forest land of W3 are very low, especially organic carbon, nitrogen (N), phosphorus (P_20_5), and potassium (K_20). This nutrient content was generated by continuous cultivation and inappropriate methods to control erosion. From 1999 to 2002, the soil nutrients slightly increased. However, they are still inadequate for good plant growth and yield. Nevertheless, there are good signals that the soil condition can still be improved.

Table 7. Soil chemical properties of sample taken from W3 from 1999 to 2002

Year	Depth (cm)	Sample location	pH		Total (%)				Available elements (mg 100 g^{-1} soil)		Exchangeable cations (mg 100 g^{-1} soil)	
			H_2O	KCl	O C	N	P_2O_5	K_2O	P_2O_5	K_2O	Ca++	Mg++
Middle part of soil profile in W3												
1999	0-20	Cultivated land	4.60	3.86	1.05	0.09	0.16	0.36	1.56	7.70	1.10	1.01
		Forest land	4.50	3.6	0.62	0.09	0.13	0.99	1.58	4.51	0.56	0.41
2001	0-20	Cultivated land	4.98	3.82	1.28	0.19	0.28	0.04	1.08	4.52	3.85	3.07
		Forest land	4.75	3.86	2.40	0.15	0.09	1.18	1.29	4.52	3.07	2.36
2002	0-20	Cultivated land	4.95	3.79	1.12	0.17	0.24	0.09	1.15	5.21	3.97	3.07
		Forest land	4.79	3.83	1.19	0.12	0.12	0.08	1.09	5.03	3.74	3.24
Lower part of soil profile in W3												
1999	20-60	Cultivated land	4.80	3.90	0.89	0.06	0.14	0.36	0.99	5.90	0.50	0.06
		Forest land	4.80	3.9	0.79	0.05	0.08	1.05	0.87	3.01	0.15	0.37
2001	20-60	Cultivated land	4.91	3.96	1.71	0.13	0.24	0.06	0.82	3.76	3.84	3.84
		Forest land	4.68	3.79	2.47	0.08	0.09	1.84	1.02	4.52	3.07	2.32
2002	20-60	Cultivated land	4.98	3.82	1.23	0.22	0.29	0.07	1.10	5.04	3.81	3.02
		Forest land	4.86	3.73	1.28	0.17	0.24	0.04	1.01	5.01	3.63	3.15

Conclusions and Perspective

The results of three years of research and monitoring showed a high interannual variability of soil loss (from 1 to 15 t ha^{-1} $year^{-1}$) in the Dong Cao Catchment in northern Vietnam. Moreover, this variation depends on both the amount and intensity of rainfall and the kind of land use. Soil loss in 2001 was six times more than in the other years. It is notable that during this year, the total annual rainfall was highest and a large proportion of the catchment was cropped with cassava. There was relatively less erosion in 2002 when the rainfall was lower and the land use was significantly changed to fallow and natural grass.

The suspended load measured during a rising flow showed that it can be higher than the bedload and can therefore represent a larger proportion of the total soil and nutrient loss. The amount of nutrients that are carried away indicates the need to reduce erosion to maintain soil fertility in the uplands.

The project has proved to be very useful for farmers, not only in terms of understanding soil erosion and nutrient loss, which cause land degradation and reduce productivity, but also in terms of farmers' enhanced capacity and improved information dissemination strategies. The farmers are now more aware of the need to conserve soil fertility to sustain high agricultural productivity. Some of the technologies they have become aware of include contour hedgerow farming, agroforestry, intercropping systems, etc. Dialogue with farmers and different stakeholders from the local government, agricultural institutes, and research programs has been conducted to develop better understanding of how river basins respond to socio-economic changes. With this program of research and development, it is expected that the local government will change their thinking on soil management. The research activities in the Dong Cao Watershed have demonstrated to farmers, policy-makers, and extension workers how much sediment yield and bedload would be lost if appropriate soil and water management technologies were not used.

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